REPORT ON THE EVALUATION OF FLOODPLAINS ALONG THE DANUBE RIVER

WP	**WP3: Floodplain evaluation**
Activity	3.2 Activity
Deliverable	3.2.1 Priority list with potential preservation and restoration areas (based on FEM-tool)
Activity leader	BOKU
Involved partners	BAFG, BOKU, CUEI, CW, DRBD, DRSV, EDUVIZIG, JCI, KOTIVIZIG, MRBA, NARW, NIHWM, SWME, TUM, USZ, VUVH, WWF HU, WWF Romania

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1. Introduction and objectives

Among all natural disasters, floods have the greatest damage potential worldwide (UNISDR 2015). In recent years, awareness was raised, leading to the development of new approaches in integrated flood risk management, as demanded by the EU Floods Directive (2007/60/EC), by integrating non-structural and structural measures for flood protection. Such new flood mitigation methods should mainly focus on preserving and/or restoring floodplains (Habersack et al. 2015). Therefore, Activity 3.2 of the Danube Floodplain project aims to identify and evaluate still hydraulically active floodplains as well as reconnection potential of areas along the whole Danube River from the spring in Germany to the Danube Delta in Romania.

First, a methodology was developed for the identification of active and potential floodplains along the Danube River. Hydraulically active floodplains are defined as all areas that are still flooded during a HQ_{100} flood event. Potential floodplains are currently not inundated in the case of a $HQ_{100,}$ but with restoration measures, these areas can be reconnected to the river system leading to inundation during a HQ_{100} event. Both floodplain types are presented in the Danube GIS[1] and the Danube Floodplain GIS, a geographic information system developed within Activity 3.1 of the project. For this report, Institute of Hydraulic Engineering and River Research at the University of Natural Resources and Life Sciences, Vienna (BOKU) did as well a preliminary analysis of former floodplains areas based on the HQ_{1000} inundation outlines to estimate how much of the former floodplains are still active or potential inundation areas. A detailed analysis and identification of the former floodplains will be done in the extension of the Danube Floodplain project in Activity 6.2.

In the next step, both floodplain types were evaluated with the Floodplain Evaluation Matrix (FEM), a holistic, integrative method for assessing hydrological, hydraulic, ecological, and socio-economic effects of a floodplain. The FEM methodology was further developed with all project partners' help to serve the project's needs best.

The last step was to create a priority list with preservation and restoration areas based on the FEM-assessment. For this process, the need for preservation and the restoration demand of a floodplain were determined.

[1] Geographic information system, using and providing geo-information services on the web, whose development is supported by the ICPDR contracting parties

2. Methodology

2.1. Identification of active, potential and former floodplains

Active floodplains:

Within Activity 3.1 and 3.2, a method was developed for the identification and delineation of hydraulically active floodplains[1]. The data basis for the identification are HQ_{100} inundation areas. A flood event with a return period of 100 years is widely accepted in the Danube region as the design discharge for flood protection measures. In 2012, the Danube FLOODRISK project (https://environmentalrisks.danube-region.eu/projects/danube-floodrisk/) created hazard and risk maps for three different scenarios (frequent event HQ_{30}, medium event HQ_{100}, extreme event HQ_{1000}) for the whole Danube and published the results in the Danube Atlas. Hence, HQ_{100} outlines were available for all countries along the Danube River. If the countries could offer better (more up-to-date) national flood hazard maps (e.g. more accurate, more recently developed), these maps were used for the identification.

Based on the inundation areas of a HQ_{100} and the following three delineation criteria, the hydraulically active floodplains were identified:

- **Ratio factor** of $width_{floodplain}/width_{river}$ (to identify the beginning and end of a floodplain)
- **Minimum size** of an active floodplain (to avoid too small floodplains for the evaluation)
- Current **hydraulic characteristics** of the floodplain, like flow paths and stages may not be altered by the delineation (identified floodplains should represent the natural flow characteristics)

These criteria cannot only be used at the Danube River but are applicable at every river. In the Danube Floodplain project, the criteria were also applied at the selected tributaries in Activity 3.3. Only the values for the first two criteria have to be adjusted for the selected river. In general, the thresholds can be selected for each river individually under consideration of specific characteristics of the river and its floodplains. For the Danube River the following values were selected:

- A ratio factor of $width_{floodplain}/width_{river} > 1:1$
- A minimum floodplain size of 500 ha
- Floodplain must be hydraulically connected, and characteristic flow behaviour is given

This methodology was developed to identify floodplains at the Danube, which should be evaluated with the Floodplain Evaluation Matrix (FEM) and displayed in the Danube GIS and Danube Floodplain GIS. All the floodplains that fulfilled the above criteria were assigned to the 1st group of floodplains. Smaller floodplain and riparian areas were assigned to the 2nd and 3rd group of floodplains, which are morphologically and ecologically valuable areas.

- **1st group:** floodplains identified according to the methodology described before, larger than 500ha, which will be evaluated and ranked by the FEM

[1] In this report, "active" and "hydraulically active floodplains" are used to describe the same type of floodplain. To simplify and avoid unnecessary words, the expression "active floodplain" is used more often.

- **2nd group:** floodplains smaller than 500 ha but with a floodplain width bigger than the width of the river. These floodplains will not be displayed or evaluated, because the focus of this study is on larger floodplain areas.
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- **3rd group:** riparian zones with a width smaller than the river width. These riparian zones will not be displayed or evaluated as the effect for flood risk management is minor but are nevertheless important for the ecology and morphology.

The methodology was then applied to the Danube River by BOKU and the identified floodplains were sent to each partner for their final approval. All identified hydraulically active floodplains were uploaded to the Danube Floodplain GIS (http://www.geo.u-szeged.hu/dfgis/). In total, 50 hydraulically active floodplains (excluding the Danube Delta) were identified. In Figure 1, all active floodplains larger than 500 ha, including the Danube Delta, are shown.

Figure 1: All identified hydraulically active floodplains larger than 500 ha along the Danube River

Potential floodplains:

After identifying all hydraulically active floodplains along the Danube, a methodology was developed for the identification of potential floodplains. The potential floodplains have the potential for reconnection to the river system during a HQ_{100} flood event. Historical maps and/or inundation outlines of a $HQ_{extreme}$ (e.g., HQ_{300} or HQ_{1000}) are used to identify former floodplain first. The Danube FLOODRISK project also provides inundation outlines for extreme flood events along the entire Danube River. The assumption was that during a $HQ_{extreme}$, the dykes would overtop, and the potential floodplains beyond the dykes would be visible. Some partners also used historical maps to identify the former floodplains. Additionally, historical conditions could be analysed by modelling a historic scenario of the river section without dams, dikes and power plants. If a partner wanted to reconnect a certain area beyond the dyke, modifications in the hydrodynamic-numerical model were necessary to ensure that the potential floodplain is reconnected during a HQ_{100} before evaluating the effects of the additional area. One example of such a modification is removing the entire or part of dyke in the model. The connection of the potential floodplain at a HQ_{100} is necessary since the FEM-parameters are evaluated for such an event. If settlements, critical infrastructures and streets are located in the former floodplain, each country decides on their own if they want to identify this area as a potential floodplain. Settlements, streets and critical infrastructures had to be protected by complementary local flood defence measures (e.g., protective walls, earth deposits/dikes). If the former floodplain is currently used by agriculture, the country also has to decide if compensation is possible or not. If the partners decide that the land's compensation is not possible, no potential floodplain will be identified. In total 24, potential floodplains were identified. In Figure 2, all potential floodplains along the Danube River are shown.

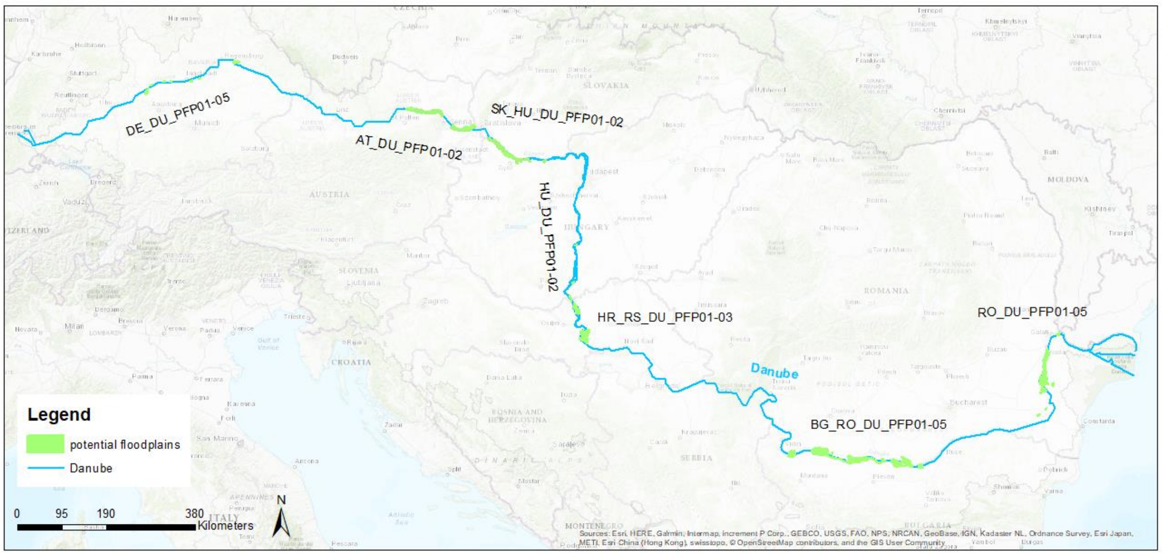


Figure 2: All identified potential floodplains along the Danube River

In the context of the project, it was decided to differentiate between two types of potential floodplains, namely potential and “operational” potential floodplains. The difference between these two types is that the “operational” potential floodplains are identified and discussed with stakeholders, technical experts and decision makers. In the following it is described how the identification of potential floodplains is working:

Step 1: Identify former floodplains by using the $HQ_{extreme}$ inundation outline from the Danube Atlas or historical maps.

Step 2: Exclude settlements, infrastructure and streets in the former floodplain.

Step 3: Exclude agricultural land where no compensation is possible or too expensive.

Step 4: Define reconnection measures (e.g., removal of dikes, cutting dikes etc.) for the remaining areas, which are the potential floodplains that are evaluated in the project.

Step 5: Discuss with stakeholders to define the “operational” potential floodplain and the detailed technical aspects of the reconnection. This is not done in the Danube Floodplain project.

Developing a method for identifying potential floodplains was a challenging task starting with the definition and identification of former floodplains ranging to the decision of which agricultural land can be used for the reconnection projects. The identified potential floodplains in the scope of the Danube Floodplain project are not representing all potential floodplains at the Danube River, but only some of them that the representatives of the individual countries identified in the project. In subchapter 3.9.1, the area of active, potential and former floodplains are compared showing that there is still potential for additional floodplains since the percentage of active + potential floodplains from the former floodplains is in some countries lower than in others. The above-described methodology was accepted by all partners and applied in each country individually.

Former floodplains:

The identification of former/historic floodplains is very challenging. Nevertheless, it is essential to know the historical condition of the floodplains to identify and understand past developments. Historical maps or inundation areas of a $HQ_{extreme}$ (e.g. return period = 100 years) can be used to identify former floodplains. If $HQ_{extreme}$ inundation outlines are used for the identification, it is assumed that most flood protection dykes are overtopped and the area behind the dyke (=former floodplain) is flooded. The detailed analysis and identification of former floodplains were not part of the WP3 and will be done to extend the Danube Floodplain project in Activity 6.2. For this report, BOKU did a preliminary analysis of former floodplain areas based on the HQ_{1000} inundation outlines, which were available from the Danube FLOODRISK project. In chapter 3.9, the results of this preliminary analysis are presented. For the detailed analysis and identification, it is recommend having a look at the Deliverable 6.2.3 (Danube Floodplain, in prep.)

2.2. Floodplain Evaluation Matrix (FEM)

2.2.1. Background

The Floodplain Evaluation Matrix (FEM) developed by the BOKU is a holistic method to evaluate river floodplains by considering multiple parameters that effect and determined the processes within floodplains Habersack et al. 2015). The project PRO_Floodplain (Habersack et al. 2008) was carried out in ERA-NET CRUE in order to develop an evaluation method for the effectiveness of floodplains in hydrological/hydraulic, ecological and sociological terms. The ecological parameters were based on GIS analysis (e.g. adapted land use), hydrodynamic-numerical modelling (e.g. Connectivity of water bodies) or with expert evaluation (e.g. potential for development of typical habitats). The sociological parameters (e.g. type of usage) were mainly based on questionnaires and surveys (Habersack et al. 2008; Habersack et al. 2015). The FEM should also serve as a method for decision support for relevant stakeholders. The FEM was already applied in different case studies in Austria and Germany and numerable parameters were identified and included based on literature research and questionnaires. Parameters for hydrology (e.g. peak reduction, flood wave translation) and hydraulics (e.g. water level change, flow velocity change) were calculated using hydrodynamic-numerical models. 2D-models are recommended for the application of the FEM. If no calibrated 2D-model is available, calibrated 1D-models can be used for the calculation too. In this project, mostly calibrated 1D-models were used, because 2D-models were not available to the partners. Most of the partners (except Austria – Hydro_AS-2D and Germany – 1D SOBEK) used 1D-HEC-RAS models.

With this methodology, a valuable decision support method is available for stakeholders and decision makers to assess multiple benefits that floodplain restoration and preservation as sustainable non-technical measures can offer. It allows the evaluation of various river reaches by setting up a priority ranking, which indicates where efforts of floodplain preservation / restoration should be spent first to obtain maximum benefits. The preservation of whole floodplains would stop the ongoing floodplain losses obtained over the last centuries.

2.2.2. Selected FEM-parameters and thresholds

For the Danube Floodplain project, the original FEM method was further developed to serve the project needs. Therefore, all possible parameters from the previous FEM application were collected and explained to the partners. Partners could also suggest additional parameters and this list was then discussed with all partners. From the list of parameters, the partners then selected which ones they see as important for the evaluation of floodplains. BOKU suggested a minimum set of parameters, which is mandatory for all partners to be calculated. All other parameters are additional ones, which can be evaluated and serve as additional information in the Danube Floodplain GIS but will not be considered for the ranking list. Nevertheless, the results will be valuable information for decision makers and, as such, be shown in the factsheet of each floodplain. The matrix itself consists of four categories: hydrology, hydraulics, ecology and socio-economics. For each category, one or two parameters were selected for the minimum set. The selected parameters and structure are presented hereafter:

Table 1: Floodplain Evaluation Matrix - Danube Floodplain project; in blue: minimum set, in green: additional parameters

Hydrology	Hydraulics	Ecology	Socio-Economics
peak reduction ΔQ	water level Δh	connectivity of floodplain water bodies	Potentially affected buildings
flood wave translation Δt		Existence of protected species	Land use
Additional parameters:			
effects (pos./neg.) in case of extreme discharges	flow velocity Δv	Existence of protected habitats	Precence of documented planning interests
	bottom shear stress	Vegetation naturalness	
		water level dynamics	
		Potential for typical habitats	
		ecological water body status	

After the calculation of the minimum parameters for the hydraulically active floodplain, the performance of each parameter is determined with the minimum parameters. Three levels of performance are possible for each parameter:

- High performance (5 points, colour code: blue)
- Medium performance (3 points, colour code: green)
- Low performance (1 point, colour code: yellow)

Based on the selected thresholds, the performance of the floodplain for each parameter can be determined. The thresholds can be selected for each river individually under consideration of specific characteristics of the river and its floodplains. It is recommended to start with the thresholds used at the Danube River and if necessary, adaptation can be made. The selected thresholds for most of the parameters are mainly based on results from previous studies and analysis (Habersack et al. 2008; BMLFUW 2014; Habersack et al. 2015; Habersack and Schobery 2020). For some new parameters, the thresholds were determined based on the results from this project according to expert knowledge. Most of the thresholds were also used at the selected tributaries in the Danube Floodplain project. Some thresholds were changed considering the different size of the tributaries and their characteristics. For further details on the FEM application at the tributaries see Danube Floodplain (2020). After determining the performance, the need for preservation and the demand for floodplain restoration (see section 2.3) can be evaluated. In Annexes A and B, the FEM Handbooks for the minimum and additional set of parameters are attached. The calculation of the parameters is described in detail in the handbooks. For each parameter, examples are given. In the next subchapters, each parameter and its thresholds are explained briefly:

2.2.2.1. Hydrology

Flood peak reduction: This parameter considers the effect of a floodplain on the peak of a flood wave. To evaluate the peak reduction for a floodplain, the peak of an input hydrograph (e.g. HQ_{100}) at the beginning of the floodplain and the peak of the output hydrograph at the end of the floodplain will be determined. The difference between the peaks is the peak reduction ΔQ_{tot} [m³/s] for the investigated floodplain or river section. For demonstrating only, the effect of the floodplains on the peak reduction, it is necessary to calculate the retention effect of the river channel too. Therefore, the peak reduction ΔQ_{RC} of the river channel is calculated with a model, where the floodplain is disconnected from the river channel by disabling these areas or by implementing fictive dykes, which cannot be overtopped. The same input hydrograph is used as for the calculation of ΔQ_{tot}. In Figure 3, the in- and output hydrographs for the river channel model (ΔQ_{RC}, Δt_{RC}) and the hydraulically active floodplain (ΔQ_{tot}, Δt_{tot}) are visible. It is shown that the retention effect of the floodplain is significant. In the absence of inundation areas, the peak reduction for the entire river reach would be close to zero, the flood wave translation would be reduced as well. For demonstrating only the effect of the floodplain on the peak reduction, ΔQ_{RC} has to be subtracted from ΔQ_{tot} (Equation 1).

$$\Delta Q = \Delta Q_{tot} - \Delta Q_{RC} [m^3 s^{-1}] \quad [1]$$

Additionally, the relative peak reduction ΔQ_{rel} [%] has to be calculated by dividing the ΔQ by the difference between Q_{max} and $Q_{bankfull}$ multiplied by 100 to make a comparison of different river reaches possible. The Q_{max} is the flood peak of the inflow wave and $Q_{bankfull}$ the discharge, where the river starts overtopping its bank.

$$\Delta Q_{rel} = \frac{\Delta Q}{(Q_{max} - Q_{Bankfull})} \times 100\ [\%] \quad [2]$$

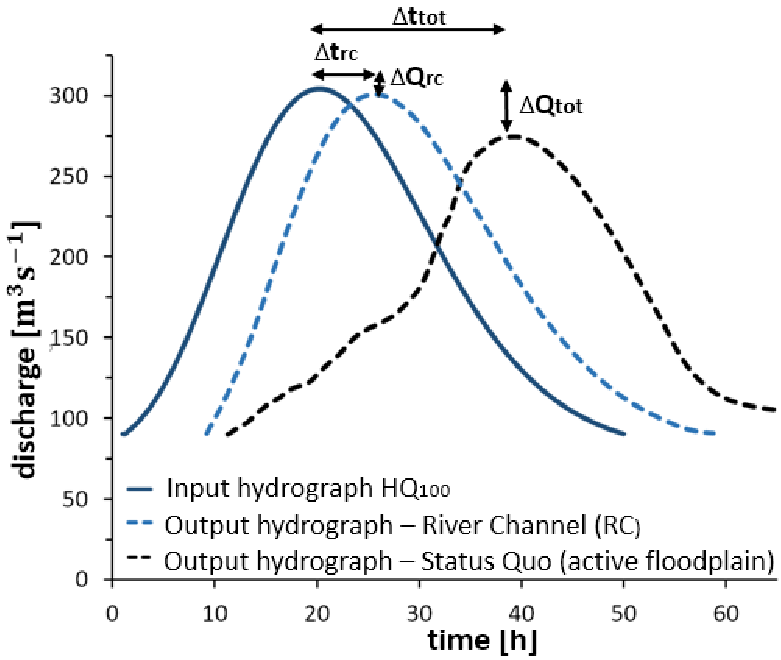


Figure 3: In- and output hydrographs for the river channel model (ΔQ_{rc}, Δt_{rc}) and the active floodplain (ΔQ_{tot}, Δt_{tot})

Thresholds: In Table 2, the thresholds are shown, which are used to determine the performance of the floodplain for the relative flood peak reduction. If the relative flood peak reduction (ΔQ_{rel}) is smaller than 1%, the performance of the floodplain is low. Between 1-2%, the performance is medium. All floodplains with a relative flood peak reduction above 2% perform high.

Table 2: Thresholds to determine the performance of the relative flood peak reduction ΔQrel in the FEM-Evaluation

Thresholds ΔQrel	
1	< 1 %
3	1 - 2 %
5	> 2 %

Flood wave translation: The flood wave translation is the second parameter required for the investigation of the process of wave attenuation due to a floodplain. This parameter is determined in a similar way as the peak reduction, namely by calculating the time difference Δt [h] between the occurrence of the out-/input hydrograph peak (Figure 3). You are using the same hydrographs as for the calculation of the peak reduction. For demonstrating only, the flood wave translation due to the floodplain, the Δt_{RC} of the river channel has to be subtracted from the Δt_{tot}.

$$\Delta t = \Delta t_{tot} - \Delta t_{RC} [h] \quad [3]$$

Thresholds: In Table 3, the thresholds are shown, which are used to determine the performance of the floodplain for the parameter flood wave translation. If the flood wave translation (Δt) is smaller than 1h, the performance of the floodplain is low. Between 1-5h, the performance is medium. All floodplains with a flood wave translation above 5h perform high.

Table 3: Thresholds to determine the performance of the flood wave translation Δt in the FEM-Evaluation

Thresholds Δt	
1	**< 1 h**
3	**1 - 5 h**
5	**> 5 h**

Effects in case of extreme discharge: Effects of floodplain areas on hydrological parameters (ΔQ, Δt) for scenarios with discharges larger ($HQ_{extreme}$) than the design discharge (HQ_{100}) of flood protection measures are also incorporated in the FEM to account for remaining risk (higher discharges due to climate change). Hydrodynamic-numerical modelling of the higher discharge (HQ_{1000}) can highlight additional capacities of floodplains or increased risks for settlements behind the dykes (e.g., by overtopping of existing dykes). The evaluation considers the effects on peak reduction and flood wave translation in each floodplain for this higher discharge compared to HQ_{100}. The calculation method is for $\Delta Q_{extreme}$ and $\Delta t_{extreme}$ the same as for ΔQ and Δt. The only difference is the higher input hydrograph. After the calculation of $\Delta Q_{extreme,rel}$ and $\Delta t_{extreme}$ a relation between ΔQ_{rel} and Δt is calculated.

$$\Delta Q_{compared} = \frac{\Delta Q_{rel}}{\Delta Q_{extreme,rel}} \times 100\ [\%] \quad [4]$$

$$\Delta t_{compared} = \frac{\Delta t}{\Delta t_{extreme,rel}} \times 100\ [\%] \quad [5]$$

Thresholds: No thresholds were selected, since no partner applied this additional parameter. and no previous results for this parameter were available. For defining appropriate thresholds, the results for several floodplains are needed.

2.2.2.2. Hydraulics

Water level change: In this project, we want to illustrate the effects of a total loss of a floodplain on the water level. It is assumed that the river is fully embanked and completely disconnected from the floodplain. The hydrodynamic-numerical model (river channel model), which was used for the calculation of ΔQ_{RC} and Δt_{RC}, can be used for the determination of the water level without floodplains (h_{RC}). For the calculation of h_{tot}, the same hydrodynamic-numerical model can be used, which is used to determine the hydrological parameters (ΔQ_{tot} and Δt_{tot}). The water levels h_{tot} and h_{RC} are observed at a defined cross-section in the middle of the river channel. It is recommended to take a mean water level across the cross-section, but it is also possible to take only one water level at a certain point in the middle of the river channel at the defined cross-section. The water level change Δh is the difference between h_{RC} and h_{tot}. The water level change Δh demonstrates the water level increase due to the total floodplain loss.

$$\Delta h = \mathrm{h}_{tot} - \mathrm{h}_{RC}[m] \quad [6]$$

Thresholds: In Table 4, the thresholds are shown, which are used to determine the performance of the floodplain for the parameter water level change. If the water level change (Δh) is smaller than 10 cm, the performance of the floodplain is low. Between 10-50 cm, the performance is medium. All floodplains with a water level change above 50 cm perform high.

Table 4: Thresholds to determine the performance of the water level change Δh in the FEM-Evaluation

Thresholds Δh	
1	< 10 cm
3	10 - 50 cm
5	> 50 cm

Flow velocity: We want to show the effects of a total loss of a floodplain on the flow velocity. We assume again that the river is fully embanked and completely disconnected from the floodplain. The hydrodynamic-numerical model (river channel model), which was used for the calculation of ΔQ_{RC} and Δt_{RC}, can be used determining the flow velocity without floodplains (v_{RC}). For the calculation of v_{tot}, the same hydrodynamic-numerical model can be used, which is used to determine the hydrological parameters (ΔQ_{tot} and Δt_{tot}). The flow velocity v_{tot} and v_{RC} are observed at a defined cross-section in the middle of the river channel. It is recommended to take a mean flow velocity across the cross-section, but it is also possible to take only one velocity at a certain point in the middle of the river channel at the defined cross-section. The flow velocity change Δv is the difference between v_{RC} and v_{tot}. The flow velocity change Δv demonstrates the velocity increase due to the total floodplain loss.

$$\Delta v = \mathrm{v}_{tot} - \mathrm{v}_{RC} [ms^{-1}] \qquad [7]$$

Thresholds: In Table 5, the thresholds are shown, which are used to determine the performance of the floodplain for the parameter flow velocity change. If the flow velocity change (Δv) is smaller than 0.1 m/s, the performance of the floodplain is low. Between 0.1-0.2 m/s, the performance is medium. All floodplains with a flow velocity change above 0.2 m/s perform high.

Table 5: Thresholds to determine the performance of the flow velocity change Δv in the FEM-Evaluation

Thresholds Δv	
1	< 0.1 m/s
3	0.1 - 0.2 m/s
5	> 0.2 m/s

Bottom shear stress: We want to show the effects of a total loss of a floodplain on the bottom shear stress. We assume again that the river is fully embanked and completely disconnected from the floodplain. The hydrodynamic-numerical model (river channel model), which was used for the calculation of ΔQ_{RC} and Δt_{RC}, can be used for the determination of the bottom shear stress without floodplains (τ_{RC}). For the calculation of τ_{tot}, the same hydrodynamic-numerical model can be used, which is used to determine the hydrological parameters (ΔQ_{tot} and Δt_{tot}). The bottom shear stress τ_{tot} and τ_{RC} are observed at a defined cross-section in the middle of the river channel. It is recommended to take a mean bottom shear stress across the cross-section, but it is also possible to take only one bottom shear stress at a certain point in the middle of the river channel at the defined cross-section. The bottom shear stress change $\Delta\tau$ is the difference between τ_{RC} and τ_{tot}. The bottom shear stress change $\Delta\tau$ demonstrates the increase of the bottom shear stress due to a loss of the floodplain.

Thresholds: In Table 6, the thresholds are shown, which are used to determine the performance of the floodplain for the parameter bottom shear stress change. If the bottom shear stress change ($\Delta\tau$) is smaller than 1.5 N/m², the performance of the floodplain is low. Between 1.5-3 N/m², the performance is medium. All floodplains with a bottom shear stress change above 3 N/m² perform high.

Table 6: Thresholds to determine the performance of the bottom shear stress change $\Delta\tau$ in the FEM-Evaluation

Thresholds τ	
1	< 1.5 N/m²
3	1.5 - 3 N/m²
5	> 3 N/m²

2.2.2.3. Ecology

Connectivity of floodplain water bodies: Longitudinal, lateral and vertical connectivity is crucial for the functionality of riverine ecosystems. Nevertheless, for simplification, the connectivity of floodplain water bodies will be investigated only in the lateral direction, which refers to the connection of the river channel and the floodplain. The parameter is determined with the help of 3 scenarios:

1. mean water level
2. bankfull flow
3. above bankfull flow

For determining the connectivity, a hydrodynamic-numerical model is necessary. With the model, which can be the same as for the calculation ofΔQ_{tot} and Δt_{tot}, the 3 scenarios are calculated. Only the input hydrographs have to be changed accordingly to the investigated scenario (mean water level, bankfull, above bankfull). The inundation areas of each scenario are used to determine the connectivity of water bodies (e.g., branches, oxbows) in the floodplain. You have to find out at which discharge the water bodies are connected. The next step is to define the "natural (historical)" status of water bodies on the floodplains. Therefore, historic maps have to be checked. There are 4 possible outcomes on the comparison between the current status and the historic status:

1. No "natural" (historical) water bodies on the floodplain
2. Existing water bodies on the floodplain (historical and current status)
3. On the historical maps "natural" (historical) water bodies existed, but at the hydraulically active floodplain no water bodies are left, due to human activity (e.g., dykes etc.)
4. On historic maps "natural" (historical) water bodies existed and are still existing, but were cut off by a dyke

If the river system is meandering, the connectivity is naturally beginning at bankfull discharge so, if this is given, it gets the best rating (5 points) in the FEM and no further steps are needed. For (historically) braided or anastomosing river types the best rating (5 points) is given when the side arms are already connected at discharges below mean water level. The detailed scenarios are listed below:

1. Water bodies connected up to mean water level / No “natural” (historical) water bodies on the floodplain / meandering river systems connected above bankfull discharge (5 points)

2. Water bodies connected at mean water level up to bankfull discharge (3 points)

3. Water bodies not connected above bankfull discharge / On the historic maps “natural” (historic) water bodies existed, but at the hydraulically active floodplain no water bodies are left (1 point)

If water bodies are cut off by a dyke, but still existing on the floodplain, it will lead to a downgrade Into the next FEM-class. E.g., Water bodies are connected up to mean flow –> 5 points, but by checking the historical maps or DEM it was discovered that the existing water bodies were cut off. This leads to a downgrade into the next class: 3 points

Thresholds: For the connectivity parameter, the method allows determining the performance without defined thresholds but with the defined ranking method as described above.

Existence of protected species: A floodplain is valuable and should be preserved if red list species or species and habitats (recognized by Natura2000) are found in the area. Therefore, this parameter will evaluate how many protected species can be found at the floodplain according to Natura2000,the Emerald Network or national legislation.

Thresholds: In Table 7, the thresholds are shown, which are used to determine the performance of the floodplain for the parameter existence of Natura 2000 protected species for the first step of the ranking process (see section 2.3). If no protected species are existing on the floodplain, the performance of the floodplain is low. Between 1-20 species, the performance is medium. All floodplains were more than 20 species are protected, perform high. These thresholds should be adapted to national legislation if Natura 2000 data is not available.

Table 7: Thresholds to determine the performance of the parameter existence of protected species in the FEM-Evaluation for the first step of the ranking process

Thresholds protected species	
1	no protected
3	1 - 20
5	> 20

In Table 8, the thresholds are shown, which are used to determine the performance of the floodplain for the parameter existence of Natura 2000 protected species for the second step of the ranking process (see section 2.3). If less than 40 protected species are existing on the floodplain, the performance of the floodplain is low. Between 40-101 species, the performance is medium. All floodplains were more than 101 species are protected, perform high. These thresholds also should be adapted to national legislation if Natura 2000 data is not available.

Table 8: Thresholds to determine the performance of the parameter existence of protected species in the FEM-Evaluation for the second step of the ranking process

Thresholds protected species	
1	< 40
3	40 - 101
5	> 101

Existence of protected habitats: This parameter shows what part of the floodplain area is designated as protected area according to the Natura 2000 or other documents about protected species or habitats like the Emerald Network. The higher the share of protected areas, the more valuable is the floodplain. Therefore, the protected area ($A_{protected}$) is divided by the floodplain area ($A_{floodplain}$) and multiplied by 100.

$$protected\ habitat = \left(\frac{A_{protected}}{A_{floodplain}}\right) * 100 \qquad [8]$$

Thresholds: In Table 9, the thresholds are shown, which are used to determine the performance of the floodplain for the parameter existence of protected habitats. If less than 33% of the floodplain area is protected, the performance of the floodplain is low. Between 33-67%, the performance is medium. If more than 67% of the floodplain area is protected, the performance is high.

Table 9: Thresholds to determine the performance of the parameter existence of protected habitats in the FEM-Evaluation

Thresholds protected habitats	
1	< 33 %
3	33 - 67 %
5	> 67 %

Vegetation naturalness: The landscape patterns of a floodplain can be a good indicator for the naturalness of vegetation. Therefore, it is possible to calculate patch-level landscape indices (like the class level landscape metric Area Weighted Mean Shape Index (AWMSI) for all land cover polygons of natural and semi natural areas (NSN). Mean Shape Index can be calculated by the V-LATE extension of ArcGIS. NSN patches with a complex shape with irregular edges indicate a higher level of naturalness. The riparian vegetation land cover dataset is available for all Danube floodplains and for most of the tributaries. This dataset can be downloaded from the Copernicus Land Monitoring Service website. Open the Copernicus Riparian Zone land cover maps with ArcGIS 10.x. For making a new shape file which will contains only the "natural or semi natural" land cover patches, select the following main land cover categories from the riparian zones land cover dataset: Woodland (code 3), Grassland (code 4), and Heathland (Code 5). Open the new "natural and semi natural" land cover map with ArcGIS 10.x. and click on the V-Late extension.

Following the V-late flowchart, you should calculate first the Perimeter and Area of each land cover polygons, clicking Area/Perimeter box. The V-late extension will automatically put these new attribute columns into the attribute table of your digital land cover map.

Follow the flowchart steps, click on Area Analysis, Edge Analysis, and Form Analysis boxes. You should select the unique id column of the polygon patches to calculate the values for the all patches. The V-late extension will automatically calculate and put the landscape indices (e.g., Shape Index = shape_idx) into the attribute table of the digital land cover map (Copernicus Riparian Zone). These landscape indexes are representing the area, and form characteristics of each land cover polygons new attribute columns. You will use only the Shape Index (MSI) data (shape_idx columns) of each land cover polygons for the further analyses.

Downloading and setting up the Geospatial Modelling Environment (GME), and R software for ArcGIS 10.x from this website (http://www.spatialecology.com/gme/gmedownload.htm). Open the GME icon in your computer. Choose and click on the "isectpolypoly" options on the left menus of the GME. This tool calculates the Area Weighted Average of MSI values of each natural and semi natural land cover polygons inside of the floodplain units (zonal polygon dataset). This tool automatically writes the results into the attribute table of the digital map of the active floodplain units (zonal polygon) dataset.

You should also select the zonal polygon shape file. This shape file will be the digital polygon map of the active floodplain units. You can put it into the "in" field (active floodplain unit data source).

You should select into this second polygon layer to process your "natural or semi natural" land cover polygon shape file, which attribute table includes yet the MSI data of each land cover polygons. You should select this shape file from your computer and select the MSI column from its attribute table. This MSI column will be the quantitative data to summarize field.

You should write into "prefixa" a short prefix to use in the summary statistic fields with AWM, the prefix should be no longer than 6 characters.

Set up the "thematic", "proportion" and "where" menus into the FALSE options, the "area weighted mean" menu (AWM) into the TRUE options, the "minimum" (MIN), "maximum" (MAX), and "area weighted sum" (AWS) menus to the FALSE options (Figure 4).

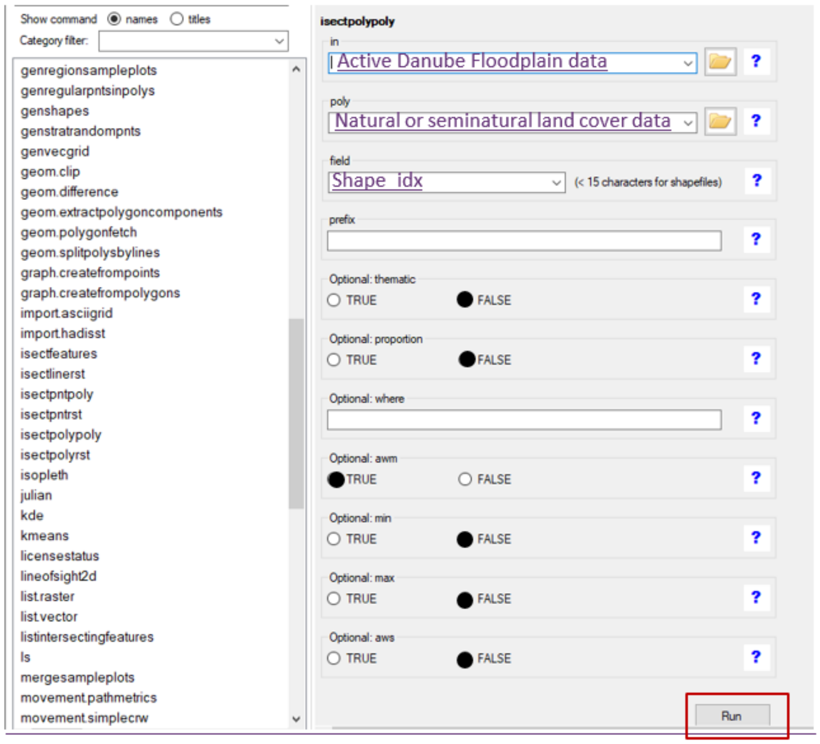


Figure 4: Input mask of the GIS tool to calculate the landscape metrics

Open the digital maps of active floodplain units (AFU) with ArcGIS 10.x. This file is containing yet the Area Weighted Mean Shape Index (AWMSI) values of each floodplain units (AFU). You should add a new field (column) into the attribute table of this shape file, and define it as the string column, which will represent the vegetation naturalness of each AFU. You should select the 0 – 3.7 AWMSI values and to write “low naturalness” into the new attribute table (in the Field calculator).
You should select the 3.71 – 6.00 AWMSI values and to write “medium naturalness” into the new attribute table.

You should select the over 6.01 AWMSI values and to write “high naturalness” into the new attribute table.

Thresholds: In Table 10, the thresholds are shown, which are used to determine the performance of the floodplain for the parameter vegetation naturalness. If the vegetation naturalness is smaller than 3.7, the performance of the floodplain is low. Between 3.71-6.01, the performance is medium. All floodplains with a vegetation naturalness above 6.02 perform high.

Table 10: Thresholds to determine the performance of the vegetation naturalness in the FEM-Evaluation

Thresholds vegetation naturalness	
1	< 3.7
3	3.71 - 6.01
5	> 6.02

Water level dynamics: In order to restore floodplain habitats, rivers and floodplains must have a water level dynamic, almost like the one that exists in the natural floodplains. For this reason, the water level dynamics are used as a FEM parameter. If significant changes have been made on the river, floodplain areas may have completely different water level dynamics. This can result in permanently (excessive) high water levels in dammed up parts of the river or in dry floodplain areas in deepened river segments. The parameters water level duration, frequency of the flood and amplitude of the water levels are summarized describing the possible water level dynamics. The historical state before the development of the river serves as a point of reference. A detailed surface assessment for this parameter would be very time-consuming so that the assessment is made with the help of experts for the whole area at once. For the evaluation, a classification based on expert knowledge has to be set up: low disturbance of natural water level dynamics leads to a high rating within FEM.

First, information about the duration, frequency and amplitude of the water level dynamics (including headwater, riverbed, dykes (natural or human-made), street dams, swells, channel-bed erosions, barrages) are collected for the current and historical state. The duration, frequency and amplitude of the water level dynamics have to be compared. The following scenarios are then part of the evaluation:

> **5 –** Duration, frequency and amplitude are **marginally** affected. Further aspects: headwaters are not obstructed, the riverbed is not deepened and there are no major obstacles for inundation
>
> **3** - Duration, frequency and amplitude are **moderately** affected. Further aspects: there are natural banks but the headwaters are dammed or dams and streets are in the floodplain
>
> **1** - Duration, frequency and amplitude are **strongly** affected. Further aspects: there are summer dykes existing, the riverbed is deepened and swells can be found

Thresholds: For the water level dynamics parameter, the method allows determining the performance without defined thresholds but with the defined ranking method as described above.

Potential for typical habitats: The typical river and floodplain habitats should have the possibility to re-establish habitats if they are not already existing. 14 habitat types typical for floodplains are included in the Habitats Directive. Not every floodplain area must consist of all, but the more habitat types exist or can be redeveloped, the more valuable this area is. The parameter evaluates how many of the typical habitats are available at the floodplain or could be restored.

Thresholds: In Table 11, the thresholds are shown, which are used to determine the performance of the floodplain for the parameter potential for typical habitats. If less than 5 typical habitats exist or can be redeveloped, the performance of the floodplain is low. Between 5-10 habitats, the performance is medium. All floodplains were more than 10 typical habitats exist or can be redeveloped, perform high.

Table 11: Thresholds to determine the performance of the parameter potential for typical habitats in the FEM-Evaluation

Thresholds typical habitats	
1	< 5
3	5 - 10
5	> 10

Ecological water body status: As part of the water framework directive, the countries should evaluate the ecological of the water bodies. If the river section of this floodplain is rated with a good or high status, it should get the best rating for this parameter. Experts will assess the potential effect of restoration measures at the floodplain on the ecological water body status to the best of their knowledge.

Thresholds: In Table 12, the thresholds are shown, which are used to determine the performance of the floodplain for the parameter ecological water body status. If the ecological water body status is bad or poor, the performance of the floodplain is low. If the water body status is moderate, the performance is medium. All floodplains with a good or high ecological water body status receive a high performance in the FEM-evaluation.

Table 12: Thresholds to determine the performance of the parameter ecological water body status in the FEM-Evaluation

Thresholds water body status	
1	bad, poor
3	moderate
5	high, good

2.2.2.4. Socio-Economics

Potentially affected buildings: This parameter determines the number of buildings on each hydraulically active floodplain. The more buildings are affected, the higher is the potential damage. To compare the results, the number of buildings will be divided by the total area of the floodplain.

Thresholds: In Table 13, the thresholds are shown, which are used to determine the performance of the floodplain for the parameter potentially affected buildings. If more than 5 buildings per km² are on the floodplain, the performance of the floodplain is low. Between 1 and 5 buildings per km² the performance is medium. All floodplains with less than 1 building per km², perform high in the FEM-evaluation.

Table 13: Thresholds to determine the performance of the parameter potentially affected buildings in the FEM-Evaluation

Thresholds affected buildings	
1	> 5 [n/km²]
3	1 - 5 [n/km²]
5	< 1 [n/km²]

Land use: Land use that is adapted to future inundation will minimize the socio-economical vulnerability of the floodplain. Therefore, flood-adapted land use (=low vulnerability) gets the highest rating, non-adapted the lowest (settlements = high vulnerability). The different types of land uses are aggregated proportional to their areas to one evaluation value for the whole floodplain.

Thresholds: In Table 14, the thresholds are shown, which are used to determine the performance of the floodplain for the land use parameter. If the land use parameter is smaller than 2, the performance of the floodplain is low. Between 2-4, the performance is medium. All floodplains with a land use parameter above 4 perform high.

Table 14: Thresholds to determine the performance of the land use parameter in the FEM-Evaluation

Thresholds land use	
1	< 2
3	2 - 4
5	> 4

Presence of documented planning interests: This parameter evaluates the presence of infrastructure or spatial development plans/projects in the floodplain area or close to it. A presence would lead to a lower rating of the floodplain. This can also include plans from other interest groups (agriculture, tourism, hunting, fishing, etc.). If you find some plans, you can analyse their content regarding development projects for building, industry and infrastructure. If such interests are shown in the documents, this should be documented at a map or at least a table including the project, the planned area in the floodplain and the planned year.

Thresholds: No thresholds were selected, since no partner applied this additional parameter.

2.3. Priority list of floodplains to preserve and restore

One major goal of the project is to provide a priority list of floodplains that should be preserved and identify floodplains that can be restored. For creating the priority list, the FEM is adapted to the project's needs. After determining the performance, the need for preservation and the demand for floodplain restoration can be evaluated. First, the need for preservation is determined. A floodplain has to be preserved if at least one parameter of the minimum set is evaluated with a 5 (high performance). After that, the restoration demand is defined. Based on the minimum parameter evaluation, each floodplain is assigned to one of three groups (low, medium, high demand for restoration). The thresholds can be selected for each river individually. In Table 15, the selected thresholds to determine the restoration demand for the Danube River are shown. In the Danube Floodplain project, the following thresholds were used: If a maximum of one parameter is evaluated with 1 (low performance) and two other parameters received a 3 (medium performance), the floodplain shows a low demand for restoration. The sum of the points received has to be ≥ 27, for getting a low demand for restoration. Floodplains with total points between 26 and 23 have medium restoration demand (Table 5). All floodplains with <23 points show a high demand for restoration. Based on the total number of points, a ranking of the floodplains is possible. It is recommended to start with the thresholds used at the Danube River and if necessary, adaptation can be made. A list of measures (Danube Floodplain, 2021) that can improve the performance of the FEM-parameters was also prepared and those measures can help reduce restoration demand.

Table 15: Used thresholds in Danube Floodplain project for the Danube River to determine the restoration demand (low, medium, high)

Ranking		
Restoration Demand	**Rule**	**Min Sum Points**
High demand	All below 23 points	< 23
Medium demand	max 2x Medium (3) and 2x Low (1) or 3x Low (1)	23 - 26
Low demand	max 2x Medium (3) and 1x Low (1)	≥ 27

3. Results

3.1. Germany

3.1.1. Active and potential floodplains

In Germany, ten hydraulically active and five potential floodplains were identified. Eight active and all potential floodplain are located in Bavaria. The other two active floodplains are in Baden-Wuerttemberg and were not evaluated in the scope of this project. In Figure 5, the floodplain ID, the location and the area of all active and potential floodplains in Germany are shown. For the active floodplain, the restoration demand is also illustrated.

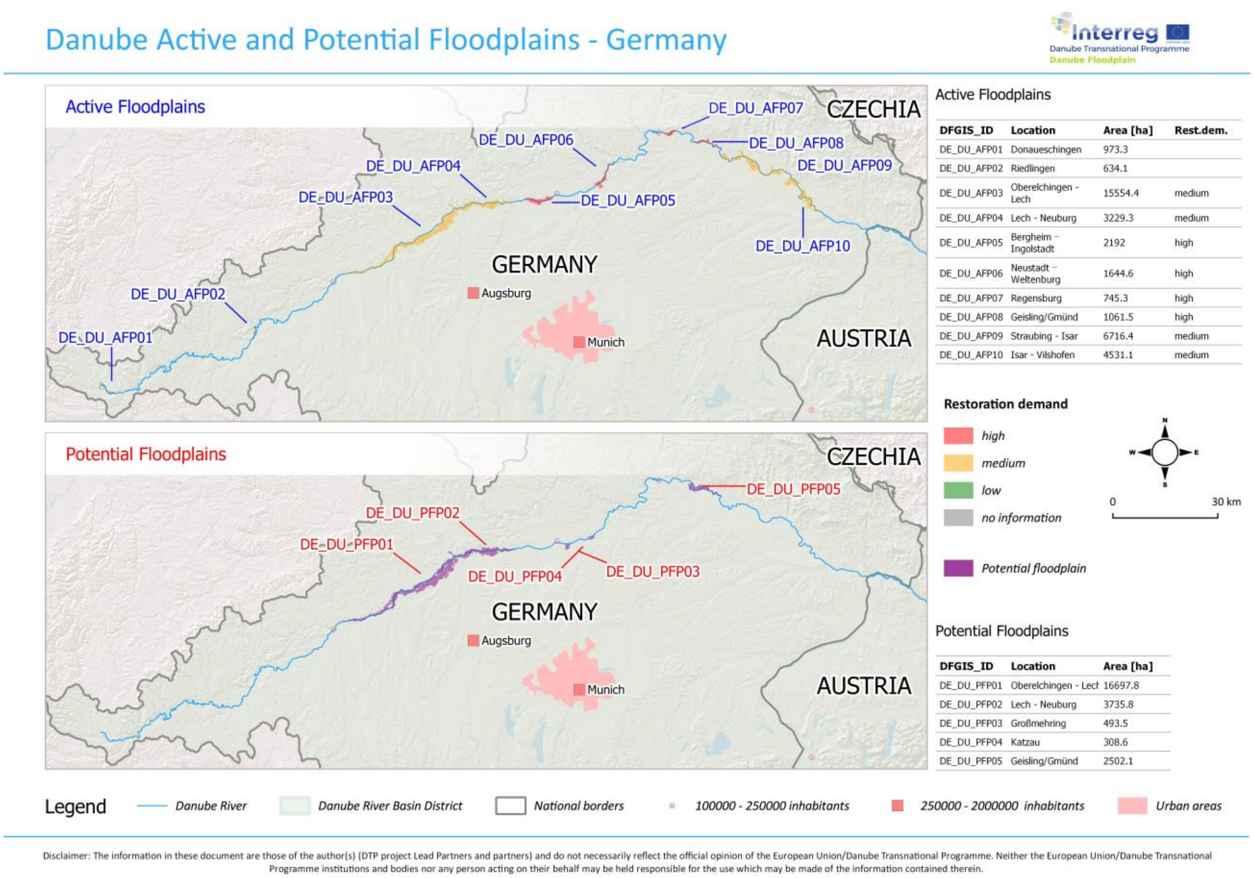


Figure 5: All active and potential floodplains along the German Danube (Danube Floodplain, 2021)

3.1.2. FEM-Evaluation – active floodplains (AFP) in Germany

Table 16 shows the results of the minimum FEM-parameters for all active floodplains along the Bavarian Danube. The relative peak reductions range from 0 to 16.98%, resulting in four floodplains with high (>2%) and four with low (<1%) performance in terms of this aspect of the hydrology. Due to the flow processes in the floodplains, the flood wave is decelerated by a range from 0.25 to 16.5 h. Four floodplains show a medium (1-5h), three a high (>5h) and one a low (<1h) performance for the flood wave translation parameter. Regarding the hydraulics, in the case of a total loss of the active floodplain, the water level in the river channel would change from 0 to 112 cm. For three floodplains, the water level would increase by more than 50 cm. Three floodplains are showing a rise between 24 and 42 cm. Only for two floodplains, the water level change is below 10 cm. From the ecological point of view, the lateral connectivity between the river channel and floodplain is impaired for all active floodplains along the German Danube by human interventions, leading to low performance for all of them. At all floodplains, more than 20 protected species are found (=high performance for the first step of the ranking). For the second step of the ranking, other thresholds are used for the protected species parameter to determine the restoration demand resulting in nine floodplains with a medium and only one with a high performance. At six floodplains, the number of affected buildings per km² is larger than 5, leading to a low performance for this parameter. Only two floodplains show a high (<1n/km²) performance. The land uses on seven floodplains have a medium vulnerability against flooding, resulting in a medium performance. Only on one floodplain, the vulnerability is low (5 – high performance).

Table 16: Results of the minimum Floodplain Evaluation Matrix (FEM) parameters for all active floodplains along the Danube River in Germany. In the last row, thresholds for each parameter to determine the performance of each floodplain. High performance (5 points) in blue. Medium performance (3 points) in green. Low performance in orange (1 point).

country	Floodplain	Hydrology		Hydraulics	Ecology			Socio-Economics	
		peak reduction (%)	flood wave translation (h)	water level change (cm)	connectivity (-)	protected species (-)		affected buildings (n/km²)	land use (-)
Germany	DE_DU_AFP_01								
	DE_DU_AFP_02								
	DE_DU_AFP_03	16.98	16.5	112	1	95	95	15.76	3.63
	DE_DU_AFP_04	2.63	9.5	89	1	54	54	15.58	3.92
	DE_DU_AFP_05	0.53	3	42	1	51	51	19.16	4.57
	DE_DU_AFP_06	0.07	1	0	1	41	41	17.93	3.40
	DE_DU_AFP_07	0.00	1.25	6	1	53	53	0.81	3.65
	DE_DU_AFP_08	0.08	0.25	24	1	53	53	0.19	3.64
	DE_DU_AFP_09	11.13	6.75	53	1	86	86	9.32	3.61
	DE_DU_AFP_10	2.83	5	38	1	**115**	**115**	11.39	3.52
FEM-rating	performance	Thresholds	Thresholds	Thresholds	Thresholds	Thresholds		Thresholds	Thresholds
	low	<1 %	<1 h	<10 cm	1	0	<40	>5 n/km²	<2
	medium	1-2 %	1-5 h	10 - 50 cm	3	1-20	41-100	1-5 n/km²	2-4
	high	>2 %	>5 h	>50 cm	5	>20	>101	<1 n/km²	>4

Based on the FEM-assessment, the need for preservation and the restoration demand are determined. All active floodplains along the German Danube should be preserved because at least one parameter is evaluated with high performance at each floodplain. Five floodplains show a high and three a medium demand for restoration (Table 17).

Table 17: Results of the need for preservation and restoration demand for all active floodplains along the Danube River in Germany. In the last row, thresholds for the need for preservation (if one minimum FEM-parameter is evaluated with 5 – high performance, the floodplain has to be preserved) and restoration demand (<23 FEM-points – high, 23-26 points – medium, ≥ 27 low demand)

Floodplain ID	Need for preservation	Parameters with high performance	Demand for restoration	FEM-points
DE_DU_AFP_01				
DE_DU_AFP_02				
DE_DU_AFP_03	yes	peak reduction, wave translation, water level change, protected species	medium demand	23
DE_DU_AFP_04	yes	peak reduction, wave translation, water level change, protected species	medium demand	23
DE_DU_AFP_05	yes	protected species	high demand	17
DE_DU_AFP_06	yes	protected species, land use	high demand	13
DE_DU_AFP_07	yes	protected species, affected buildings	high demand	17
DE_DU_AFP_08	yes	protected species, affected buildings	high demand	17
DE_DU_AFP_09	yes	peak reduction, wave translation, water level change, protected species	medium demand	23
DE_DU_AFP_10	yes	peak reduction, protected species	high demand	21
FEM-ranking	Need for preservation	threshold	restoration demand	threshold
	yes	at least one parameter evaluated with 5	low	≥ 27
			medium	23-26
	no	no parameter evaluated with 5	high	<23

3.1.3. FEM-Evaluation – potential floodplains (PFP) in Germany

Table 18 shows the results of the minimum FEM-parameters for all potential floodplains along the German Danube. The relative peak reductions range from 0 to 17.62%, resulting in two floodplains with high (>2%) and three with low (<1%) performance. The flood wave is decelerated from 0 up to 19 h. Two floodplains show a medium (1-5h), two a high (>5h) and one a low (<1h) performance for the flood wave translation parameter. In the case of a total loss of the potential floodplain, the water level in the river channel would change from 0 to 117 cm. For three floodplains, the water level would increase by more than 50 cm. One floodplain shows a rise of 25 cm and for another one, the water level would not change. The lateral connectivity between the river channel and floodplain is still impaired for all potential floodplains along the German Danube by human interventions, leading to low performance for all of them. At three floodplains, more than 20 and at two between 1 and 20 protected species are found. At four floodplains, the number of affected buildings per km² is larger than 5, leading to a low performance for this parameter. Only one floodplain shows a medium (1-5 n/km²) performance for the affected building's parameter. The land uses on four floodplains have a medium vulnerability against flooding, resulting in a medium performance. Only on one floodplain, the vulnerability is low (5 – high performance).

Table 18: Results of the minimum Floodplain Evaluation Matrix (FEM) parameters for all identified potential floodplains along the Danube River in Germany. In the last row, thresholds for each parameter to determine the performance of each floodplain. High performance (5 points) in blue. Medium performance (3 points) in green. Low performance in orange (1 point).

country	Floodplain ID	Hydrology		Hydraulics	Ecology		Socio-Economics	
		peak reduction (%)	flood wave translation (h)	water level change (cm)	connectivity (-)	protected species (-)	affected buildings (n/km²)	land use (-)
Germany	DE_DU_PFP01	**17.62**	**19**	**117**	**1**	**95**	14.95	3.61
	DE_DU_PFP02	2.41	11	108	**1**	54	16.78	3.89
	DE_DU_PFP03	0.35	0	52	**1**	17	5.07	**4.29**
	DE_DU_PFP04	0.02	2	0	**1**	15	**1.94**	3.67
	DE_DU_PFP05	0.33	5	25	**1**	53	6.63	3.31
FEM-rating	performance	Thresholds	Thresholds	Thresholds	Thresholds	Thresholds	Thresholds	Thresholds
	1 (low)	<1 %	<1 h	<10 cm	1	0	>5 n/km²	<2
	3 (medium)	1-2 %	1-5 h	10 - 50 cm	3	1-20	1-5 n/km²	2-4
	5 (high)	>2 %	>5 h	>50 cm	5	>20	<1 n/km²	>4

3.1.4. Example of a floodplain factsheet (DE_DU_AFP_03)

The active floodplain DE_DU_AFP_03 starts at Oberelchingen and ends at the confluence of the Lech River. The total floodplain area is 155.5 km². The FEM-Evaluation shows that there is a need for preservation of this floodplain and a medium demand for restoration, due to the performance of the evaluated parameters. In Figure 6, the evaluation results are illustrated for each parameter and the coloured background indicates the performance (high – blue, medium – green, low – yellow) of the parameter. The performance is determined using the selected thresholds presented in chapter 2.2.2.

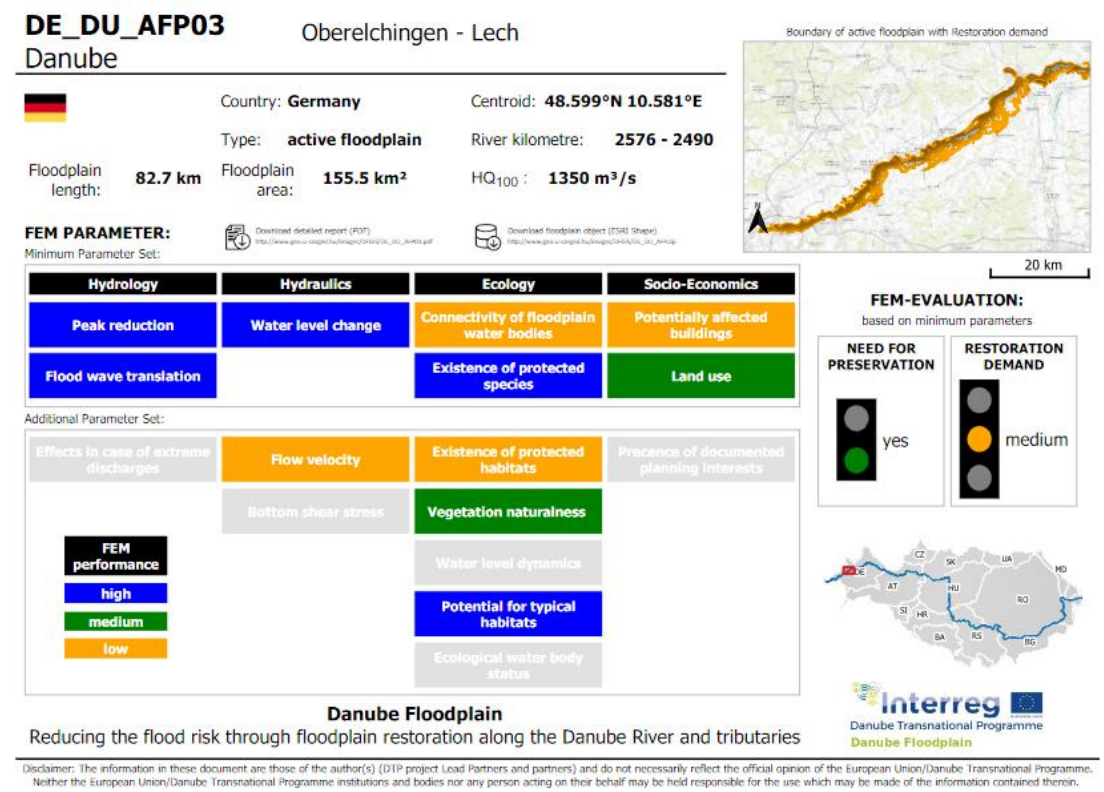
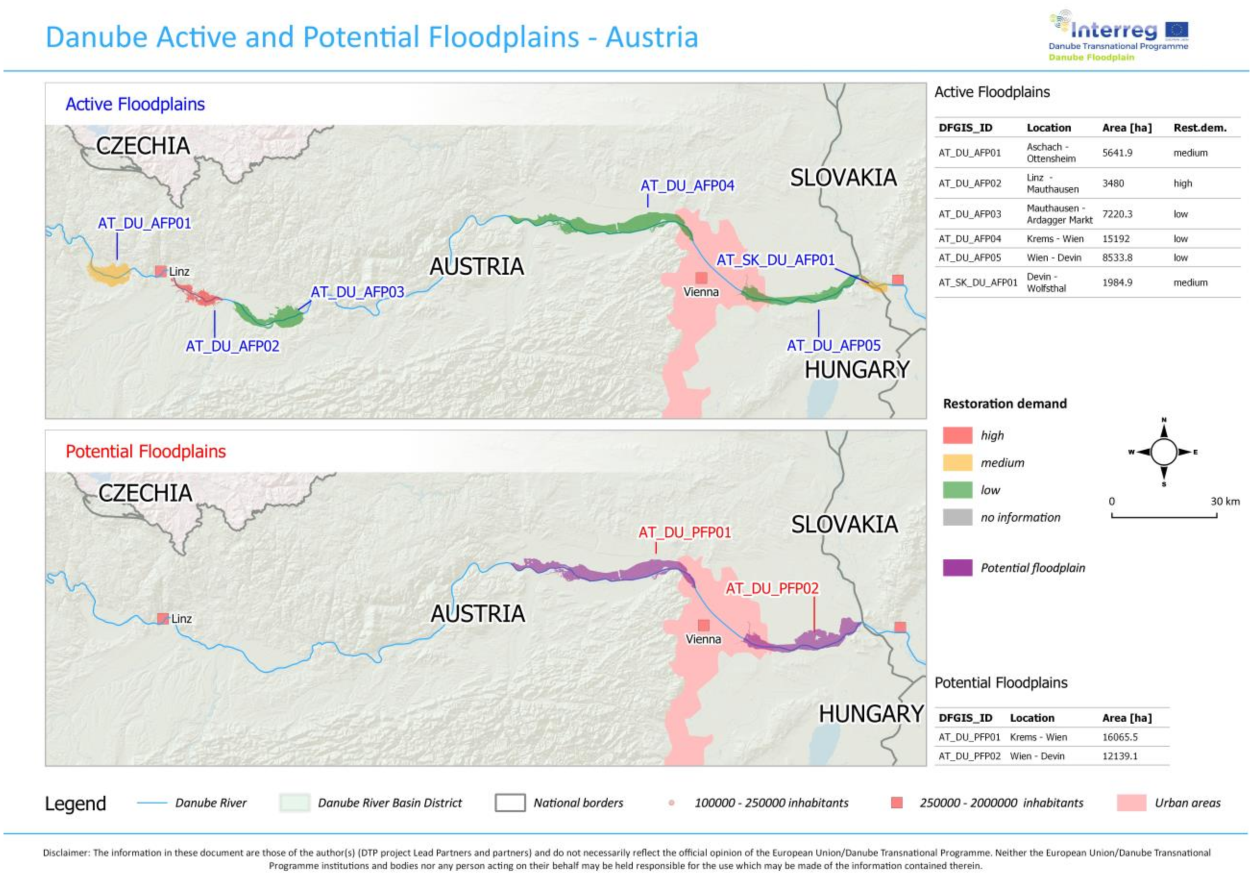


Figure 6: Factsheet for the active floodplain DE_DU_AFP_03

3.2. Austria

3.2.1. Active and potential floodplains

In Austria, five hydraulically active and two potential floodplains were identified. One active floodplain was identified along the Austrian/Slovakian section of the Danube River. In Figure 7, the floodplain ID, the location and the area of all active and potential floodplains in Austria are shown. For the active floodplain, the restoration demand is also illustrated.



Active Floodplains

DFGIS_ID	Location	Area [ha]	Rest.dem.
AT_DU_AFP01	Aschach - Ottensheim	5641.9	medium
AT_DU_AFP02	Linz - Mauthausen	3480	high
AT_DU_AFP03	Mauthausen - Ardagger Markt	7220.3	low
AT_DU_AFP04	Krems - Wien	15192	low
AT_DU_AFP05	Wien - Devin	8533.8	low
AT_SK_DU_AFP01	Devin - Wolfsthal	1984.9	medium

Potential Floodplains

DFGIS_ID	Location	Area [ha]
AT_DU_PFP01	Krems - Wien	16065.5
AT_DU_PFP02	Wien - Devin	12139.1

Figure 7: All active and potential floodplains along the Austrian Danube (Danube Floodplain, 2021)

3.2.2. FEM-Evaluation – active floodplains (AFP) in Austria

Table 19 shows the results of the minimum FEM-parameters for all active floodplains along the Austrian Danube. The relative peak reductions range from 1.21 to 15.64%, resulting in four floodplains with high (>2%) and two with medium (1-2%) performance. Due to the flow processes in the floodplains, the flood wave is decelerated from 2.5 to 20.5 h. Three floodplains show a high (>5h) and three a medium (1-5h) performance for the flood wave translation parameter. In the case of a total loss of the active floodplain, the water level in the river channel would change from 64 to 172 cm. The water level would increase by more than 50 cm for all floodplains, leading to high performance (>50cm). The lateral connectivity between the river channel and floodplain is impaired for most (five out of six) active floodplains along the Austrian Danube by human interventions, leading to low performance. Only one floodplain achieves a medium performance in terms of connectivity. More than 20 protected species are found at five floodplains, resulting in high performance for the first step of the ranking (=need for preservation). At one floodplain, 20 protected species can be found, leading to medium performance. For the second step of the ranking, other thresholds are used for the protected species parameter to determine the restoration demand resulting in two floodplains with a high, three with a medium and only one with a low performance. At three floodplains, the number of affected buildings per km² is larger than 5, leading to a low performance for this parameter. For the other three floodplains, a medium performance was assessed. The land uses on four floodplains have a medium vulnerability against flooding, resulting in a medium performance. Only at two floodplains, the vulnerability is low (5 – high performance).

Table 19: Results of the minimum Floodplain Evaluation Matrix (FEM) parameters for all active floodplains along the Danube River in Austria and the Austria/Slovakian section. In the last row, thresholds for each parameter to determine the performance of each floodplain. High performance (5 points) in blue. Medium performance (3 points) in green. Low performance in orange (1 point).

country	Floodplain	Hydrology		Hydraulics	Ecology			Socio-Economics	
		peak reduction (%)	flood wave translation (h)	water level change (cm)	connectivity (-)	protected species (-)		affected buildings (n/km²)	land use (-)
Austria, Slovakia	AT_DU_AFP_01	15.64	5.5	64	1	20	20	19.58	3.40
	AT_DU_AFP_02	1.52	2.5	172	1	62	62	14.04	3.76
	AT_DU_AFP_03	8.24	5.5	68	1	85	85	3.52	3.81
	AT_DU_AFP_04	12.60	20.5	83	1	113	113	18.63	4.68
	AT_DU_AFP_05	4.68	5	109	3	**116**	**116**	1.38	4.74
	AT_SK_DU_AFP_01	1.21	4	81	1	51	51	3.98	3.56
FEM-rating	performance	Thresholds	Thresholds	Thresholds	Thresholds	Thresholds		Thresholds	Thresholds
	low	<1 %	<1 h	<10 cm	1	0	<40	>5 n/km²	<2
	medium	1-2 %	1-5 h	10 - 50 cm	3	1-20	41-100	1-5 n/km²	2-4
	high	>2 %	>5 h	>50 cm	5	>20	>101	<1 n/km²	>4

Based on the FEM-assessment, the need for preservation and the restoration demand are determined. All active floodplains along the Austrian Danube should be preserved because at least one parameter is evaluated with 5 points (high performance) at each floodplain. Two floodplains show a low, one a medium and three a high demand for restoration (Table 20).

Table 20: Results of the need for preservation and restoration demand for all active floodplains along the Danube River in Austria and the Austrian/Slovakian section. In the last row, thresholds for the need for preservation (if one minimum FEM-parameter is evaluated with 5 – high performance, the floodplain has to be preserved) and restoration demand (<23 FEM-points – high, 23-26 points – medium, ≥ 27 low demand)

Floodplain ID	Need for preservation	Parameters with high performance	Demand for restoration	FEM-points
AT_DU_AFP_01	yes	peak reduction, wave translation, water level change	high demand	21
AT_DU_AFP_02	yes	water level change, protected species	high demand	21
AT_DU_AFP_03	yes	peak reduction, wave translation, water level change, protected species	medium demand	25
AT_DU_AFP_04	yes	peak reduction, wave translation, water level change, protected species, land use	low demand	27
AT_DU_AFP_05	yes	peak reduction, wave translation, water level change, protected species, land use	low demand	29
AT_SK_DU_AFP_01	yes	water level change, protected species	high demand	21
FEM-ranking	Need for preservation	threshold	restoration demand	threshold
	yes	at least one parameter evaluated with 5	low	≥ 27
			medium	23-26
	no	no parameter evaluated with 5	high	<23

3.2.3. FEM-Evaluation – potential floodplains (PFP) in Austria

Table 21 shows the results of the minimum FEM-parameters for all potential floodplains along the Austrian Danube. The performance of all minimum hydrological and hydraulic FEM-parameters is for both floodplains high. The relative peak reductions range from 8.51 to 13.06 %. The potential floodplains would lead to a flood wave translation from 6.25 to 22 h. In the case of a total loss of the potential floodplain, the water level in the river channel would change from 65 to 154 cm. The lateral connectivity is for one floodplain low and for the other medium. In both potential floodplains there are around 115 protected species leading to high performance in the FEM-evaluation. At one floodplain, the number of affected buildings per km² is much larger (17.65 n/km²) than 5, leading to low performance. The other potential floodplain shows a medium (1-5 n/km²) performance for the affected building's parameter. Both potential floodplains have a low vulnerability against flooding in terms of land use, resulting in high performance for this parameter in the FEM-evaluation.

Table 21: Results of the minimum Floodplain Evaluation Matrix (FEM) parameters for all identified potential floodplains along the Danube River in Austria. In the last row, thresholds for each parameter to determine the performance of each floodplain. High performance (5 points) in blue. Medium performance (3 points) in green. Low performance in orange (1 point).

country	Floodplain ID	Hydrology		Hydraulics	Ecology		Socio-Economics	
		peak reduction (%)	flood wave translation (h)	water level change (cm)	connectivity (-)	protected species (-)	affected buildings (n/km²)	land use (-)
Austria	AT_DU_PFP01	**13.06**	**22**	65	1	113	17.65	4.75
	AT_DU_PFP02	8.51	6.25	**154**	**3**	**116**	**1.01**	**4.85**
FEM-rating	performance	Thresholds	Thresholds	Thresholds	Thresholds	Thresholds	Thresholds	Thresholds
	1 (low)	<1 %	<1 h	<10 cm	1	0	>5 n/km²	<2
	3 (medium)	1-2 %	1-5 h	10 - 50 cm	3	1-20	1-5 n/km²	2-4
	5 (high)	>2 %	>5 h	>50 cm	5	>20	<1 n/km²	>4

3.2.4. Example of a floodplain factsheet (AT_DU_AFP_05)

The active floodplain AT_DU_AFP_05 starts at Wien and ends at the confluence of the Morava River. The total floodplain area is 85.3 km². The FEM-evaluation shows that there is a need for preservation of this floodplain and a low demand for restoration, due to the high performance of the evaluated parameters. In, the evaluation results are shown for each parameter and the coloured background indicates the performance (high – blue, medium – green, low – yellow) of the parameter. The performance is determined using the selected thresholds presented in chapter 2.2.2.

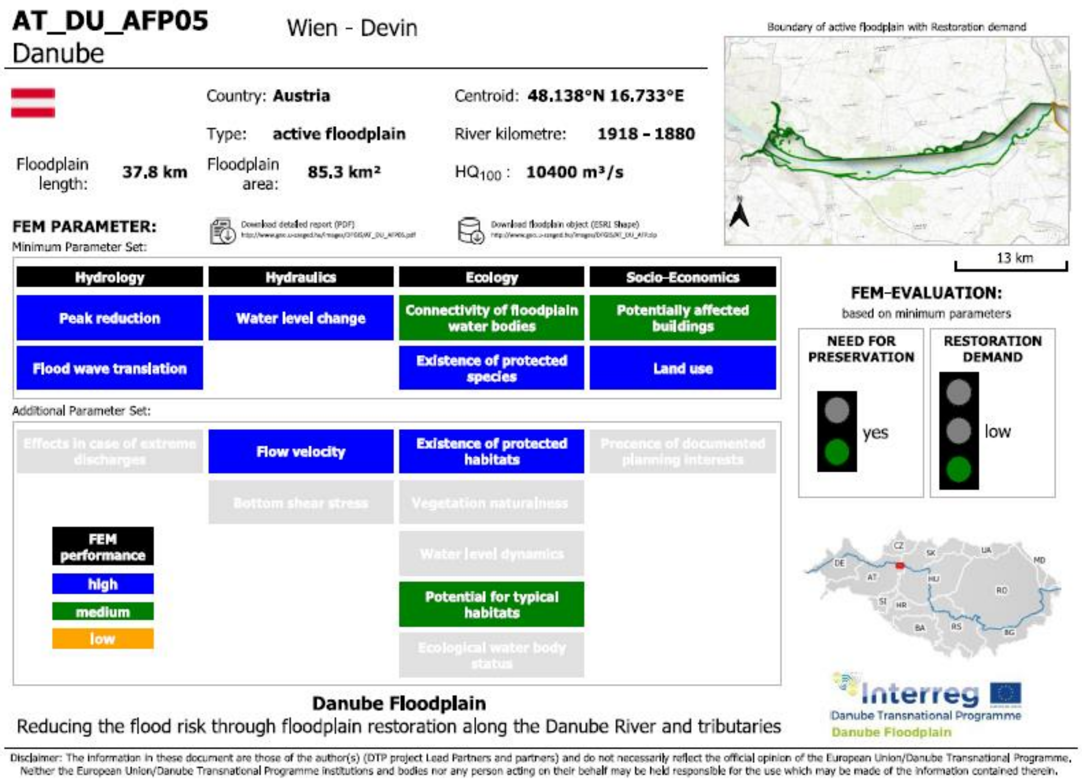


Figure 8: Factsheet for the active floodplain AT_DU_AFP_05

3.3. Slovakia/Hungary

3.3.1. Active and potential floodplains

At the transboundary Slovakian and Hungarian section of the Danube River, five active and one potential floodplains were identified. In Figure 9, the floodplain ID, the location and the area of all active and potential for all floodplains along the Slovakian/Hungarian section are shown. For the active floodplain, the restoration demand is also illustrated.

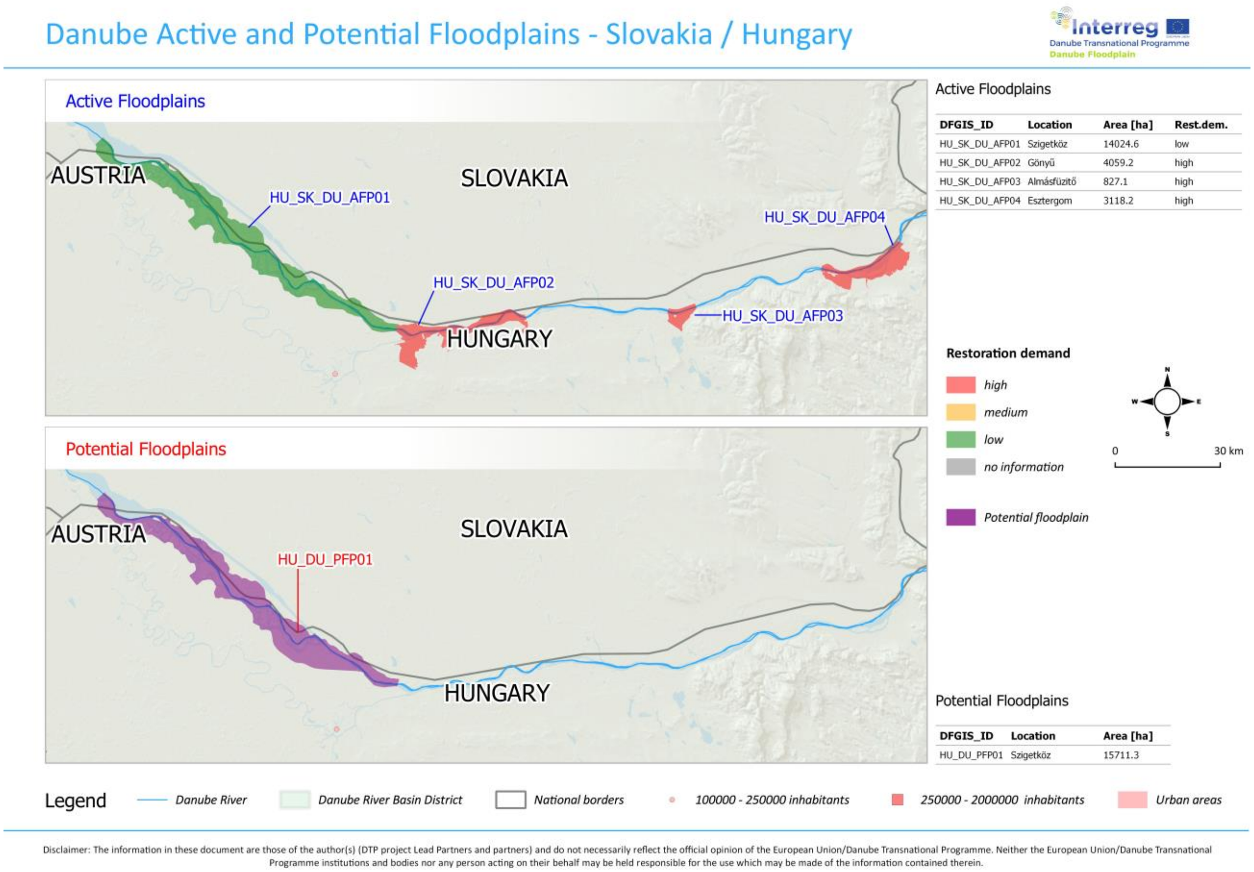


Figure 9: All active and potential floodplains along the Slovakian/Hungarian Danube (Danube Floodplain, 2021)

3.3.2. FEM-Evaluation – active (AFP) floodplains at the Slovakian/Hungarian section of the Danube River

Table 22 shows the results of the minimum FEM-parameters for all active floodplains along the Slovakian/Hungarian section of the Danube River*. One floodplain have a peak reduction of 11.4%, resulting in high performance (>2%) in the FEM-evaluation. The peak reduction for all other floodplains is less than 1%, leading to low performance (<1%). Due to the flow processes in the floodplains, the flood wave is decelerated from 0 to 7 h. One floodplain shows a high (>5h), two a medium (1-5h) and two a low (<1h) performance for the flood wave translation parameter. In the case of a total loss of the active floodplain, the water level in the river channel would change only for one floodplain above 50 cm, leading to high performance. For most other floodplains, the water level change in the river would be between 18 and 30 cm, resulting in medium performance. One floodplain shows a low performance (>10 cm) for this parameter. The lateral connectivity between the river channel and floodplain is impaired for three out five active floodplains along the Hungarian Danube by human interventions, leading to low performance. Two floodplains achieve a medium performance in terms of connectivity. More than 20 protected species are found at all floodplains, resulting in high performance for the first step of the ranking (=need for preservation). For the second step of the ranking, other thresholds are used for the protected species parameter to determine the restoration demand resulting in medium performance for all floodplains. At three floodplains, the number of affected buildings per km² is larger than 5, leading to a low performance for this parameter. For the other two floodplains, a medium performance was assessed. The land uses on three floodplains have a low vulnerability against flooding, resulting in a high performance. At two floodplains, the vulnerability is medium (3 – medium performance).

Table 22: Results of the minimum Floodplain Evaluation Matrix (FEM) parameters for all active floodplains along the Slovakian/Hungarian Danube section. In the last row, thresholds for each parameter to determine the performance of each floodplain. High performance (5 points) in blue. Medium performance (3 points) in green. Low performance in orange (1 point).

country	Floodplain	Hydrology		Hydraulics	Ecology			Socio-Economics	
		peak reduction (%)	flood wave translation (h)	water level change (cm)	connectivity (-)	protected species (-)		affected buildings (n/km²)	land use (-)
Slovakia, Hungary	HU_SK_DU_AFP_01	11.40	7	**158**	3	**70**	**70**	4.79	4.88
	HU_SK_DU_AFP_02	0.60	2	18	1	59	59	10.42	4.21
	HU_SK_DU_AFP_03	0.06	0	19	1	56	56	4.71	3.57
	HU_SK_DU_AFP_04	0.39	2	29	3	56	56	8.08	3.74
	HU_SK_DU_AFP_05	0.79	0.4	1	1	56	56	34.77	4.08
FEM-rating	performance	Thresholds	Thresholds	Thresholds	Thresholds	Thresholds		Thresholds	Thresholds
	low	<1 %	<1 h	<10 cm	1	0	<40	>5 n/km²	<2
	medium	1-2 %	1-5 h	10 - 50 cm	3	1-20	41-100	1-5 n/km²	2-4
	high	>2 %	>5 h	>50 cm	5	>20	>101	<1 n/km²	>4

*) Disclaimer on the hydraulic modelling approach:
The Hungarian colleagues chose a different modelling approach than all the other partners. They used a continuous hydraulic model to calculate the hydrological and hydraulic parameters for the Hungarian floodplains. All the other partners created separate models for each floodplain to calculate these parameters. The Hungarian colleagues also used a continuous model for the river channel model, assuming that all floodplains are lost and determined the impact on the water level. The main consequence of this is that the hydraulic parameter water level change becomes larger than if one uses a separate model for each individual floodplain. Therefore, the hydrological and hydraulic results for the Hungarian floodplains should only be compared among each other, as the results were obtained using the same method.

Based on the FEM-assessment, the need for preservation and the restoration demand are determined. All active floodplains along the Slovakian/Hungarian Danube section should be preserved because at least one parameter is evaluated with 5 points (high performance) at each floodplain. Four floodplains show a high and one a low demand for restoration based on the FEM-evaluation (Table 20).

Table 23: Results of the need for preservation and restoration demand for all active floodplains along the Slovakian/Hungarian Danube section. In the last row, thresholds for the need for preservation (if one minimum FEM-parameter is evaluated with 5 – high performance, the floodplain has to be preserved) and restoration demand (<23 FEM-points – high, 23-26 points – medium, ≥ 27 low demand)

Floodplain ID	Need for preservation	Parameters with high performance	Demand for restoration	FEM-points
HU_SK_DU_AFP_01	yes	peak reduction, wave translation, water level change, protected species, land use	low demand	29
HU_SK_DU_AFP_02	yes	protected species, land use	high demand	17
HU_SK_DU_AFP_03	yes	protected species	high demand	15
HU_SK_DU_AFP_04	yes	protected species	high demand	17
HU_SK_DU_AFP_05	yes	protected species, land use	high demand	13
FEM-ranking	Need for preservation	threshold	restoration demand	threshold
	yes	at least one parameter evaluated with 5	low	≥ 27
			medium	23-26
	no	no parameter evaluated with 5	high	<23

3.3.3. Example of a floodplain factsheet (HU_SK_DU_AFP01)

The active floodplain HU_SK_DU_AFP01 is 140.2 km² large. The FEM-Evaluation showed that there is a need for preservation of this floodplain and a low demand for restoration, due to the high performance of the evaluated parameters. In Figure 10, the evaluation results are shown for each parameter and the coloured background indicates the performance (high – blue, medium – green, low – yellow) of the parameter. The performance is determined using the selected thresholds presented in chapter 2.2.2.

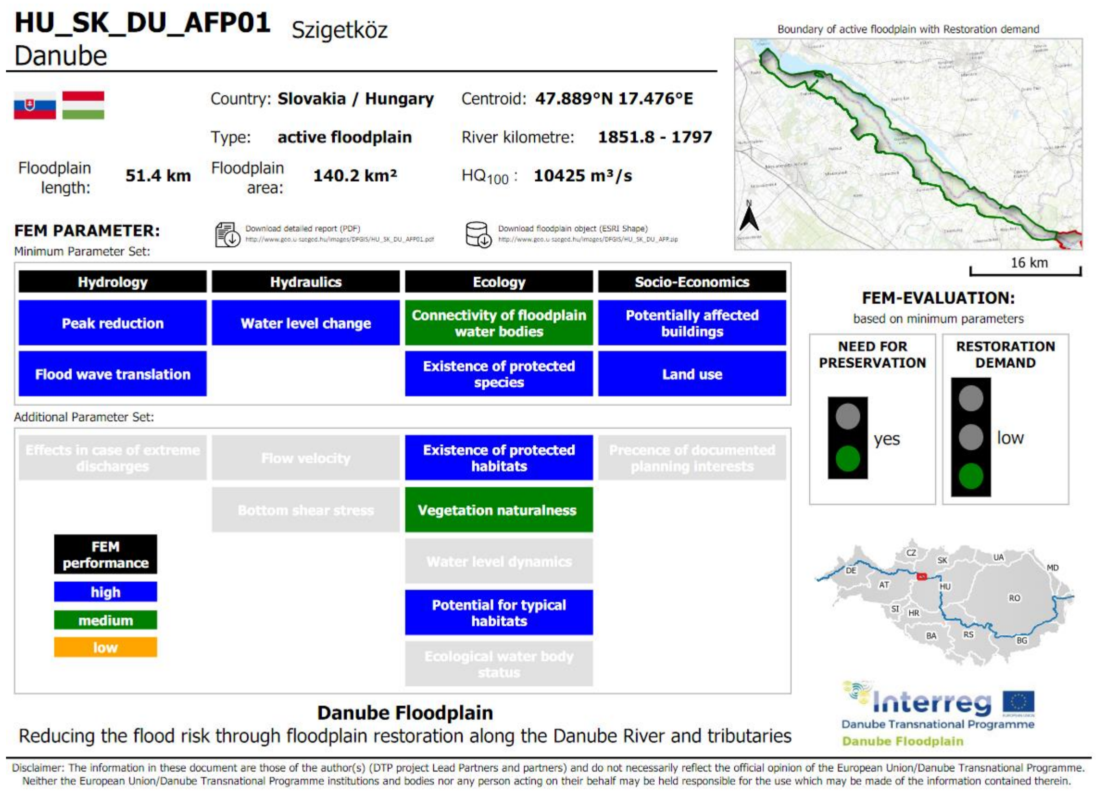
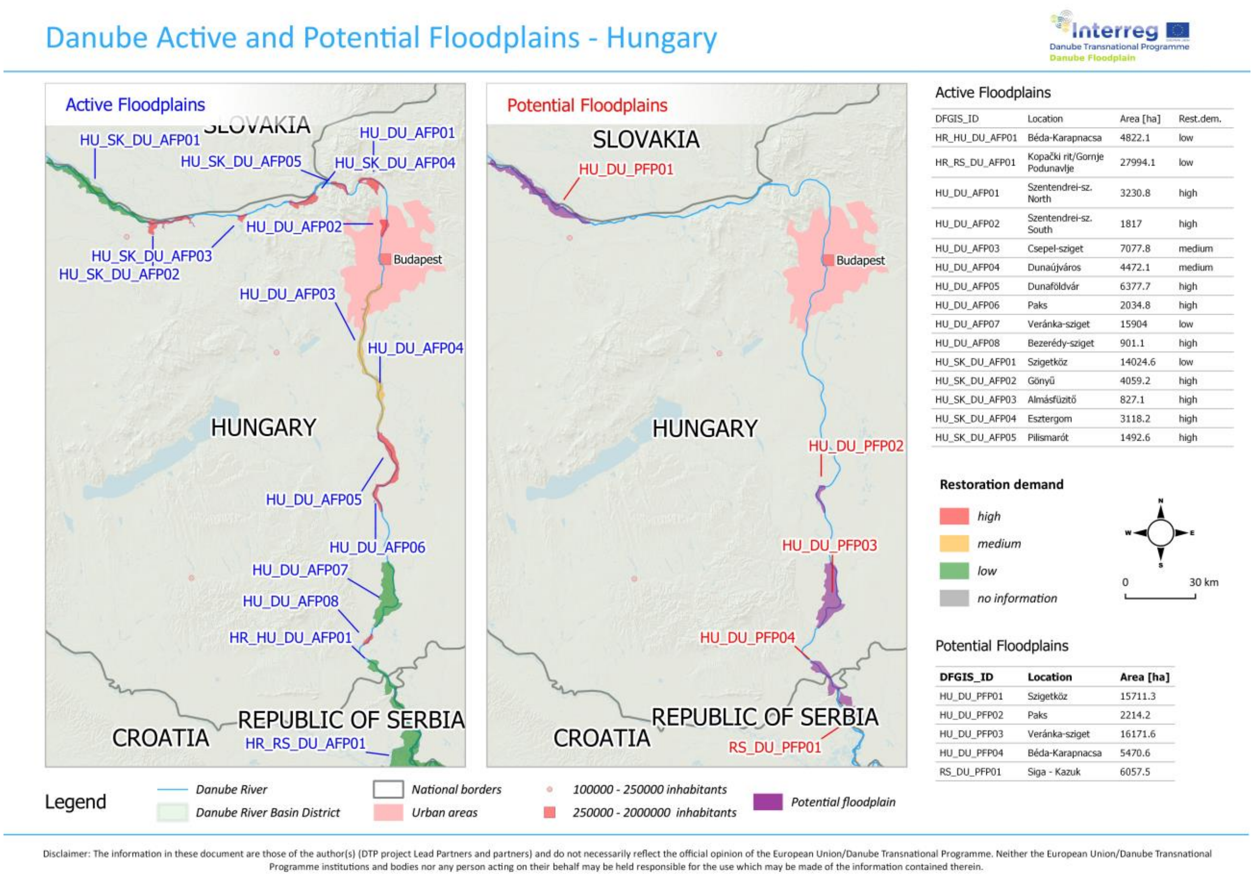


Figure 10: Factsheet for the active floodplain HU_SK_DU_AFP01

3.4. Hungary

3.4.1. Active and potential floodplains

At the Hungarian section of the Danube River, eight active and four potential floodplains were identified. A transboundary floodplain (HR_HU_AFP01) between Hungary, Croatia and Serbia was also identified. The results of this transboundary floodplain are also presented in this chapter. In Figure 11, the floodplain ID, the location and the area of all active and potential for all floodplains along the Hungarian section are shown. For the active floodplain, the restoration demand is also illustrated.



Active Floodplains

DFGIS_ID	Location	Area [ha]	Rest.dem.
HR_HU_DU_AFP01	Béda-Karapnacsa	4822.1	low
HR_RS_DU_AFP01	Kopački rit/Gornje Podunavlje	27994.1	low
HU_DU_AFP01	Szentendrei-sz. North	3230.8	high
HU_DU_AFP02	Szentendrei-sz. South	1817	high
HU_DU_AFP03	Csepel-sziget	7077.8	medium
HU_DU_AFP04	Dunaújváros	4472.1	medium
HU_DU_AFP05	Dunaföldvár	6377.7	high
HU_DU_AFP06	Paks	2034.8	high
HU_DU_AFP07	Veránka-sziget	15904	low
HU_DU_AFP08	Bezerédy-sziget	901.1	high
HU_SK_DU_AFP01	Szigetköz	14024.6	low
HU_SK_DU_AFP02	Gönyű	4059.2	high
HU_SK_DU_AFP03	Almásfüzitő	827.1	high
HU_SK_DU_AFP04	Esztergom	3118.2	high
HU_SK_DU_AFP05	Pilismarót	1492.6	high

Potential Floodplains

DFGIS_ID	Location	Area [ha]
HU_DU_PFP01	Szigetköz	15711.3
HU_DU_PFP02	Paks	2214.2
HU_DU_PFP03	Veránka-sziget	16171.6
HU_DU_PFP04	Béda-Karapnacsa	5470.6
RS_DU_PFP01	Siga - Kazuk	6057.5

Figure 11: All active and potential floodplains along the Hungarian Danube (Danube Floodplain, 2021)

3.4.2. FEM-Evaluation – active floodplains (AFP) in Hungary

Table 24 shows the results of the minimum FEM-parameters for all active floodplains along the Hungarian section of the Danube River*.The relative peak reductions range from 0.05 to 5.22 resulting in two floodplains with high (>5%), four with medium (1-2%) and three with low (<1%). performance. Due to the flow processes in the floodplains, the flood wave is decelerated from 0 to 7 h. Three floodplains show a high (>5h), three a medium (1-5h) and three a low (<1h) performance for the flood wave translation parameter. In the case of a total loss of the active floodplain, the water level in the river channel would change for almost all floodplains more than 50 cm, leading to high performance. Only two floodplains show a low and a medium performance. The lateral connectivity is for one floodplain low and for the others medium. More than 20 protected species are found at all floodplains, resulting in high performance for the first step of the ranking (=need for preservation). For the second step of the ranking, other thresholds are used for the protected species parameter to determine the restoration demand resulting in four floodplains with a medium and five with a low performance. Only at four floodplains (two medium and two high performance), the number of affected buildings per km² is less than 5, leading to five floodplains with a low performance. Most of the active floodplains at the Hungarian section have a low vulnerability against flooding (=high performance). One floodplain shows a medium performance.

Table 24: Results of the minimum Floodplain Evaluation Matrix (FEM) parameters for all active floodplains along the Hungarian Danube section. In the last row, thresholds for each parameter to determine the performance of each floodplain. High performance (5 points) in blue. Medium performance (3 points) in green. Low performance in orange (1 point).

country	Floodplain	Hydrology		Hydraulics	Ecology			Socio-Economics	
		peak reduction (%)	flood wave translation (h)	water level change (cm)	connectivity (-)	protected species (-)		affected buildings (n/km²)	land use (-)
Hungary	HU_DU_AFP_01	2.61	0	73	1	56	56	24.48	3.88
	HU_DU_AFP_02	0.05	3	34	3	35	35	25.37	4.25
	HU_DU_AFP_03	1.69	6	76	3	33	33	7.85	4.23
	HU_DU_AFP_04	1.03	7	79	3	33	33	8.52	4.42
	HU_DU_AFP_05	1.49	1	2	3	27	27	4.01	4.05
	HU_DU_AFP_06	0.34	0.5	86	3	27	27	2.61	4.69
	HU_DU_AFP_07	5.22	7	120	3	75	75	12.62	4.42
	HU_DU_AFP_08	0.20	0	125	3	**82**	**82**	0.99	4.95
	HU_HR_DU_AFP_01	1.41	5	128	3	**82**	**82**	0.14	4.91
FEM-rating	performance	Thresholds	Thresholds	Thresholds	Thresholds	Thresholds		Thresholds	Thresholds
	low	<1 %	<1 h	<10 cm	1	0	<40	>5 n/km²	<2
	medium	1-2 %	1-5 h	10 - 50 cm	3	1-20	41-100	1-5 n/km²	2-4
	high	>2 %	>5 h	>50 cm	5	>20	>101	<1 n/km²	>4

*) Disclaimer on the hydraulic modelling approach:
The Hungarian colleagues chose a different modelling approach than all the other partners. They used a continuous hydraulic model to calculate the hydrological and hydraulic parameters for the Hungarian floodplains. All the other partners created separate models for each floodplain to calculate these parameters. The Hungarian colleagues also used a continuous model for the river channel model, assuming that all floodplains are lost and determined the impact on the water level. The main consequence of this is that the hydraulic parameter water level change becomes larger than if one uses a separate model for each individual floodplain

Based on the FEM-assessment, the need for preservation and the restoration demand are determined. All active floodplains along the Hungarian Danube section should be preserved because at least one parameter is evaluated with 5 points (high performance) at each floodplain. Five floodplains show a high, two a medium and two a low demand for restoration based on the FEM-evaluation (Table 25).

Table 25: Results of the need for preservation and restoration demand for all active floodplains along the Hungarian Danube section. In the last row, thresholds for the need for preservation (if one minimum FEM-parameter is evaluated with 5 – high performance, the floodplain has to be preserved) and restoration demand (<23 FEM-points – high, 23-26 points – medium, ≥ 27 low demand)

Floodplain ID	Need for preservation	Parameters with high performance	Demand for restoration	FEM-points
HU_DU_AFP_01	yes	peak reduction, water level change, protected species	high demand	19
HU_DU_AFP_02	yes	protected species, land use	high demand	17
HU_DU_AFP_03	yes	wave translation, water level change, protected species, land use	medium demand	23
HU_DU_AFP_04	yes	wave translation, water level change, protected species, land use	medium demand	23
HU_DU_AFP_05	yes	protected species, land use	high demand	19
HU_DU_AFP_06	yes	water level change, protected specie, land use	high demand	19
HU_DU_AFP_07	yes	peak reduction, wave translation, water level change, protected species, land use	low demand	27
HU_DU_AFP_08	yes	water level change, protected specie, land use, affected buildings	high demand	22
HU_HR_DU_AFP_01	yes	wave translation, water level change, protected species, affected buildings, land use	low demand	27
FEM-ranking	Need for preservation	threshold	restoration demand	threshold
	yes	at least one parameter evaluated with 5	low	≥ 27
			medium	23-26
	no	no parameter evaluated with 5	high	<23

3.4.3. FEM-Evaluation – potential floodplains (PFP) in Hungary

Table 26 shows the results of the minimum FEM-parameters for all potential floodplains along the Hungarian Danube. The relative peak reductions range from 0.42 to 11.61%, resulting in two floodplains with high (>2%), one with medium (1-2%) and one with low (<1%) performance. The flood wave is decelerated from 3 up to 9 h. Three floodplains show a medium (1-5h) and one a high (>5h) performance for the flood wave translation parameter. In the case of a total loss of the potential floodplain, the water level in the river channel would increase by more than 50 cm for all potential floodplains leading to a high performance. The lateral connectivity between the river channel and floodplain is still impaired for all potential floodplains along the Hungarian Danube by human interventions, leading to medium performance for all of them. At all floodplains, more than 20 protected species are found. Only at one floodplain less than 1 building is found per km² (=high performance). At three floodplains, the number of affected buildings per km² is between 1 and 5 (=medium performance). The land uses on all four floodplains show a low vulnerability against flooding, resulting in a high performance.

Table 26: Results of the minimum Floodplain Evaluation Matrix (FEM) parameters for all identified potential floodplains along the Danube River in Hungary. In the last row, thresholds for each parameter to determine the performance of each floodplain. High performance (5 points) in blue. Medium performance (3 points) in green. Low performance in orange (1 point).

Country	Floodplain ID	Hydrology		Hydraulics	Ecology		Socio-Economics	
		peak reduction (%)	flood wave translation (h)	water level change (cm)	connectivity (-)	protected species (-)	affected buildings (n/km²)	land use (-)
Hungary	HU_DU_PFP01	**11.61**	3	66	**3**	70	5.00	4.75
	HU_DU_PFP02	0.42	3	96	**3**	27	2.00	4.56
	HU_DU_PFP03	5.37	**9**	125	**3**	75	3.00	4.81
	HU_DU_PFP04	1.65	5	**130**	**3**	**82**	**0**	**4.90**
FEM-rating	performance	Thresholds	Thresholds	Thresholds	Thresholds	Thresholds	Thresholds	Thresholds
	1 (low)	<1 %	<1 h	<10 cm	1	0	>5 n/km²	<2
	3 (medium)	1-2 %	1-5 h	10 - 50 cm	3	1-20	1-5 n/km²	2-4
	5 (high)	>2 %	>5 h	>50 cm	5	>20	<1 n/km²	>4

3.4.4. Example of a floodplain factsheet (HU_DU_AFP07)

The active floodplain Veranka-Sziget (HU_DU_AFP07) has an area of 85.3 km². The FEM-Evaluation showed that there is a need for preservation of this floodplain and a low demand for restoration, due to the high performance of the evaluated parameters. In, the evaluation results are shown for each parameter and the coloured background indicates the performance (high – blue, medium – green, low – yellow) of the parameter. The performance is determined using the selected thresholds presented in chapter 2.2.2.

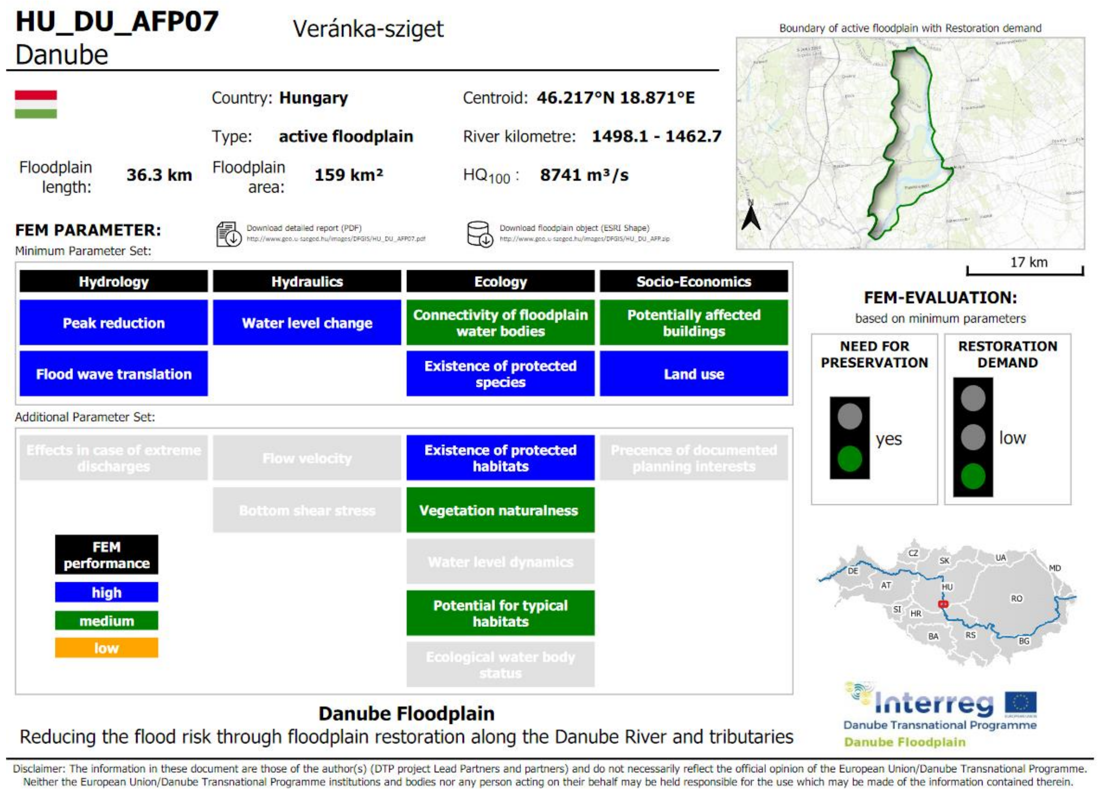


Figure 12: Factsheet of the floodplain HU_DU_AFP07

3.5. Croatia/Serbia

3.5.1. Active and potential floodplains

At the Croatian/Serbian section of the Danube River, five active and three potential floodplains (on the Serbian side) were identified. InFigure 13, the floodplain ID, the location and the area of all active and potential for all floodplains along the Croatian/Serbian section are shown. For the active floodplain, the restoration demand is also illustrated.

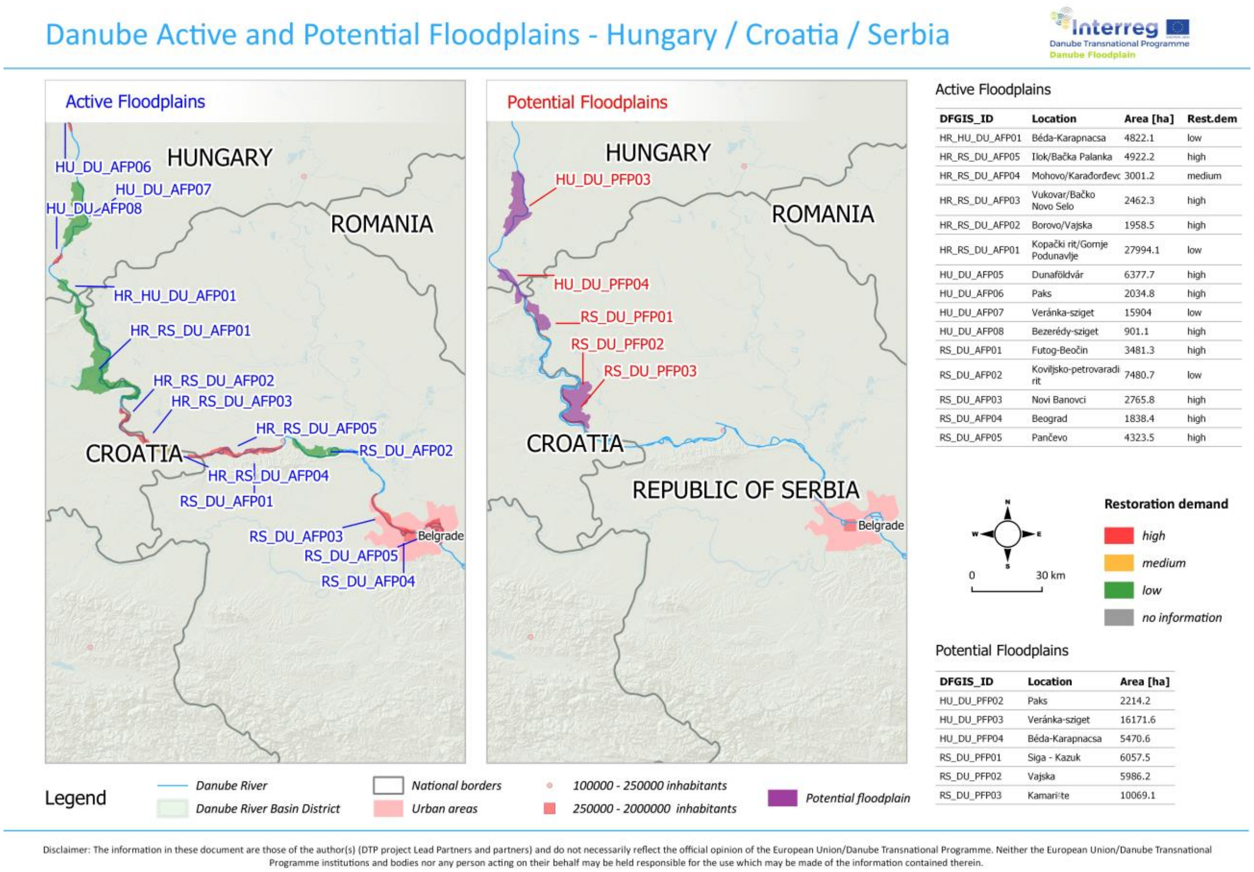


Figure 13: All active and potential floodplains along the Croatian/Serbian Danube section (Danube Floodplain, 2021)

3.5.2. FEM-Evaluation – active floodplains (AFP) at the Croatian/Serbian section of the Danube

Table 24 shows the results of the minimum FEM-parameters for all active floodplains along the Croatian/Serbian section of the Danube River. Only one floodplain shows a high relative peak reduction of 4.04%, resulting in high performance (>2%) in the FEM-evaluation. The peak reduction for all other floodplains is less than 1%, leading to a low performance (<1%). Due to the flow processes in the floodplains, the flood wave is decelerated from 2 to 41.5 h. Two floodplains show a high (>5h) and three a medium (1-5h) performance for the flood wave translation parameter. In the case of a total loss of the active floodplain, the water level in the river channel would change only for one floodplain above 50 cm, leading to high performance. For all the other floodplains, the water level change in the river channel would be between 15 and 48 cm, resulting in medium performance. The lateral connectivity between the river channel and floodplain is impaired for four out five active floodplains along the Croatian/Serbian Danube by human interventions, leading to low performance. One floodplain achieves a medium performance in terms of connectivity. More than 20 protected species are found at all floodplains, resulting in high performance for the first step of the ranking (=need for preservation). For the second step of the ranking, other thresholds are used for the protected species parameter to determine the restoration demand resulting in two floodplains with a high and three with a medium performance*. At three floodplains, the number of affected buildings per km² is between 1-5 leading to medium performance. Two floodplains achieve a high performance for this parameter. All floodplains at the Croatian/Serbian Danube have a low vulnerability against flooding (=high performance).

Table 27: Results of the minimum Floodplain Evaluation Matrix (FEM) parameters for all active floodplains along the Croatian/Serbian Danube section. In the last row, thresholds for each parameter to determine the performance of each floodplain. High performance (5 points) in blue. Medium performance (3 points) in green. Low performance in orange (1 point).

country	Floodplain	Hydrology		Hydraulics	Ecology			Socio-Economics	
		peak reduction (%)	flood wave translation (h)	water level change (cm)	connectivity (-)	protected species (-)		affected buildings (n/km²)	land use (-)
Croatia, Serbia	RS_HR_DU_AFP_01	4.04	41.5	70	1	**144**	**144**	1.78	4.90
	RS_HR_DU_AFP_02	0.14	2	15	1	80	80	0.87	4.80
	RS_HR_DU_AFP_03	0.25	2.5	30	1	80	80	0.53	4.97
	RS_HR_DU_AFP_04	0.28	2.5	16	3	103	103	1.20	4.96
	RS_HR_DU_AFP_05	0.68	5	48	1	87	87	3.70	4.82
FEM-rating	performance	Thresholds	Thresholds	Thresholds	Thresholds	Thresholds		Thresholds	Thresholds
	low	<1 %	<1 h	<10 cm	1	0	<40	>5 n/km²	<2
	medium	1-2 %	1-5 h	10 - 50 cm	3	1-20	41-100	1-5 n/km²	2-4
	high	>2 %	>5 h	>50 cm	5	>20	>101	<1 n/km²	>4

*) Disclaimer on the number of protected species in the common HR-RS section of the Danube River:

Not yet having Natura 2000 fully transposed in the relevant legislative and aiming at providing as harmonised data as possible for the common HR-RS section of the Danube River, the Serbian Project partner (JCI) used available information on protected species stated in the EMERALD network for RS_HR_DU_AFP01, RS_HR_DU_AFP04 and RS_HR_DU_AFP05 where protected areas "Gornje Podunavlje", "Karadjordjevo" and "Tikvara" and "Begecka Jama" (respectively) exist. The exercise of counting the total number of protected species in these active floodplains is carried out based on NATURA 2000 data for HR and EMERALD information for RS and agreed between two partners (CW and JCI). Having no data in RS for another two common active floodplains RS_HR_DU_AFP02 and RS_HR_DU_AFP03, the number of protected species is based exclusively on the Croatian data.

Based on the FEM-assessment, the need for preservation and the restoration demand are determined. All active floodplains along the Croatian/Serbian Danube section should be preserved because at least one parameter is evaluated with 5 points (high performance) at each floodplain. One floodplain shows a low demand for restoration. Three floodplains have a high and one a medium demand for restoration based on the FEM-evaluation (Table 28).

Table 28: Results of the need for preservation and restoration demand for all active floodplains along the Croatian/Serbian Danube section. In the last row, thresholds for the need for preservation (if one minimum FEM-parameter is evaluated with 5 – high performance, the floodplain has to be preserved) and restoration demand (<23 FEM-points – high, 23-26 points – medium, ≥ 27 low demand)

Floodplain ID	Need for preservation	Parameters with high performance	Demand for restoration	FEM-points
RS_HR_DU_AFP_01	yes	peak reduction, water level change, wave translation, protected species, land use	low demand	29
RS_HR_DU_AFP_02	yes	protected species, affected buildings, land use	high demand	21
RS_HR_DU_AFP_03	yes	protected species, affected buildings, land use	high demand	21
RS_HR_DU_AFP_04	yes	protected species, land use	medium demand	23
RS_HR_DU_AFP_05	yes	protected species, land use	high demand	19
FEM-ranking	Need for preservation	threshold	restoration demand	threshold
	yes	at least one parameter evaluated with 5	low	≥ 27
			medium	23-26
	no	no parameter evaluated with 5	high	<23

3.5.3. FEM-Evaluation – potential floodplains (PFP) at the Croatian/Serbian section of the Danube

Table 26 shows the results of the minimum FEM-parameters for all potential floodplains along the Croatian/Serbian Danube. The potential floodplains at this section are on the Serbian side. The relative peak reductions range from 0.92 to 2.73%, resulting in one floodplain with high (>2%) and two with low (<1%) performance. All floodplains show a high performance for the flood wave translation parameter (>5h). In the case of a total loss of the potential floodplain, the water level in the river channel would increase by more than 50 cm for two potential floodplains leading to a high performance. For one potential floodplain, the water level would increase only 9 cm (=low performance). The lateral connectivity between river and floodplain water bodies would be for two floodplains restored resulting in high performance. At the other floodplain, the connectivity would be partly impaired (=medium performance). At all floodplains, more than 20 protected species are found*. Only at one floodplain, the number of affected buildings per km² is between 1 and 5 (=medium performance). For the other twos, less than 1 building per km² is found. The land uses have for two floodplains a medium and for one a low vulnerability against flooding.

Table 29: Results of the minimum Floodplain Evaluation Matrix (FEM) parameters for all identified potential floodplains along the Croatian/Serbian Danube River. In the last row, thresholds for each parameter to determine the performance of each floodplain. High performance (5 points) in blue. Medium performance (3 points) in green. Low performance in orange (1 point).

Country	Floodplain ID	Hydrology		Hydraulics	Ecology		Socio-Economics	
		peak reduction (%)	flood wave translation (h)	water level change (cm)	connectivity (-)	protected species (-)	affected buildings (n/km²)	land use (-)
Serbia	RS_DU_PFP01	2.73	16	66	3	173	0.17	4.95
	RS_DU_PFP02	0.92	11	9	5	240	0.25	3.05
	RS_DU_PFP03	0.92	8	193	5	240	1.62	3.30
FEM-rating	performance	Thresholds	Thresholds	Thresholds	Thresholds	Thresholds	Thresholds	Thresholds
	1 (low)	<1 %	<1 h	<10 cm	1	0	>5 n/km²	<2
	3 (medium)	1-2 %	1-5 h	10 - 50 cm	3	1-20	1-5 n/km²	2-4
	5 (high)	>2 %	>5 h	>50 cm	5	>20	<1 n/km²	>4

*) Disclaimer on the number of protected species in the common HR-RS section of the Danube River:

Not yet having Natura 2000 fully transposed in the relevant legislative and aiming at providing as harmonised data as possible for the common HR-RS section of the Danube River, the Serbian Project partner (JCI) used available information on protected species stated in the EMERALD network for RS_HR_DU_AFP01, RS_HR_DU_AFP04 and RS_HR_DU_AFP05 where protected areas "Gornje Podunavlje", "Karadjordjevo" and "Tikvara" and "Begecka Jama" (respectively) exist. The exercise of counting the total number of protected species in these active floodplains is carried out based on NATURA 2000 data for HR and EMERALD information for RS and agreed between two partners (CW and JCI). Having no data in RS for another two common active floodplains RS_HR_DU_AFP02 and RS_HR_DU_AFP03, the number of protected species is based exclusively on the Croatian data.

3.5.4. Example of a floodplain factsheet (HR_RS_DU_AFP01)

The active floodplain HR_RS_DU_AFP01 is one of the largest floodplains with an area of 279.9 km². The FEM-Evaluation showed that there is a need for preservation of this floodplain and a low demand for restoration, due to the high performance of the evaluated parameters. In Figure 14, Figure 22 the evaluation results are shown for each parameter and the coloured background indicates the performance (high – blue, medium – green, low – yellow) of the parameter. The performance is determined using the selected thresholds presented in chapter 2.2.2.

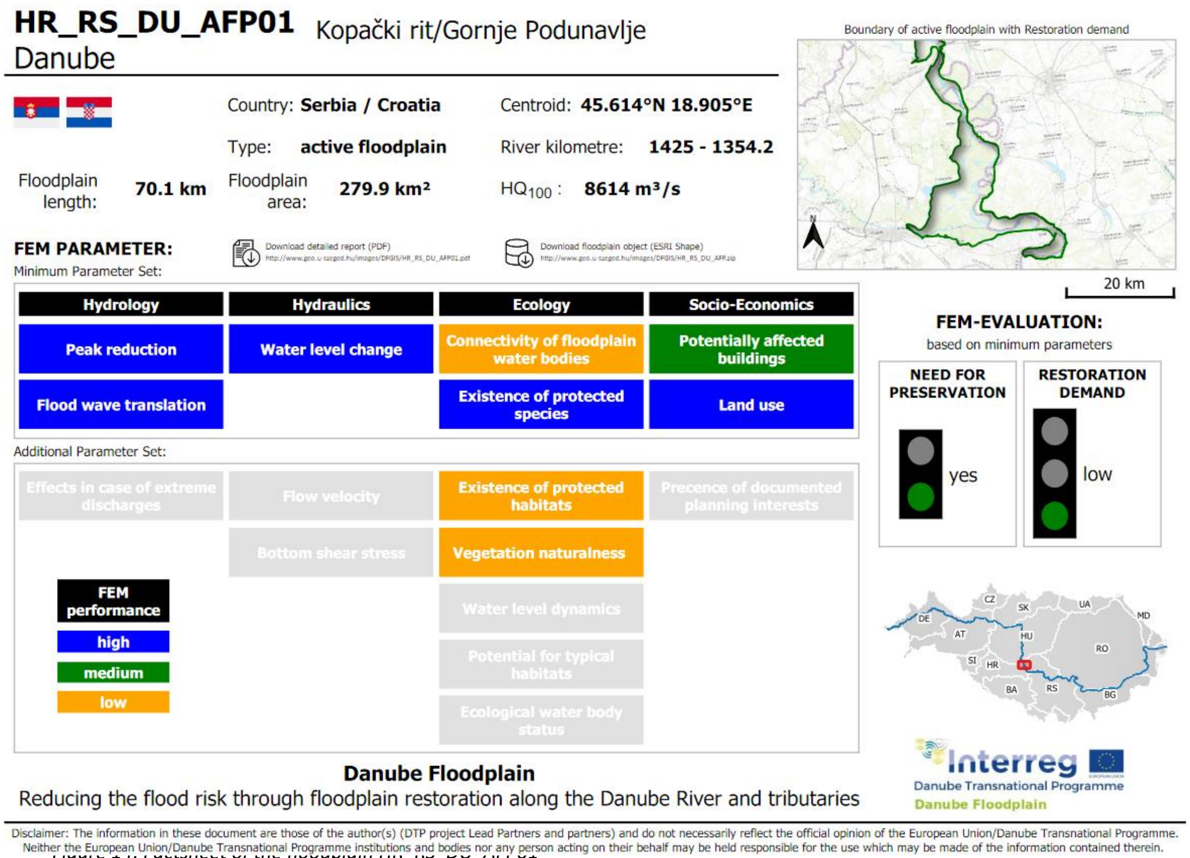


Figure 14: Factsheet of the floodplain HR_RS_DU_AFP01

3.6. Serbia

3.6.1. Active floodplains

At the Serbian section of the Danube River, five active and three potential floodplains were identified. The potential floodplains were presented in the last chapter. In Figure 15, the floodplain ID, the location, the area and the restoration demand of all active floodplains along the Serbian section are shown.

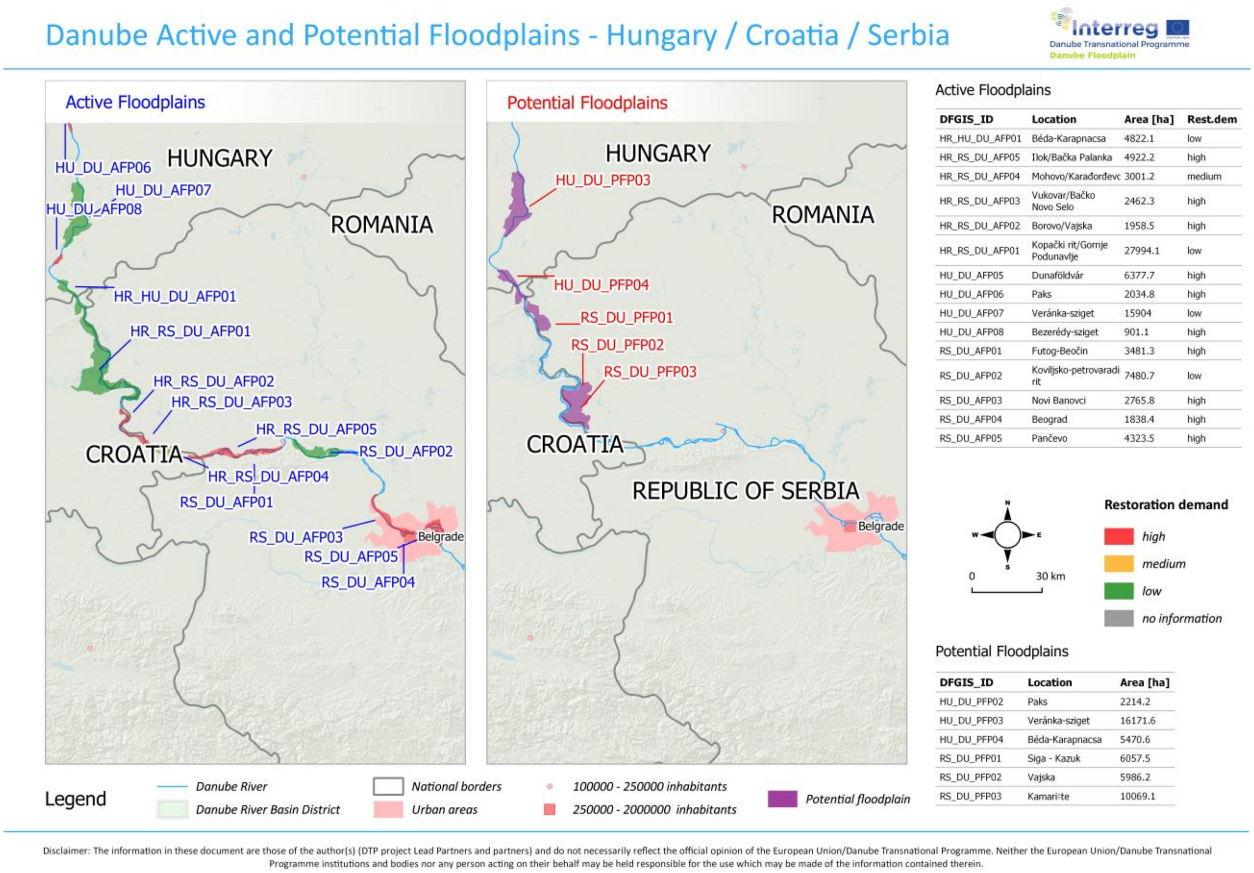


Figure 15: All active and potential floodplains along the Serbian Danube section (Danube Floodplain, 2021)

3.6.2. FEM-Evaluation – active floodplains (AFP) in Serbia

Table 30 shows the results of the minimum FEM-parameters for all active floodplains along the Serbian section of the Danube River. Only one floodplain shows a relative peak reduction above 2%, resulting in high performance in the FEM-evaluation. The peak reduction for all other floodplain is less than 1%, leading to low performance (<1%). Due to the flow processes in the floodplains, the flood wave is decelerated from 2.5 to 7.5 h. One floodplains shows a high (>5h) and four a medium (1-5h) performance for the flood wave translation parameter. In the case of a total loss of the active floodplain, the water level in the river channel would change only for one floodplain above 10 cm, leading to one medium and four low performances. The lateral connectivity between the river channel and floodplain is impaired for all active floodplains leading to two low and three medium performances for the connectivity parameter. More than 20 protected species are found at all floodplains, resulting in high performance for the first step of the ranking (=need for preservation). For the second step of the ranking, other thresholds are used for the protected species parameter to determine the restoration demand resulting in two floodplains with a high and three with a medium performance*. At three floodplains, the number of affected buildings per km^2 is less than 1 leading to a high performance. The other two floodplains receive a low and a medium performance. All floodplains at the Serbian section have a low vulnerability against flooding (=high performance).

Table 30: Results of the minimum Floodplain Evaluation Matrix (FEM) parameters for all active floodplains along the Serbian Danube section. In the last row, thresholds for each parameter to determine the performance of each floodplain. High performance (5 points) in blue. Medium performance (3 points) in green. Low performance in orange (1 point).

country	Floodplain	Hydrology		Hydraulics	Ecology			Socio-Economics	
		peak reduction (%)	flood wave translation (h)	water level change (cm)	connectivity (-)	protected species (-)		affected buildings (n/km^2)	land use (-)
Serbia	RS_DU_AFP_01	0.66	3	17	1	59	59	22.20	4.62
	RS_DU_AFP_02	2.21	7.5	8	1	**271**	**271**	0.13	4.95
	RS_DU_AFP_03	0.02	4	3	3	70	70	0.00	4.97
	RS_DU_AFP_04	0.27	3	1	3	60	60	0.27	4.79
	RS_DU_AFP_05	0.01	2.5	1	3	149	149	1.53	4.71
FEM-rating	performance	Thresholds	Thresholds	Thresholds	Thresholds	Thresholds		Thresholds	Thresholds
	low	<1 %	<1 h	<10 cm	1	0	<40	>5 n/km^2	<2
	medium	1-2 %	1-5 h	10 - 50 cm	3	1-20	41-100	1-5 n/km^2	2-4
	high	>2 %	>5 h	>50 cm	5	>20	>101	<1 n/km^2	>4

*) Disclaimer on the number of protected species in the RS section of the Danube River:

Not yet having Natura 2000 fully transposed in the relevant legislative, the Serbian Project partner (JCI) provided the information on protected species based on either information available in Studies on Protected Areas or on unofficial estimation supplied by relevant experts from the Nature conservation Institutes.

Based on the FEM-assessment, the need for preservation and the restoration demand are determined. All active floodplains along the Serbian Danube section should be preserved because at least one parameter is evaluated with 5 points (high performance) at each floodplain. One floodplain shows a low demand for restoration. All the other floodplains have high demand for restoration based on the FEM-evaluation (Table 31).

Table 31: Results of the need for preservation and restoration demand for all active floodplains along the Serbian Danube section. In the last row, thresholds for the need for preservation (if one minimum FEM-parameter is evaluated with 5 – high performance, the floodplain has to be preserved) and restoration demand (<23 FEM-points – high, 23-26 points – medium, ≥ 27 low demand)

Floodplain ID	Need for preservation	Parameters with high performance	Demand for restoration	FEM-points
RS_DU_AFP_01	yes	protected species, land use	high demand	17
RS_DU_AFP_02	yes	peak reduction, wave translation, protected species, affected buildings, land use	low demand	27
RS_DU_AFP_03	yes	protected species, affected buildings, land use	high demand	21
RS_DU_AFP_04	yes	protected species, affected buildings, land use	high demand	21
RS_DU_AFP_05	yes	protected species, land use	high demand	21
FEM-ranking	Need for preservation	threshold	restoration demand	threshold
	yes	at least one parameter evaluated with 5	low	≥ 27
			medium	23-26
	no	no parameter evaluated with 5	high	<23

3.6.3. Example of a floodplain factsheet (RS_DU_AFP02)

The active floodplain RS_DU_AFP02 is 74.8 km² large. The FEM-Evaluation showed that there is a need for preservation of this floodplain and a low demand for restoration, due to the high performance of the evaluated parameters. In Figure 16, the evaluation results are shown for each parameter and the coloured background indicates the performance (high – blue, medium – green, low – yellow) of the parameter. The performance is determined using the selected thresholds presented in chapter 2.2.2

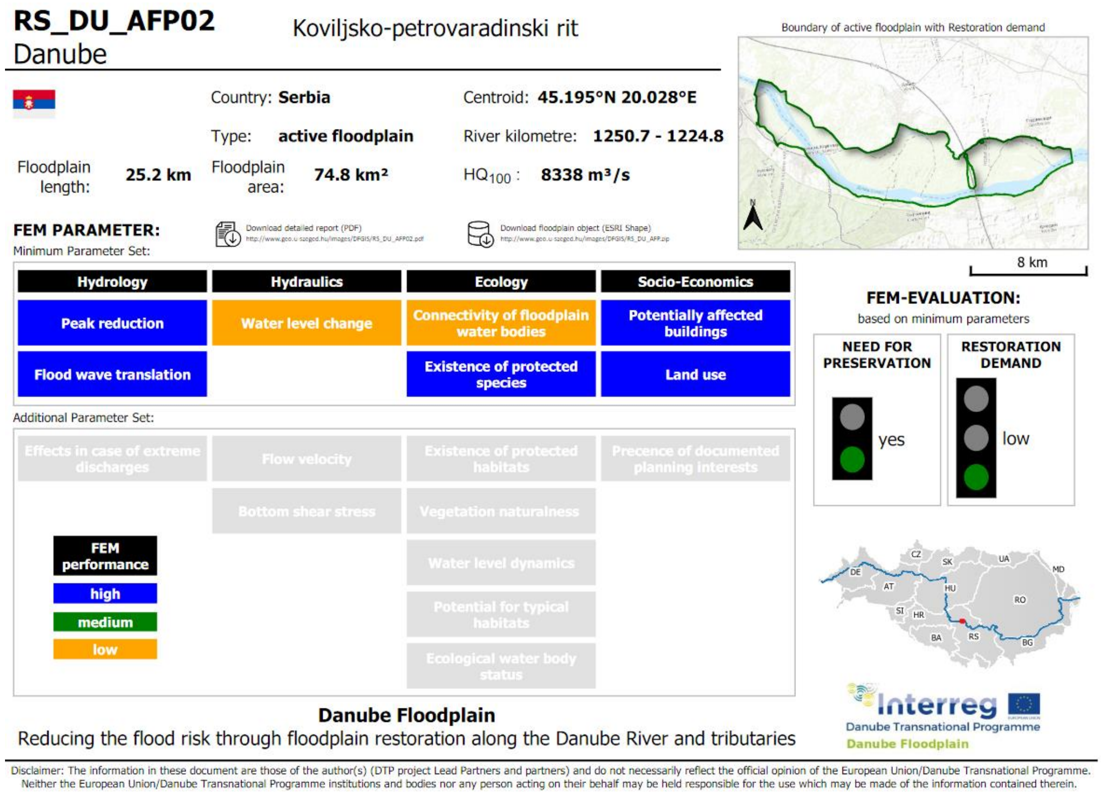


Figure 16: Factsheet of the floodplain RS_DU_AFP02

3.7. Bulgaria/Romania

3.7.1. Active and potential floodplains

At the Bulgarian/Romanian section of the Danube River, six active and five potential floodplains were identified. In Figure 17, the floodplain ID, the location, the area and the restoration demand of all active and potential floodplains along the Bulgarian/Romanian section are shown. For the active floodplain, the restoration demand is also illustrated.

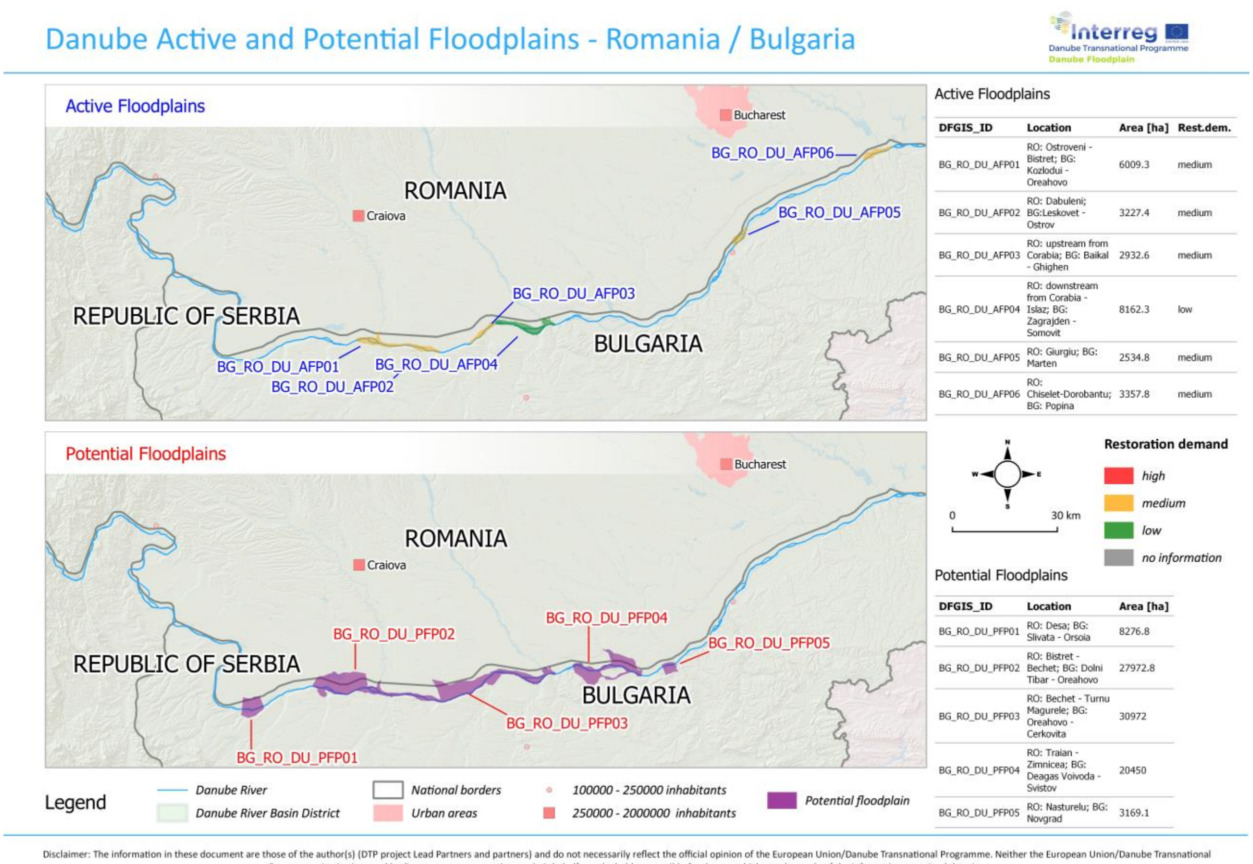


Figure 17: All active and potential floodplains along the Bulgarian/Romanian Danube section (Danube Floodplain, 2021

3.7.2. FEM-Evaluation – active floodplains (AFP) at the Bulgarian/Romanian section of the Danube

Table 32 shows the results of the minimum FEM-parameters for all active floodplains along the Bulgarian/Romanian section of the Danube River. All floodplains show a relative peak reduction below 1%, resulting in low performance in the FEM-evaluation. Due to the flow processes in the floodplains, the flood wave is decelerated from 1 to 4 h. Hence, all floodplains were evaluated with a 3 (=medium performance). In the case of a total loss of the active floodplain, the water level in the river channel would change between 12 and 13 cm for three floodplains (=medium performance) and between 4 and 8 cm (=low performance) for the other three. The lateral connectivity between the river channel and floodplain is impaired for all active floodplains leading to medium performances for the connectivity parameter. More than 20 protected species are found at all floodplains, resulting in high performance for the first step of the ranking (=need for preservation). For the second step of the ranking, other thresholds are used for the protected species parameter to determine the restoration demand resulting in five floodplains with a high and one with a medium performance. At all floodplains less than 1 building per km² is found (=high performance). All floodplains at the Bulgarian/Romanian section have a low vulnerability against flooding (=high performance).

Table 32: Results of the minimum Floodplain Evaluation Matrix (FEM) parameters for all active floodplains along the Bulgarian/Romanian Danube section. In the last row, thresholds for each parameter to determine the performance of each floodplain. High performance (5 points) in blue. Medium performance (3 points) in green. Low performance in orange (1 point).

country	Floodplain	Hydrology		Hydraulics	Ecology			Socio-Economics	
		peak reduction (%)	flood wave translation (h)	water level change (cm)	connectivity (-)	protected species (-)		affected buildings (n/km²)	land use (-)
Bulgaria, Romania	RO_BG_DU_AFP_01	0.22	1	8	3	176	176	0.38	4.82
	RO_BG_DU_AFP_02	0.01	2	4	3	164	164	0.00	4.94
	RO_BG_DU_AFP_03	0.01	2	7	3	131	131	0.24	4.31
	RO_BG_DU_AFP_04	0.06	4	12	3	161	161	0.21	4.40
	RO_BG_DU_AFP_05	0.03	2	13	3	165	165	0.28	4.62
	RO_BG_DU_AFP_06	0.01	2	12	3	67	67	0.15	4.65
FEM-rating	performance	Thresholds	Thresholds	Thresholds	Thresholds	Thresholds		Thresholds	Thresholds
	low	<1 %	<1 h	<10 cm	1	0	<40	>5 n/km²	<2
	medium	1-2 %	1-5 h	10 - 50 cm	3	1-20	41-100	1-5 n/km²	2-4
	high	>2 %	>5 h	>50 cm	5	>20	>101	<1 n/km²	>4

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Based on the FEM-assessment, the need for preservation and the restoration demand are determined. All active floodplains along the Bulgarian/Romanian Danube section should be preserved because at least one parameter is evaluated with 5 points (high performance) at each floodplain. All floodplains show a medium demand for restoration (Table 33).

Table 33: Results of the need for preservation and restoration demand for all active floodplains along the Bulgarian/Romanian Danube section. In the last row, thresholds for the need for preservation (if one minimum FEM-parameter is evaluated with 5 – high performance, the floodplain has to be preserved) and restoration demand (<23 FEM-points – high, 23-26 points – medium, ≥ 27 low demand)

Floodplain ID	Need for preservation	Parameters with high performance	Demand for restoration	FEM-points
RO_BG_DU_AFP_01	yes	protected species, affected buildings, land use	medium demand	23
RO_BG_DU_AFP_02	yes	protected species, affected buildings, land use	medium demand	23
RO_BG_DU_AFP_03	yes	protected species, affected buildings, land use	medium demand	23
RO_BG_DU_AFP_04	yes	protected species, affected buildings, land use	medium demand	25
RO_BG_DU_AFP_05	yes	protected species, affected buildings, land use	medium demand	25
RO_BG_DU_AFP_06	yes	protected species, affected buildings, land use	medium demand	25
FEM-ranking	Need for preservation	threshold	restoration demand	threshold
	yes	at least one parameter evaluated with 5	low	≥ 27
			medium	23-26
	no	no parameter evaluated with 5	high	<23

3.7.3. FEM-Evaluation – potential floodplains (PFP) at the Bulgarian/Romanian section of the Danube

Table 34 shows the results of the minimum FEM-parameters for all potential floodplains along the Bulgarian/Romanian Danube. All floodplains show a relative peak reduction below 1%, resulting in low performance in the FEM-evaluation. Due to the flow processes in the floodplains, the flood wave is decelerated from 1 to 22 h leading to two floodplains with high and three with medium performances. In the case of a total loss of the potential floodplain, the water level in the river channel would change between 6 and 84 cm resulting in two medium and low performances. Only one floodplain receives a high performance (>50 cm). All floodplains are still partly impaired by human interventions leading to medium performance for the lateral connectivity. More than 100 protected species are found at all floodplains, resulting in high performance for this parameter. At most floodplains (only one exception) less than 1 building per km² is found (=high performance). At one floodplain 1.23 buildings per km² are found (=medium performance). Three out of five floodplains at the Bulgarian/Romanian section have a low vulnerability against flooding (=high performance).The other two have a medium vulnerability (=medium performance).

Table 34: Results of the minimum Floodplain Evaluation Matrix (FEM) parameters for all identified potential floodplains along the Bulgarian/Romanian Danube River. In the last row, thresholds for each parameter to determine the performance of each floodplain. High performance (5 points) in blue. Medium performance (3 points) in green. Low performance in orange (1 point).

Country	Floodplain ID	Hydrology		Hydraulics	Ecology		Socio-Economics	
		peak reduction (%)	flood wave translation (h)	water level change (cm)	connectivity (-)	protected species (-)	affected buildings (n/km²)	land use (-)
Bulgaria, Romania	BG_RO_DU_PFP01	0.04	1	6	3	153	0.05	4.05
	BG_RO_DU_PFP02	0.27	9	23	3	205	0.02	3.99
	BG_RO_DU_PFP03	0.67	22	84	3	198	0.09	4.04
	BG_RO_DU_PFP04	0.19	4	7	3	200	0.23	3.93
	BG_RO_DU_PFP05	0.05	2	11	3	157	1.23	4.11
FEM-rating	performance	Thresholds	Thresholds	Thresholds	Thresholds	Thresholds	Thresholds	Thresholds
	1 (low)	<1 %	<1 h	<10 cm	1	0	>5 n/km²	<2
	3 (medium)	1-2 %	1-5 h	10 - 50 cm	3	1-20	1-5 n/km²	2-4
	5 (high)	>2 %	>5 h	>50 cm	5	>20	<1 n/km²	>4

3.7.4. Example of a floodplain factsheet (BG_RO_DU_AFP01)

The active floodplain BG_RO_DU_AFP01 is 60.1 km² large. The FEM-Evaluation showed that there is a need for preservation of this floodplain and a medium demand for restoration, due to the performance of the evaluated parameters. In Figure 18, the evaluation results are shown for each parameter and the coloured background indicates the performance (high – blue, medium – green, low – yellow) of the parameter. The performance is determined using the selected thresholds presented in chapter 2.2.2

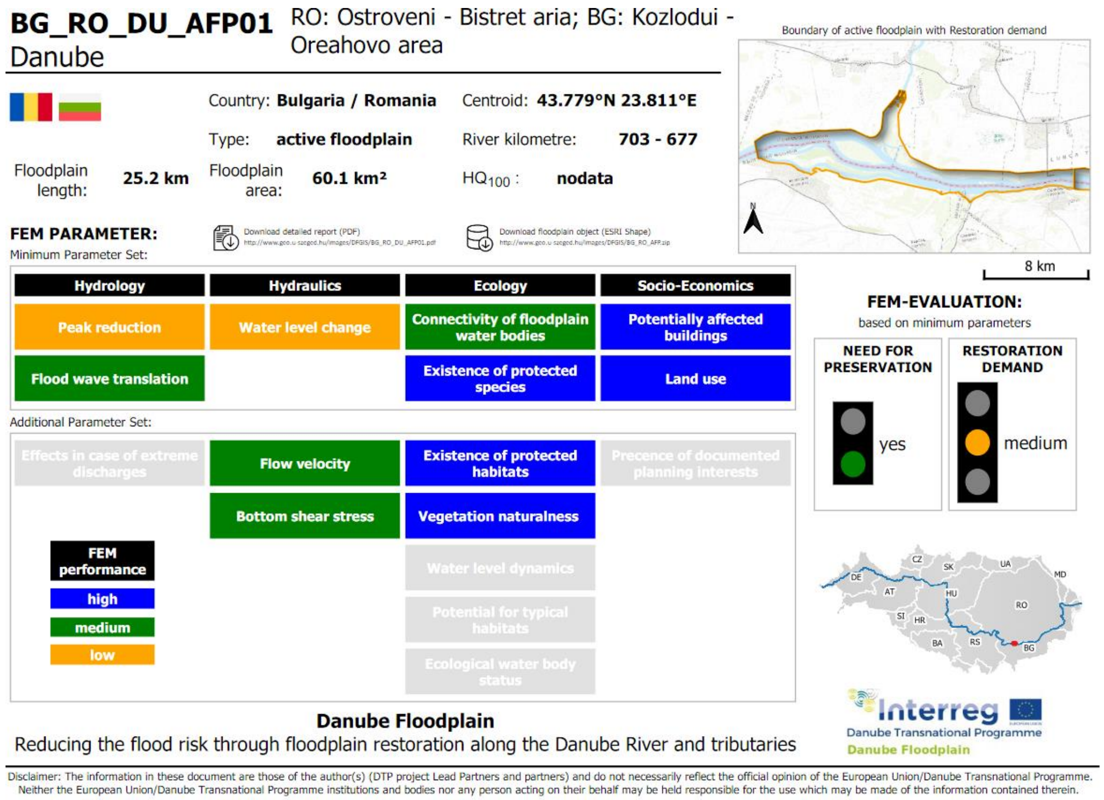
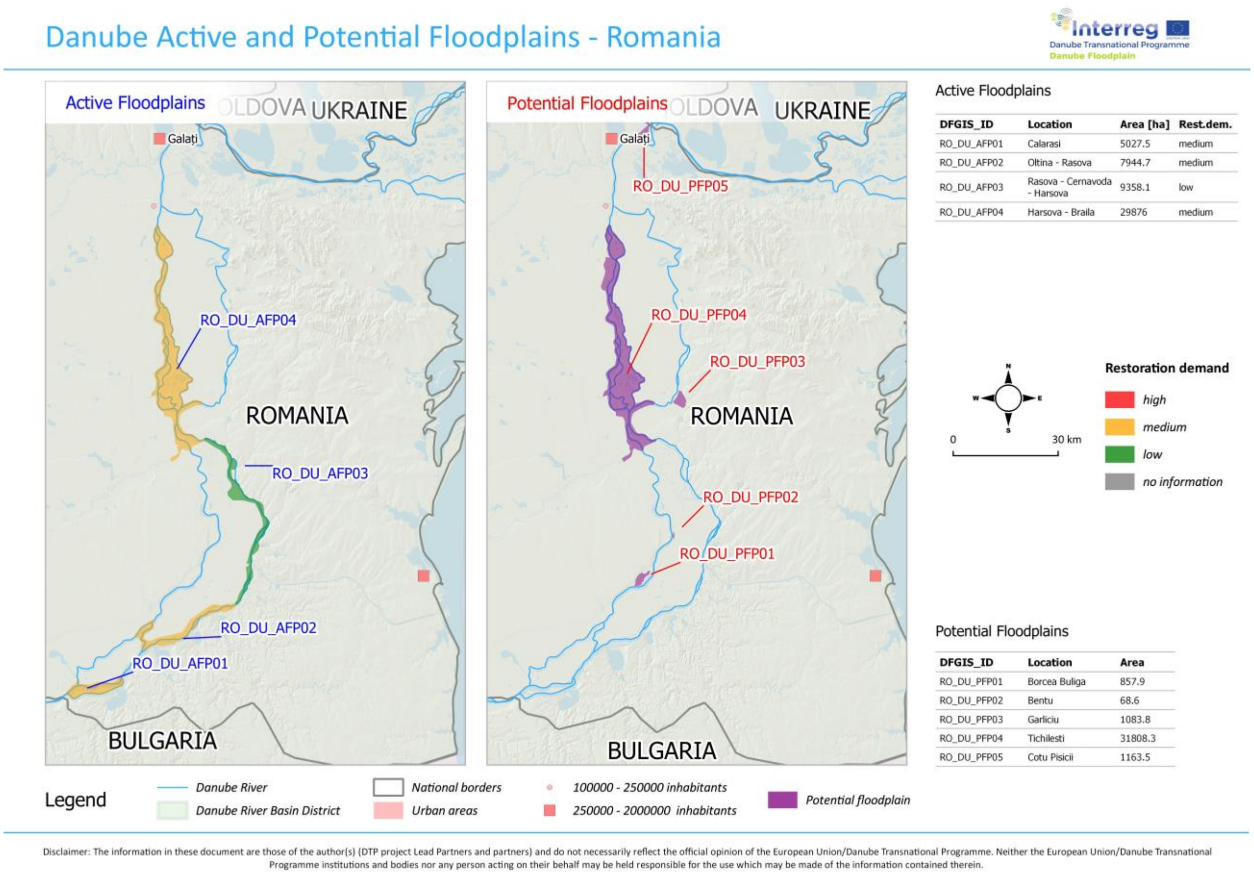


Figure 18: Factsheet of the floodplain BG_RO_DU_AFP01

3.8. Romania

3.8.1. Active and potential floodplains

At the Romanian section of the Danube River, four active and five potential floodplains were identified. In Figure 19, the floodplain ID, the location, the area and the restoration demand of all active and potential floodplains along the Romanian section are shown. For the active floodplain, the restoration demand is also illustrated.



Active Floodplains

DFGIS_ID	Location	Area [ha]	Rest.dem.
RO_DU_AFP01	Calarasi	5027.5	medium
RO_DU_AFP02	Oltina - Rasova	7944.7	medium
RO_DU_AFP03	Rasova - Cernavoda - Harsova	9358.1	low
RO_DU_AFP04	Harsova - Braila	29876	medium

Potential Floodplains

DFGIS_ID	Location	Area
RO_DU_PFP01	Borcea Buliga	857.9
RO_DU_PFP02	Bentu	68.6
RO_DU_PFP03	Garliciu	1083.8
RO_DU_PFP04	Tichilesti	31808.3
RO_DU_PFP05	Cotu Pisicii	1163.5

Figure 19: All active and potential floodplains along the Romanian Danube section (Danube Floodplain, 2021)

3.8.2. FEM-Evaluation – active floodplains (AFP) in Romania

Table 35 shows the results of the minimum FEM-parameters for all active floodplains along the Romanian section of the Danube River. All floodplains show a relative peak reduction below 1%, resulting in low performance in the FEM-evaluation. Due to the flow processes in the floodplains, the flood wave is decelerated by 1 to 39 h leading to two floodplains with high and medium performances. In the case of a total loss of the active floodplain, the water level in the river channel would change between 12 and 57 cm resulting in three medium (10-50 cm) and one high (>50 cm) performances. All floodplains are still partly impaired by human interventions leading to medium performance for the lateral connectivity. More than 100 protected species are found at all floodplains, resulting in high performance for both ranking steps (need for preservation, restoration demand). At all floodplains less than 1 building per km² is found (=high performance). All active floodplains along the Romanian section show a low vulnerability against flooding (=high performance).

Table 35: Results of the minimum Floodplain Evaluation Matrix (FEM) parameters for all active floodplains along the Romanian Danube section. In the last row, thresholds for each parameter to determine the performance of each floodplain. High performance (5 points) in blue. Medium performance (3 points) in green. Low performance in orange (1 point).

country	Floodplain	Hydrology		Hydraulics	Ecology			Socio-Economics	
		peak reduction (%)	flood wave translation (h)	water level change (cm)	connectivity (-)	protected species (-)		affected buildings (n/km²)	land use (-)
Romania	RO_DU_AFP_01	0.02	1	24	3	116	116	0.56	4.98
	RO_DU_AFP_02	0.27	5	34	3	161	161	0.14	4.97
	RO_DU_AFP_03	0.44	11	57	3	180	180	0.45	4.87
	RO_DU_AFP_04	0.23	39	12	3	240	240	0.13	4.95
FEM-rating	performance	Thresholds	Thresholds	Thresholds	Thresholds	Thresholds		Thresholds	Thresholds
	low	<1 %	<1 h	<10 cm	1	0	<40	>5 n/km²	<2
	medium	1-2 %	1-5 h	10 - 50 cm	3	1-20	41-100	1-5 n/km²	2-4
	high	>2 %	>5 h	>50 cm	5	>20	>101	<1 n/km²	>4

Based on the FEM-assessment, the need for preservation and the restoration demand are determined. All active floodplains along the Romanian Danube section should be preserved because at least one parameter is evaluated with 5 points (high performance) at each floodplain. Two floodplains show a low and two a medium demand for restoration (Table 36).

Table 36: Results of the need for preservation and restoration demand for all active floodplains along the Bulgarian/Romanian Danube section. In the last row, thresholds for the need for preservation (if one minimum FEM-parameter is evaluated with 5 – high performance, the floodplain has to be preserved) and restoration demand (<23 FEM-points – high, 23-26 points – medium, ≥ 27 low demand)

Floodplain ID	Need for preservation	Parameters with high performance	Demand for restoration	FEM-points
RO_DU_AFP_01	yes	protected species, affected buildings, land use	medium demand	25
RO_DU_AFP_02	yes	protected species, affected buildings, land use	medium demand	25
RO_DU_AFP_03	yes	wave translation, water level, change, protected species, affected buildings, land use	low demand	29
RO_DU_AFP_04	yes	wave translation, protected species, affected buildings, land use	low demand	27
FEM-ranking	Need for preservation	threshold	restoration demand	threshold
	yes	at least one parameter evaluated with 5	low	≥ 27
			medium	23-26
	no	no parameter evaluated with 5	high	<23

3.8.3. FEM-Evaluation – potential floodplains (PFP) in Romania

Table 37 shows the results of the minimum FEM-parameters for all potential floodplains along the Romanian Danube. All floodplains show a relative peak reduction below 1%, resulting in low performance in the FEM-evaluation. Due to the flow processes in the floodplains, the flood wave is decelerated from 0.5 to 3 h leading to one floodplain with low (<1h) and four with medium (1-5h) performance. In the case of a total loss of the potential floodplain, the water level in the river channel would change for two floodplains above 10 cm (13 cm and 28 cm = medium performance). For all other floodplains the water level change would be below 10 cm (=low performance). All floodplains are still partly impaired by human interventions leading to medium performance for the lateral connectivity. More than 20 protected species are found at all floodplains, resulting in high performance for this parameter. At most floodplains (only one exception) less than 1 building per km² is found (=high performance). At one floodplain 2.15 buildings per km² are found (=medium performance). Four out of five potential floodplains at the Romanian section have a medium vulnerability against flooding (=medium performance).The other one has a low vulnerability (=high performance).

Table 37: Results of the minimum Floodplain Evaluation Matrix (FEM) parameters for all identified potential floodplains along the Romanian Danube River. In the last row, thresholds for each parameter to determine the performance of each floodplain. High performance (5 points) in blue. Medium performance (3 points) in green. Low performance in orange (1 point).

Country	Floodplain ID	Hydrology		Hydraulics	Ecology		Socio-Economics	
		peak reduction (%)	flood wave translation (h)	water level change (cm)	connectivity (-)	protected species (-)	affected buildings (n/km²)	land use (-)
Romania	RO_DU_PFP01	0.14	1	6	3	83	0	2.96
	RO_DU_PFP02	0.05	0.5	1	3	79	0	3.00
	RO_DU_PFP03	0.08	1	13	3	61	0.83	3.19
	RO_DU_PFP04	0.03	3	28	3	281	0.24	4.83
	RO_DU_PFP05	0.07	1	6	3	33	2.15	3.04
FEM-rating	performance	Thresholds	Thresholds	Thresholds	Thresholds	Thresholds	Thresholds	Thresholds
	1 (low)	<1 %	<1 h	<10 cm	1	0	>5 n/km²	<2
	3 (medium)	1-2 %	1-5 h	10 - 50 cm	3	1-20	1-5 n/km²	2-4
	5 (high)	>2 %	>5 h	>50 cm	5	>20	<1 n/km²	>4

3.8.4. Example of a floodplain factsheet (BG_RO_DU_AFP01)

The active floodplain RO_DU_AFP04 is with 298.8 km² the largest one along the Danube River. The FEM-Evaluation showed that there is a need for preservation of this floodplain and a medium demand for restoration, due to the performance of the evaluated parameters. In Figure 20, the evaluation results are shown for each parameter and the coloured background indicates the performance (high – blue, medium – green, low – yellow) of the parameter. The performance is determined using the selected thresholds presented in chapter 2.2.2

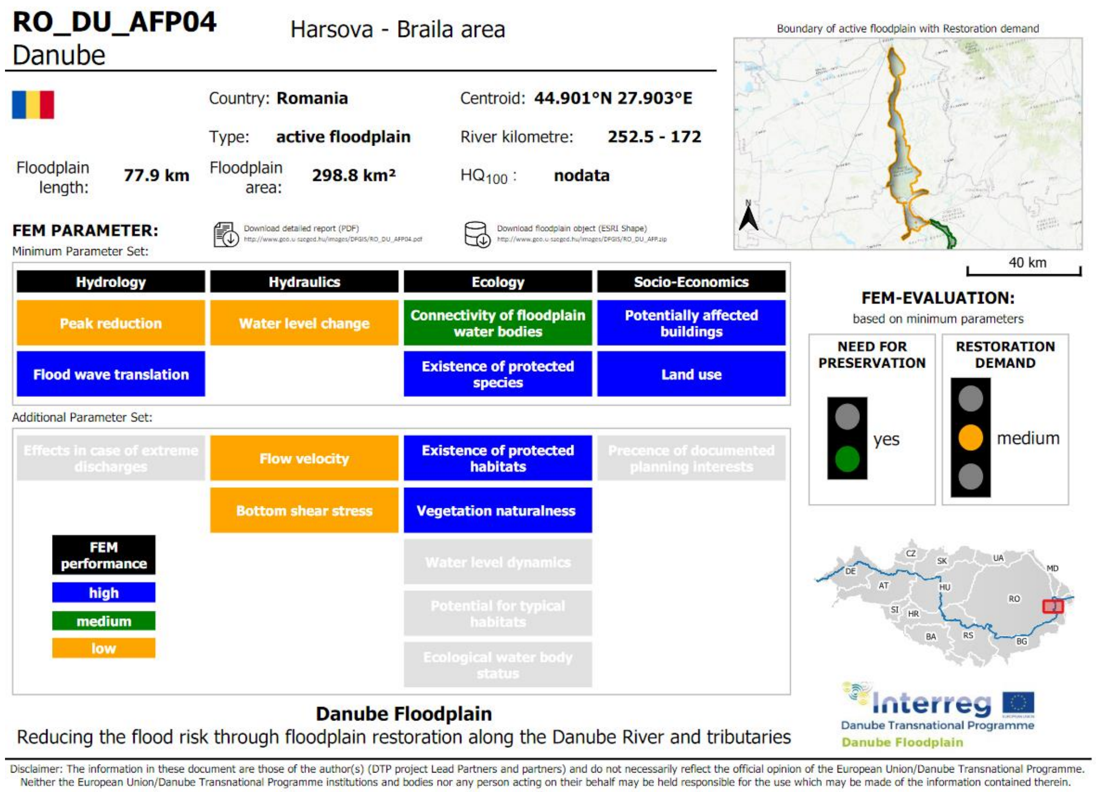


Figure 20: Factsheet for the active floodplain RO_DU_AFP04

3.9. Basin-wide analysis

3.9.1. Analysis of active, potential and former floodplains

In this section, selected results from the basin-wide analyses in the Danube Floodplain project are presented for active, potential and former floodplains along the Danube River. Since the Danube Delta is a special case, it was not included in the 50 identified hydraulically active floodplains and not evaluated with the FEM. Therefore, it also was excluded from the following analysis. In Figure 21, all floodplains were sorted from up- to downstream and each floodplain area is shown. A trendline was inserted that shows only a slight increase in the area towards the lower part of the Danube River. Out of the 50 floodplains (without the Danube Delta) only five floodplains have an area above 150 km² and are located in different countries (DE, AT, HU, RS-HR, RO). 32 floodplains have an area below 50 km² and the mean value for all floodplains lies at 57.63 km².

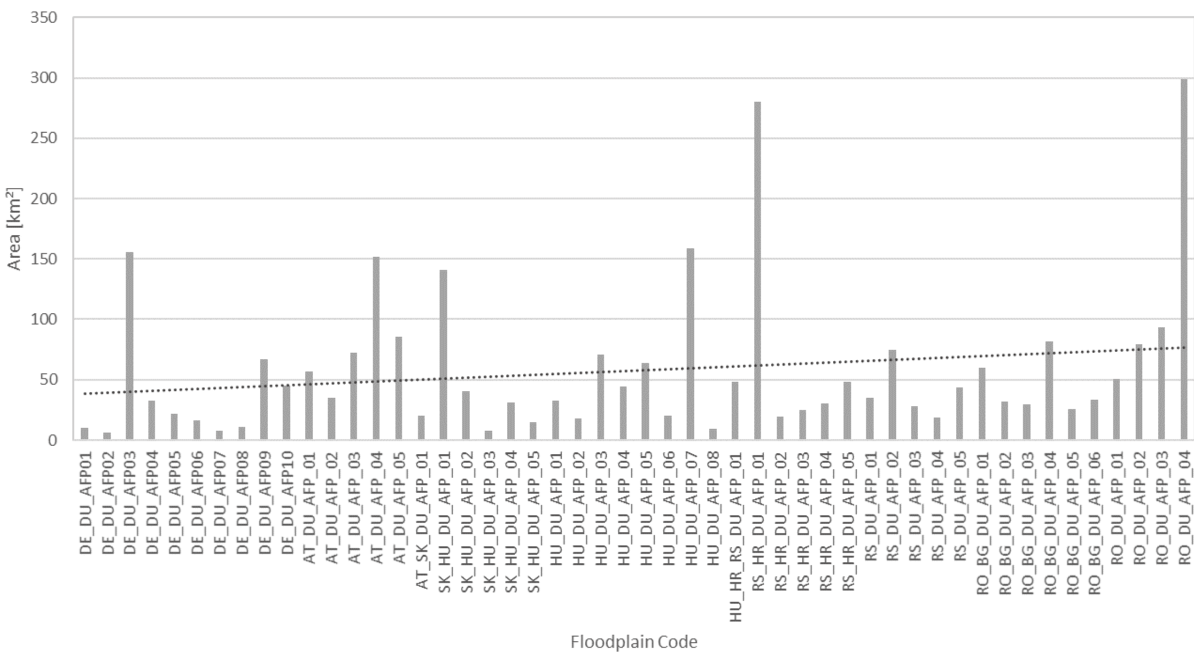


Figure 21: Area distribution of active Danube Floodplains from up- to downstream including the trendline

In total, 24 potential floodplains were identified. Half of them are extensions of active floodplains. The other half are additional areas that are now flooded in the case of a HQ_{100}. In Figure 22, the areas of the potential floodplains are presented. The orange bar only shows the additional floodplain area. The yellow one illustrates the total area of the extension and the active floodplain.

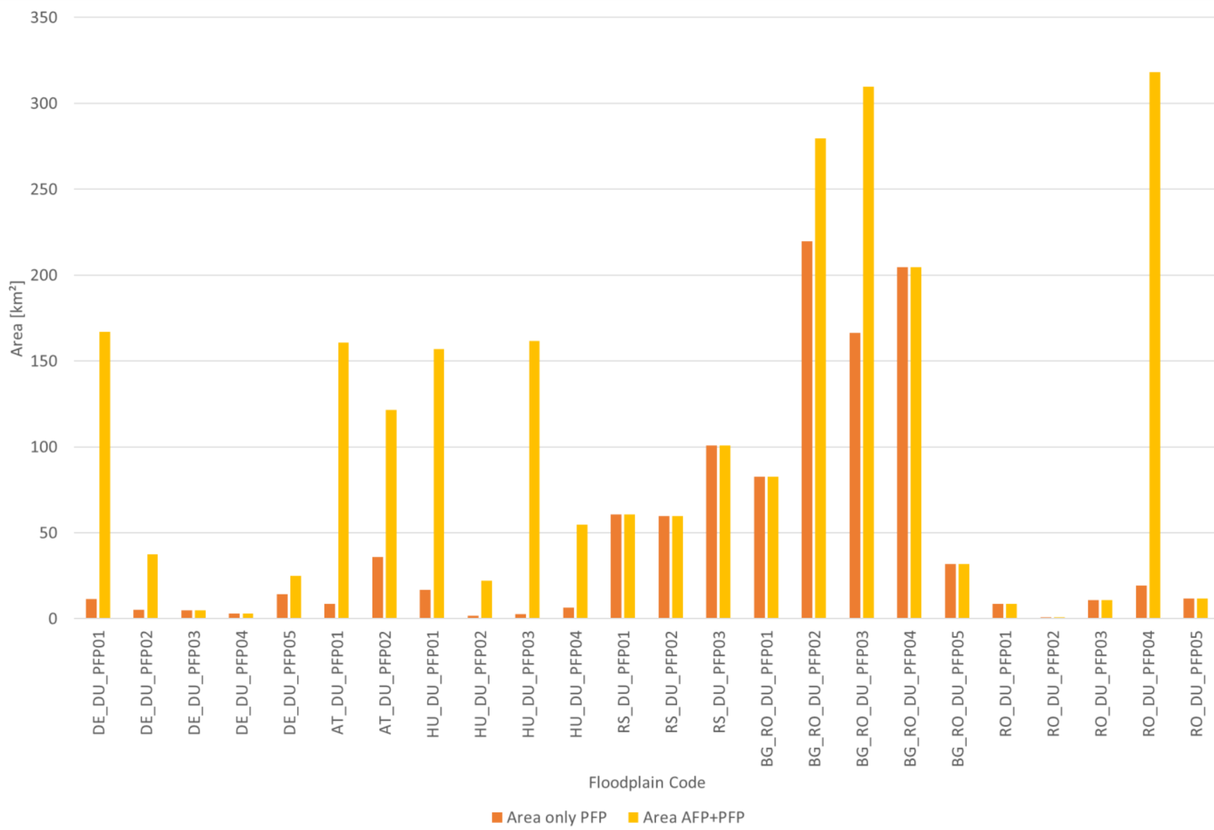
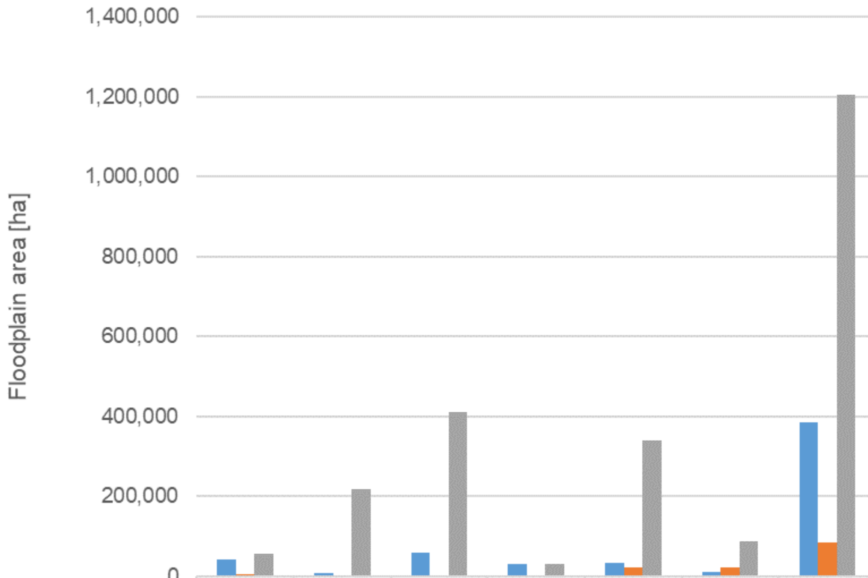


Figure 22: Area distribution of potential floodplains (in orange area of the additional area; in yellow: area of active + additional area)

In Figure 23, the active, potential and former floodplains in each country are compared with each other. The detailed analysis and identification of former floodplains were not part of the WP3 and will be done in the extension of the Danube Floodplain project in Activity 6.2. For this report, BOKU did a preliminary analysis of former floodplain areas based on the HQ_{1000} inundation outlines available from the Danube FLOODRISK project (https://environmentalrisks.danube-region.eu/projects/danube-floodrisk/) for all countries except Germany. It was assumed that during a HQ_{1000}, flood protection measures would be overtopped, and the former floodplain area would be flooded. This approach was a simplification since it was not possible in the project's scope to remove all flood protection measures along the Danube River and calculate the inundation area of a HQ100 to show the former floodplain areas. For the detailed analysis and identification of former floodplains, it is recommended to look at the Deliverable 6.2.3 (Danube Floodplain, in prep.). Most of the former floodplain areas were in Romania, followed by Hungary, Serbia, Slovakia and Bulgaria (Figure 23). To assess how much of the former floodplain is still a hydraulically active or a potential floodplain, the percentage of the active and active + potential floodplains from the former floodplains is illustrated for each country in Figure 24. This comparison shows that Austria (75%) and Croatia (95%) preserved most of the former floodplains as hydraulically active floodplains. Austria can increase the preserved percentage of hydraulically floodplains even to 84% if the potential floodplains are also reconnected. In Romania, 32% of the former floodplain area still exists as active floodplains. In the other countries (Slovakia, Hungary, Serbia, Bulgaria) the percentage is less than 15%. Bulgaria can increase the percentage from 12% with the potential floodplains to 37%.



	AT	SK	HU	HR	RS	BG	RO
active FP [ha]	41,476	8,928	59,500	29,430	33,106	10,135	383,396
potential FP [ha]	4,479	0	2,773	9	22,112	22,157	83,429
former FP [ha]	54,992	218,003	411,520	31,089	338,048	87,305	1,205,54

Figure 23: Area analysis of active, potential and former floodplains along the Danube River (without Germany due to data availability)

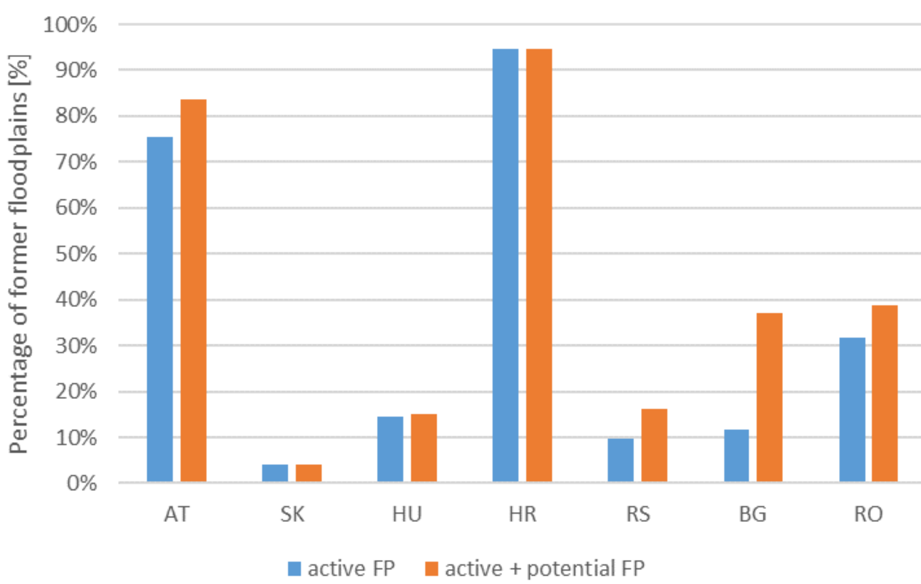


Figure 24: Area analysis of active, potential and former floodplains in relation to the former floodplains along the Danube River (without Germany due to data availability)

Figure 25 shows the percentage of the floodplain area for each country. Transboundary floodplains are presented independently and not included to one country (e.g. 8% of the floodplain area is along the Slovakian/Hungarian border). Almost half (46%) of the active floodplain area is found at the Middle Danube. The other 54% are distributed equally between the Upper and Lower Danube sections (Figure 26). The potential floodplains identified in this project are located mostly (53%) at the Lower Danube. 26% are found at the middle section and 22% at the Upper Danube.

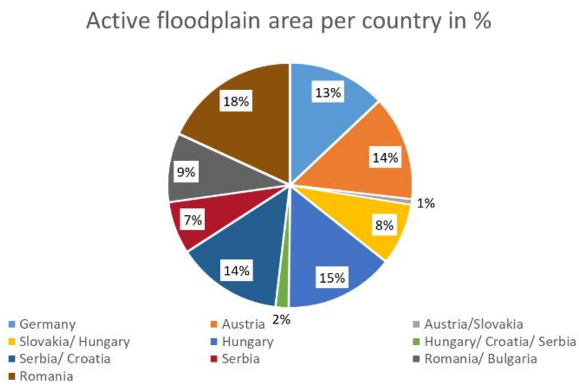


Figure 25: Active floodplain area per country in percentage

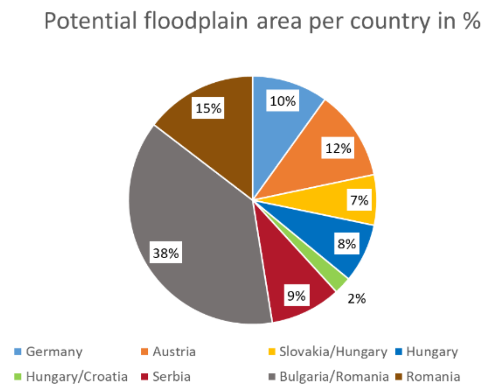


Figure 26: Potential floodplain area per country in percentage

In Figure 27, the land uses for all active floodplains at the Danube River are shown. The percentage of artificial surfaces varies between 0 and 6.85%, with a mean value of 2.04%. Agricultural areas vary between 0.40 and 96.15% with a mean value of 24.95% whereas the Forest and semi-natural areas vary between 0 and 94.91% with a mean value of 41.09%. Wetlands are only present at 20 out of 50 active floodplains and mostly located at the Lower Danube. A tendency is visible from up- to downstream, showing that agricultural use is decreasing on the floodplains. At the upper and middle part of the Danube, the floodplains have, in general, a higher percentage of agricultural areas and a lower percentage of forest and semi-natural areas. This is not the case at some floodplains in Austria and some along the Slovakian and Hungarian border.

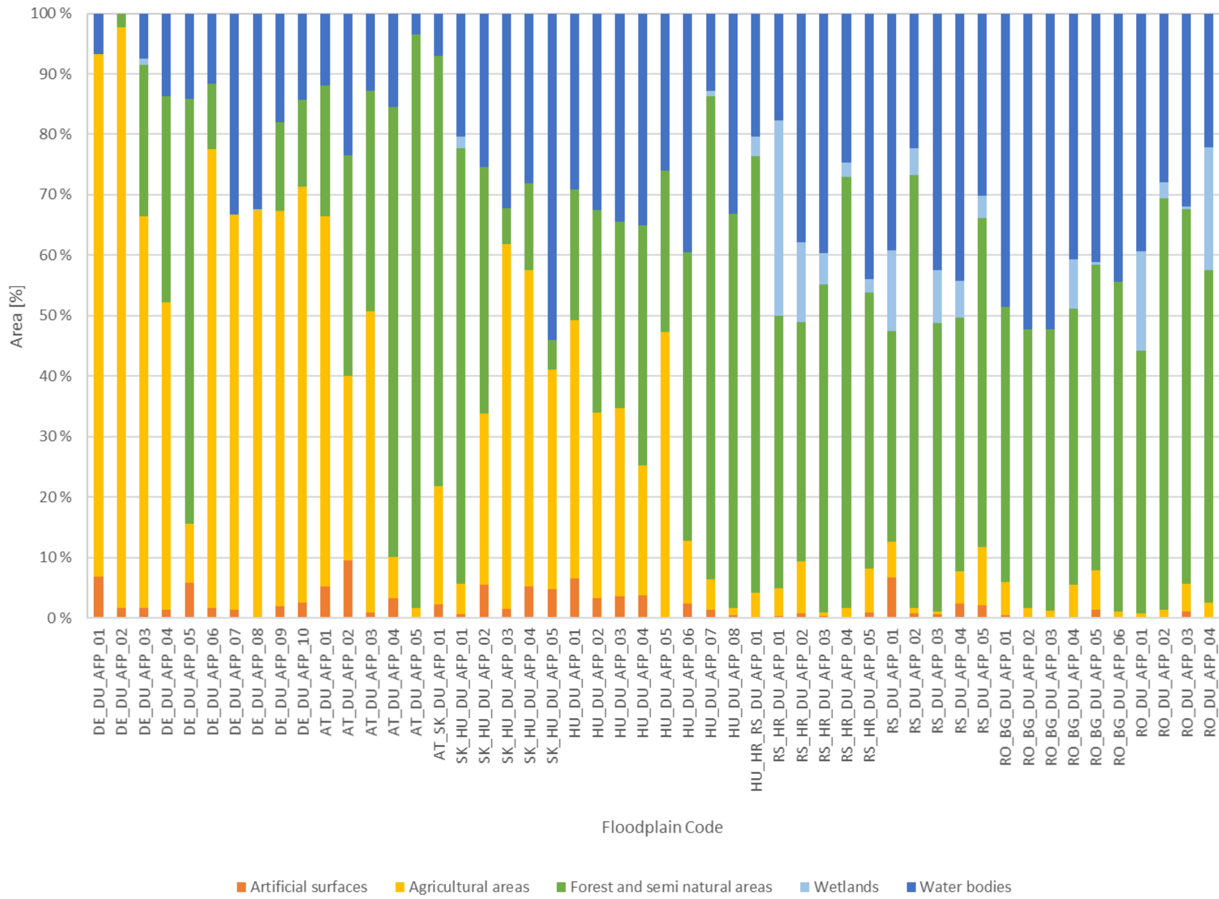


Figure 27: Distribution of land use classes in percentage for all active Danube floodplains from up- to downstream

3.9.2. Analysis for the minimum FEM-parameters for the active floodplains along the Danube River

In this chapter, all the results for the minimum FEM-parameters of all active floodplains along the Danube River are presented, compared and discussed.

In Figure 28, the results of the hydrological parameter relative flood peak reduction for all active floodplain along the Danube River are presented. The relative flood peak reduction ranges from 0 to 17%, with a mean of 2.4%. There is a clear tendency visible from up- to downstream since the highest values are at the Upper Danube and the lowest peak reductions are at the Lower Danube section. The high relative peak reduction at some floodplains in Germany (DE_DU_AFP_03 and 09) and Austria (AT_DU_AFP_01, 03 and 04) can be explained by dykes from hydropower plants. In Austria, these dykes are only overtopped at higher discharges (approximately at a HQ5), which leads to a higher peak reduction. Besides, more former floodplains (75%) are preserved in Austria than in other countries (Figure 24), which has also an effect on the flood peak reduction.

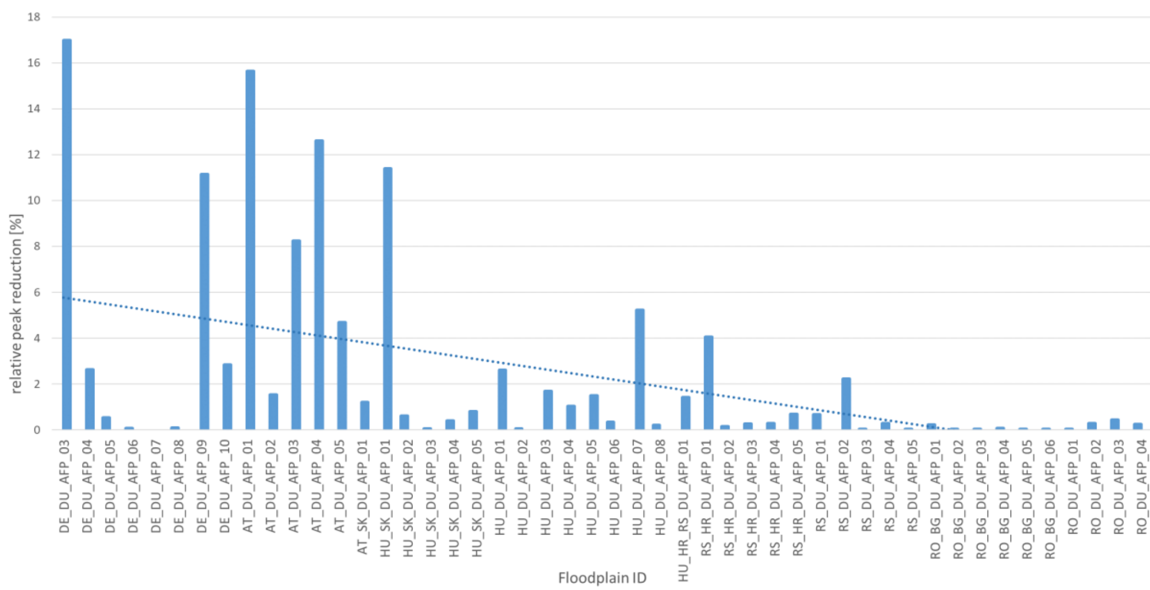


Figure 28: Relative flood peak reduction for all active floodplains along the Danube River including a trendline

Figure 29 provides an overview of the flood wave translation due to the active floodplain along the Danube River. The maximum translation (41.5 h) was simulated at a transboundary floodplain (RS_HR_DU_AFP01) between Serbia and Croatia. At three floodplains (SK_HU_DU_AFP03, HU_DU_AFP01, HU_DU_AFP08) the flood wave translation is less than 0.5 h. The mean value for the flood wave translation parameter is around 5.5 h. The flood wave translation shows a more constant tendency than the peak reduction. Two large outliers in Serbia and Romania ensure that the flood wave translation tends to increase downstream. Without these two outliers, the tendency would be reversed.

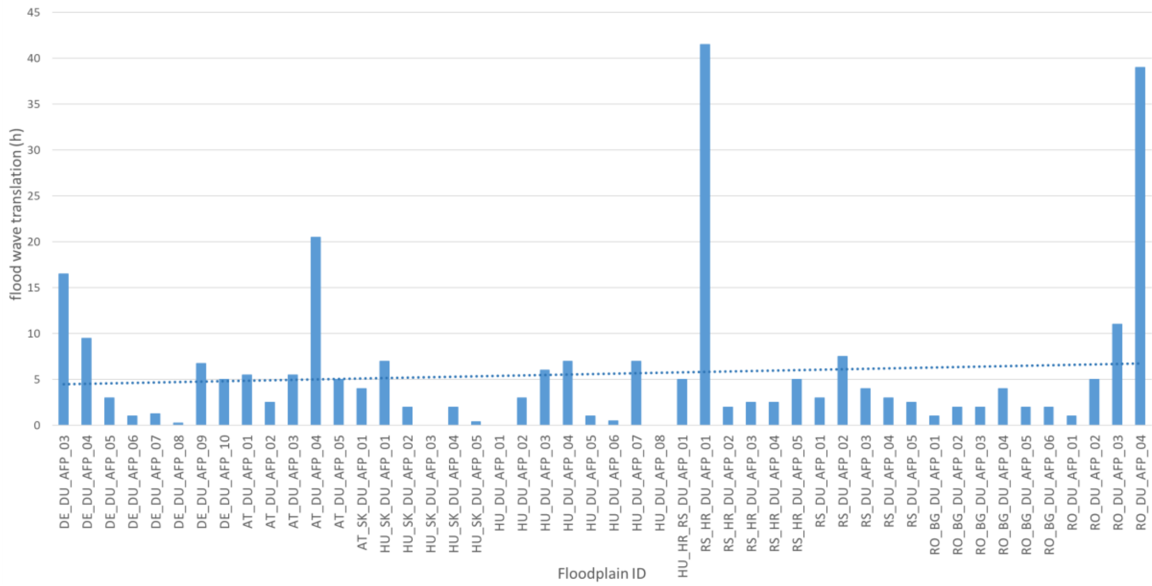


Figure 29: Flood wave translation for all active floodplains along the Danube River including a trendline

Figure 30 shows the water level change in the case of a total loss of the active floodplain for all active floodplains. The simulated water level changes are between 0 and 172cm. The mean is 45.58 cm. There is also a decreasing tendency from up- to downstream visible. One reason for that might be that a higher percentage of the former floodplains is preserved in the upstream areas and disconnecting these areas from the river would lead to higher water level in the river channel at the Upper Danube.

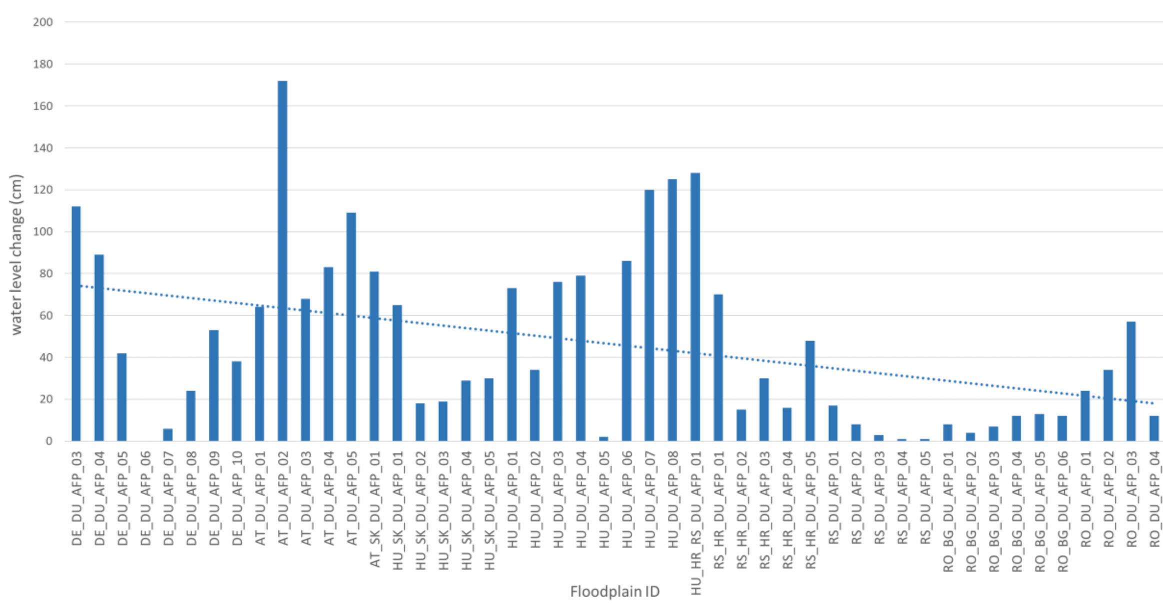


Figure 30: Water level change for all active floodplains along the Danube River including a trendline

The number of protected species shows a slightly upwards tendency from up- to downstream (Figure 31). The number ranges from 20 to 271 species at one floodplain leading to a mean of 74.33. On the upstream floodplains, the agricultural usage is significantly higher than at the downstream areas, reducing the potential habitat for different species.

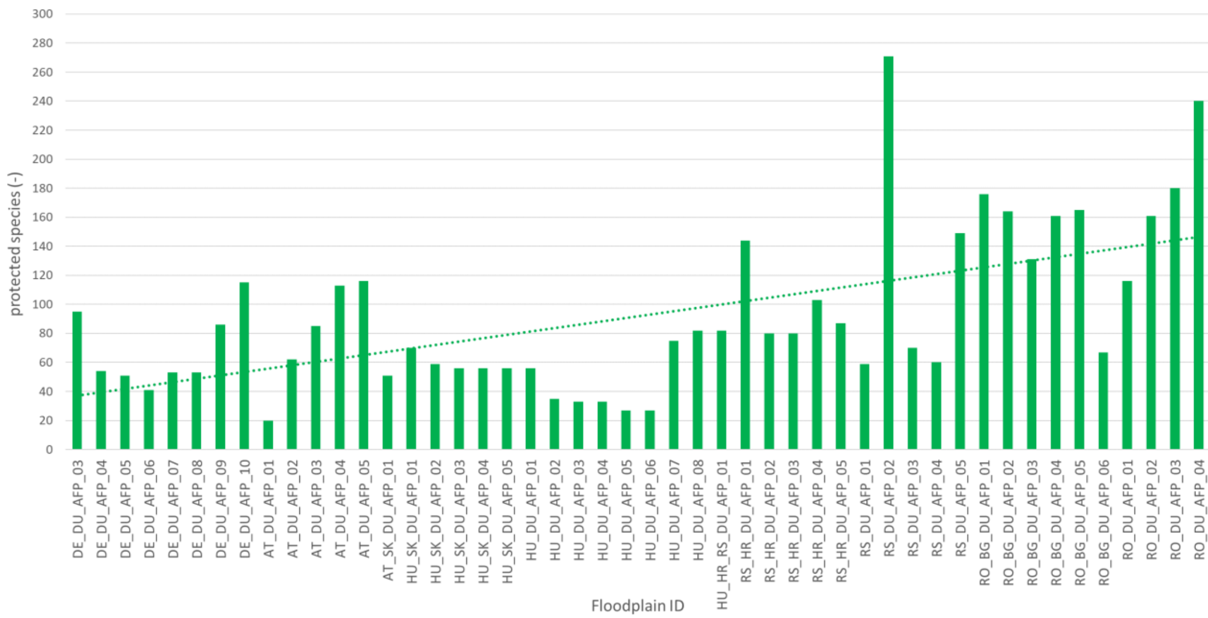


Figure 31: Number of protected species on active floodplains along the Danube River including a trendline

In Figure 32, the FEM performance of all active floodplains (high=5; medium=3; low=1) for the minimum FEM parameter connectivity of floodplain water bodies is presented. In Germany and Austria, almost all floodplains received a low performance for the connectivity. In the Middle and Lower section of the Danube, the active floodplains have mostly a medium performance. No active floodplain received the best evaluation (high performance=5).

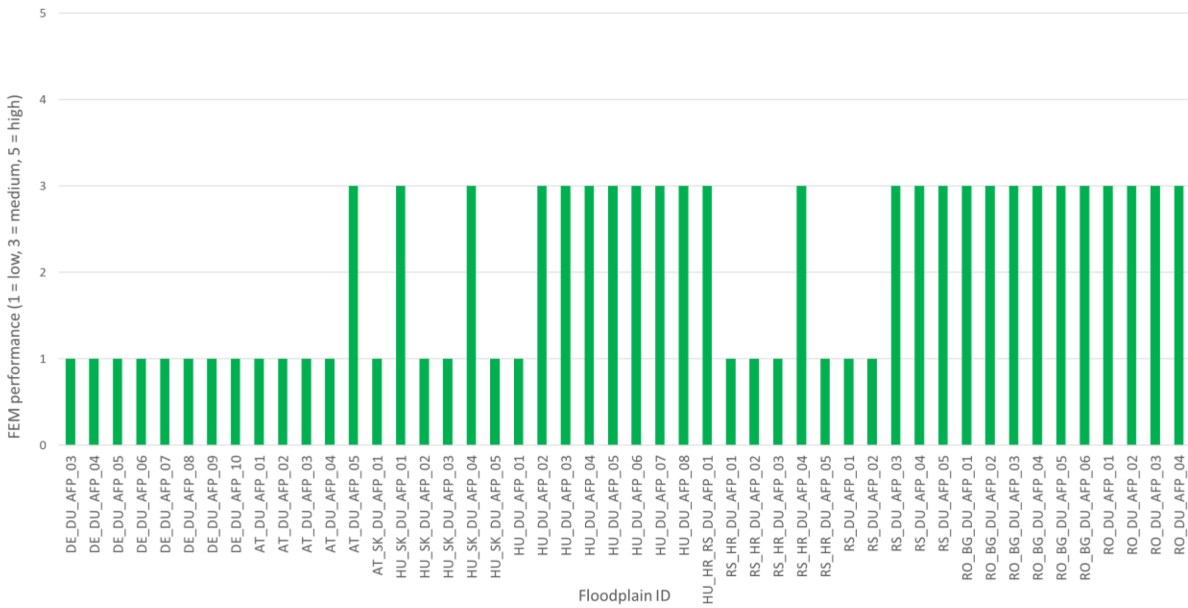


Figure 32: FEM performance (high=5; medium=3; low=1) for the parameter "connectivity of floodplain water bodies" of all active floodplains along the Danube River

One factor that is extremely relevant regarding the damage potential and thus the vulnerability at the floodplains is the number of affected buildings. For each floodplain the number of affected buildings per km² was calculated and a trendline was included (Figure 33. The numbers vary between 0 Nr/km² and 34.77 buildings per km². The mean value lies by 6.98 Nr/km². There is a clear tendency visible from up- to downstream, where the numbers are strongly decreasing. The peak lies at the middle section of the Danube and almost no buildings are affected in the floodplains along the Lower Danube.

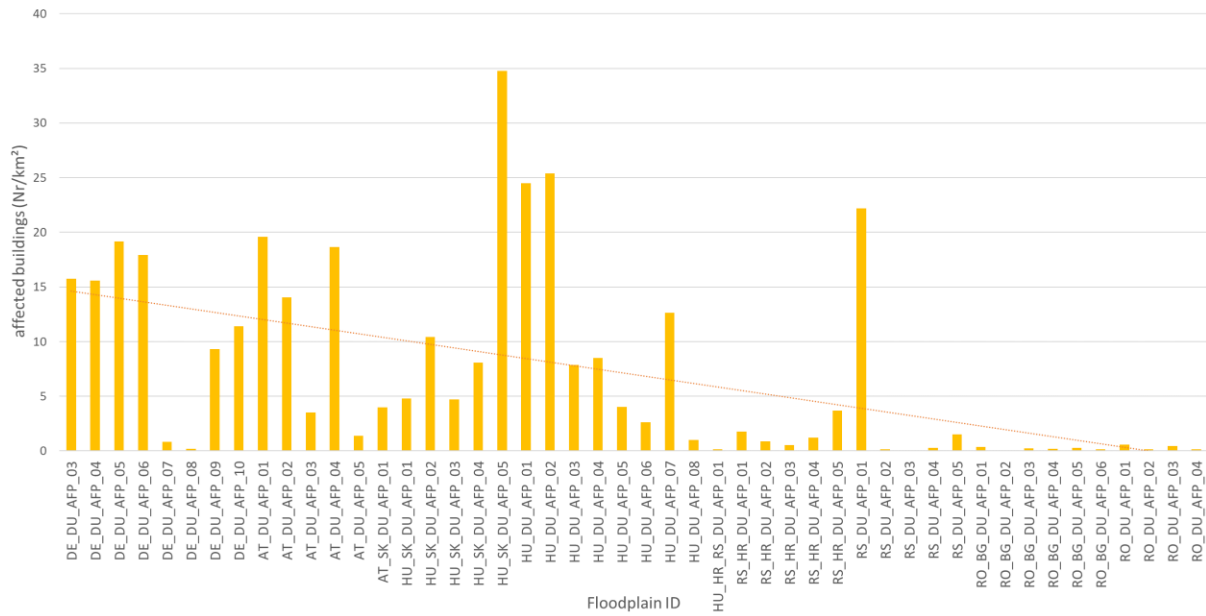


Figure 33: Distribution of affected buildings per km² for all active Danube floodplains from up- to downstream including a trendline

In Figure 34, the performance of each active floodplain for the minimum FEM-parameter "land use" is shown. If the land use parameter is above 4, the vulnerability of the land use is low on the floodplain. Most active floodplains at the Middle and Lower Danube have a low vulnerability (=high performance in the FEM-evaluation) against flooding. At the Upper Danube, most floodplains are demonstrating a medium vulnerability.

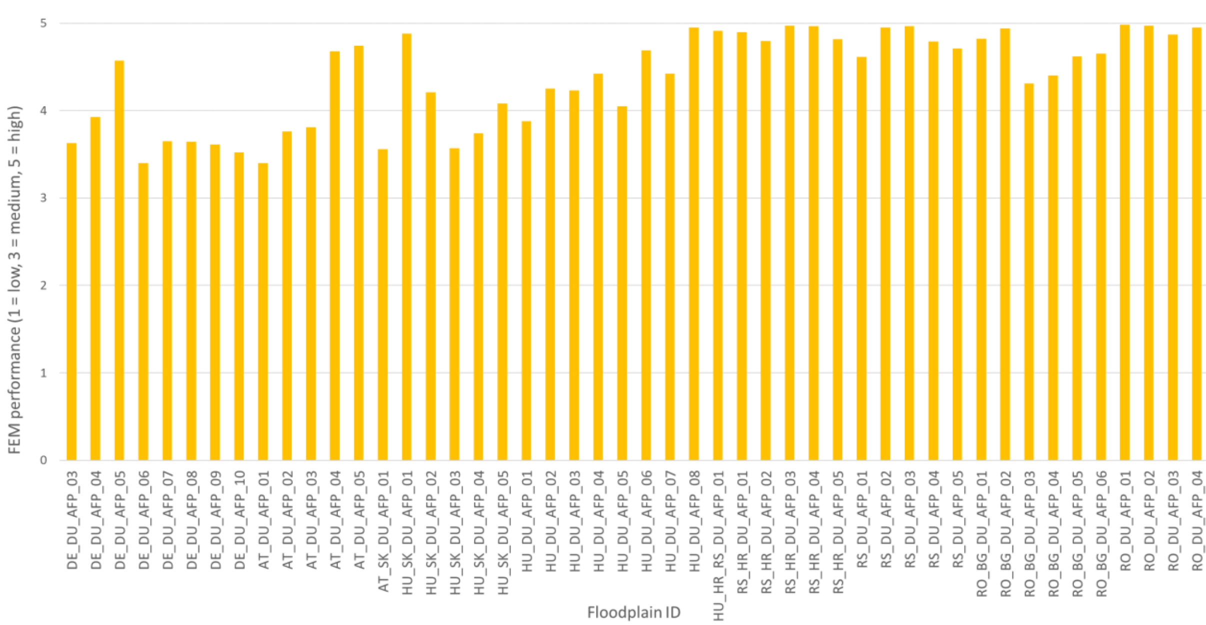


Figure 34: FEM performance for the land use parameter of all active floodplains at the Danube River (high performance = low vulnerability; medium performance = medium vulnerability; low performance = high vulnerability)

Figure 35 provides an overview of the results for the minimum FEM-parameters incl. ranking (need for preservation + restoration demand) for all active floodplains along the Danube River. In the subchapters 3.1 to 3.8, the individual FEM-results are presented and summarized. In Annex C, all results for the additional parameters are presented.

	Floodplain		Hydrology: peak reduction (%)	Hydrology: flood wave translation (h)	Hydraulics: water level change (cm)	Ecology: connectivity (-)	Ecology: protected species (-)		Socio-Economics: affected buildings (n/km²)	Socio-Economics: land use (-)	Ranking: Need for preservation	Ranking: Restoration demand
Germany	DE_DU_AFP_01	1										
	DE_DU_AFP_02	2										
	DE_DU_AFP_03	3	16.98	16.5	112	1	95	95	15.76	3.63	yes	medium
	DE_DU_AFP_04	4	2.63	9.5	89	1	54	54	15.58	3.92	yes	medium
	DE_DU_AFP_05	5	0.53	3	42	1	51	51	19.16	4.57	yes	high
	DE_DU_AFP_06	6	0.07	1	0	1	41	41	17.93	3.40	yes	high
	DE_DU_AFP_07	7	0.00	1.25	6	1	53	53	0.81	3.65	yes	high
	DE_DU_AFP_08	8	0.08	0.25	24	1	53	53	0.19	3.64	yes	high
	DE_DU_AFP_09	9	11.13	6.75	53	1	86	86	9.32	3.61	yes	medium
	DE_DU_AFP_10	10	2.83	5	38	1	115	115	11.39	3.52	yes	high
Austria, Slovakia	AT_DU_AFP_01	11	15.64	5.5	64	1	20	20	19.58	3.40	yes	high
	AT_DU_AFP_02	12	1.52	2.5	172	1	62	62	14.04	3.76	yes	high
	AT_DU_AFP_03	13	8.24	5.5	68	1	85	85	3.52	3.81	yes	medium
	AT_DU_AFP_04	14	12.60	20.5	83	1	113	113	18.63	4.68	yes	low
	AT_DU_AFP_05	15	4.68	5	109	3	116	116	1.38	4.74	yes	low
	AT_SK_DU_AFP_01	16	1.21	4	81	1	51	51	3.98	3.56	yes	high
Slovakia, Hungary	HU_SK_DU_AFP_01	17	11.40	7	65	3	70	70	4.79	4.88	yes	low
	HU_SK_DU_AFP_02	18	0.60	2	18	1	59	59	10.42	4.21	yes	high
	HU_SK_DU_AFP_03	19	0.06	0	19	1	56	56	4.71	3.57	yes	high
	HU_SK_DU_AFP_04	20	0.39	2	29	3	56	56	8.08	3.74	yes	high
	HU_SK_DU_AFP_05	21	0.79	0.4	1	1	56	56	34.77	4.08	yes	high
Hungary	HU_DU_AFP_01	22	2.61	0	73	1	56	56	24.48	3.88	yes	high
	HU_DU_AFP_02	23	0.05	3	34	3	35	35	25.37	4.25	yes	high
	HU_DU_AFP_03	24	1.69	6	76	3	33	33	7.85	4.23	yes	medium
	HU_DU_AFP_04	25	1.03	7	79	3	33	33	8.52	4.42	yes	medium
	HU_DU_AFP_05	26	1.49	1	2	3	27	27	4.01	4.05	yes	high
	HU_DU_AFP_06	27	0.34	0.5	86	3	27	27	2.61	4.69	yes	high
	HU_DU_AFP_07	28	5.22	7	120	3	75	75	12.62	4.42	yes	low
	HU_DU_AFP_08	29	0.20	0	125	3	82	82	0.99	4.95	yes	high
	HU_HR_DU_AFP_01	30	1.41	5	128	3	82	82	0.14	4.91	yes	low
Croatia, Serbia	RS_HR_DU_AFP_01	31	4.04	41.5	70	1	144	144	1.78	4.90	yes	low
	RS_HR_DU_AFP_02	32	0.14	2	15	1	80	80	0.87	4.80	yes	high
	RS_HR_DU_AFP_03	33	0.25	2.5	30	1	80	80	0.53	4.97	yes	high
	RS_HR_DU_AFP_04	34	0.28	2.5	16	3	103	103	1.20	4.96	yes	medium
	RS_HR_DU_AFP_05	35	0.68	5	48	1	87	87	3.70	4.82	yes	high
Serbia	RS_DU_AFP_01	36	0.66	3	17	1	59	59	22.20	4.62	yes	high
	RS_DU_AFP_02	37	2.21	7.5	8	1	271	271	0.13	4.95	yes	low
	RS_DU_AFP_03	38	0.02	4	3	3	70	70	0.00	4.97	yes	high
	RS_DU_AFP_04	39	0.27	3	1	3	60	60	0.27	4.79	yes	high
	RS_DU_AFP_05	40	0.01	2.5	1	3	149	149	1.53	4.71	yes	high
Bulgaria, Romania	RO_BG_DU_AFP_01	41	0.22	1	8	3	176	176	0.38	4.82	yes	medium
	RO_BG_DU_AFP_02	42	0.01	2	4	3	164	164	0.00	4.94	yes	medium
	RO_BG_DU_AFP_03	43	0.01	2	7	3	131	131	0.24	4.31	yes	medium
	RO_BG_DU_AFP_04	44	0.06	4	12	3	161	161	0.21	4.40	yes	medium
	RO_BG_DU_AFP_05	45	0.03	2	13	3	165	165	0.28	4.62	yes	medium
	RO_BG_DU_AFP_06	46	0.01	2	12	3	67	67	0.15	4.65	yes	medium
Romania	RO_DU_AFP_01	47	0.02	1	24	3	116	116	0.56	4.98	yes	medium
	RO_DU_AFP_02	48	0.27	5	34	3	161	161	0.14	4.97	yes	low
	RO_DU_AFP_03	49	0.44	11	57	3	180	180	0.45	4.87	yes	low
	RO_DU_AFP_04	50	0.23	39	12	3	240	240	0.13	4.95	yes	low
FEM-rating	performance		Thresholds	Thresholds	Thresholds	Thresholds	Thresholds		Thresholds	Thresholds	Thresholds	Thresholds
	low		<1 %	<1 h	<10 cm	1	0	<40	>5 n/km²	<2	at least one parameter evaluated with 5	≥ 27
	medium		1-2 %	1-5 h	10 - 50 cm	3	1-20	41-100	1-5 n/km²	2-4		23-26
	high		>2 %	>5 h	>50 cm	5	>20	>101	<1 n/km²	>4	no parameter evaluated with 5	<23

Figure 35: Overview of the results for the minimum FEM-parameters incl. ranking (need for preservation + restoration demand) for all active floodplains along the Danube River

3.9.3. Analysis for the minimum FEM-parameters for the identified potential floodplains along the Danube River

Figure 36 provides an overview of the results for the minimum FEM-parameters for all identified potential floodplains along the Danube River. The relative peak reductions range from 0 to 17.62%, resulting in six floodplains with high (>2%) and eighteen (<1%) with low performance. Due to the flow processes in the floodplains, the flood wave is decelerated from 0 to 22 h. Nine floodplains showed a high (>5h), twelve a medium (1-5h) and two a low (<1h) performance for the flood wave translation parameter. In the case of a total loss of the active floodplain, the water level in the river channel would change from 0 to 193 cm. The water level would increase by more than 50 cm for twelve floodplains, leading to high performance (>50cm). The water level would increase between 10-50 cm for five floodplains, resulting in a medium performance. Nine floodplains showed a low performance (<10cm) for this parameter. At two potential floodplains, the lateral connectivity between the river channel and the floodplains was restored, leading to high performance. In six floodplains, the connectivity is still impaired by human intervention resulting in low performance. For sixteen floodplains, the lateral connectivity is partly disturbed (medium performance). On most of the potential floodplains (22 out of 24), more than 20 protected species are living. At the other two floodplains, at least 15 protected species are found. At eleven floodplains, the number of affected buildings per km² is less than 1, leading to high performance for this parameter. For eight floodplains, a medium performance (1-5 n/km²) was assessed. At five floodplains, more than 5 buildings are found per km² resulting in low performance. Half of the potential floodplains have a land use which has a low vulnerability against flooding (high performance). The other half shows a medium vulnerability (=medium performance).

country	Floodplain		Hydrology		Hydraulics	Ecology		Socio-Economics	
			peak reduction (%)	flood wave translation (h)	water level change (cm)	connectivity (-)	protected species	affected buildings	land use (-)
Germany	DE_DU_PFP01	1	17.62	19	117	1	95	14.95	3.61
	DE_DU_PFP02	2	2.41	11	108	1	54	16.78	3.89
	DE_DU_PFP03	3	0.35	0	52	1	17	5.07	4.29
	DE_DU_PFP04	4	0.02	2	0	1	15	1.94	3.67
	DE_DU_PFP05	5	0.33	5	25	1	53	6.63	3.31
Austria	AT_DU_PFP01	6	13.06	22	65	1	113	17.65	4.75
	AT_DU_PFP02	7	8.51	6.25	154	3	116	1.01	4.85
Hungary	HU_DU_PFP01	8	0.90	3	66	3	70	5.00	4.75
	HU_DU_PFP02	9	0.20	3	96	3	27	2.00	4.56
	HU_DU_PFP03	10	2.75	9	125	3	75	3.00	4.81
	HU_DU_PFP04	11	0.80	5	130	3	82	0	4.90
Serbia	RS_DU_PFP01	12	2.73	16	66	3	173	0.17	4.95
	RS_DU_PFP02	13	0.92	11	9	5	240	0.25	3.05
	RS_DU_PFP03	14	0.92	8	193	5	240	1.62	3.30
Bulgaria, Romania	BG_RO_DU_PFP01	15	0.04	1	6	3	153	0.05	4.05
	BG_RO_DU_PFP02	16	0.27	9	23	5	205	0.02	3.99
	BG_RO_DU_PFP03	17	0.67	22	84	3	198	0.09	4.04
	BG_RO_DU_PFP04	18	0.19	4	7	5	200	0.23	3.93
	BG_RO_DU_PFP05	19	0.05	2	11	3	157	1.23	4.11
Romania	RO_DU_PFP01	20	0.14	1	6	5	83	0	2.96
	RO_DU_PFP02	21	0.05	0.5	1	5	79	0	3.00
	RO_DU_PFP03	22	0.08	1	13	3	61	0.83	3.19
	RO_DU_PFP04	23	0.03	3	8	3	281	0.24	4.83
	RO_DU_PFP05	24	0.07	1	6	5	33	2.15	3.04
FEM-rating	performance		Thresholds	Thresholds	Thresholds	Thresholds	Thresholds	Thresholds	Thresholds
	low		<1 %	<1 h	<10 cm	1	0	>5 n/km²	<2
	medium		1-2 %	1-5 h	10 - 50 cm	3	1-20	1-5 n/km²	2-4
	high		>2 %	>5 h	>50 cm	5	>20	<1 n/km²	>4

Figure 36: Overview of the results for the minimum FEM-parameters for all identified potential floodplains along the Danube River

4. Conclusions

In Activity 3.2 of the Danube Floodplain project, active and potential floodplains along the Danube River were identified and evaluated with the Floodplain Evaluation Matrix (FEM). The FEM is an integrative method for assessing hydrological, hydraulic, ecological and socio-economic effects of floodplains with different parameters. The method was further developed and adapted with all project partners' help to serve the project's needs best.

Methods for the identification of active, potential and former floodplains were developed. In total, 50 active and 24 potential floodplains were identified. In this project, potential floodplains are those former floodplains from which settlements, infrastructure, streets and, in some cases, agriculture land are excluded. The total area of former floodplains was also estimated. The analysis and comparison of all three floodplain types showed that only a small portion of the former floodplains is an active or a potential floodplain currently. However, there are significant differences between the individual countries. In Austria (75%) and Croatia (95%) most of the former floodplains are preserved as hydraulically active floodplains. Austria can increase the preserved percentage even to 84% if the potential floodplains are also reconnected. In Romania, 32% of the former floodplain area still exists as active floodplains. In the other countries (Slovakia, Hungary, Serbia, Bulgaria) the percentage is less than 15%. Bulgaria can increase the share from 12% with the potential floodplains to 37%. This analysis showed that the potential for the reconnection of former floodplain areas is quite different between the individual countries. One reason for these differences is that the extension of the valley bottom differs significantly in the different states, resulting in much larger former floodplains in the middle and lower section of the Danube River. Even though 24 potential floodplains were identified in the scope of the Danube Floodplain project, the percentage of active + potential floodplains from the former floodplains is still quite low in some countries. One future goal should be to increase these numbers and identify even more potential floodplains. There is still potential, especially in countries with a low percentage of active + potential floodplains from the former floodplains. The identified potential floodplains in the scope of the Danube Floodplain project are not representing all potential floodplains at the Danube River, but only some of them that the representatives of the individual countries identified in the project.

Active and potential floodplains were evaluated with the FEM. For each identified floodplain, the minimum FEM-parameters were calculated. The evaluation with hydrological, hydraulic, ecological and socio-economic parameters showed that each active floodplain is valuable and should be preserved. From Germany to Romania, there is a slight tendency that hydrological and hydraulic parameters perform better. In contrast to this, the ecological and socio-economic parameters are performing better at floodplains along the Middle and Lower Danube. The high relative peak reduction at some floodplains in Germany (DE_DU_AFP_03 and 09) and Austria (AT_DU_AFP_01, 03 and 04) might be explained by dykes from hydropower plants. In Austria, these dykes are only overtopped at higher discharges (approximately at a HQ_5), which leads to a higher peak reduction. On the other hand, the flood wave translation showed a more constant tendency from Germany to Romania than the peak reduction. Two large outliers in Serbia (RS_HR_DU_AFP_01) and Romania (RO_DU_AFP_04) ensured that the flood wave translation slightly tends to increase downstream. Without these two outliers, the trend would be reversed. The minimum hydraulic parameter demonstrated the water level change in the river channel in the case of a total loss of the active floodplain. There is a decreasing tendency of the water level change from up- to downstream. One reason for that might be that a higher percentage of the former floodplains is preserved and disconnecting these areas from the river would lead to higher water level in the river channel at the Upper Danube. The number of protected species on floodplains is increasing from up- to downstream. On the upstream floodplains, the agricultural usage is significantly higher than at the downstream areas, reducing the potential habitat for different species. The connectivity of floodplain water bodies is impaired by human intervention at all active floodplains, especially along the Upper Danube. At the floodplains along the Lower Danube, almost no buildings exist on the floodplains leading to low vulnerability of these areas.

Based on the minimum FEM-parameters, the restoration demand (high, medium, low) for each active floodplain was determined. In general, each restoration measure at any floodplain regardless of the restoration demand is seen as valuable and desirable. In the Danube Floodplain manual (Danube Floodplain, 2021) win-win measures are listed which can improve the performance of the FEM-parameters. An improvement of the FEM performance can also change the determined restoration demand. The best-case scenario would be that all active floodplains show a low restoration demand.

For the assessment of the FEM, different data sets and models are necessary that have uncertainties. Hydraulic models are widely used in flood risk management to design flood protection measures and prepare flood hazard maps despite uncertainties in flood frequency, roughness parameteristation et cetera. All used models in the project were calibrated. Most partners used 1D-models for the assessments, where available 2D-models were applied. In general, 2D-models should be preferred before 1D-models investigating hydraulic behavior on floodplains. Nevertheless, if adequate data is available and a thorough calibration of the 1D-model is performed, 1D-models can be used for simulating the retention effects of floodplains.

Despite certain limitations and uncertainties in the analyses, identifying and analyzing active, potential and former floodplains are necessary for sustainable flood risk and floodplain management. The evaluation of the floodplains with the FEM using hydrological, hydraulic, ecological and socio-economics parameters creates an adequate basis for further steps to achieve sustainable water management, emphasizing reducing flood risk, improving the ecological situation and considering socio-economic processes. Further assessments of floodplains at other rivers are desirable.

5. Literature

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Annex

A. FEM-Handbook - minimum set

Table of content

Introduction

The Danube Floodplain project aims to improve transnational water management and flood risk prevention while maximizing benefits for biodiversity conservation. Preservation and/or restoration of floodplains play a key role in an integrated flood risk management. Therefore, it is important to identify the active and potential floodplains as well as an evaluation of their effects in terms of flood risk reduction, ecological benefits and socio-economic aspects.

This handbook is a guidance for all countries in the Danube River Basin that have to evaluate their floodplains with the Floodplain Evaluation Matrix (FEM). The handbook gives a detailed description of each FEM parameter from the minimum class, a workflow on how to calculate the parameter, some examples and the selected thresholds in the Danube Floodplain project. This minimum class of parameters were accepted by all project partners and have to be applied at selected active and potential floodplain that was identified in WP3.

1. Hydrology

1.1. Flood peak reduction – ΔQ

1.1.1 Description

The flood peak reduction considers the effect of a floodplain on the peak of a flood wave. In order to evaluate the peak reduction for a floodplain, the peak of an input hydrograph (e.g. HQ_{100}) at the beginning of the floodplain and the peak of the output hydrograph at the end of the floodplain will be determined. The difference between the peaks is the peak reduction ΔQ [m³/s] for the investigated floodplain. The retention effect of the river channel has to be considered as well. Therefore, the peak reduction ΔQ_{RC} of the river channel is calculated with a model, where the floodplains is disconnected from the river channel by disabling these areas or by implementing fictive dykes. For demonstrating only the effect of the floodplains on the peak reduction, it is necessary to subtract ΔQ_{RC} from the ΔQ, which was calculated before. For comparison of different river reaches a relative value is used. Therefore, the peak reduction is divided by the HQ_{100} for the whole river in the country and then multiplied by 100 to get the percentage (see formula [2]).

1.1.2 Source

For the determination of the peak reduction, results of unsteady hydrodynamic-numerical 2D-simulations are preferred, which should be calibrated and validated with recorded flood waves at different gauging stations. Using 1D-models is also possible. Other options to calculate the peak reduction would be observed flood waves at different gauging stations within the reach or engineering approaches. If engineering approaches are necessary due to lack of data, a separate handbook will be provided, where these approaches are explained.

1.1.3 Workflow

Step 1: Selecting hydrological input data

You can take the input hydrograph of the closest gauging station upstream of the floodplain from a recorded flood event close to HQ_{100} (e.g. 2006, 2010, 2013) and adjust it (e.g. Scale it to HQ_{100} peak value) or you can use hydrographs from existing hydrodynamic models that are HQ_{100}. If nothing is available, TUM can provide hydrographs from the SWIM model. You should at least use one hydrograph for each floodplain, if possible two (a steep and a flat one). If there are any tributaries within the delineated floodplain, unsteady and/or steady hydrological input data will be used. In general, unsteady hydrological input data should be preferred for all tributaries. Especially for larger tributaries, unsteady flood waves should be used[2]. Concerning the hydrological input data of the tributaries, you have some options:

Concerning the hydrological input data of the tributaries there are two options. If you have input hydrographs from the real event for the Danube and the tributary and you use it at the Danube by scaling it to a HQ_{100},

[2] If no data from gauging stations is available for the main tributaries, TUM could provide you flood waves from the SWIM model

then the tributary hydrograph should be scaled in the same rate (and not automatically to a HQ_{100}). If you have don't have hydrographs of this real event at the tributary, you can use a steady or unsteady HQ_{100} hydrograph as input.

The documentation of the used flood waves/hydrological input data is very important. You have to provide us your used data.

For generating your final input hydrograph, which you are using for the determination of ΔQ, you have to add the discharge of all tributaries to your input hydrograph of the Danube, to make sure that the new final input hydrograph is larger than the calculated output hydrograph (Figure A 1).

Step 2: Calculating output hydrograph at end of floodplain and computing ΔQ_{tot}
You can use a 2D model or if not available, a 1D model to calculate the output hydrograph at a cross section at the end of the floodplain. If no model is available an engineering approach can be used. This would be for example the Gauckler-Manning-Strickler formula. If a 1D model is used the modeler should make sure that the floodplain flow characteristics are correctly modeled. In order to compute ΔQ_{tot} it is necessary to calculate the difference between the peak of the input and the output flood wave.

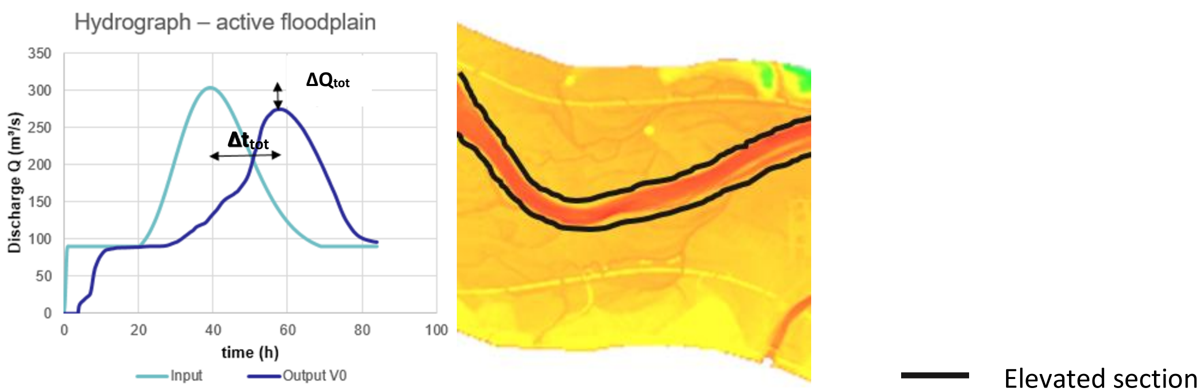


Figure A 1: FEM-parameter flood peak reduction ΔQtot for active floodplains

Step 3: Calculating ΔQ_{RC} of the river channel
To demonstrate only the effect of the floodplains on the peak reduction, it is necessary to run the model a second time with disconnected or disabled floodplains and foreland to calculate the retention effect of the river channel. For disconnecting the floodplains in the model, possible approaches are to deactivate the floodplain or to elevate a section next to the river. After running the simulation, the peak of the new generated output hydrograph has to be subtracted from the input hydrograph to determine ΔQ_{RC} (Figure A 2).

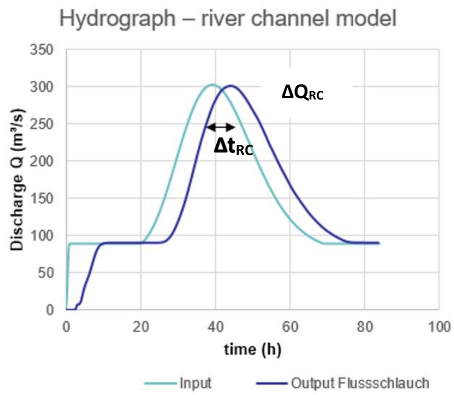


Figure A 2: FEM-parameter flood peak reduction ΔQ_{RC} for the river channel

Step 4: Calculating ΔQ and ΔQ_{rel}

The first calculation of ΔQ_{tot} gives the retention effects of the floodplains as well of the river channel. ΔQ_{RC} shows only the effect of the river channel on the flood peak. Therefore, it is necessary to subtract ΔQ_{RC} from the ΔQ_{tot} for demonstrating only the effect of the floodplains on the peak reduction.

$$\Delta Q = \Delta Q_{tot} - \Delta Q_{RC} [m^3 s^{-1}] \qquad [1]$$

Additionally, the relative peak reduction ΔQ_{rel} [%] has to be calculated by dividing the ΔQ by the difference between Q_{max} and $Q_{bankfull}$ multiplied by 100 to make a comparison of different river reaches possible. The Q_{max} is the flood peak of the inflow wave and $Q_{bankfull}$ the discharge, where the river starts overtopping its bank.

$$\Delta Q_{rel} = \frac{\Delta Q}{(Q_{max} - Q_{bankfull})} \times 100\ [\%] \qquad [2]$$

Step 5: Plausibility check of calculated ΔQ

For checking the plausibility of the modelling results, it is necessary to compare the calculated ΔQ with an observed ΔQ_{obs} (Figure A 3), which was measured during a flood event close to the used hydrograph in the model in terms of return period and shape of the flood wave. For determining the observed ΔQ_{obs}, two measured hydrographs are used. The measured hydrograph from the closest gauging station at the beginning/or upstream and at end of the floodplain/or downstream are necessary to determine the observed ΔQ_{obs}.

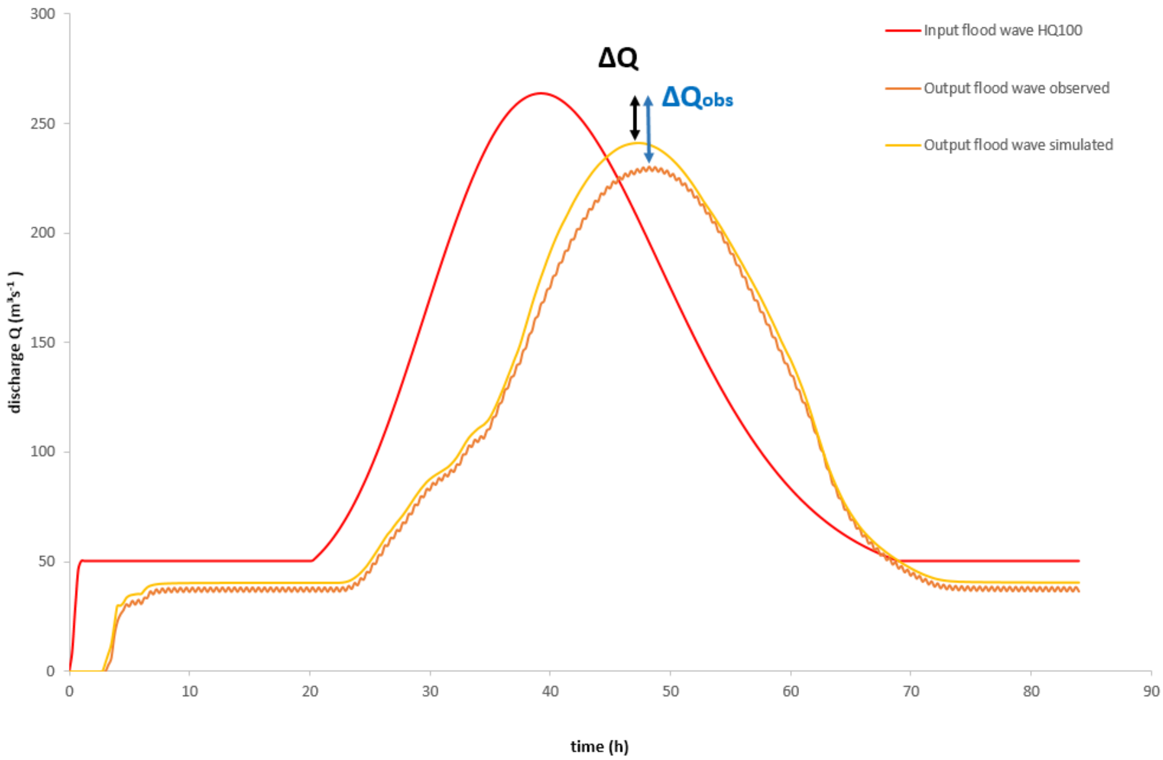


Figure A 3:Comparison of the observed ΔQobs with the calculated ΔQ with the help of the observed and simulated output hydrographs

Hydrological longitudinal section of a flood event, which shows the Q_{max} at all available gauging stations, can deliver also information about the observed ΔQ_{obs} (Figure A 4).

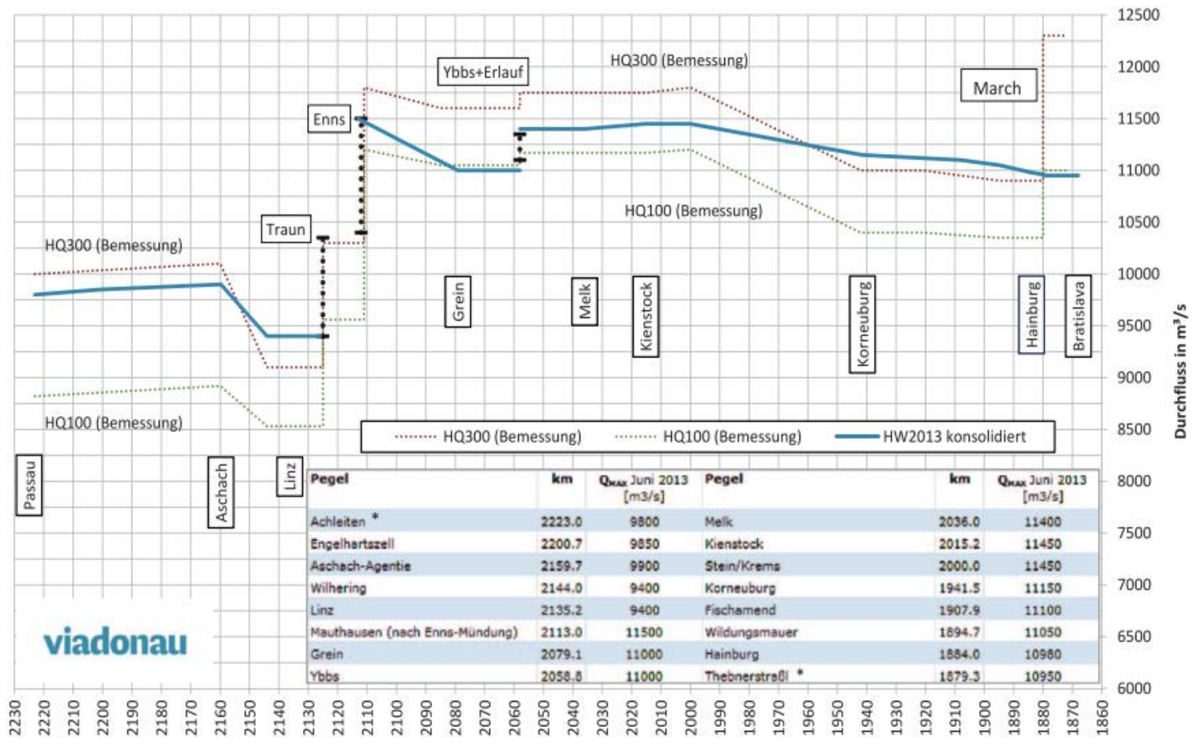


Figure A 4: Hydrological longitudinal section of the flood wave 2013 in Austria (source: Pörky energy GmbH)

Furthermore, if results for the ΔQ are available from 2D and 1D model, they have to be compared.

1.1.4 Example

Austria uses the recorded flood event from 2002 as a steep input hydrograph and the flood event from 1954 as a flat input hydrograph (Figure A 5). The available 2D model is then used to calculate the output hydrographs for both events. The ΔQ_{RC} of the river channel model is then subtracted.

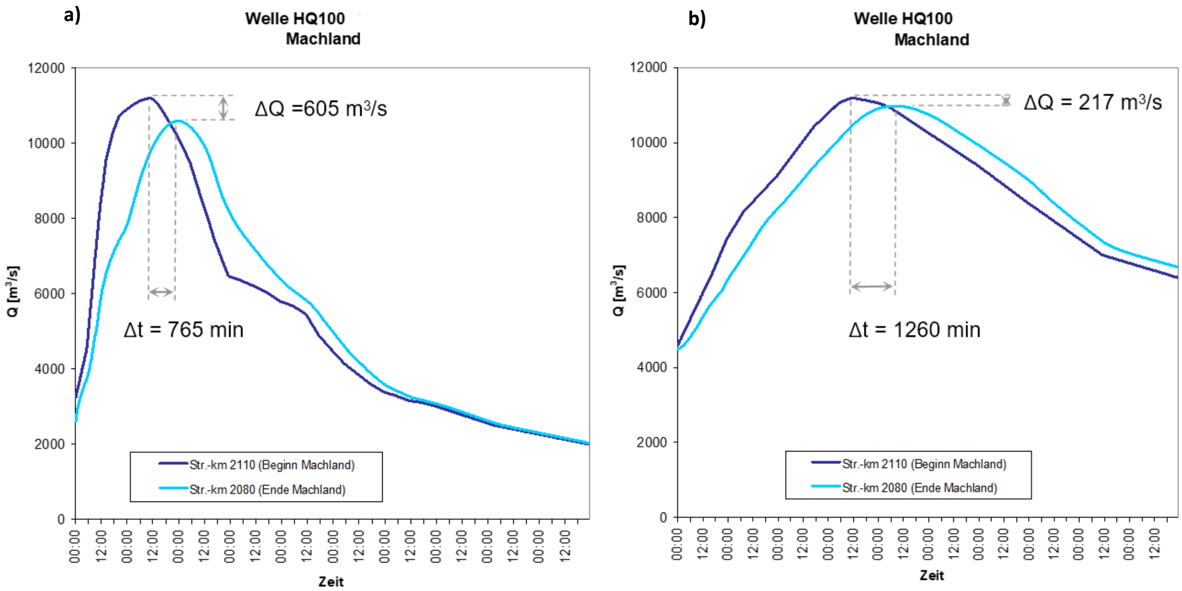
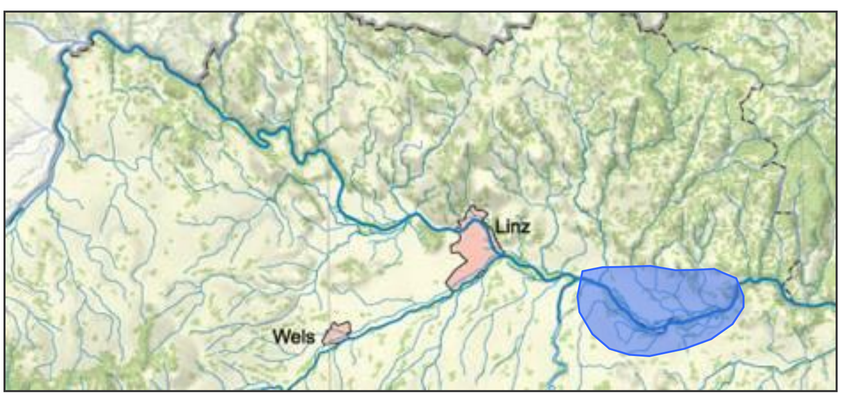


Figure A 5: Flood peak reduction - example Austria (Machland)

In the last step the ΔQ_{rel} was calculated by using the flood peak of the inflow wave (11.203 m³/s).



	Machland
ΔQ	605 m^3/s
ΔQrel	5,4 %

Figure A 6: Flood peak reduction relative for a steep flood wave (2002) - example Austria (Machland)

1.1.5 Thresholds

In Table A 1, the thresholds are shown, which are used to determine the performance of the floodplain for the relative flood peak reduction. If the relative flood peak reduction (ΔQ_{rel}) is smaller than 1%, the performance of the floodplain is low. Between 1-2%, the performance is medium. All floodplains with a relative flood peak reduction above 2% perform high.

Table A 1: Thresholds to determine the performance of the relative flood peak reduction ΔQrel in the FEM-Evaluation

Thresholds ΔQrel	
1	< 1 %
3	1 - 2 %
5	> 2 %

1.2. Flood wave translation – Δt

1.2.1 Description

The flood wave translation is the second parameter required for the investigation of the process of wave attenuation due to a floodplain. This parameter is determined in a similar way as the peak reduction, namely by calculating the time difference Δt [h] between the occurrence of the output/input hydrograph peak. Therefore, you can use the same hydrographs, which were calculated for the peak reduction, but this time you determine the time when the peak of the flood waves occur and calculate the difference between them.

1.2.2 Source

For the determination of the flood wave translation, results of unsteady hydrodynamic-numerical 2D-simulations are preferred, which should be calibrated and validated with recorded flood waves at different gauging stations. Using 1D-models is also possible. Other options to calculate the flood wave translation would be observed flood waves at different gauging station within the reach or engineering approaches. If engineering approaches are necessary due to lack of data, a separate handbook will be provided, where these approaches are explained.

1.2.3 Workflow

Step 1: Using output hydrograph at end of floodplain and calculating Δt_{tot}

You can use the same output hydrograph for calculating the flood wave translation Δt_{tot} as for the modelling of the ΔQ (Figure A 7). It is recommended to model and calculate both parameter at the same time. In order to compute Δt_{tot}, it is necessary to determine the time when the peak of the flood waves (input/output) occur and calculate the difference between them.

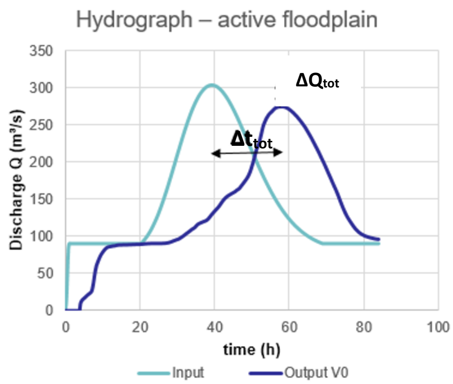


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Figure A 7: FEM-parameter flood wave translation Δt_{tot} for active floodplains

Step 2: Calculating the Δt_{RC} for the river channel

You can use the output hydrograph from the modelling of ΔQ_{RC} for calculating the flood wave translation Δt_{RC} for the river channel. In order to compute Δt_{RC}, it is necessary to determine the time when the peak of the flood waves (input/output) occur and calculate the difference between them (Figure A 8).

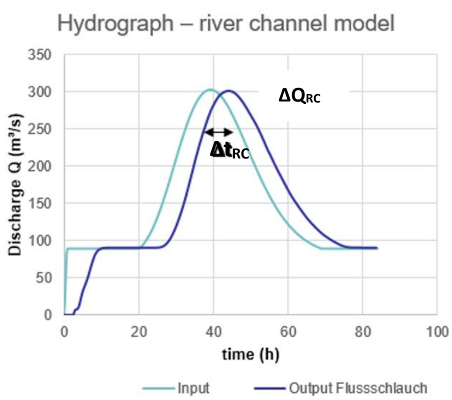


Figure A 8: FEM-parameter flood wave translation Δt_{RC} for the river channel

Step 3: Calculating Δt

The first calculation of Δt_{tot} shows the effects of the floodplains as well of the river channel on the travel time of the flood wave. Δt_{RC} demonstrates only the effect of the river channel on the travel time. Therefore, it is necessary to subtract Δt_{RC} from the Δt_{tot} for demonstrating only the effect of the floodplains on the travel time.

$$\Delta t = \Delta t_{tot} - \Delta t_{RC} [h] \quad [3]$$

Step 4: Plausibility check of calculated Δt

For checking the plausibility of the modelling results, it is necessary to compare the calculated Δt with an observed Δt_{obs}, which were measured during a flood event close to the used hydrograph in the model in terms of return period and shape of the flood wave. For determining the observed Δt_{obs}, two measured hydrographs are used. The measured hydrograph from the closest gauging station at the beginning and at end of the floodplain are necessary to determine the observed Δt_{obs} (Figure A 9).

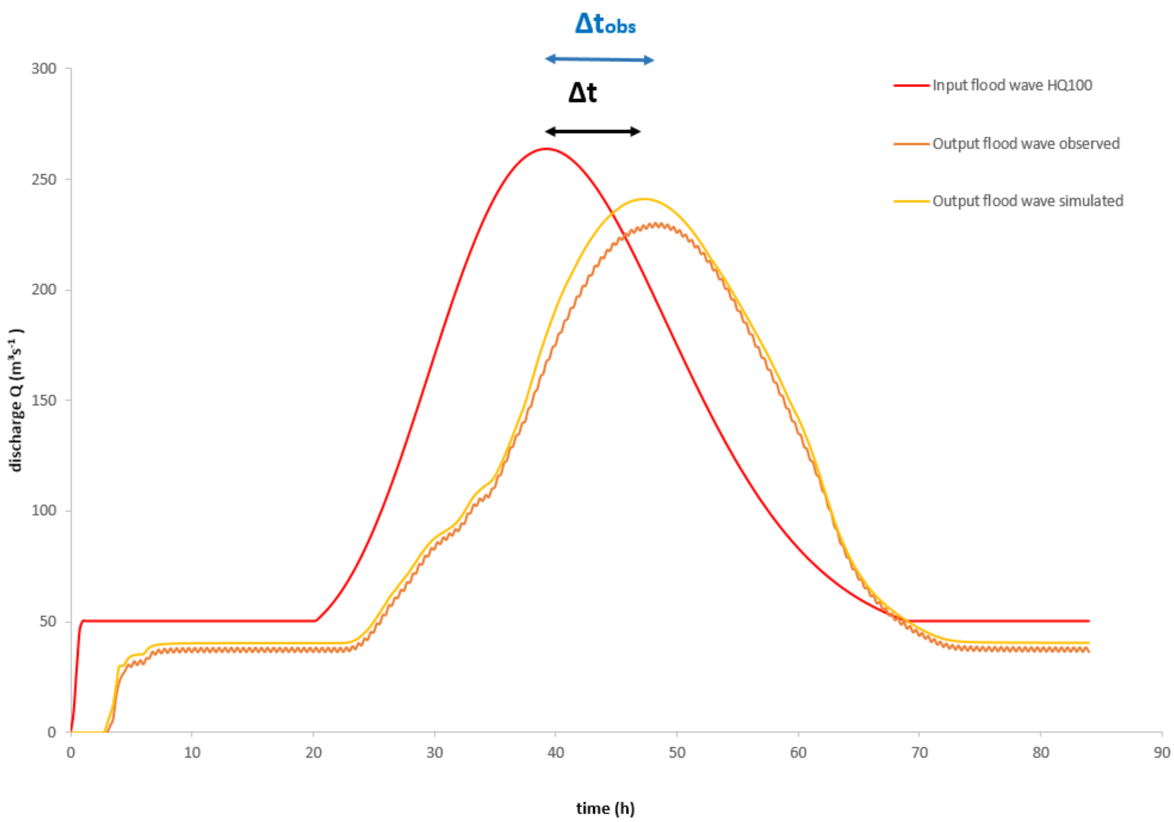


Figure A 9: Comparison of the observed Δt_{obs} with the calculated Δt with the help of the observed and simulated output hydrographs

Furthermore, if results for the Δt are available from 2D and 1D model, they have to be compared.

1.2.4 Example

Austria uses the recorded flood event from 2002 as a steep input hydrograph and the flood event from 1954 as a flat input hydrograph. The available 2D model is used to calculate the output hydrograph for both events. The Δt_{RC} of the river channel model is then subtracted (Figure A 10).

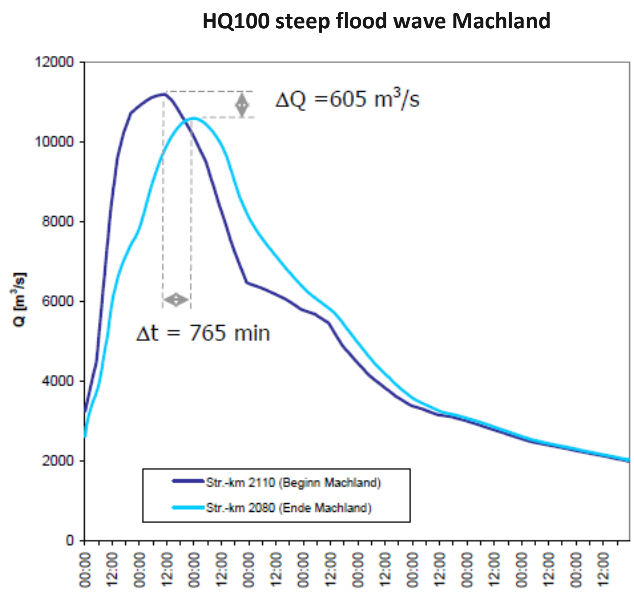


Figure A 10: Flood wave translation - example Austria (Machland)

1.2.5 Thresholds

In Table A 2, the thresholds are shown, which are used to determine the performance of the floodplain for the parameter flood wave translation. If the flood wave translation (Δt) is smaller than 1h, the performance of the floodplain is low. Between 1-5h, the performance is medium. All floodplains with a flood wave translation above 5h perform high.

Table A 2: Thresholds to determine the performance of the flood wave translation Δt in the FEM-Evaluation

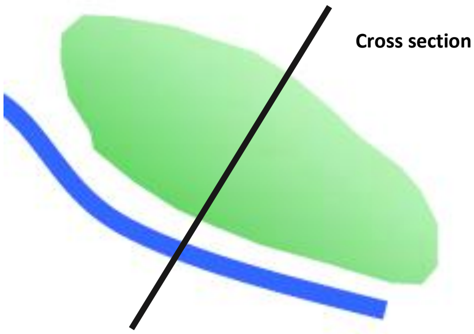
Thresholds Δt	
1	< 1 h
3	1 - 5 h
5	> 5 h

2. Hydraulics

2.1 Water level change – Δh

2.1.1 Description

A hydrodynamic-numerical model is used to determine the influence of changes in floodplain geometry (e.g. by dyke-shifting). Reducing or extending floodplain widths by modelling of fictive dykes exhibits how big changes in the water level surface of the scenarios (Δh) can be. The observed values can be calculated in a cross section at the middle or/and end of the floodplain or in the next settlement. In this project, we want to show the effects of a total loss of a floodplain on the water level. Therefore, we can use the model, which we were using for the calculation of ΔQ_{RC} and Δt_{RC} within this model we have disconnected the floodplains and foreland from the river channel by fictive dykes.



This parameter is also used for showing the effects on potential removal of dykes to reconnect potential floodplains. The removal of the dykes would mean changes of the geometry in the model, which would be necessary to show the effects on the water level.

2.1.2 Source

Comparison of the water surfaces of different scenarios using an unsteady hydrodynamic model (2D, 1D) or engineering approaches.

2.1.3 Workflow

Step 1: Calculating water level for a HQ_{100} with the active floodplain (h_{tot})

You can use the same hydrodynamic-numerical calculation, which is used to determine the hydrological parameters (ΔQ_{tot} and Δt_{tot}). At a defined cross-section (e.g. in the middle of the floodplain) you determine the calculated water level h_{tot} in the middle of the river channel.

Step 2: Calculating water level for a HQ_{100} without floodplain (h_{RC})

In the next step, you use the same hydrodynamic-numerical calculation, which was used to determine the hydrological parameters (ΔQ_{RC} and Δt_{RC}) and you determine the calculated water level (h_{RC}) on the same spot as in step 1.

Step 3: Calculating the Δh

In the last step, you have to compute the Δh by subtracting the calculated water level without floodplains (h_{RC}) from the water level (h_{tot}) with active floodplain. The water level change Δh demonstrates the increase of the water level due to a loss of the floodplain.

$$\Delta \mathrm{h} = \mathrm{h}_{\mathrm{tot}} - \mathrm{h}_{\mathrm{RC}}[\mathrm{m}] \quad [5]$$

2.1.4 Example

In Austria, the water level changes were calculated by shifting an existing dyke 50% closer to the river, 100% closer to the river and also one scenario where the dyke was moved away. The results showed an increase of the water level in the cross section in the middle of the floodplain of 112 cm (Figure A 11). In General, there has to be calculated only one scenario where the floodplain is disconnected completely (eg. by elevation of a section close to the river to simulate a dyke).

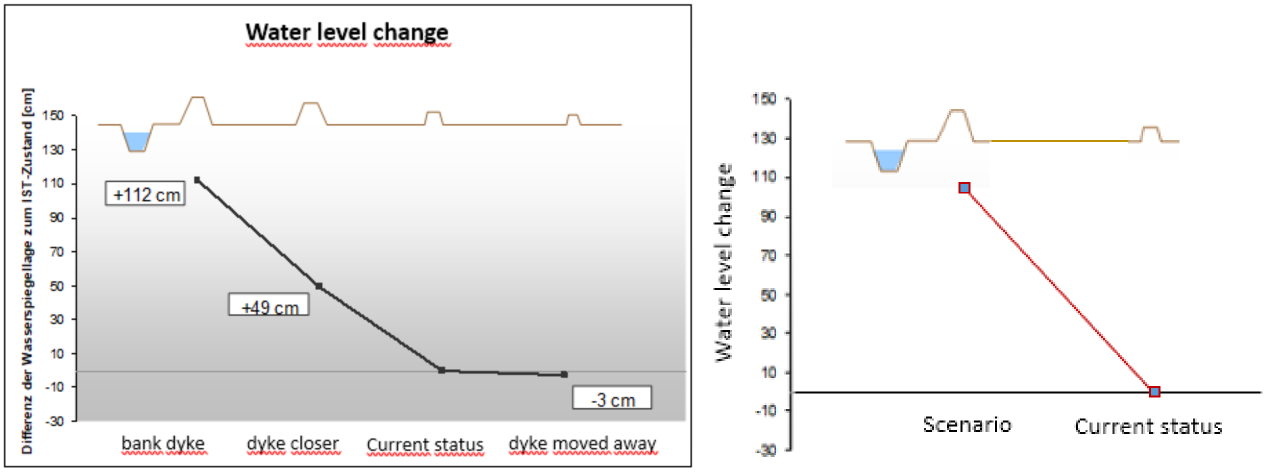


Figure A 11: water level change - example Austria (Machland)

2.1.5 Thresholds

In Table A 3, the thresholds are shown, which are used to determine the performance of the floodplain for the parameter water level change. If the water level change (Δh) is smaller than 10 cm, the performance of the floodplain is low. Between 10-50 cm, the performance is medium. All floodplains with a water level change above 50 cm perform high.

Table A 3: Thresholds to determine the performance of the water level change Δh in the FEM-Evaluation

Thresholds Δh	
1	< 10 cm
3	10 - 50 cm
5	> 50 cm

3. Ecology

3.1 Connectivity of floodplain water bodies

3.1.1 Description

Connectivity is crucial for the functioning of riverine ecosystems. The longitudinal connectivity describes the connectivity in the up- and downstream direction and is especially relevant for the exchange of populations of water organisms and their migration during their life cycle, the lateral connectivity refers to the connection of the river channel and the floodplain and the vertical connectivity is the connection of the river channel and the ground water table in the floodplain (which might be crucial for small temporary water bodies in the floodplain). For simplification, the connectivity of floodplain water bodies will be investigated only in the lateral direction with the help of 3 Scenarios:

4. mean water level (from gauging stations)
5. bankfull flow (1D/2D modeling)
6. above bankfull flow

3.1.2 Source

Unsteady hydrodynamic-numerical 2D-/1D-model can be used.

3.1.3 Workflow

Step 1: Calculate 3 scenarios

The three scenarios (mean water flow, bankfull flow and above bankfull flow) have to be calculated with a 2D or a 1D model. If you use a 1D model, make sure, the flow behavior of the floodplain is correctly simulated.

Step 2: Determine connectivity

The 3 scenarios now help you to determine the connectivity of the water bodies (e.g. branches, oxbows) in the floodplain. You have to find out, at which discharge the water bodies are connected.

Step 3: Checking historic maps

For determination the “natural (historic)” status of water bodies on the floodplain historic maps have to be checked. There are 4 possible outcomes on the comparison between the current status and the historic status:

1. No “natural” (historic) water bodies on the floodplain
2. Existing water bodies on the floodplain (historic and current status)
3. On the historic maps “natural” (historic) water bodies existed, but at the active floodplain no water bodies are left, due to human activity (e.g. dykes etc.)
4. On historic maps “natural” (historic) water bodies existed and are still existing, but were cut off by a dyke

Step 4: FEM-Ranking*

If the river system is meandering, the connectivity is naturally beginning at bankfull discharge so, if this is given, it gets the best rating (5 points) in the FEM and no further steps are needed. For (historically) braided or anastomosing river types the best rating (5 points) is given when the side arms are already connected at discharges below mean water level. The detailed scenarios are listed below:

1. Water bodies connected up to mean water level / No “natural” (historic) water bodies on the floodplain / meandering river systems connected above bankfull discharge (5 points)
2. Water bodies connected at mean water level up to bankfull discharge (3 points)

3. Water bodies not connected above bankfull discharge / On the historic maps "natural" (historic) water bodies existed, but at the active floodplain no water bodies are left (1 point)

* If water bodies are cut off by a dyke but still existing on the floodplain, it will lead to a downgrade into the next FEM-class. E.g. Water bodies are connected up to mean flow –> 5 points, but by checking the historic maps it was discovered that the existing water bodies were cut off. This leads to a downgrade into the next class: 3 points

3.1.4 Thresholds

For the connectivity parameter, the method allows determining the performance without defined thresholds

3.2 Existence of protected species

3.2.1 Description

A floodplain is valuable and should be preserved if red list species or species and habitats (recognized by Natura2000, Emerald network or national legislation) are found on the area.

3.2.2 Source

In case of the European Union countries the Natura 2000 database can be used while countries where such information is not available (e.g., Serbia) can use the equivalent Emerald Network database or other relevant national sources.

3.2.3 Workflow

Step 1: Downloading Natura2000 or Emerald Network datasets
First of all you have to open the Natura 2000 viewer at http://natura2000.eea.europa.eu/. There you can go to the floodplain you focus on and select the datasets that are available there. One layer is for the EC Bird Directive and one layer is for the habitats Directive.

Emerald Network (https://emerald.eea.europa.eu/) states Species listed in Resolution 6[3] and site evaluation for them, as well as Other important species of flora and fauna.

Information from the national legislation (e.g., Studies on the Protection) can be also used.

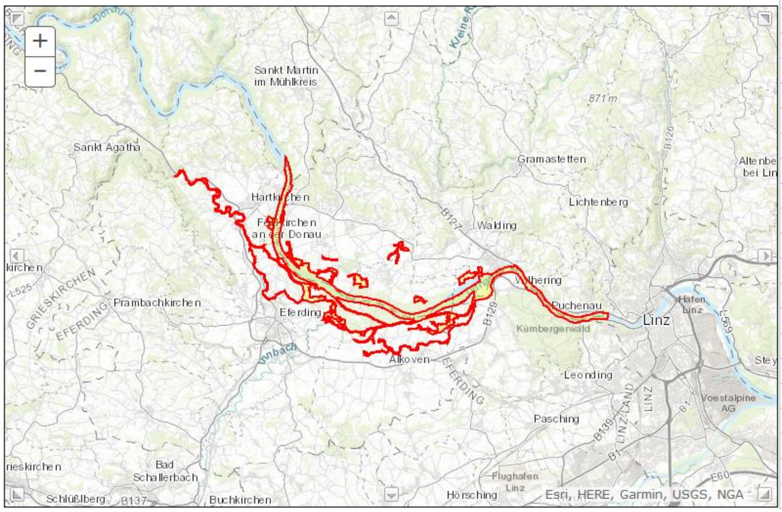
Step 2: Counting number of protected species
The datasets can be downloaded as PDFs. There you can go to the chapter "Habitat types present on the site" and count all habitat types that occur at the floodplain. If available, you can open the second document for the birds and count all species that are listed in the chapter "Species referred to in Article 4 of Directive"

Step 3: Summarizing all protected species
In the final step, you have to add the two amounts of species/groups together, which gives you an overall number for the floodplain. This is the basis for the evaluation of this parameter

[3] Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention)

3.2.4 Example

Parts of the area of the Eferdinger Becken in Austria are protected by the Habitats Directive, but it is not a protected area according to the birds directive. The total amount of protected species in the Natura 2000 data is 20 (Figure A 12).



Eferdinger Becken			
Group	**Code**	**Scientific Name**	**Type**
F	1130	Aspius aspius	p
M	1308	Barbastella barbastellus	r
M	1337	Castor fiber	p
F	1163	Cottus gobio	p
I	1086	Cucujus cinnaberinus	p
F	2555	Gymnocephalus baloni	p
F	1157	Gymnocephalus schraetzer	p
M	1355	Lutra lutra	p
F	1145	Misgurnus fossilis	p
M	1321	Myotis emarginatus	r
I	1084	Osmoderma eremita	p
F	5339	Rhodeus amarus	p
F	6145	Romanogobio uranoscopus	p
F	5329	Romanogobio vladykovi	p
F	5345	Rutilus virgo	p
F	5197	Sabanejewia balcanica	p
A	1166	Triturus cristatus	p
I	1032	Unio crassus	p
F	1160	Zingel streber	p
F	1159	Zingel zingel	p
	Number:	**20**	

Figure A 12: Existence of protected species - example Austria (Eferdinger Becken)

3.2.5 Thresholds

In Table A 4, the thresholds are shown, which are used to determine the performance of the floodplain for the parameter existence of protected species for the first step of the ranking process. If no protected species are existing on the floodplain, the performance of the floodplain is low. Between 1-20 species, the performance is medium. All floodplains were more than 20 species are protected, perform high.

Table A 4: Thresholds to determine the performance of the parameter existence of protected species in the FEM-Evaluation for the first step of the ranking process

Thresholds protected species	
1	no protected
3	1 - 20
5	> 20

In Table A 5, the thresholds are shown, which are used to determine the performance of the floodplain for the parameter existence of protected species for the second step of the ranking process. If less than 40 protected species are existing on the floodplain, the performance of the floodplain is low. Between 40-101 species, the performance is medium. All floodplains were more than 101 species are protected, perform high.

Table A 5: Thresholds to determine the performance of the parameter existence of protected species in the FEM-Evaluation for the second step of the ranking process

Thresholds protected species	
1	< 40
3	40 - 101
5	> 101

In both steps different thresholds can be defined based on the national conditions.

4. Socio-Economics

4.1 Potentially affected buildings

4.1.1 Description

This parameter determines the number of buildings on each active floodplain. The more buildings are affected, the higher is the potential damage.

4.1.2 Source

Orthophotos, digital cadastral maps or land charge register can be used.

4.1.3 Workflow

Step 1: Collecting suitable data set(s)

The steps strongly depend on available data. If possible you should collect the information from digital cadastral maps or shape files including the buildings in the floodplain area. If this data is not available, you can also use the latest available orthophotos or even Google Earth.

Step 2: Counting affected buildings

If you upload your data into the GIS, you can easily see which buildings are inside the floodplain. It is also possible to let the GIS automatically count the number of shapes in the area. If you use orthophotos, it may be a bit difficult, but it is possible to count the affected buildings based on the manually created point shapefile. If a building is only partially in the floodplain area, it is counted as well.

Step 3: Dividing the number of buildings by the area of the floodplain

For comparing the results of this parameter, it is necessary to divide the number of the buildings by the area of the floodplain.

4.1.4 Example

For Austria, we counted the number of buildings by using a GIS layer that included all buildings as polygon shapes (Figure A 13). The Eferdinger Becken is 53.16 km² large and there are 1044 buildings on the floodplain. After dividing the amount by the area, it gives 19.63 buildings/km².

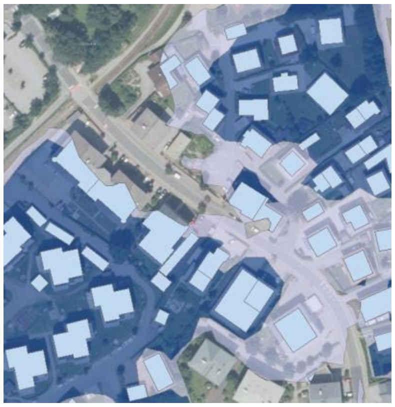


Figure A 13: potentially affected buildings - example Austria (Feldbach)

4.1.5 Thresholds

In Table A 6, the thresholds are shown, which are used to determine the performance of the floodplain for the parameter potentially affected buildings. If more than 5 buildings per km² are on the floodplain, the performance of the floodplain is low. Between 1 and 5 buildings per km² the performance is medium. All floodplains with less than 1 building per km², perform high in the FEM-evaluation.

Table A 6: Thresholds to determine the performance of the parameter potentially affected buildings in the FEM-Evaluation

Thresholds affected buildings	
1	> 5 [n/km²]
3	1 - 5 [n/km²]
5	< 1 [n/km²]

4.2 Land use

4.2.1 Description

Land use that is adapted to future inundation will minimize the socio-economical vulnerability of the floodplain. Therefore, flood-adapted land use (=low vulnerability) gets the highest rating, non-adapted the lowest (settlements=high vulnerability). The different types of land uses are aggregated proportional to their areas to one evaluation value for the whole floodplain.

4.2.2 Source

CORINE land cover dataset should be used and checked with aerial photos.

4.2.3 Workflow

Step 1: Downloading and prepare CORINE land cover dataset

The dataset can be downloaded from the Copernicus database https://land.copernicus.eu/pan-european/corine-land-cover/clc2018 and loaded into a GIS. Then it has to be edited with the help of the floodplain polygon shape to cut the boundaries according to the floodplain. Additionally, it should be checked if the land cover classes are matching with the latest aerial photos of the area.

Step 2: GIS-analysis of the floodplain CLC data set (CLC)

With the GIS analysis tool (e.g. ArcGIS zonal statistics) it is possible to get an output table with all land cover classes of the data set and the corresponding area of the floodplain. This table will later be expanded with the evaluation value for each class.

Step 3: Determining the vulnerability of the floodplain based on the land use

Each land use class was assigned to one of three groups based on the vulnerability against flooding (Table A 7). E.g. land uses like urban fabric or industrial units have a high vulnerability (=low performance (1) – in the FEM-evaluation).

Table A 7: Land use types of the Corine Land Cover data set with corresponding FEM-evaluation (1=low, 3=medium, 5=high performance) based on the vulnerability against flooding

CLC_CO	LABEL2	LABEL3	FEM-evaluation	RGB
111	Urban fabric	Continuous urban fabric	1	230-000-077
112	Urban fabric	Discontinuous urban fabric	1	255-000-000
121	Industrial, commercial and transport units	Industrial or commercial units	1	204-077-242
122	Industrial, commercial and transport units	Road and rail networks and associated land	1	204-000-000
123	Industrial, commercial and transport units	Port areas	1	230-204-204
124	Industrial, commercial and transport units	Airports	1	230-204-230
131	Mine, dump and construction sites	Mineral extraction sites	1	166-000-204
132	Mine, dump and construction sites	Dump sites	1	166-077-000
133	Mine, dump and construction sites	Construction sites	1	255-077-255
141	Artificial, non-agricultural vegetated areas	Green urban areas	1	255-166-255
142	Artificial, non-agricultural vegetated areas	Sport and leisure facilities	1	255-230-255
211	Arable land	Non-irrigated arable land	3	255-255-168
212	Arable land	Permanently irrigated land	3	255-255-000
213	Arable land	Rice fields	3	230-230-000
221	Permanent crops	Vineyards	3	230-128-000
222	Permanent crops	Fruit trees and berry plantations	3	242-166-077
223	Permanent crops	Olive groves	3	230-166-000
231	Pastures	Pastures	3	230-230-077
241	Heterogeneous agricultural areas	Annual crops associated with permanent crops	3	255-230-166
242	Heterogeneous agricultural areas	Complex cultivation patterns	3	255-230-077
243	Heterogeneous agricultural areas	Land principally occupied by agriculture, with significant areas of natu	3	230-204-077
244	Heterogeneous agricultural areas	Agro-forestry areas	3	242-204-166
311	Forests	Broad-leaved forest	5	128-255-000
312	Forests	Coniferous forest	5	000-166-000
313	Forests	Mixed forest	5	077-255-000
321	Scrub and/or herbaceous vegetation asso	Natural grasslands	5	204-242-077
322	Scrub and/or herbaceous vegetation asso	Moors and heathland	5	166-255-128
323	Scrub and/or herbaceous vegetation asso	Sclerophyllous vegetation	5	166-230-077
324	Scrub and/or herbaceous vegetation asso	Transitional woodland-shrub	5	166-242-000
331	Open spaces with little or no vegetation	Beaches, dunes, sands	3	230-230-230
332	Open spaces with little or no vegetation	Bare rocks	5	204-204-204
333	Open spaces with little or no vegetation	Sparsely vegetated areas	5	204-255-204
334	Open spaces with little or no vegetation	Burnt areas	3	000-000-000
335	Open spaces with little or no vegetation	Glaciers and perpetual snow	not relevant	166-230-204
411	Inland wetlands	Inland marshes	5	166-166-255
412	Inland wetlands	Peat bogs	5	077-077-255
421	Maritime wetlands	Salt marshes	not relevant	204-204-255
422	Maritime wetlands	Salines	not relevant	230-230-255
423	Maritime wetlands	Intertidal flats	5	166-166-230
511	Inland waters	Water courses	5	000-204-242
512	Inland waters	Water bodies	5	128-242-230
521	Marine waters	Coastal lagoons	5	000-255-166
522	Marine waters	Estuaries	5	166-255-230
523	Marine waters	Sea and ocean	5	230-242-255

Step 4: Calculating the total FEM-value

The areas with different vulnerabilities are summed up in the respective group (1 – low, 3 – medium, 5 – high performance). E.g. the total area of areas with a high vulnerable land use are recorded. A weighted FEM value is then calculated by multiplying the number of points, which depends on the vulnerability, by the area by the total area (Table A 9). The resulting values of the three groups are then summed to obtain one's FEM value for the floodplain.

4.2.4 Example

For Austria, we downloaded the CORINE land cover data set from the Copernicus webpage and cut the data with the help of the floodplain polygon shape (Figure A 14).

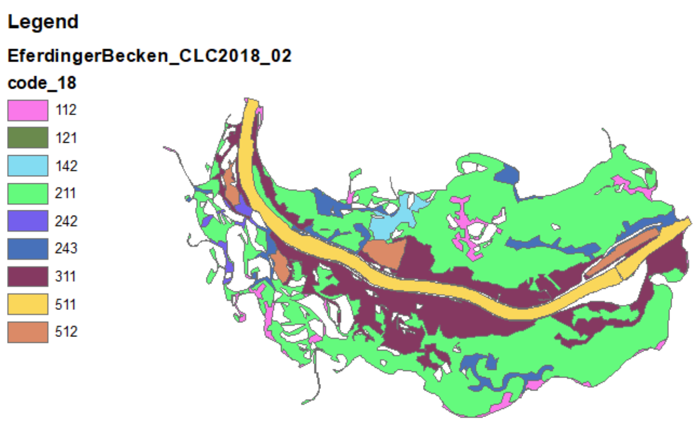


Figure A 14: land use - example Austria (Eferdinger Becken)

Afterwards we used the ArcGIS zonal statistics tool to produce a table with the land cover classes and the corresponding areas in the floodplain (Table A 8).

Table A 8: land use table - example Austria (Eferdinger Becken)

Area ha	Label	FEM-evaluation
209	Discontinuous urban fabric	1
2	Industrial or commercial units	1
78	Sport and leisure facilities	1
3072	Non-irrigated arable land	3
60	Complex cultivation patterns	3
331	Land principally occupied by agriculture, with significant a	3
1221	Broad-leaved forest	5
163	Water bodies	5

We summed up all areas with low, medium and high performance and calculated the weighted FEM-value for this floodplain.

Table A 9: Calculation of the weighted FEM-value for the Eferdinger Becken

FEM-evaluation	Area (ha)		Total
1	290	1*290/5136 = 0.06	3.43
3	3462	3*3462/5136 = 2.02	
5	1384	5*1384/5136 = 1.35	
Sum	5136		

4.2.5 Thresholds

In Table A 10, the thresholds are shown, which are used to determine the performance of the floodplain for the land use parameter. If the land use parameter is smaller than 2, the performance of the floodplain is low. Between 2-4, the performance is medium. All floodplains with a land use parameter above 4 perform high.

Table A 10: Thresholds to determine the performance of the land use parameter in the FEM-Evaluation

Thresholds land use	
1	< 2
3	2 - 4
5	> 4

B. FEM-Handbook - additional parameters

Table of Contents

Introduction

The Danube Floodplain project aims to improve transnational water management and flood risk prevention while maximizing benefits for biodiversity conservation. Preservation and/or restoration of floodplains play a key role in an integrated flood risk management. Therefore, it is important to identify the active and potential floodplains as well as to evaluate their effects in terms of flood risk reduction, ecological benefits and socio-economic aspects.

This handbook is a guidance for all countries in the Danube River Basin that have to evaluate their floodplains with the Floodplain Evaluation Matrix (FEM). The handbook gives a detailed description of each FEM parameter from the medium and extended class, a workflow on how to calculate the parameter, some examples and the selected thresholds. These additional parameters were accepted by all project partners and can be applied at selected active and potential floodplain if the partners decide to do so.

1. Hydrology

1.1. Effects in case of extreme discharge

1.1.1 Description

Effects of floodplain areas on hydrological parameters (ΔQ, Δt) for scenarios with discharges larger (HQ_{1000}) than the design discharge (HQ_{100}) of flood protection measures (remaining risk, higher risk, e.g. climate change) are also incorporated in the FEM. Hydrodynamic-numerical modelling of the higher discharge (HQ_{1000}) can highlight additional capacities of floodplains or increased risks for settlements behind the dykes, e.g. by overtopping of existing dykes. The evaluation considers the effects on peak reduction and flood wave translation in each floodplain for this higher discharge compared to HQ_{100}.

1.1.2 Source

For the determination of the peak reduction, results of unsteady hydrodynamic-numerical 2D-simulations are preferred, which should be calibrated and validated with recorded flood waves at different gauging stations. Using 1D-models is also possible. Other options to calculate the peak reduction would be observed flood waves at different gauging stations within the reach or engineering approaches. If engineering approaches are necessary due to lack of data, a separate handbook will be provided, where these approaches are explained.

1.1.3 Workflow

Step 1: Selecting hydrological input data

You can take the input hydrograph of the closest gauging station upstream of the floodplain from a recorded flood event and adjust it (e.g. scale it to HQ_{1000} peak value) or you can use hydrographs from existing hydrodynamic models that are HQ_{1000}[4]. You should at least use one hydrograph for each floodplain, if possible two (a steep and a flat one). If there are any tributaries within the delineated floodplain, unsteady and/or steady hydrological input data will be used. In general, unsteady hydrological input data should be preferred for all tributaries. Especially for larger tributaries unsteady flood waves should be used. If no data is available for the main tributaries, TUM could provide you flood waves from the SWIM model. For smaller tributaries, it is possible to use steady hydrological input data. The documentation of the used flood waves/hydrological input data is very important. You have to provide us your used data.

Step 2: Calculating output hydrograph at end of floodplain and computing $\Delta Q_{extreme,tot}$

You can use a 2D model or if not available, a 1D model to calculate the output hydrograph at a cross section at the end of the floodplain. If no model is available an engineering approach can be used. This would be for example the Gauckler-Manning-Strickler formula. If a 1D model is used the modeler should make sure that the floodplain flow characteristics are correctly modeled. In order to compute $\Delta Q_{extreme,tot}$ it is necessary to calculate the difference between the peak of the input and the output flood wave (Figure B 1).

[4] If nothing is available, TUM can provide hydrographs from the SWIM model for the whole Danube basin

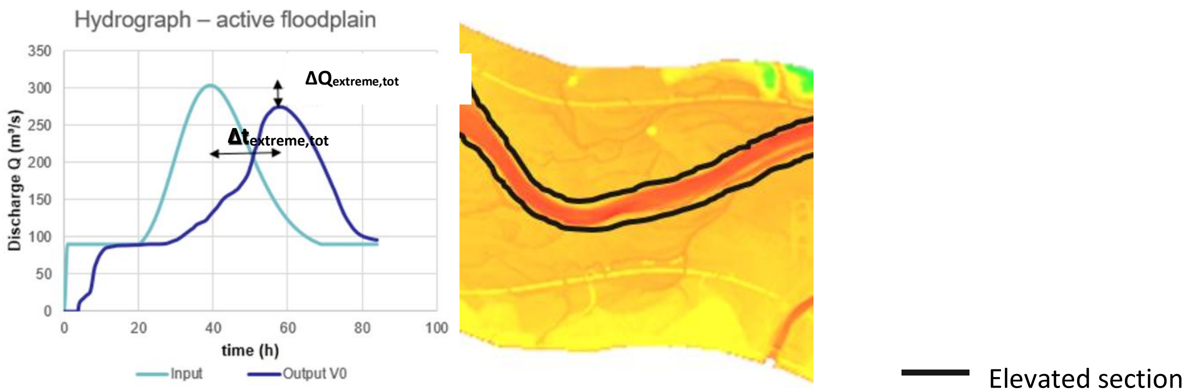


Figure B 1: FEM-parameter flood peak reduction ΔQextreme,tot for active floodplains

Step 3: Calculating $\Delta Q_{extreme,RC}$ of the river channel

To demonstrate only the effect of the floodplains on the peak reduction, it is necessary to run the model a second time with disconnected or disabled floodplains and foreland to calculate the retention effect of the river channel. For disconnecting the floodplains in the model, possible approaches are to deactivate the floodplain or to elevate a section next to the river. After running the simulation, the peak of the new generated output hydrograph has to be subtracted from the input hydrograph to determine $\Delta Q_{extreme,RC}$ (Figure B 2).

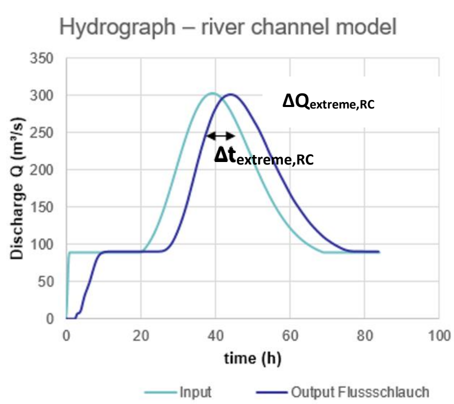


Figure B 2: FEM-parameter flood peak reduction $\Delta Q_{extreme,RC}$ for the river channel

Step 4: Calculating $\Delta Q_{extreme}$ and $\Delta Q_{extreme,rel}$

The first calculation of $\Delta Q_{extreme,tot}$ gives the retention effects of the floodplains as well of the river channel. $\Delta Q_{extreme,RC}$ shows only the effect of the river channel on the flood peak. Therefore, it is necessary to subtract $\Delta Q_{extreme,RC}$ from the $\Delta Q_{extreme,tot}$ for demonstrating only the effect of the floodplains on the peak reduction.

$$\Delta Q_{extreme} = \Delta Q_{extreme,tot} - \Delta Q_{extreme,RC} [m^3 s^{-1}] \quad [1]$$

Additionally, the $\Delta Q_{extreme,rel}$ [%] has to be calculated by dividing the ΔQ by the $Q_{extreme,max}$ multiplied by 100 to make a comparison of different river reaches possible. The $Q_{extreme,max}$ is the flood peak of the inflow wave.

$$\Delta Q_{extreme,rel} = \frac{\Delta Q_{extreme}}{Q_{extreme,max}} \times 100\ [\%] \quad [2]$$

Step 5: Using output hydrograph at end of floodplain and calculating $\Delta t_{extreme,tot}$

You can use the same output hydrograph for calculating the flood wave translation $\Delta t_{extreme,tot}$ as for the modelling of the $\Delta Q_{extreme}$. It is recommended to model and calculate both parameter at the same time. In order to compute $\Delta t_{extreme,tot}$ it is necessary to determine the time when the peak of the flood waves (input/output) occur and calculate the difference between them (Figure B 3).

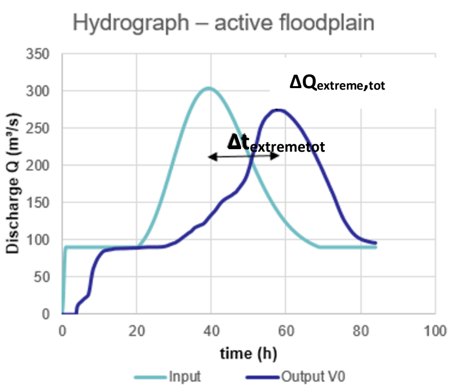


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Figure B 3: FEM-parameter flood wave translation $\Delta t_{extreme,tot}$ for active floodplains

Step 6: Calculating the $\Delta t_{extreme,RC}$ for the river channel

You can use the output hydrograph from the modelling of $\Delta Q_{extreme,RC}$ for calculating the flood wave translation $\Delta t_{extreme,RC}$ for the river channel. In order to compute $\Delta t_{extreme,RC}$, it is necessary to determine the time when the peak of the flood waves (input/output) occur and calculate the difference between them (Figure B 4).

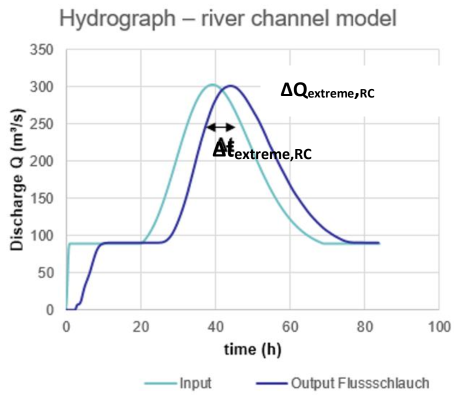


Figure B 4: FEM-parameter flood wave translation $\Delta t_{extreme,RC}$ for the river channel

Step 7: Calculating $\Delta t_{extreme}$ and $\Delta t_{extreme,rel}$

The first calculation of $\Delta t_{extreme,tot}$ shows the effects of the floodplains as well of the river channel on the travel time of the flood wave. $\Delta t_{extreme,RC}$ demonstrates only the effect of the river channel on the travel time. Therefore, it is necessary to subtract $\Delta t_{extreme,RC}$ from the $\Delta t_{extreme,tot}$ for demonstrating only the effect of the floodplains on the travel time.

$$\Delta t_{extreme} = \Delta t_{extreme,tot} - \Delta t_{extreme,RC} [h] \quad [3]$$

Step 8: Compare ΔQ_{rel} with $\Delta Q_{extreme,rel}$ and Δt with $\Delta t_{extreme}$

Now you calculate the relation between the ΔQ_{rel} and the $\Delta Q_{extreme,rel}$

$$\Delta Q_{compared} = \frac{\Delta Q_{rel}}{\Delta Q_{extreme,rel}} \times 100\ [\%] \quad [5]$$

And the relation between the Δt and the $\Delta t_{extreme,}$

$$\Delta t_{compared} = \frac{\Delta t}{\Delta t_{extreme}} \times 100\ [h] \quad [6]$$

1.1.4 Thresholds

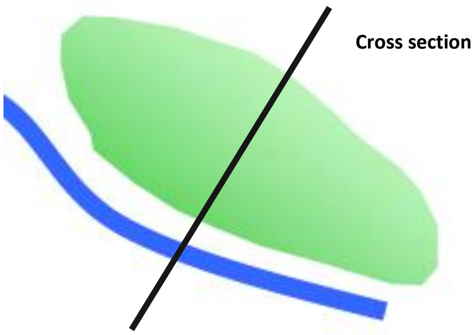
No thresholds were defined for this parameter, since no partner applied it.

2. Hydraulics

2.1 Flow velocity – Δv

2.1.1 Description

A hydrodynamic-numerical model is used to determine the influence of changes in floodplain geometry (e.g. by dyke-shifting). Reducing or extending floodplain widths by modelling of fictive dykes exhibits how big changes in the flow velocity of the scenarios (Δv) can be. The observed values can be calculated in a cross section at the middle or/and end of the floodplain or in the next settlement. With this parameter, we want to show the effects of a total loss of a floodplain on the flow velocity in the river channel. Therefore, we can use the model, which we were using for the calculation of ΔQ_{RC} and Δt_{RC}. Within this model we have disconnected the floodplains and foreland from the river channel by fictive dykes.



This parameter is also used for showing the effects on potential removal of dykes to reconnect potential floodplains. The removal of the dykes would mean changes of the geometry in the model, which would be necessary to show the effects on the flow velocity.

2.1.2 Source

Comparison of the flow velocity of different scenarios using an unsteady hydrodynamic model (2D, 1D) or engineering approaches.

2.1.3 Workflow

Step 1: Calculating flow velocity for a HQ_{100} with the active floodplain (v_{tot})

You can use the same hydrodynamic-numerical calculation, which is used to determine the hydrological parameters (ΔQ_{tot} and Δt_{tot}). At a defined cross-section (e.g. in the middle of the floodplain) you determine the calculated flow velocity v_{tot} in the middle of the river channel.

Step 2: Calculating flow velocity for a HQ_{100} without floodplain (v_{RC})

In the next step, you use the same hydrodynamic-numerical calculation, which was used to determine the hydrological parameters (ΔQ_{RC} and Δt_{RC}) and you determine the calculated flow velocity (v_{RC}) on the same spot as in step 1.

Step 3: Calculating the Δv

In the last step, you have to compute the Δv by subtracting the calculated flow velocity without floodplains (v_{RC}) from the flow velocity (v_{tot}) with active floodplain. The flow velocity change Δv demonstrates the increase of the flow velocity due to a loss of the floodplain.

$$\Delta v = v_{tot} - v_{RC}[cms^{-1}] \quad [7]$$

2.1.4 Example

In Austria the flow velocity changes were calculated by shifting an existing dyke 50% closer to the river, 100% closer to the river and also one scenario where the dyke was moved away. The results showed an increase of the flow velocity in the cross section in the middle of the floodplain of 25 cms^{-1}. In general, only one scenario has to be calculated where the floodplain is disconnected completely (e.g. by elevation of a section close to the river to simulate a dyke) (Figure B 5).

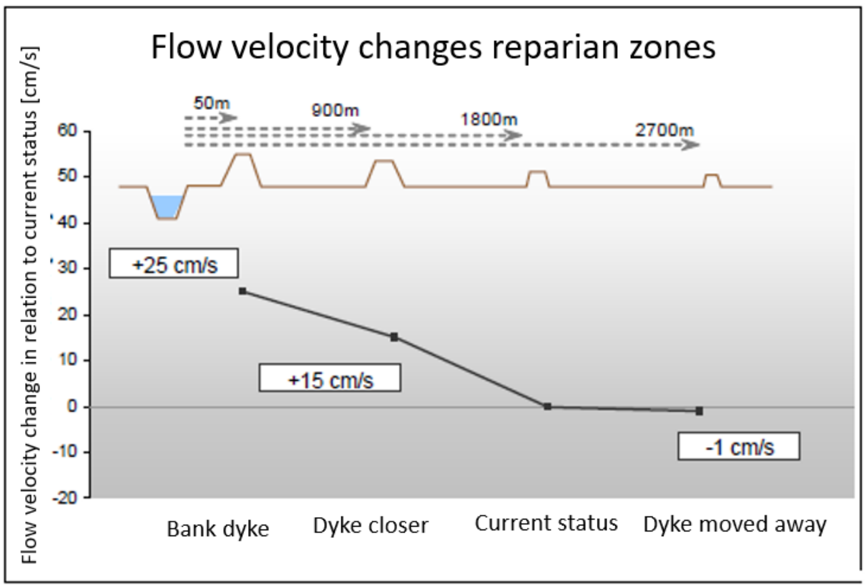


Figure B 5: flow velocity change – example Austria (Machland)

2.1.5 Thresholds

In Table 5, the thresholds are shown, which are used to determine the performance of the floodplain for the parameter flow velocity change. If the flow velocity change (Δv) is smaller than 0.1 m/s, the performance of the floodplain is low. Between 0.1-0.2 m/s, the performance is medium. All floodplains with a flow velocity change above 0.2 m/s perform high (Table B 1).

Table B 1: Thresholds to determine the performance of the flow velocity change Δv in the FEM-Evaluation

Thresholds Δv	
1	< 0.1 m/s
3	0.1 - 0.2 m/s
5	> 0.2 m/s

2.2 Bottom shear stress – Δτ

2.2.1 Description

A hydrodynamic-numerical model is used to determine the influence of changes in floodplain geometry (e.g. by dyke-shifting). Reducing or extending floodplain widths by modelling of fictive dykes exhibits how big changes in the bottom shear stress of the scenarios (Δτ) can be. The observed values can be calculated in a cross section at the middle or/and end of the floodplain or in the next settlement. With this parameter, we want to show the effects of a total loss of a floodplain on the bottom shear stress. Therefore, we can use the model, which we were using for the calculation of ΔQ_{RC} and Δt_{RC} within this model we have disconnected the floodplains and foreland from the river channel by fictive dykes.

This parameter is also used for showing the effects on potential removal of dykes to reconnect potential floodplains. The removal of the dykes would mean changes of the geometry in the model, which would be necessary to show the effects on the bottom shear stress.

2.2.2 Source

Comparison of the bottom shear stress of different scenarios using an unsteady hydrodynamic model (2D, 1D) or engineering approaches.

2.2.3 Workflow

Step 1: Calculating bottom shear stress for a HQ_{100} with the active floodplain (τ_{tot})

You can use the same hydrodynamic-numerical calculation, which is used to determine the hydrological parameters (ΔQ_{tot} and Δt_{tot}). At a defined cross-section (e.g. in the middle of the floodplain) you determine the calculated bottom shear stress τ_{tot} in the middle of the river channel.

Step 2: Calculating bottom shear stress for a HQ_{100} without floodplain (τ_{RC})

In the next step, you use the same hydrodynamic-numerical calculation, which was used to determine the hydrological parameters (ΔQ_{RC} and Δt_{RC}) and you determine the calculated bottom shear stress (τ_{RC}) on the same spot as in step 1.

Step 3: Calculating the Δτ

In the last step, you have to compute the Δτ by subtracting the calculated bottom shear stress without floodplains (τ_{RC}) from the bottom shear stress (τ_{tot}) with active floodplain. The bottom shear stress change Δτ demonstrates the increase of the bottom shear stress due to a loss of the floodplain.

$$\Delta\tau = \tau_{tot} - \tau_{RC} [\mathrm{Nm^{-2}}] \quad [8]$$

2.2.4 Example

In Austria the bottom shear stress changes were calculated by shifting an existing dyke 50% closer to the river, 100% closer to the river and also one scenario where the dyke was moved away. The results showed an increase of the bottom shear stress in the cross section in the middle of the floodplain of 26,61 N/m² (Figure B 6). In general, only one scenario has to be calculated where the floodplain is disconnected.

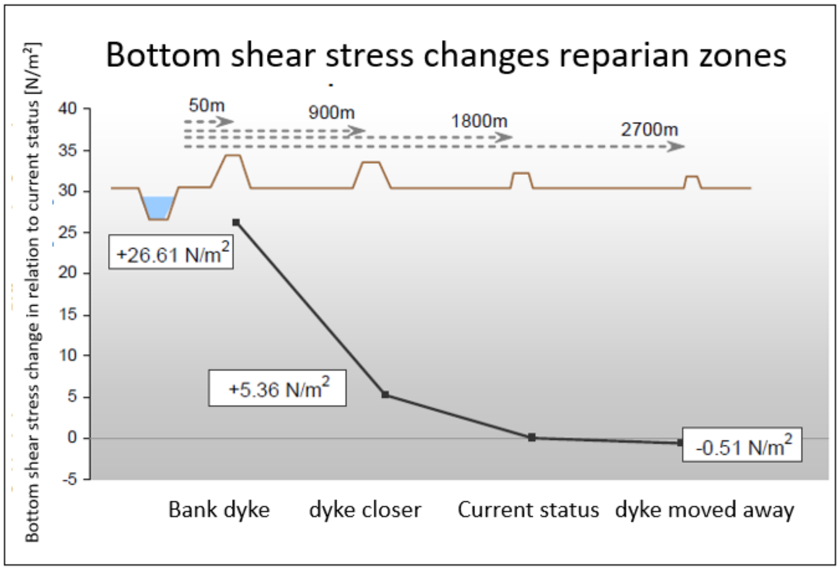


Figure B 6: bottom shear stress change – example Austria (Machland)

2.2.5 Thresholds

In Table B 2, the thresholds are shown, which are used to determine the performance of the floodplain for the parameter bottom shear stress change. If the bottom shear stress change (Δτ) is smaller than 1.5 N/m², the performance of the floodplain is low. Between 1.5-3 N/m², the performance is medium. All floodplains with a bottom shear stress change above 3 N/m² perform high.

Table B 2: Thresholds to determine the performance of the bottom shear stress change Δτ in the FEM-Evaluation

Thresholds τ	
1	< 1.5 N/m²
3	1.5 - 3 N/m²
5	> 3 N/m²

3. Ecology

3.1 Existence of protected habitats

3.1.1 Description

This parameter shows what part of the floodplain area is designated as protected area according to the Natura 2000 or other documents about protected species or habitats like the Emerald Network. The higher the share of protected areas, the more valuable is the floodplain.

3.1.2 Source

In case of the European Union countries the Natura 2000 database can be used and non-EU member states can use the equivalent Emerald Network database.

3.1.3 Workflow

Step 1: Downloading Natura 2000 or Emerald Network datasets
First of all, you have to go to the Natura 2000 webpage https://www.eea.europa.eu/data-and-maps/data/natura-10#tab-gis-data and download the latest version of the Natura 2000 areas as shape file. Countries not being in the Natura 2000 network should obtain shape files from other sources (e.g. national databases on nature protection areas) since they are not downloadable from the Emerald viewer (http://emerald.eea.europa.eu/).

Step 2: GIS analysis of protected area on the floodplain
Use ArcGIS or a similar software to show both the shapes of your active floodplain and the downloaded Natura 2000 (or equivalent) shapes. One possible way is to create a new feature class in the same folder where the Natura 2000 dataset was saved. Then open the Editor mode and select from the Natura 2000 polygons all that are located on your floodplains. Copy them to the newly created feature class. Now you can remove the original layer from your map. Go to the edit mode of the new feature class and use the "Clip" tool to cut the Natura 2000 polygons to the shape of your floodplains. Make sure, that the tool does not cut away polygon parts that are not part of one floodplain, but part of another floodplain. Now you can open the attribute table and look up the area of the Natura 2000 habitats that are located in your floodplains. Other ways which lead to a similar result are also possible.

Step 3: Calculating the parameter
Look at each floodplain and select the protected areas in GIS. Add all areas on the floodplain together, but don't calculate areas twice if two polygons lay above each other (this can happen if you have protected areas according to the Habitats and the Birds Directive). Then divide this area by the total floodplain area and multiply it by 100 to get the percentage of protected habitats on your floodplain.

$$\text{protected habitat} = \left(\frac{A_{\text{protected}}}{A_{\text{floodplain}}}\right) * 100 \qquad [9]$$

3.1.4 Example

The Eferdinger Becken in Austria has only a part of it protected by the Habitats Directive. In the graphic you can see the whole floodplain in green and the protected area in purple (Figure B 7). The area was then cut to the floodplain shape to calculate the part which lies in the floodplain (green).

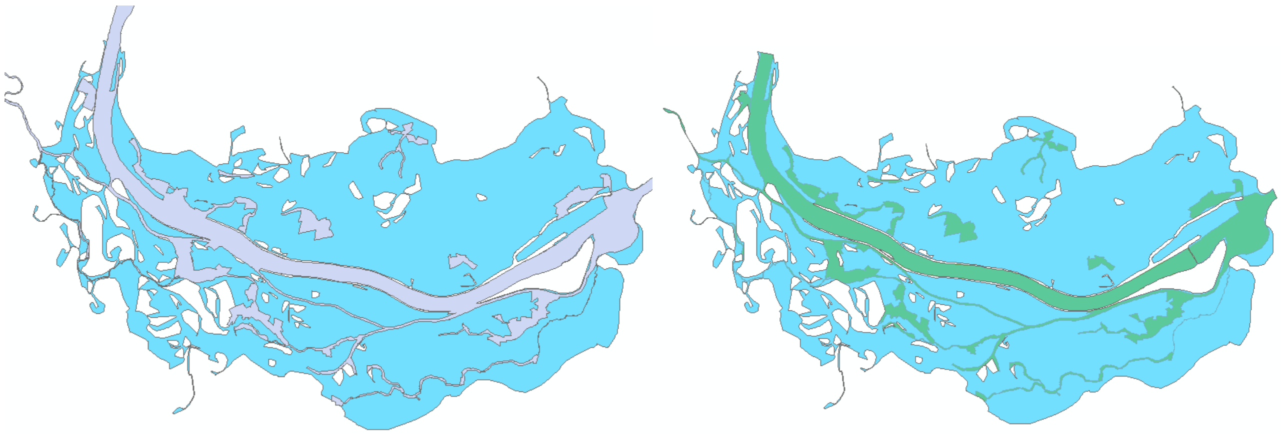


Figure B 7: Natura 2000 area at Eferdinger Becken

The parameter was calculated in the following way:

$$\text{protected habitat} = \left(\frac{A_{\text{protected}}}{A_{\text{floodplain}}}\right) * 100 = \left(\frac{10{,}31\ \text{km}^2}{53{,}16\ \text{km}^2}\right) * 100 = 19{,}40\ \% \qquad [10]$$

3.1.5 Thresholds

In Table B 3, the thresholds are shown, which are used to determine the performance of the floodplain for the parameter existence of protected habitats. If less than 33% of the floodplain area is protected, the performance of the floodplain is low. Between 33-67%, the performance is medium. If more than 67% of the floodplain area is protected, the performance is high.

Table B 3: Thresholds to determine the performance of the parameter existence of protected habitats in the FEM-Evaluation

Thresholds protected habitats	
1	< 33 %
3	33 - 67 %
5	> 67 %

3.2 Vegetation naturalness

3.2.1 Description

The landscape patterns of a floodplain can be a good indicator for the naturalness of vegetation. Therefore it is possible to calculate patch-level landscape indices (like the class level landscape metric Area Weighted Mean Shape Index (AWMSI) for all land cover polygons of natural and semi natural areas (NSN). Mean Shape Index can be calculated by the V-LATE extension of ArcGIS. NSN patches with a complex shape with irregular edges indicate a higher level of naturalness.

Because this method is very scale sensitive, and the detailed land cover data (Copernicus vegetation zones) are available only for the active floodplains, we offer to use this method only for estimation the vegetation naturalness of the active floodplain units. See details in: Szilassi P. et.al (2017) The link between landscape pattern and vegetation naturalness on a regional scale. In: Ecological Indicators (81) 252-259.pp

3.2.2 Source

The riparian vegetation land cover dataset is available from the whole Danube floodplain and most of the tributaries too. This dataset can be downloaded from the Copernicus Land Monitoring Service website:

https://land.copernicus.eu/local/riparian-zones/land-cover-land-use-lclu-image

3.2.3 Workflow

Step 1: Downloading and preparing Riparian vegetation land cover database.
The riparian vegetation land cover dataset is available for all Danube floodplains and for most of the tributaries. This dataset can be downloaded from the Copernicus Land Monitoring Service website:

https://land.copernicus.eu/local/riparian-zones/land-cover-land-use-lclu-image

Step 2: Downloading and setting up the V-LATE - Vector-based Landscape Analysis Tools Extension, for ArcGIS10.x
Downloading and setting up the V-LATE - Vector-based Landscape Analysis Tools Extension, for ArcGIS 10.x from this website:

https://sites.google.com/site/largvlate/gis-tools/v-late

Step 3: Making a new land cover map which contains only the "natural or semi natural" land cover patches
Open the Copernicus Riparian Zone land cover maps with ArcGIS 10.x. For making a new shape file which will contains only the "natural or semi natural" land cover patches, select the following main land cover categories from the riparian zones land cover dataset: Woodland (code 3), Grassland (code 4), and Heathland (Code 5)

Step 4: Calculation of the perimeter area values, and other landscape indexes representing the area and shape characteristics of each "natural or semi natural" land cover polygons
Open the new "natural and semi natural" land cover map with ArcGIS 10.x. and click on the V-Late extension.

Following the V-late flowchart, you should calculate first the Perimeter and Area of each land cover polygons, clicking Area/Perimeter box. The V-late extension will automatically put these new attribute columns into the attribute table of your digital land cover map.

Follow the flowchart steps, click on Area Analysis, Edge Analysis, and Form Analysis boxes. You should select the unique id column of the polygon patches to calculate the values for the all patches. The V-late extension will automatically calculate and put the landscape indices (e.g. Shape Index = shape_idx) into the attribute table of the digital land cover map (Copernicus Riparian Zone). These landscape indexes are representing the area, and form characteristics of each land cover polygons in the new attribute columns. You will use only the Shape Index (MSI) data (shape_idx columns) of each land cover polygons for the further analyses.

Step 5: Downloading and setting up the Geospatial Modelling Environment (GME), for ArcGIS 10.x
Downloading and setting up the Geospatial Modelling Environment (GME), and R software for ArcGIS 10.x from this website, following the instructions:

http://www.spatialecology.com/gme/gmedownload.htm

You can download the user's manual from this website:

http://www.spatialecology.com/gme/images/SpatialEcologyGME.pdf

Step 6: Calculation of Area Weighted Mean values of Shape Index (MSI) of the natural and semi natural land cover patches for every active floodplain units (AFU) by Geospatial Modelling Environment (GME).
Open the GME icon in your computer. Choose and click on the "isectpolypoly" options on the left menus of the GME. This tool calculates the Area Weighted Average of MSI values of each natural and semi natural land cover polygons inside of the floodplain units (zonal polygon dataset). This tool writes automatically the results into the attribute table of the digital map of the active floodplain units (zonal polygon) dataset.

You should also select the zonal polygon shape file. This shape file will be the digital polygon map of the active floodplain units. You can put it into the "in" field (active floodplain unit data source). You should select into this second polygon layer to process your "natural or semi natural" land cover polygon shape file, which attribute table includes yet the MSI data of each land cover polygons. You should select this shape file from your computer and select the MSI column from its attribute table. This MSI column will be the quantitative data to summarize field.

You should write into "prefixa" a short prefix to use in the summary statistic fields with AWM, the prefix should be no longer than 6 characters.

Set up the "thematic", "proportion" and "where" menus into the FALSE options, the "area weighted mean" menu (AWM) into the TRUE options, the "minimum" (MIN), "maximum" (MAX), and "area weighted sum" (AWS) menus to the FALSE options (Figure B 8).

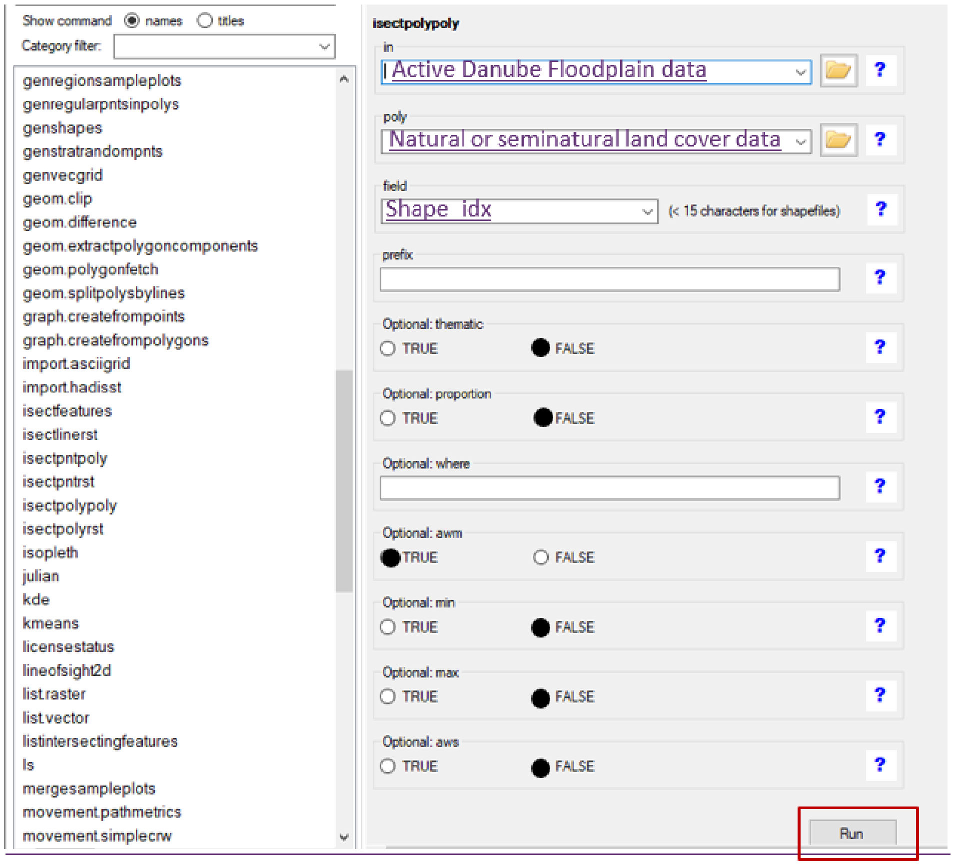


Figure B 8: Input mask of the GIS tool to calculate the landscape metrics

Step 7: Estimating the vegetation naturalness of active floodplain units (AFU) based on the shape characteristics of natural and semi natural land cover polygons of the riparian zones

Open the digital maps of active floodplain units (AFU) with ArcGIS 10.x. This file is containing yet the Area Weighted Mean Shape Index (AWMSI) values of each floodplain units (AFU). You should add a new field (column) into the attribute table of this shape file, and define it as the string column, which will represent the vegetation naturalness of each AFU. You should select the 0 – 3.7 AWMSI values and to write “low naturalness” into the new attribute table (in the Field calculator).

You should select the 3.71 – 6.00 AWMSI values and to write “medium naturalness” into the new attribute table.

You should select the over 6.01 AWMSI values and to write “high naturalness” into the new attribute table.

3.2.4 Example

USZ calculated the AWMSI values of each Hungarian Vegetation Monitoring quadrants along the Danube River, based on its Natural and semi natural land cover patches. Based on this AWMSI values they could estimate the vegetation naturalness of each Hungarian Vegetation Mapping Units along the Danube River (Figure B 9).

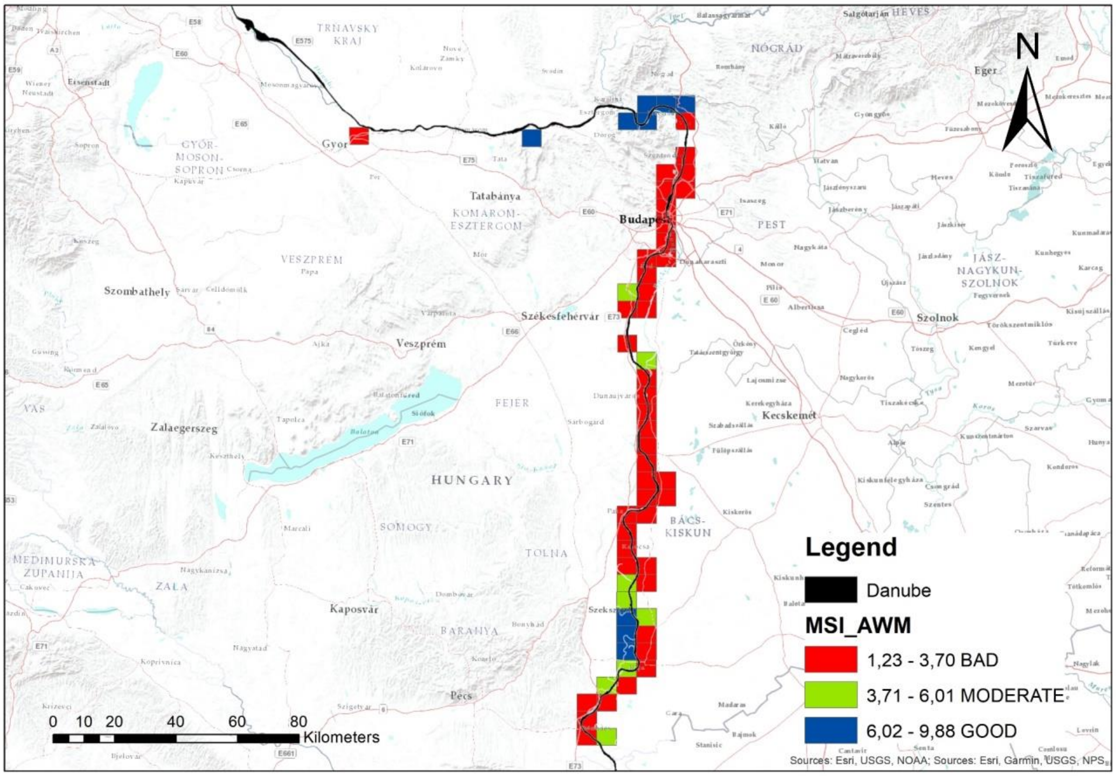


Figure B 9: Vegetation naturalness - example Hungary

3.2.5 Thresholds

In Table B 4, the thresholds are shown, which are used to determine the performance of the floodplain for the parameter vegetation naturalness. If the vegetation naturalness is smaller than 3.7, the performance of the floodplain is low. Between 3.71-6.01, the performance is medium. All floodplains with a vegetation naturalness above 6.02 perform high.

Table B 4: Thresholds to determine the performance of the vegetation naturalness in the FEM-Evaluation

Thresholds vegetation naturalness	
1	< 3.7
3	3.71 - 6.01
5	> 6.02

3.3 Water level dynamics

3.3.1 Description

In order to restore floodplain habitats, rivers and floodplains must have a water level dynamic, almost like the one that exists in the natural floodplains. For this reason the water level dynamics are used as a FEM parameter. If important changes have been made on the river, floodplain areas may have completely different water level dynamics. This can result in permanently (excessive) high water levels in dammed up parts of the river or in dry floodplain areas in deepened river segments. An uncontrolled retention is impossible where barrages have been built, which means that this is also a criterion for exclusion with a view to the implementation of non-technical floodplain enlargements.

In the floodplain areas are other barriers, mostly of anthropogenic origin, which can, even after removal of the front river dyke, prevent the water level dynamics from affecting the whole area. However, there are also natural landscapes which create obstacles for incoming water, such as river banks which have developed naturally.

The parameters water level duration, frequency of the flood and amplitude of the water levels are summarized to describe the possible water level dynamics. Every spatial point has its own typical water level dynamics in relation to its altitude above the river. The historical state before the development of the river serves as a point of reference. A detailed surface assessment for this parameter would be very time-consuming, so that the assessment is made with the help of experts for the whole area at once. For the evaluation, a classification on the basis of expert knowledge has to be set up: low disturbance of natural water level dynamics leads to a high rating within FEM.

3.3.2 Source

Expert knowledge is needed to evaluate this parameter.

3.3.3 Workflow

Step 1: Collection of information about current state
An expert should collect information about the duration, frequency and amplitude of the water level dynamics including the following factors: headwater, riverbed, dykes (natural or man-made), street dams, swells, channel-bed erosions, barrages

Step 2: Collection information about historical state
The expert has to collect the same information (duration, frequency, amplitude, other factors) also for the historical state.

Step 3: Comparison of current with historical state
Now the current state has to be compared with the historical state. The duration, frequency and amplitude of the water level dynamics have to be compared. The following scenarios are then part of the evaluation:

5 – Duration, frequency and amplitude are **marginally** affected. Further aspects: headwaters are not obstructed, the river bed is not deepened and there are no major obstacles for inundation

3 - Duration, frequency and amplitude are **moderately** affected. Further aspects: there are natural banks but the headwaters are dammed or dams and streets are in the floodplain

1 - Duration, frequency and amplitude are **strongly** affected. Further aspects: there are summer dykes existing, the riverbed is deepened and swells can be found

3.3.4 Example

The water level dynamics parameter was evaluated at the Morava floodplain south of Zwentendorf (Figure B 10). The March River still has a near natural discharge regime in its lower part only influenced by some reservoirs at the tributaries. The still meandering channel with low incision rates and some cut-off meanders close to the proposed area is also under good hydro-morphological conditions. Therefore the following evaluation was given:

- Duration: marginally affected → 5
- Frequency: marginally affected → 5
- Amplitude: marginally affected → 5

As there are no further aspects relevant, the total evaluation is 5 “marginally affected”.

Figure B 10: March floodplain south of Zwentendorf

3.3.5 Thresholds

For the water level dynamics parameter, the method allows determining the performance without defined thresholds.

3.4 Potential for typical habitats

3.4.1 Description

The typical river and floodplain habitats should have the possibility to re-establish habitats if they are not already existing. 14 habitat types typical for floodplains are included in the Habitats Directive. Not every area must include all, but the more habitat types exist or can be redeveloped, the more valuable is this area.

3.4.2 Source

In case of the European Union countries the Natura 2000 database can be used and Serbia can use the equivalent Emerald Network database. Additionally, the pilot sites can use the data from the habitat modelling of Act. 4.2

3.4.3 Workflow

Step 1: Downloading Natura2000 or Emerald Network datasets

First of all you have to open the Natura 2000 viewer at http://natura2000.eea.europa.eu/. There you can go to the floodplain of interest and then you have to select the datasets that are available there. One layer is for the Habitats Directive.

Step 2: Analysing available habitat types typical for floodplains

The datasets from the Habitats Directive can be downloaded as a PDF at each floodplain (Table B 5). There you can go to the chapter “3.1 Habitat types present on the site and assessment for them” and compare which of the habitats typical for floodplains are available at this specific floodplain.

Table B 5: typical floodplain habitat types

Number	Name
3130	Oligotrophic to mesotrophic standing waters
3140	Hard oligo-mesotrophic waters with benthic vegetation of *Chara spp.*
3150	Natural eutrophic lakes
3160	Natural dystrophic lakes and ponds
3260	Water courses of plain to montane levels with *Ranunculion fluitantis* vegetation
3270	Rivers with muddy banks with *Chenopodion rubri p.p.* and *Bidention p.p.* vegetation
6410	Molinia meadows
6430	*Hydrophilous tall herb* fringe communities
6440	Alluvial meadows of river valleys of the *Cnidion dubii*
7210*	Calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae*
7230	Alkaline fens
9160	Sub-Atlantic and medio-European oak or oak-hornbeam forests (*Stellario-Carpinetum*)
91E0*	Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior*
91F0	Riparian mixed forests along the great rivers

The sign ‘*’ indicates priority habitat types

Now you can create a list of the available floodplain specific habitats for each floodplain. It is also relevant to list listing the habitats that are currently not present but could additionally occur or being re-established. An expert judgment is needed for this.

3.4.4 Example

At the floodplain NP Donauauen the Habitats Directive lists 14 protected Habitats and from that list 8 habitats are typically for floodplains (Figure B 11). Until now, no expert evaluation for the habitats that could additionally occur was made.

NP Donauauen		8
Code	**Name**	
3130	Oligotrophic to mesotrophic standing water	1
3150	Natural eutrophic lakes with Magnopotamic	1
3260	Water courses of plain to montane levels w	1
3270	Rivers with muddy banks with Chenopodior	1
6110	Rupicolous calcareous or basophilic grasslar	0
6190	Rupicolous pannonic grasslands (Stipo-Festu	0
6210	Semi-natural dry grasslands and scrubland f	0
6240	Sub-Pannonic steppic grasslands	0
6430	Hydrophilous tall herb fringe communities c	1
6440	Alluvial meadows of river valleys of the Cni	1
6510	Lowland hay meadows (Alopecurus pratens	0
8310	Caves not open to the public	0
9180	Tilio-Acerion forests of slopes, screes and ra	0
91E0	Alluvial forests with Alnus glutinosa and Fra	1
91F0	Riparian mixed forests of Quercus robur, Ul	1
91H0	Pannonian woods with Quercus pubescens	0

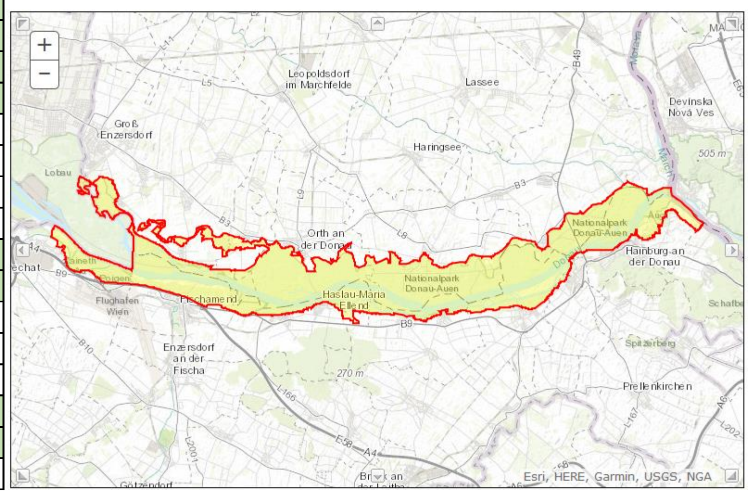


Figure B 11: protected Habitat types - NP Donauauen

3.4.5 Thresholds

In Table B 6, the thresholds are shown, which are used to determine the performance of the floodplain for the parameter potential for typical habitats. If less than 5 typical habitats exist or can be redeveloped, the performance of the floodplain is low. Between 5-10 habitats, the performance is medium. All floodplains were more than 10 typical habitats exist or can be redeveloped, perform high.

Table B 6: Thresholds to determine the performance of the parameter potential for typical habitats in the FEM-Evaluation

Thresholds typical habitats	
1	< 5
3	5 - 10
5	> 10

3.5 Ecological water body status

3.5.1 Description

As part of the water framework directive, the countries should evaluate the ecological and chemical status of the water bodies as well as the chemical and quantitative status of groundwater bodies in the floodplain. If the river section of this floodplain is rated for the ecological water body status with a good or very good status, it should get a high ranking.

3.5.2 Source

To identify the ecological water body status you can use the national implementation documents of the Water Framework Directive.

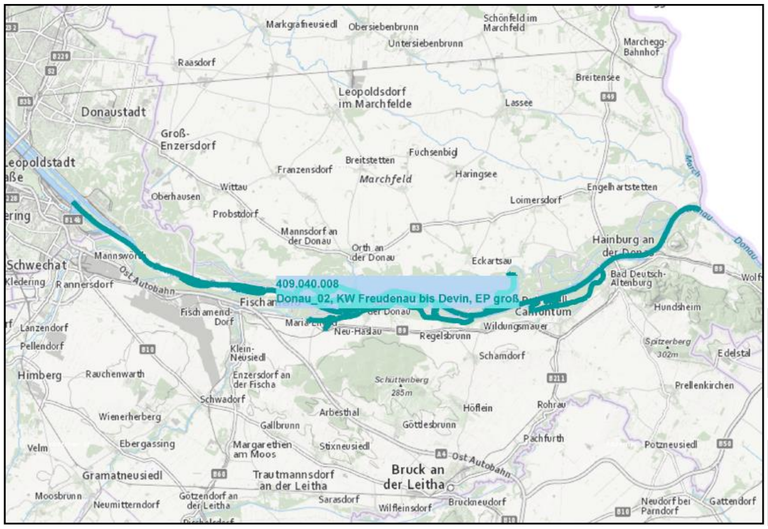
3.5.3 Workflow

Step 1: Downloading implementation documents of the water framework directive
Each European country has developed some national implementation documents for the Water Framework Directive. They should be available for you for all river water bodies and the groundwater bodies. You can look up which waterbody is part of your floodplain (e.g. Danube section) and in which groundwater body it lies.

Step 2: Collecting information of the ecological water body status
The downloaded documents should include an evaluation section where the ecological water body status is described. Extract this information for each floodplain in a table.

3.5.4 Example

In Austria the floodplain NP Donauauen is part of the Danube waterbody between KW Freudenau and Devin (Figure B 12).



NP Donauauen	
Waterbody:	Danube
Ecological	2 (good)
Chemical	1 (very good)

Figure B 12: Waterbody Danube between power plant Freudenau and Devin

3.5.5 Example

In Table B 7, the thresholds are shown, which are used to determine the performance of the floodplain for the parameter ecological water body status. If the ecological water body status is bad or poor, the performance of the floodplain is low. If the water body status is moderate, the performance is medium. All floodplains with a good or high ecological water body status receive a high performance in the FEM-evaluation.

Table B 7: Thresholds to determine the performance of the parameter ecological water body status in the FEM-Evaluation

Thresholds water body status	
1	bad, poor
3	moderate
5	high, good

4. Socio-Economics

4.1 Presence of documented planning interests

4.1.1 Description

This parameter evaluates the presence of infrastructure or spatial development plans/projects in the floodplain area or close to it. A presence would lead to a lower ranking of the floodplain. This can also include plans from other interest groups (agriculture, tourism, hunting, fishing, etc.)

4.1.2 Source

Basis of the evaluation can be municipal spatial plans, urban plans, plans on space and land use or other development plans.

4.1.3 Workflow

Step 1: Searching for relevant documents

On each floodplain you have to search for available spatial plans, urban plans or other development plans and ask your national or local authorities.

Step 2: Analysing the planning interests

If you find some plans you can analyse their content in terms of development projects for building, industry and infrastructure. If such interests are shown in the documents this should be documented at a map or at least a table including the project, the planned area in the floodplain and the planned year.

4.1.4 Thresholds

No thresholds were selected, since no partner applied this additional parameter

C. Overview of the FEM-results for the additional parameters

Table C 1: Overview of the results for the additional FEM-parameters for all active floodplains along the Danube River (Partners could choose, which parameter they want to calculate)

	Floodplain	Hydraulics: flow velocity change (m/s)	Hydraulics: bottom shear stress (N/m²)	Ecology: Existence of protected habitats (%)	Ecology: Vegetation naturalness (-)	Ecology: Potential for typical habitas (-)	Ecology: ecological water body status (-)
Germany	DE_DU_AFP_01						
	DE_DU_AFP_02						
	DE_DU_AFP_03	0.03		12	4.58	11	moderate
	DE_DU_AFP_04	0.43		52	5.69	5	3
	DE_DU_AFP_05	0.08		77	6.23	6	3
	DE_DU_AFP_06	0.00		60	3.42	7	3
	DE_DU_AFP_07	0.07		10	5.27	6	3
	DE_DU_AFP_08	-0.05		94	3.09	6	3
	DE_DU_AFP_09	-0.02		45	4.05	9	3
	DE_DU_AFP_10	0.02		51	6.89	9	3
Austria, Slovakia	AT_DU_AFP_01	0.15		19		3	3
	AT_DU_AFP_02	1.06		6		5	3
	AT_DU_AFP_03	1.27		50		7	3
	AT_DU_AFP_04	0.14		92		8	3
	AT_DU_AFP_05	0.24		98		8	2
	AT_SK_DU_AFP_01	0.17		36		8	2
Slovakia, Hungary	HU_SK_DU_AFP_01			99	4.06	13	3
	HU_SK_DU_AFP_02			68	3.96	13	3
	HU_SK_DU_AFP_03			41	5.11	11	3
	HU_SK_DU_AFP_04			60	6.08	11	3
	HU_SK_DU_AFP_05			53	3.29	11	3
Hungary	HU_DU_AFP_01			60	5.88	11	3
	HU_DU_AFP_02			66	2.59	11	3
	HU_DU_AFP_03			57	5.30	11	3
	HU_DU_AFP_04			59	3.91	11	3
	HU_DU_AFP_05			53	4.98	6	3
	HU_DU_AFP_06			75	4.26	6	3
	HU_DU_AFP_07			96	5.83	6	3
	HU_DU_AFP_08			99	4.45	6	3
	HU_HR_DU_AFP_01			97	4.82	6	3
Croatia, Serbia	RS_HR_DU_AFP_01						
	RS_HR_DU_AFP_02						
	RS_HR_DU_AFP_03						
	RS_HR_DU_AFP_04						
	RS_HR_DU_AFP_05						
Serbia	RS_DU_AFP_01						
	RS_DU_AFP_02						
	RS_DU_AFP_03						
	RS_DU_AFP_04						
	RS_DU_AFP_05						
Bulgaria, Romania	RO_BG_DU_AFP_01	0.18	1.91	79	9.33		3
	RO_BG_DU_AFP_02	0.18	2.09	95	6.10		3
	RO_BG_DU_AFP_03	0.45	3.85	64	6.20		3
	RO_BG_DU_AFP_04	0.28	1.24	94	11.84		3
	RO_BG_DU_AFP_05	0.49	3.77	22	6.01		3
	RO_BG_DU_AFP_06	0.40	3.89	97	6.83		3
Romania	RO_DU_AFP_01	0.04	0.54	96	8.30		3
	RO_DU_AFP_02	0.06	0.91	100	10.30		3
	RO_DU_AFP_03	0.02	1.09	97	14.75		3
	RO_DU_AFP_04	0.03	0.21	99	18.71		3
FEM-rating	performance	Thresholds	Thresholds	Thresholds	Thresholds	Thresholds	Thresholds
	low	<0.1 m/s	< 1.5 N/m²	< 33 %	< 3.7	< 5	4 - 5
	medium	0.1 - 0.2 m/s	1.5 - 3 N/m²	33 - 67 %	3.7 - 6.01	5 - 10	3
	high	> 0.2 m/s	> 3 N/m²	>67 %	> 6.01	> 11	1 - 2

D. All factsheets for the active and potential floodplains along the Danube River