# WP6

## *Deliverable D 6.1.1*

*Upgraded Floodplain Evaluation Matrix Tool as GIS add-on or as standalone tool*

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| **Work Package (WP6)** | Floodplain tools optimization, application and dissemination |
| **Activity 6.1** | Application: Floodplain Evaluation Matrix Tool in pilot sites |
| **Deliverable 6.1.1** | Upgraded Floodplain Evaluation Matrix Tool as GIS add-on or as standalone tool |
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# 1. Summary

In Workpackage (WP) 6, the FEM-Tool (Floodplain Evaluation Matrix – Tool) was further developed, improving the usability and the speed of the assessment. The tool was developed in the open-source QGIS environment as a plugin and can evaluate floodplains and assess restoration projects/measures. It can use input data from hydraulic modelling, ecosystem services (ESS) analysis, ecological assessments, habitat modelling, stakeholder and extended cost-benefit analysis to determine if a restoration project is recommended or not. The tool allows identifying hydraulically active floodplains, determining the need for preservation and restoration demand of them based on the results of the Floodplain Evaluation Matrix (FEM). This method uses hydrological, hydraulic, ecological and socio-economics parameters to assess the effects of the floodplain on flood risk reduction, ecology and socio-economics. The FEM-Tool supports the application of the FEM and allows storing the results. After identifying the floodplains, the current state (status quo) of a hydraulically active floodplain is evaluated with a minimum set of parameters, including at least one parameter of each category (hydrology, hydraulics, ecology, socio-economics). Additional parameters can also be assessed, but it is not mandatory. After evaluating the current state, planned restoration projects can be assessed, starting with a stakeholder analysis followed by assessing the project and its effects. Therefore, the FEM method is applied again, but a more detailed analysis is conducted, including three mandatory additional parameters. This more in-depth analysis assumes that the restoration project is implemented and the FEM parameters are recalculated. The results are compared with the FEM results of the current state. If the FEM evaluation is improving after the restoration project and the additional analysis (stakeholder analysis, additional parameters, ecosystem services, habitat modelling) favors the project, it is recommended to implement it.

This handbook gives an overview of the concept of the FEM-Tool in chapter 2. In chapter 3, the application of the tool in QGIS is described with an example.

## 2. Introduction

The FEM-Tool allows collecting all relevant data from hydraulic modelling, ecosystem services, ecological assessments, habitat modelling, stakeholder and extended cost-benefit analysis to assess restoration projects. Figure 1 shows an overview of all possible input data that can be included in the tool.

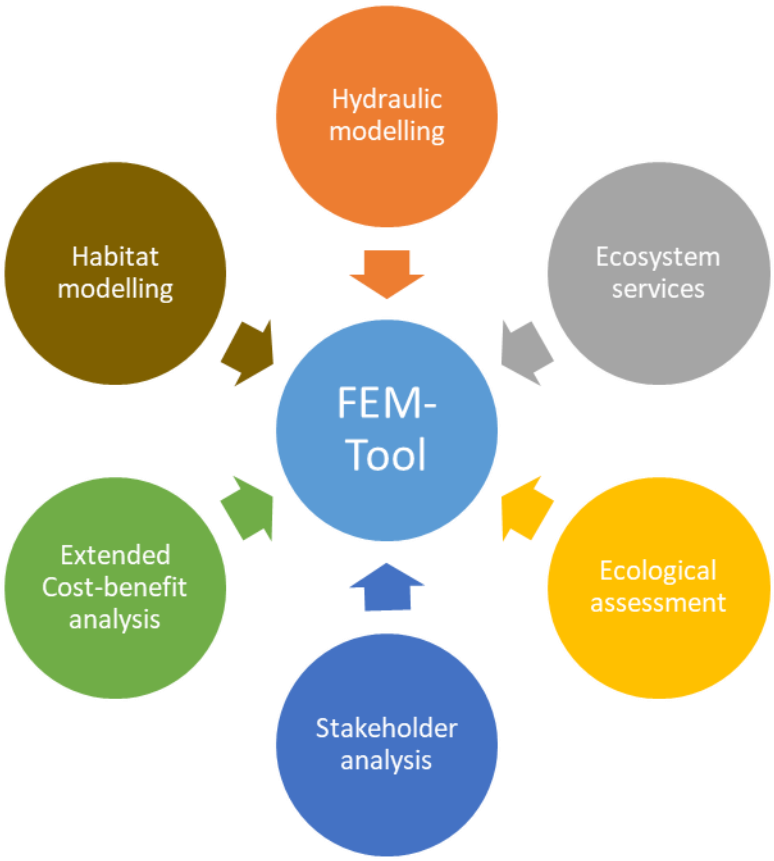


*Figure 1: Overview about all possible input data that can be included in the FEM-Tool*

The FEM-Tool offers the possibility to enter all relevant input data and supports the FEM application. With the FEM, floodplains and restoration measures/projects can be assessed leading to a recommendation if a restoration project should implemented or not. The evaluation of a restoration project with the FEM-Tool is based on two main steps. First, the evaluation of the current state of an active floodplain with the FEM method followed by an assessment of the restoration state, including stakeholder analysis, FEM analysis, ecosystem services, habitat modelling etc. In Figure 2, a schematic overview including the workflow of the FEM-Tool is shown.

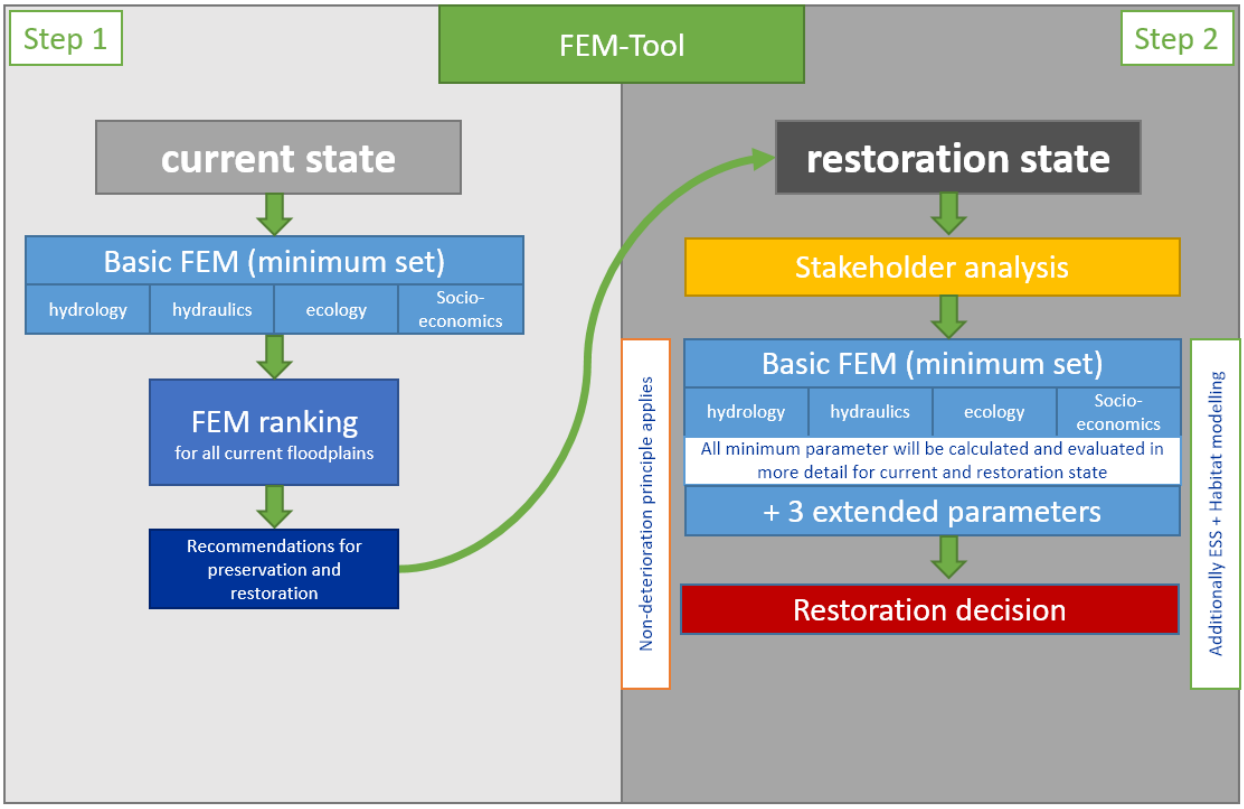


*Figure 2: Schematic overview including the workflow of the FEM-Tool*

The first step of the FEM-Tool is assessing the current state of an active floodplain with the FEM method. In D3.2.1 (Danube Floodplain, 2021a), the FEM method and the methodology for the identification of active floodplains are described in detail. Here, we give only a short overview about concept of the FEM method. For further information about the calculation of the parameters, determination need for preservation, restoration demand etc. please have a look at D3.2.1 (Danube Floodplain, 2021a).

If the goal of an assessment is only to evaluate the effects of floodplains on flood risk reduction, ecology and socio-economics, only the 1st step of the FEM-Tool can be applied and no further analyses are necessary. If a restoration measure/project should be evaluated then the 2nd step of the evaluation with the FEM-Tool starts with a stakeholder analysis. In the tool, we implemented a simple stakeholder analysis where all affected stakeholders their interests and power (high, medium, low) can be listed. Planned measures for stakeholder involvement can be described as well.

A more in-depth FEM evaluation follows the stakeholder analysis to determine the effects of the restoration project. During this more in-depth analysis, it is assumed that the restoration project is implemented and the FEM parameters are recalculated. For the recalculation of the minimum FEM parameters, more detailed data sets are used than it is necessary for the assessment of the current state of the floodplain with the FEM method. For example, to calculate the hydrological and hydraulic

parameters 2D models must be used. For the 1st step (assessment of the current state), it is recommended to use 2D models as well, but there is the exception that 1D models can be used for this step if no 2D models are available. This exception is for the 2nd step not given. For the ecological parameters (connectivity of floodplain water bodies, protected species), more detailed data sets should be used e.g. on-site analysis with experts to determine the protected species living on the floodplain. To evaluate the land use vulnerability, more detailed maps than the CORINE land cover data set should be used. Besides, the usage of more detailed data sets for the evaluation, at least three additional parameters are recommended. The user can select these additional parameters. One parameter that is highly recommended to include in the assessment is the extended cost-benefit analysis parameter. In D4.3.1 (Danube Floodplain, 2021b), it is described how to apply the extended CBA. The FEM results, assessed with the more detailed data sets after the restoration, are compared with the FEM results of the current state. If one FEM parameter is improving and the additional analysis (stakeholder analysis, additional parameters, ecosystem services, habitat modelling) favors the project, it is recommended to implement it.

The floodplain's ecosystem services can also be assessed and entered into the FEM-Tool. In D4.2.2 (Danube Floodplain, 2020a), the results of the ecosystem services assessment in the Danube Floodplain project are presented and the methodology is described. The results of a habitat modelling can also be summarized in the FEM-Tool. In D4.2.3 (Danube Floodplain, 2020b), the habitat modelling at pilot sites along in the Danube region is summarized and described.

Based on the assembled data in the FEM-Tool from hydraulic modelling, ecosystem services, ecological assessments, habitat modelling, stakeholder and cost-benefit analysis, a decision should be made if a restoration project should be implemented.

# 3. FEM-Tool

## 3.1 Installing

For installing and using the FEM-Tool the open-source QGIS software is needed. To install the tool on your computer, do the following:

1. Download and install the free software QGIS (recommended version 3.16) from the website: https://www.qgis.org/en/site/forusers/download.html
2. Download and save the ZIP-File with the code of the FEM-Tool from the website: https://github.com/boku-iwa/Floodplain-Evaluation-Matrix-Tool
3. Open QGIS and click on the tab "Plugins" → "Manage and Install Plugins" → "Install from ZIP" → Browse to the downloaded ZIP-file from step 2 and click on "Install Plugin"

After the three steps, you should see the logo of the FEM-Tool in your plugin toolbar in QGIS (see red square in Figure 3).

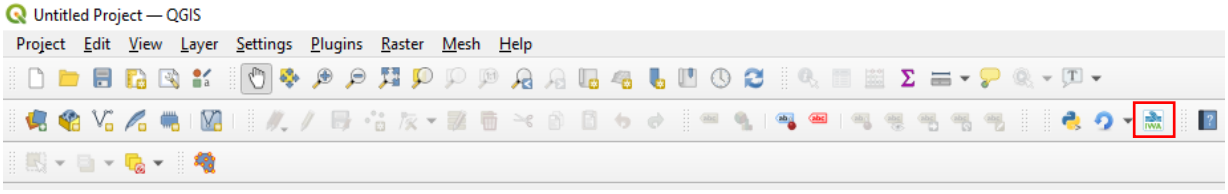


*Figure 3: QGIS toolbar with the FEM-Tool in red square*

## 3.2 Starting the FEM-Tool

When you run the FEM-Tool plugin, you will see the main window as shown in Figure 4.

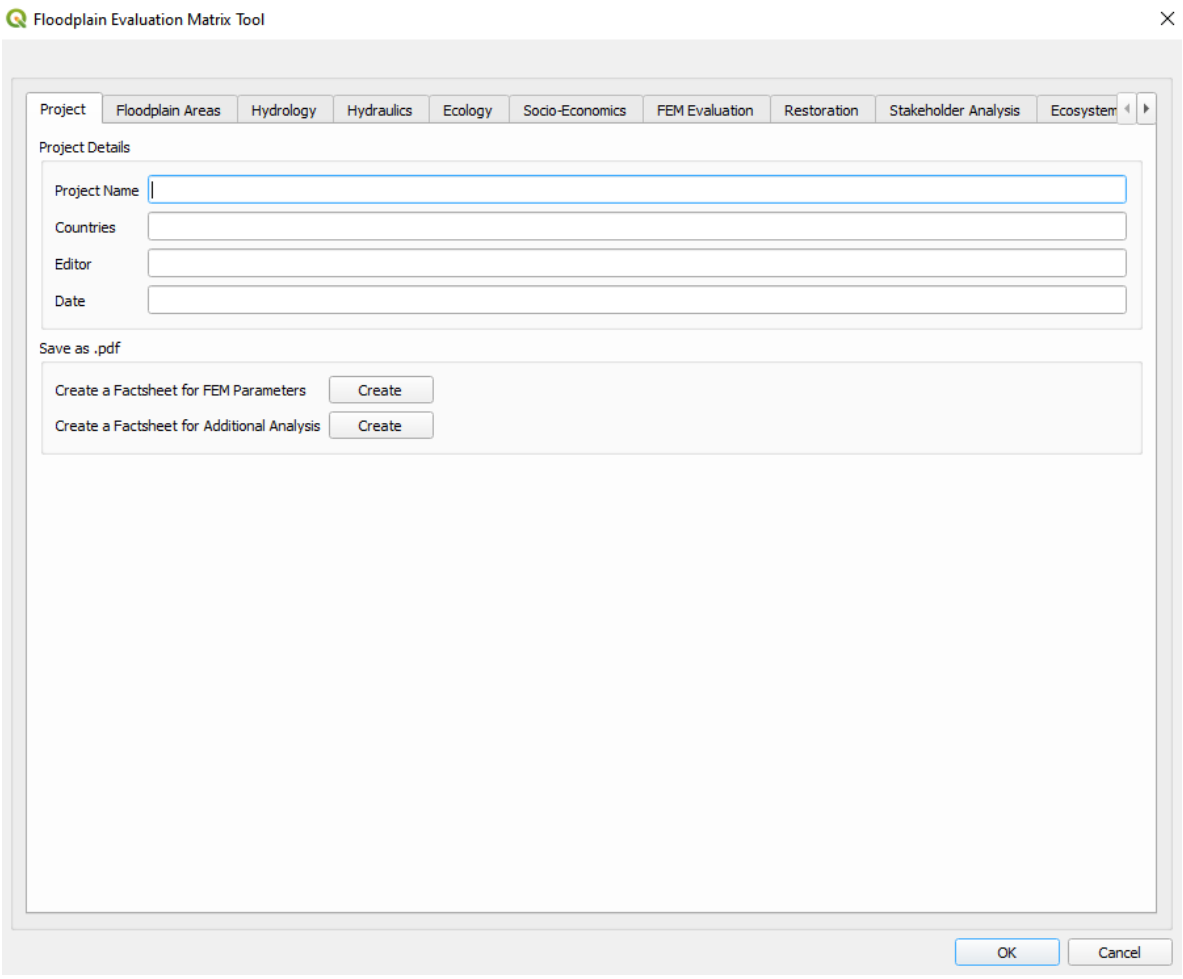


*Figure 4: Main window of the FEM-Tool*

At the top of the FEM-Tool main window is a menu bar with the following options:

**Project:** This option is used for file and project management. Here, you can define the project name, the investigated countries, the editor, and the date. It is also possible to create the "FEM-Parameter" and the "Additional Analysis" factsheets and save them as pdf files. All the information defined in the options explained below is saved in these factsheets and can be used for decision making.

**Floodplain Areas:** This option allows you to identify floodplain areas automatically. You can load the centerline of a river, the river width during mean water level and the inundated areas during a flood event (e.g. $HQ_{100}$). Additionally, you can define the delineation criteria (distance between floodplains, river width, Number of higher than, ratio factor) to identify floodplain areas automatically. The area can be calculated for loaded or identified floodplains, and a default attribute table for a floodplain can be created.

**Hydrology:** This option is used to calculate the minimum hydrological FEM-parameter, relative peak reduction $\Delta Q_{rel}$ and the flood wave translation $\Delta t$. To calculate these parameters, an input hydrograph, the Qbankfull and two output hydrographs (with and without floodplain see Appendix A) have to be imported. The results can be added to the attribute table. Additionally, it is possible to calculate the relative peak reduction $\Delta Q_{rel}$ and the flood wave translation $\Delta t$ after a restoration measure and see the differences between the current and the restoration state.

**Hydraulics:** This option allows to store the results for the water levels $h_{tot}$ and $h_{RC}$, which have to be calculated accordingly to the minimum FEM-handbook (see Appendix A) and to calculate the water level change ($\Delta h$) with $h_{tot}$ and $h_{RC}$. Additionally, in the tab "Additional parameters" the flow velocity change ($\Delta v$) and the bottom shear stress change ($\Delta \tau$) can be calculated after $v_{RC}$ and $v_{tot}$ and $\tau_{tot}$ and $\tau_{RC}$ were determined accordingly to the FEM-handbook for additional parameters (see Appendix B). All the mentioned parameters can also be determined after implementing a restoration measure to see the effects on the hydraulic FEM-parameters.

**Ecology:** This option is used to store the results of the ecological minimum and additional FEM-parameters for the current situation and after an implemented restoration measure. The minimum parameters are the protected species and the connectivity of floodplain water bodies. The additional parameters include: Protected Habitats; Vegetation Naturalness; Water Level Dynamics; Potential for Typical Habitats; Ecological Water Body Status, Invasive Species.

**Socio-Economics:** This option allows to store the results of the socio-economic minimum and additional FEM-parameters for the current situation and after an implemented restoration measure. The minimum parameters are a land use parameter and the number of potentially affected buildings. The additional parameters include: the Presence of documented Planning Interests and an Extended Cost-Benefit Factor after implementing a restoration measure (see Appendix C).

**FEM-Evaluation:** This option is used to define the thresholds of the parameters for the FEM-evaluation. In the evaluation, the need for preservation and the restoration demand of a floodplain is determined. For the thresholds, defined default or new values can be used. Based on the defined thresholds, the FEM-evaluation for the minimum and additional parameter for the current status and after a restoration measure or project can be applied.

**Restoration:** This option allows determining if a restoration measure or project is recommended or not based on the FEM. It considers and compares the results of the FEM-evaluation for the current status and the situation after the implemented restoration.

**Stakeholder Analysis:** This option allows listing all affected stakeholders their interests and power (high, medium, low). Planned measures for the stakeholder involvement can be described as well.

**Ecosystem Services:** This option is used to store the information about existing ecosystem services on the floodplain and their intensity (very low, low, medium, high, very high) for the current status as well as for restoration state. For more details on ecosystem services, please look at the D4.2.2 (Danube Floodplain, 2020a), where the applied methods and results are described.

**Habitat Modelling:** This option allows storing the information about the lateral connectivity during a $HQ_{2-5}$ for the current and the restoration state. The area of different habitat types (floodplain, backwater, channel) and the occurred flow velocities can be stored as well. For more details on habitat modelling, please look at the D4.2.3 (Danube Floodplain, 2020b), where the habitat modelling at pilot sites in the Danube region is summarized and described.

## 3.3 Working with the FEM-Tool

In this chapter, we are showing the application of the FEM-Tool at a floodplain along the Austrian Danube.

### 3.3.1 "Project": Setting project details

First, we can set some general project details such as the project name, country, editor and the starting date. Within this option, we can also create the "FEM-Parameter" and the "Additional Analysis" factsheets (Figure 5).

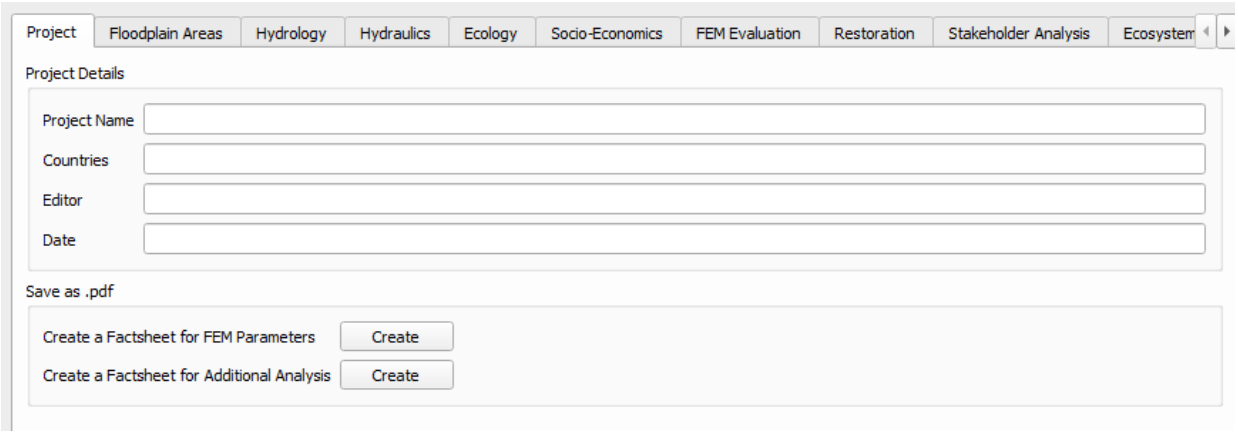


*Figure 5: General project window including the option to create the "FEM-Parameter" and the "Additional Analysis" factsheets*

The "FEM-Factsheet" contains the information about the performances (1-low, 3-medium, 5-high) of the hydrological, hydraulic, ecological and socio-economic parameters in the FEM-evaluation. Additionally, the "Need for Preservation" and the "Restoration Demand" are presented. In Figure 6, the "FEM-Factsheet" is shown in the draft version in the layout manager of QGIS. Here, the layout of the factsheet can be adapted.

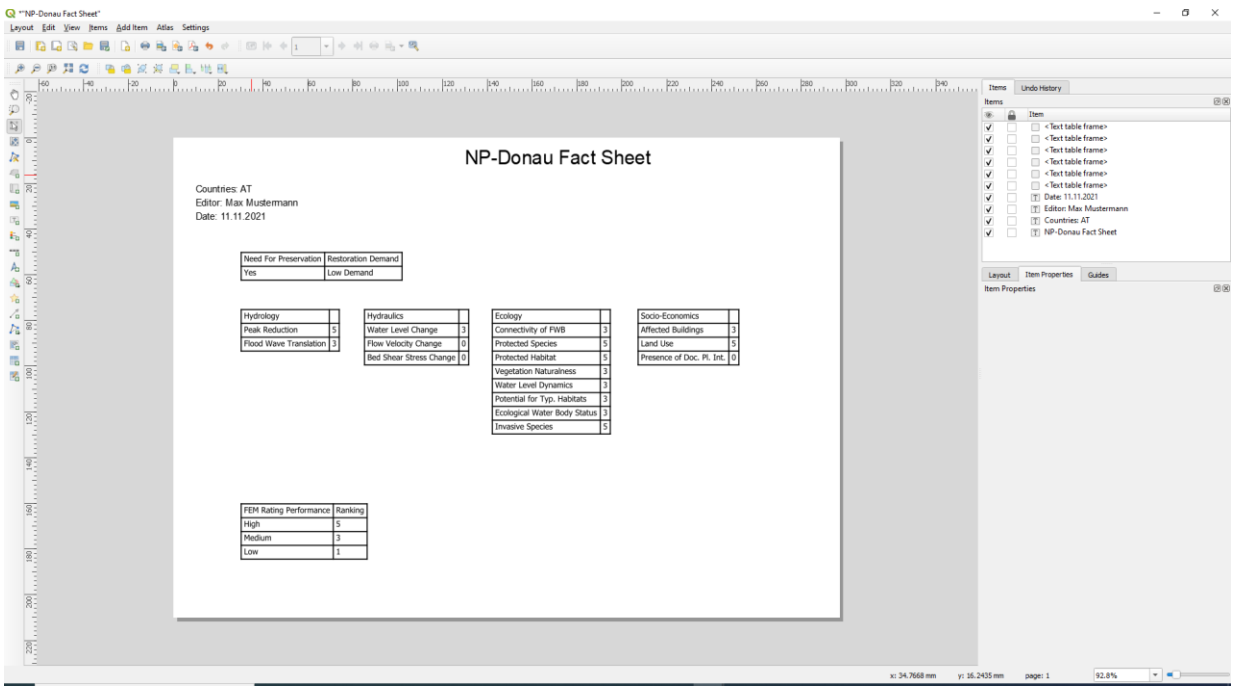


*Figure 6: "FEM-Factsheet" in the layout manager of QGIS shows the performances of the FEM-parameters (1-low, 3-medium, 5-high), the "Need for Preservation" (Yes or No) and the "Restoration Demand" (low, medium, high)*

The "Additional Factsheet" contains the information of the option “Restoration” about the performance of the minimum FEM-parameters for the current and the restored status. Additionally, the identified stakeholders and the planned measures for them, defined in the option “Stakeholder Analysis”, are presented as well as the stored data from the options “Ecosystem Services” and “Habitat Modelling”. In Figure 7, the “Additional Factsheet” is shown in the draft version in the layout manager of QGIS. Here, the layout of the factsheet can be adapted. The factsheet can be exported clicking “Layout” → “Export as pdf”. Both factsheets can be used as a basis for decision-making in flood risk and floodplain management.

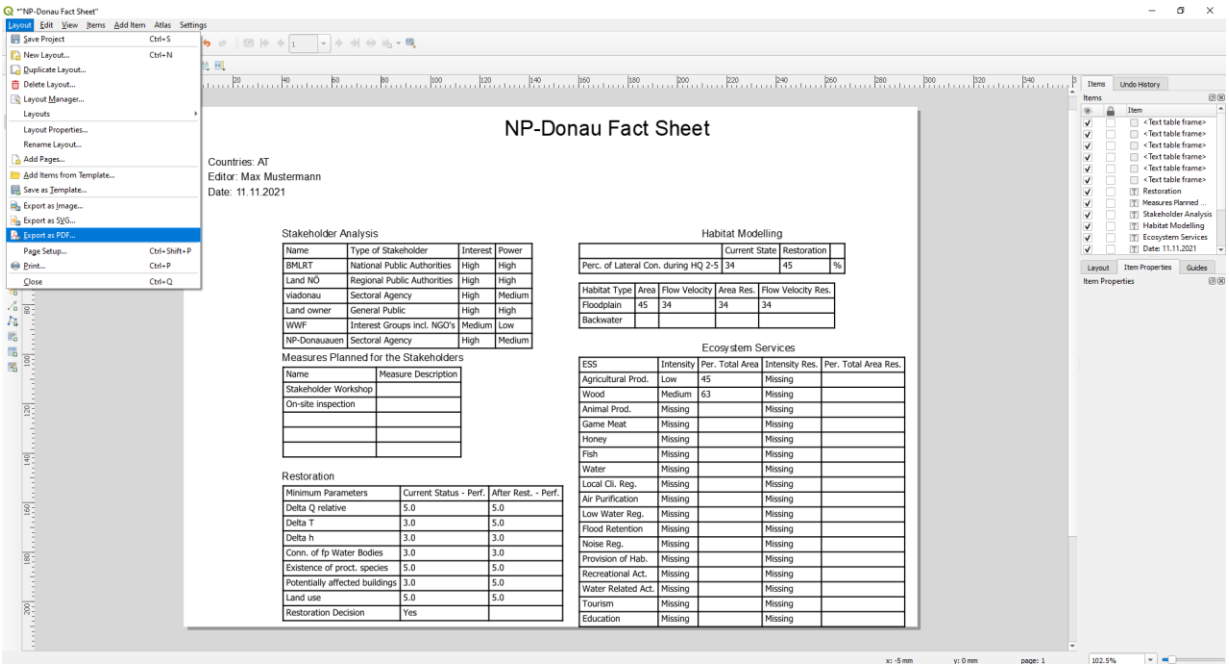


*Figure 7: "Additional Factsheet" in the layout manager of QGIS shows the performance of the minimum FEM-parameters for the current and the restored status, the stakeholder analysis, the results of the ecosystem services and habitat modelling. In the left upper corner, it is shown how the factsheet can be exported as a .pdf file.*

### 3.3.2 "Floodplain Areas": Identification of active floodplains

With the option "Floodplain Areas" it is possible to identify active floodplains along a river automatically. This chapter shows you how we used this option to identify hydraulically active floodplains along the Austrian Danube River. The developed method for identifying active floodplains described in D3.2.1 (Danube Floodplain, 2021a) uses the following three delineation criteria:

- Ratio factor of $width_{floodplain}/width_{river}$ > 1:1
- Minimum floodplain size of 500 ha
- 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)

The last criterion shows that full automation of the delineation is not possible since checking manual work by the operator is still necessary. Nevertheless, the FEM-Tool allows accelerating the identification process a lot. Therefore, we need the centerline of the river as a shape file in a polyline format and import it into the tool. If the shape file was successfully loaded, next to the name of the shape file "imported" will be written (Figure 8). Additionally, the inundation area of a $HQ_{100}$ is needed and has to be imported as a shape file in a polyline format. Each of these shape files has to be one continuous file. If one of the shape files consists of two or more separated lines, merge them. The

river channel can also be imported as a shape file in polyline format, but it is not necessary for the delineation process. The developed method for identifying active floodplains in D3.2.1 (Danube Floodplain, 2021a) had to be adopted to accelerate the identification process. Additional delineation criteria, such as the "distance between the floodplains" and the "No. of points higher than", had to be defined as well as the average "river width" during mean water level and the "ratio factor". Here, we are presenting the meaning of these threshold criteria's below:

The criteria about the selection of a floodplain relies on three factors:

- Distance between the floodplains
- No. of points higher than
- River width

As a first step to identify the floodplains, the polyline of the inundation area automatically transformed into QgsPoint, which is a function of (X, Y) coordinate system (e.g. EPSG:3035). The distance between each QgsPoint(X,Y) belongs to the inundation area and the centerline is automatically calculated. In the event that the calculated distance is greater than the River width, the QgsPoint(X,Y) at that particular point in the coordinate system is considered as a floodplain, otherwise it is considered part of the river. Thus, the river width describes the distance between two QgsPoint(X,Y) in the coordinate system reads:

$$r = \sqrt{\mathrm{QgsPoint}_1(\mathrm{X},\mathrm{Y}) + \ \mathrm{QgsPoint}_2(\mathrm{X},\mathrm{Y})} \qquad (1)$$

The dimension of the river width, a scalar variable, is therefore not in meters but the distance between the coordinates. Based on our parametric analysis, a recommended value has been provided in the tool.

During our preliminary tests, we have identified small scale, additional floodplain areas which may not be considered as a floodplain with a significant effect on flood risk reduction which are normally in the focus of an investigation. This behavior is a result of the complex shape of the inundation area. In order to prevent this, a value can be added to get rid of smaller floodplain areas that are not part of an evaluation process. Hence, we have introduced another logic referred to as "No. of Points higher than", a scalar variable, in order to remove these smaller floodplains. The number lower than this threshold removes the automatically identified floodplains.

The last factor, referred to as "Distance between the floodplains", a scalar variable, describes the occurrence of an inundation area within the tool. If one floodplain is very close to another floodplain very often, it is better to give the user the possibility to decide if the floodplain should be only one or separated. The user needs to consider the hydraulic characteristics such as flow paths and stages and potential tributaries during this decision process. For giving the user this option, the "Distance between floodplains" threshold has been introduced.

The tool provides default values for the delineation criteria (Figure 8), but depending on the project needs or river section (might be different for Upper, Middle and Lower sections), these values can be adapted. In our example, the default values are: "distance between the floodplains" = 5000 m; "river width" = 1100 ; "No. of points higher than" = 5; "ratio factor" = 1. **IMPORTANT:** Click on "import" to load the values before clicking "compute".

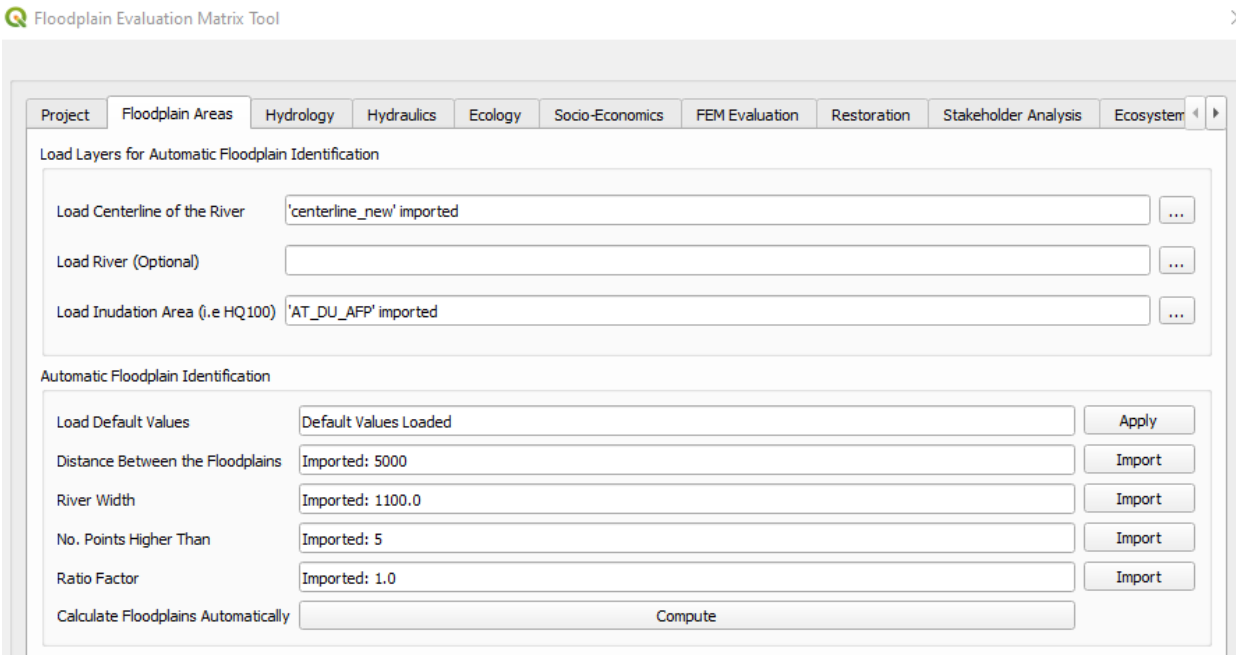


*Figure 8: Option "Floodplain Areas" for identifying hydraulically active floodplains. In the first part, necessary input data (Centerline of the River; Inundation Area) is imported. The second part defines the delineation criteria (with default values) for the identification process.*

Depending on the length of the study area, the computation process can take some minutes (for 350 km it took 7 min). After the computation process is finished the following data sets were created:

- Floodplain_X → represents the automatically suggested floodplains from the tool
- River_Centerline_Floodplains → represents the centerline of the suggested floodplains and can be used to determine the starting and ending point of the floodplain
- Centerline of the River → represents the centerline of the River for the entire study area
- Inundation Area → represents the inundation area of a certain HQ for the entire study area

All the created data sets are in point format. To identify the active floodplains, the data sets "Floodplain_X" are used. Since a fully automatic delineation is not desirable due the 3rd delineation criterion (current hydraulic characteristics) and to have the option to consider large tributaries as starting or ending points of floodplains, the final delineation is done manually by the user. In Figure 8, the first two suggested floodplains ("Floodplain_0"; "Floodplain_1") are shown. All the other data sets are not displayed by deactivating the layer.

*Figure 9: Two suggested floodplains along the Austrian Danube River*

The next step is checking and finalizing the identification process manually. Therefore, the inundation area of a $HQ_{100}$ that we already needed before is imported again. The easiest way to import the shape file (polyline format) is to use the "drag & drop" function of QGIS. This means you go to your folder where the shape file is stored, mark the .shp file, and drag it into the main window of QGIS. We need to transform the polyline now into a polygon. We are using the function "polygonize", which you can find in the processing toolbox ("Processing" → "Toolbox" → searching for polygonize). As an input layer, you choose the inundation area of your entire study area and under "Polygons" you save the newly created shape file, clicking save to file (Figure 10).

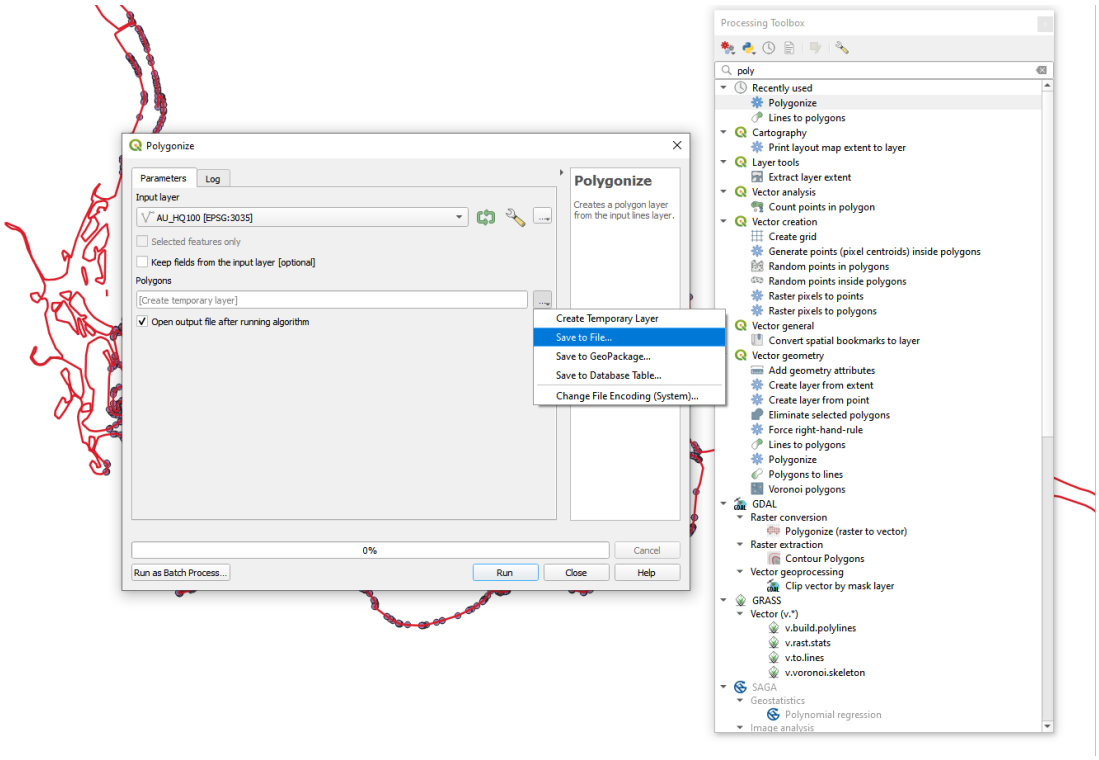


*Figure 10: Using the function "polygonize" to create a polygon from the inundation area that were in our example in a polyline format.*

We saved our shape file as "AT_DU_AFP_PG". This shape file can be used for the final delineation of all active floodplains in your study area. The created shape file is added to QGIS automatically. In Figure 11, parts of the newly created polygon ("AT_DU_AFP_PG"), the inundation areas in a polyline format and the points of the first suggested floodplain ("Floodplain_0") are shown.

*Figure 11: Parts of the newly created polygon in brown ("AT_DU_AFP_PG"), the inundation areas in a polyline format (red lines) and the points of the first suggested floodplain ("Floodplain_0") are shown.*

An aerial picture can be loaded, assisting with the final delineation of the start and end point of the floodplain. There are different ways in QGIS to load an aerial imagery. One way is to install the plugin "OpenLayers Plugin" which allows importing Google Maps, Bing Maps, OpenStreetMap and more layers. You can install the plugin clicking on Plugins → Manage and Install Plugins → All → searching for OpenLayers Plugin → Install it. Afterward, you can find the plugin under "Web" and add an aerial imagery from the different providers. In our example, we used "Bing Maps" → "Bing Aerial".

Next, we delineate the first final floodplain. Therefore, we export first the polygon "AT_DU_AFP_PG" as a shape file (Right-click on the layer "AT_DU_AFP_PG" → "Export" → "as feature" → File name "AT_DU_AFP01") and store it. Please make sure that "add saved file to map" is activated then click "OK". In the Danube Floodplain project we a naming convention to give each floodplain a unique and identifiable code. The code consists of four different parts. The first part is the country code with two characters, the second is the river code with two characters, the third floodplain type (AFP = active; PFP = potential; FFP = former floodplain) and the fourth is the consecutive number within the country.

The polygon "AT_DU_AFP01" is ready for the final adaptation, but before that, it is necessary to make the aerial imagery visible (Right -click on the layer "AT_DU_AFP_PG" → "Properties" → "Symbology" → "Opacity" → "43%"). Now, we can use the point data set from the "Floodplain_0", the aerial imagery and the inundation area to find the start and end of the floodplain and cut the polygon "AT_DU_AFP01" at the identified points. Normally, the point data set from the "Floodplain_X" layers

marks these start and end points quite well. You just have to look where the first points appear, and where they end. Sometimes the user can make minor adjustments to find a better starting or ending points based on the inundation area and the aerial imagery. In our first example, we moved the beginning of the floodplain further down to a bridge. Right after the bridge, the river is overtopping its banks during a $HQ_{100}$, leading to the start of the first floodplain. We cut the polygon at the bridge using the "Toogle Editing" function. Before that, we have to make sure that the right layer is selected.

Hence, select the layer "AT_DU_AFP01" and click on "Toogle Editing" then click on the function "Split Features".

Then draw the line where the polygon should be cut and end the line by a right-click. In Figure 12, the red line shows where the polygon is cut and the floodplain is beginning.

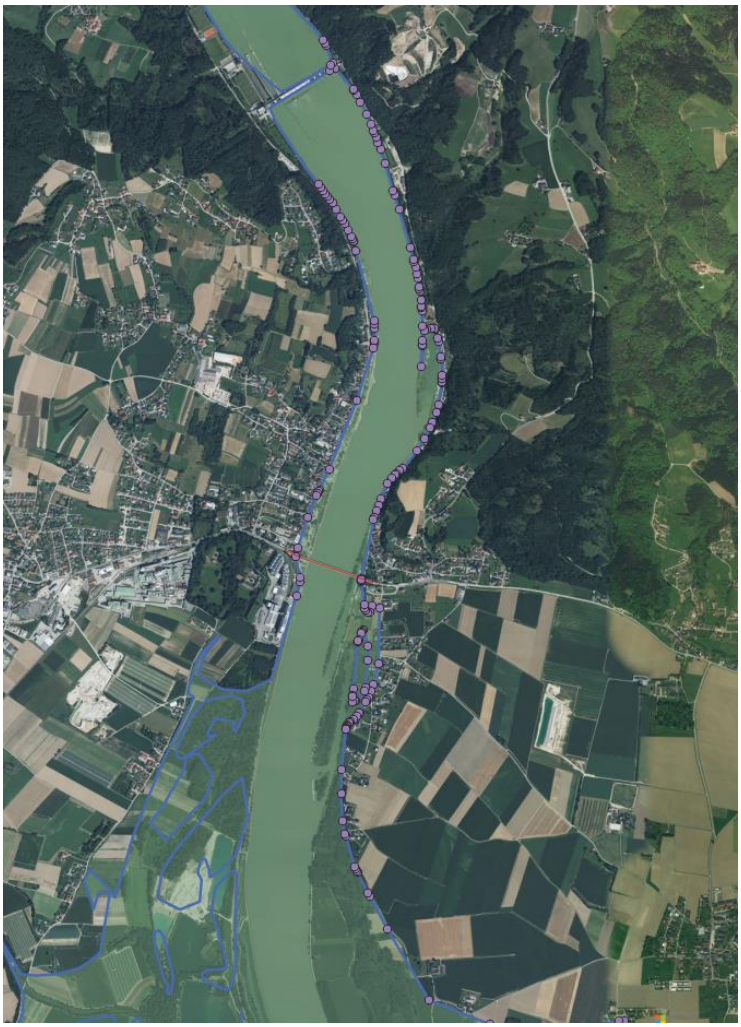

*Figure 12: Start (red line) of the first floodplain in Austria. Blue lines show the inundation area as polylines. Purple points show the "Floodplain_0" layer.*

The last point of the "Floodplain_0" layer indicates the end of the floodplain, but the user determines the most reasonable ending for the floodplain, marked with the red line in Figure 13 for our example. To cut the polygon "AT_DU_AFP01" the same workflow is used ("Toogle Editing" → "Split Features"). Then the changes must be saved by "Save Layer Edits"

*Figure 13: End (red line) of the first floodplain in Austria. Blue lines show the inundation area as polylines. Purple points show the "Floodplain_0" layer.*

Before finalizing the delineation, we need to delete all the unnecessary polygons of the "AT_DU_AFP01" layer. We select the created polygon with "Select Features by Single Click or Area" by clicking in the middle of the suggested floodplain. The polygon is marked yellow, and the polygon's points are marked as red crosses (Figure 14).

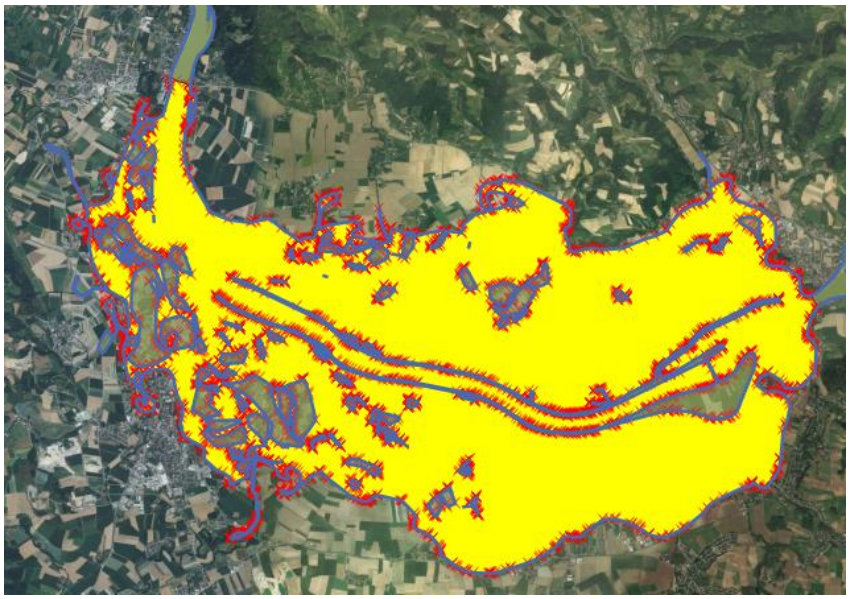

*Figure 14: Created and selected polygon in yellow. Points of the polygon are marked with red crosses. Blues lines show the inundation area in a polyline format.*

Then we right-click on the layer "AT_DU_AFP01" → Open Attribute Table → Invert Selection → Delete selected features.

We save the changes "Save Layer Edits" and deactivate the editor by clicking on "Toggle Editing". In Figure 15, the final version of the first active floodplain in Austria (AT_DU_AFP01) is shown.

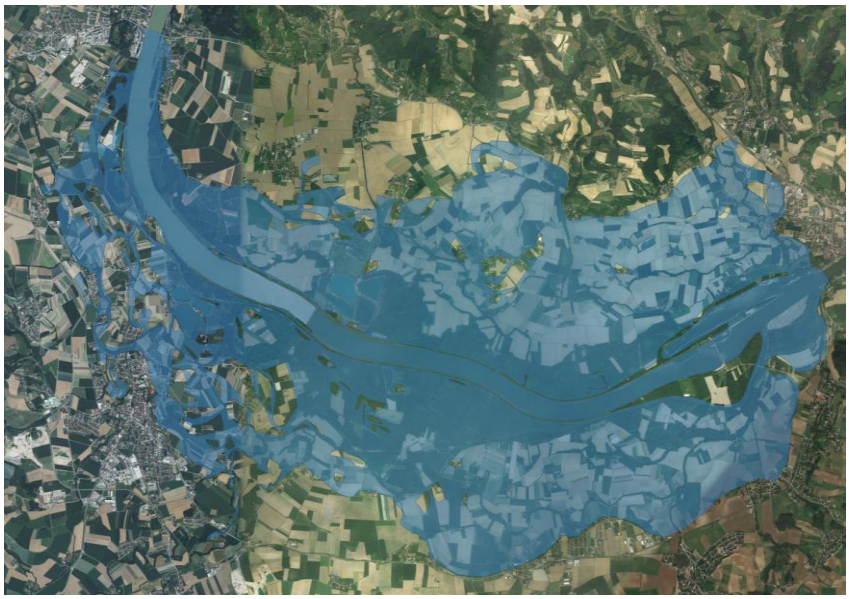

*Figure 15: Final delineation of the first active floodplain along the Danube River in Austria (AT_DU_AFP01).*

The same workflow as described above is used to delineate the final versions of all active floodplains along a river or river reach. After the final version is delineated, the area has to be checked since one delineation criterion is the minimum size (e.g. 500 ha) of a floodplain. In our example, it is 500 ha, but this is a flexible value that can be changed accordingly to the project needs (smaller investigated rivers etc.). The FEM-Tool allows determining the area easily. Therefore, you can use the option "Floodplain Area". Here you can load a single floodplain (Figure 16). Then you use the option "Select Floodplain Layer" and select the imported floodplain. After that, the area is calculated and then it is recommended to click on "import" so the area can be used to calculate the FEM-parameters.

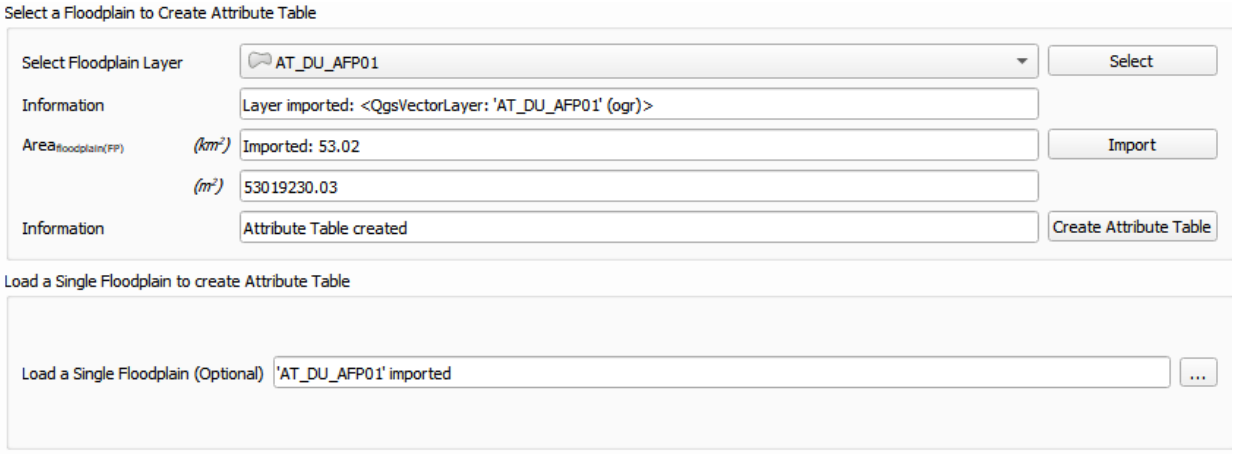


*Figure 16: Option "Floodplain Areas" used calculating the area of AT_DU_AFP01.*

As you can see in Figure 16, you also have the opportunity to create an attribute table for the selected floodplain by clicking "Create Attribute Table". The attribute table that is created is based on the D3.2.2 (Danube Floodplain, 2020c) and adapted to the tool's needs. In Table 1, the structure of the attribute table is shown..

*Table 1: Structure of the created attribute table based on D3.2.2 (Danube Floodplain 2020c)*

| **Name of field** | **data type/length** | **Full name of the parameter** | **Unit** | **Example** |
|---|---|---|---|---|
| DFGIS_ID | text/50 | ID of the floodplains | | HU_DU_AFP03 |
| FP_Type | text/25 | Active, former, potential | | active |
| Location | text/254 | Name/location of the floodplain | | Upstream from Novi Sad |
| Transbound | text/10 | Countries sharing the floodplain | | HR, RS |
| Area | numeric, double | Area (ha) | ha | 6716 |
| FPlength | numeric, double | Length of the floodplain | km | 18.6 |
| Chan_width | numeric, double | Width of the channel | m | 450 |
| delta_Q | numeric, double | peak reduction ΔQ | % | 1.87 |
| delta_t | numeric, double | flood wave translation Δt | h | 1.5 |
| delta_h | numeric, double | water level change Δh | cm | 0.7 |
| C_fp_wb | numeric, double | Connectivity of floodplain water bodies | no unit, direct FEM evaluation | 3 |

| | | | | |
|---|---|---|---|---|
| Prot_spp | numeric, double | Existence of protected species | Nr | 25 |
| Building | numeric, double | potentially affected buildings | Nr/km² | 52 |
| Land_use | numeric, double | Land use | no unit, direct FEM evaluation | 4.8 |
| R_delta_Q | numeric, double | FEM Rating of peak reduction ΔQ | 1, 3 or 5 | 1 |
| R_delta_t | numeric, double | FEM Rating of flood wave translation Δt | 1, 3 or 5 | 5 |
| R_delta_h | numeric, double | FEM Rating of water level change Δh | 1, 3 or 5 | 3 |
| R_C_fp_wb | numeric, double | FEM Rating of Connectivity | 1, 3 or 5 | 3 |
| R_Prot_spp | numeric, double | FEM Rating of Existence of protected species | 1, 3 or 5 | 5 |
| R_Building | Numeric, double | FEM Rating of potentially affected buildings | 1, 3 or 5 | 1 |
| R_Land_use | numeric, double | FEM of Rating of Land use | 1, 3 or 5 | 3 |
| Hyd_eff | numeric, double | effects in case of extreme discharge | % for dQ and h for dt | 1.2 / 3 |
| delta_v | numeric, double | flow velocity Δv | cm/s | 1.3 |
| prot_hab | numeric, double | Existence of protected habitats | % | 12.5 |
| veg_nat | numeric, double | Vegetation naturalness | no unit, direct FEM evaluation | 3.2 |
| WL_dyn | numeric, double | water level dynamics | no unit, direct FEM evaluation | 3 |
| p_int | numeric, double | Presence of documented planning interests | no unit, direct FEM evaluation | 5 |
| Invasive_s | Numeric, double | Invasive species | - | - |
| R_invasive | Numeric, double | FEM Rating of invasive species | 1,3, or 5 | - |
| Ext_CBA | Numeric, double | Extended Cost-Benefit Analysis | - | - |
| R_ext_CBA | Numeric, double | FEM Rating of the extended Cost-Benefit Analysis | 1, 3 or 5 | - |
| R_Hyd_eff | numeric, double | FEM Rating of effects in case of extreme discharge | 1, 3 or 5 | 1 |

| | | | | |
|---|---|---|---|---|
| R_delta_v | numeric, double | FEM Rating of flow velocity Δv | 1, 3 or 5 | 5 |
| R_prot_hab | numeric, double | FEM Rating of Existence of protected habitats | 1, 3 or 5 | 3 |
| R_veg_nat | numeric, double | FEM Rating of Vegetation naturalness | 1, 3 or 5 | 3 |
| R_WL_dyn | Numeric, double | FEM Rating of water level dynamics | 1, 3 or 5 | 5 |
| R_pl_int | numeric, double | FEM Rating of Presence of documented planning interests | 1, 3 or 5 | 5 |
| delt_Tau | numeric, double | bottom shear stress Δτ | N/m² | 2.5 |
| p_tp_hab | numeric, double | potential for typical habitats | Nr out of 14 (0 to 14) | 12 |
| wb_status | text/25 | ecological water body status | high, good, moderate, poor, bad | moderate |
| R_delt_Tau | numeric, double | FEM Rating of bottom shear stress Δτ | 1, 3 or 5 | 3 |
| R_p_tp_hab | numeric, double | FEM Rating of potential for typical habitats | 1, 3 or 5 | 5 |
| R_wb_stat | numeric, double | FEM Rating of ecological water body status | 1, 3 or 5 | 1 |
| Restoration | numeric, text/25 | Restoration demand | Lower, medium, higher | medium |
| HQ100 | numeric, double | Peak discharge of a HQ100 | $m^3/s$ | 9272 |
| km_from | numeric, double | River kilometer start | km | 1636.6 |
| km_to | numeric, double | River kilometer end | km | 1590.8 |

As described in D3.2.1 (Danube Floodplain, 2021a), the developed method for identifying active floodplains recommends considering tributaries that significantly affect the hydrology of the river as the start and end point of floodplains. In Austria, we separated a floodplain, the FEM-Tool automatically identified as one floodplain, due to a significant tributary (first white arrow in Figure 17) into two floodplains (AT_DU_AFP02; AT_DU_AFP03). This process has to be done manually and is recommended for the largest tributaries of a river.

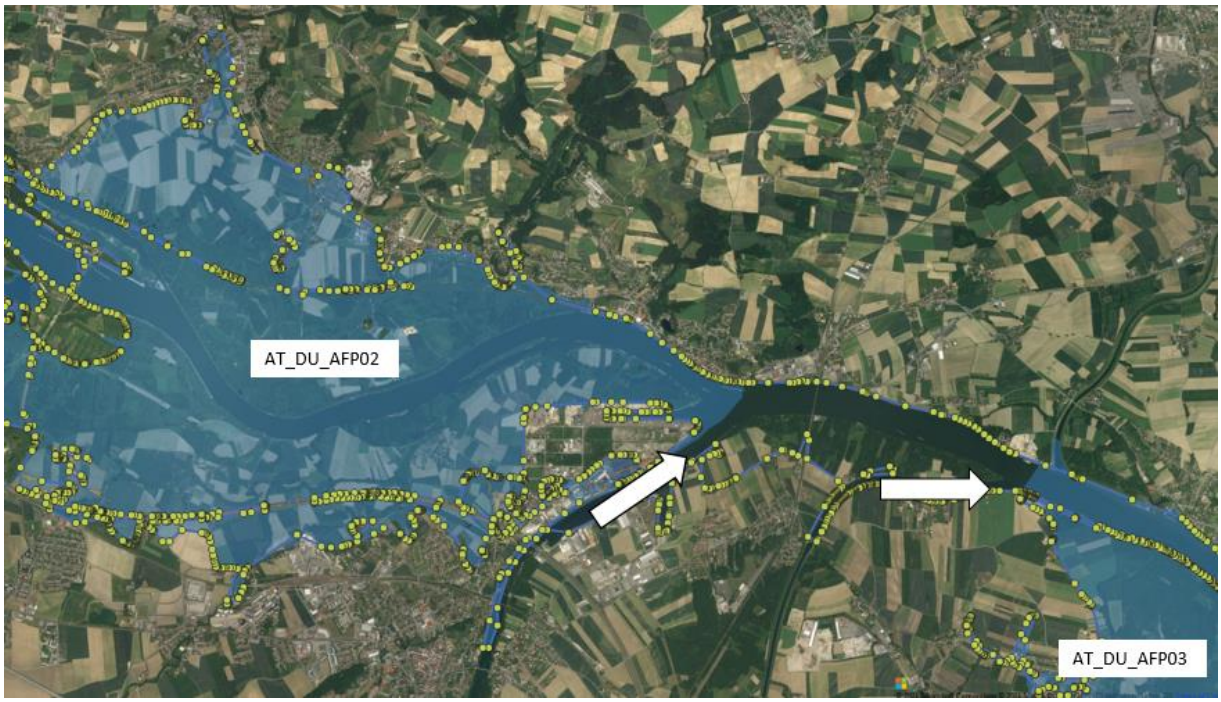


*Figure 17: Hydraulically active floodplains (AT_DU_AFP02; AT_DU_AFP03) along the Austrian Danube separated due to the confluences of tributaries (white arrows).*

***Challenges for automatically delineation***

As described in 3.3.2, the code uses XY coordinates for the delineation and this causes challenges if the river is flowing from north to south or from south to north. Based on the identification logic, the shape files with most of the points changing in the QgsPoint(Y) direction may result inaccuracies in the computation of the inundation areas. Nevertheless, the function still supports the user to delineate hydraulically active floodplain areas.

### 3.3.3 "Hydrology": Calculation of hydrological FEM-parameters

With the option "Hydrology", we calculate the hydrological FEM-parameters relative peak reduction $\Delta Q_{rel}$ and flood wave translation $\Delta t$. Therefore, the input hydrograph has to be imported as a .txt file (Figure 18). The first column shows the time step in a 15 min (0.25 h) interval (other intervals such as 0.5 h or 1 h are also possible, but 15 min (0.25 h) is recommended). In the second column, the discharge is defined in $m^3/s$. **IMPORTANT:** The first and the second column are separated by a space. If a tab separates the two columns, the calculation will not work. Additionally, all hydrographs need to have the same amount of rows.

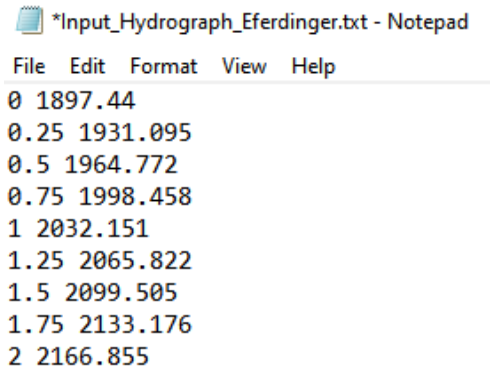


*Figure 18: Parts of an input hydrograph for the calculation of the hydrological FEM-parameters for a floodplain in Austria. First column shows the time step. Second the discharge in $m^3/s$. The two columns are separated by a space.*

Next, two output hydrographs have to be imported. For both, the same format principles apply as for the input hydrograph (first column: Time step, second: discharge, separated by a space). The first output hydrograph with floodplain (FP) represents the retention effects of the river channel and the connected floodplain. The second output hydrograph without floodplain (FP) only represents the retention effects of the river channel since the floodplain was disconnected in the hydraulic model from the river. Both output hydrographs are necessary for calculating the correct relative peak reduction $\Delta Q_{rel}$ and flood wave translation $\Delta t$ of a floodplain. After the two output hydrographs were imported the $Q_{bankfull}$ has to be defined in $m^3/s$ and imported. In our example, the $Q_{bankfull}$ for the Austrian floodplain AT_DU_AFP01 is 5520 $m^3/s$. With these four input parameters, the relative peak reduction $\Delta Q_{rel}$ and flood wave translation $\Delta t$ can be computed. Before calculating the relative peak reduction $\Delta Q_{rel}$, the $\Delta Q_{tot}$, $\Delta Q_{RC}$ and $\Delta Q$ have to be computed within the tool by clicking on "compute". The same applies to the flood wave translation $\Delta t$ where first $\Delta t_{tot}$ and $\Delta t_{RC}$ need to be calculated. In Figure 19, the calculated hydrological FEM-parameters are shown. The relative peak reduction $\Delta Q_{rel}$ is 15.63 % and the flood wave translation $\Delta t$ is 5.5 h. By clicking on "Add", the calculated values are added to the attribute table. A more detailed description of the calculation method of the FEM-parameters can be found in the FEM-handbook see Annex A.

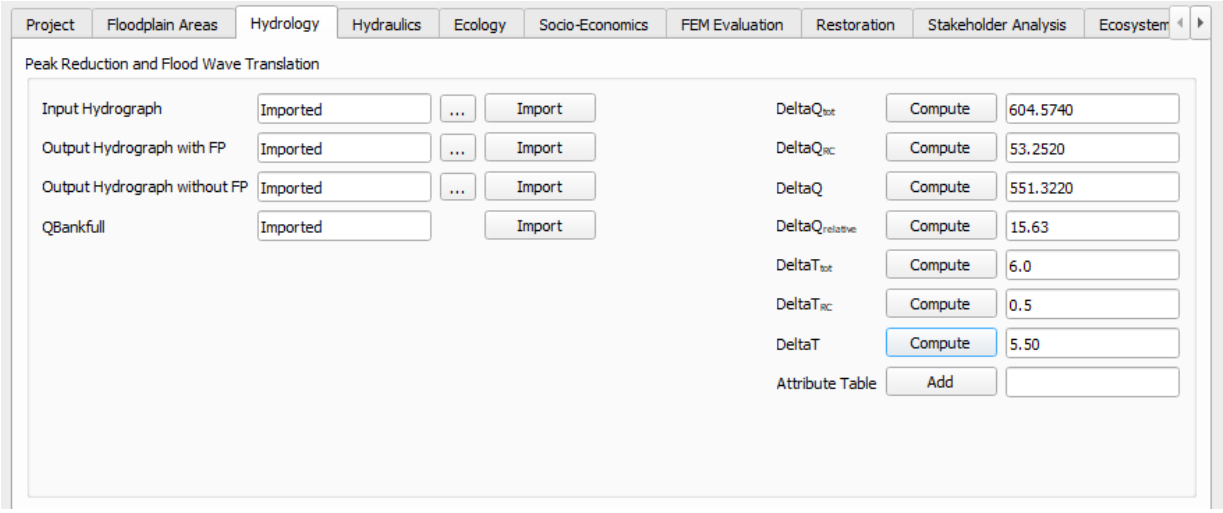


*Figure 19: Option "Hydrology" with imported input, output hydrographs, defined $Q_{bankfull}$ and the calculated hydrological FEM-parameters relative peak reduction $\Delta Q_{rel}$ and flood wave translation $\Delta t$.*

If a restoration measure or project should be evaluated with the FEM-Tool, the option “Hydrology” allows calculating the relative peak reduction $\Delta Q_{rel}$ and flood wave translation $\Delta t$ after successfully implementing the restoration measure/project in the hydraulic model. For a successful application of the FEM-Tool, it is also necessary to calculate the relative peak reduction $\Delta Q_{rel}$ and flood wave translation $\Delta t$ for the current status (before the restoration). The calculated hydrological FEM-parameters for both scenarios (current status vs. after restoration) are then compared and are taken into account for the recommendation if the restoration should be implemented or not. In Figure 20, the calculated hydrological FEM-parameters are shown for both scenarios (current and after restoration). The relative peak reduction $\Delta Q_{rel}$ is 18.02 % and the flood wave translation $\Delta t$ is 6.75 h after the implementation of the restoration, which is an increase from 2.39 % and 1.25 h compared to the current status. The results of both scenarios are then used in the option “Restoration” to find the decision if the restoration measure or project should be implemented or not.

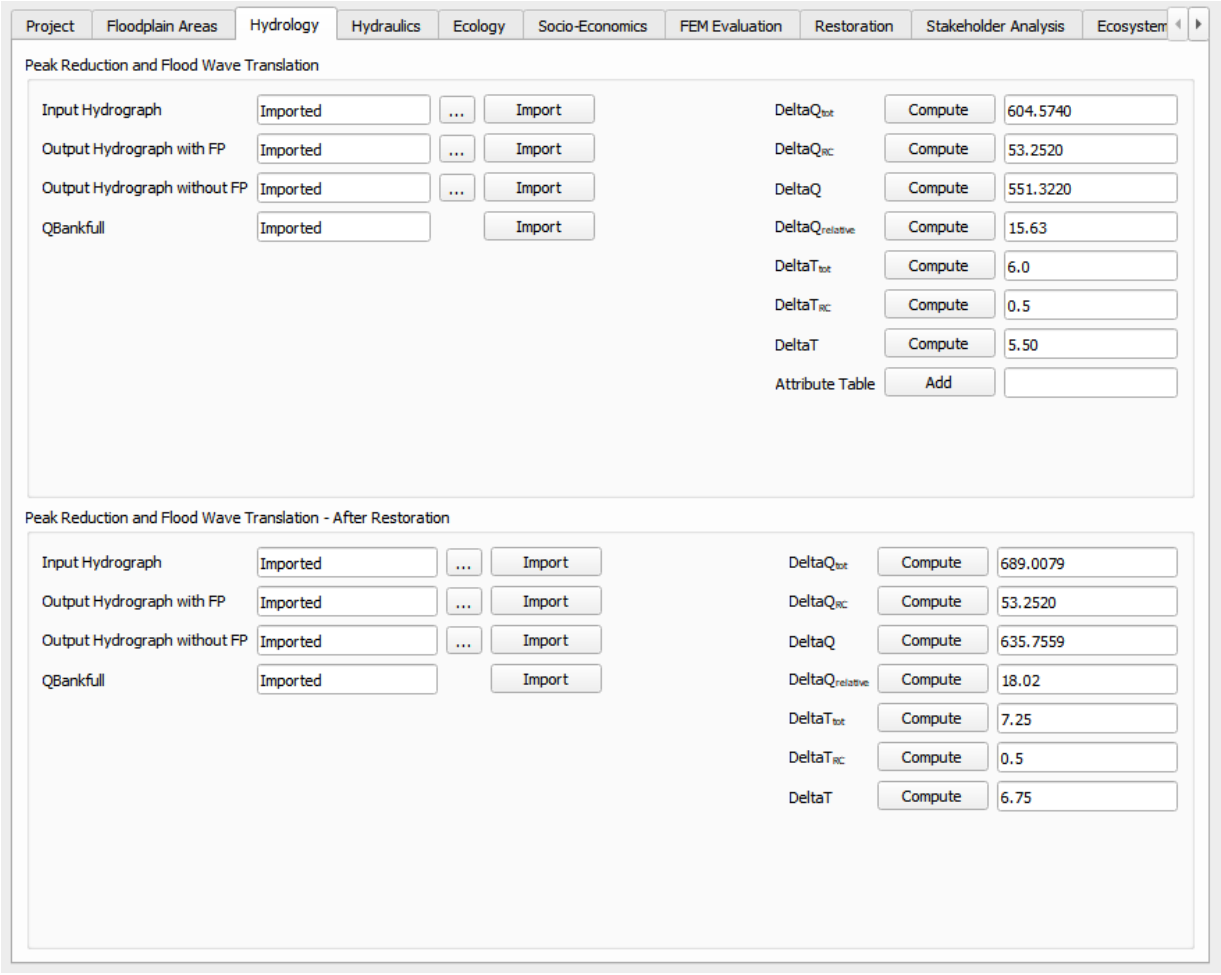


*Figure 20: Option "Hydrology" with imported input, output hydrographs, defined $Q_{bankfull}$ and the calculated hydrological FEM-parameters relative peak reduction $\Delta Q_{rel}$ and flood wave translation $\Delta t$ for the current status and after restoration.*

### 3.3.4 "Hydraulics": Calculation of hydraulic FEM-parameters

With the option "Hydraulics", we store the results of the water levels $h_{tot}$ and $h_{RC}$, which have to be calculated accordingly to the minimum FEM-handbook (see Appendix A) and calculate the water level change (Δh). In our example, the water level $h_{tot}$ was calculated with 8.23 m and $h_{RC}$ is 10.07m. The results are imported and then the water level change (Δh) was computed, resulting in a change of 1.84 m (Figure 21). The option "Hydraulics" also allows computing the water level change after a restoration measure or project was implemented into the hydraulic model. In Figure 21, the results for the water levels $h_{tot}$ and $h_{RC}$ after restoration were also imported and the water level change (Δh) computed. By clicking on "Add", the calculated values are added to the attribute table.

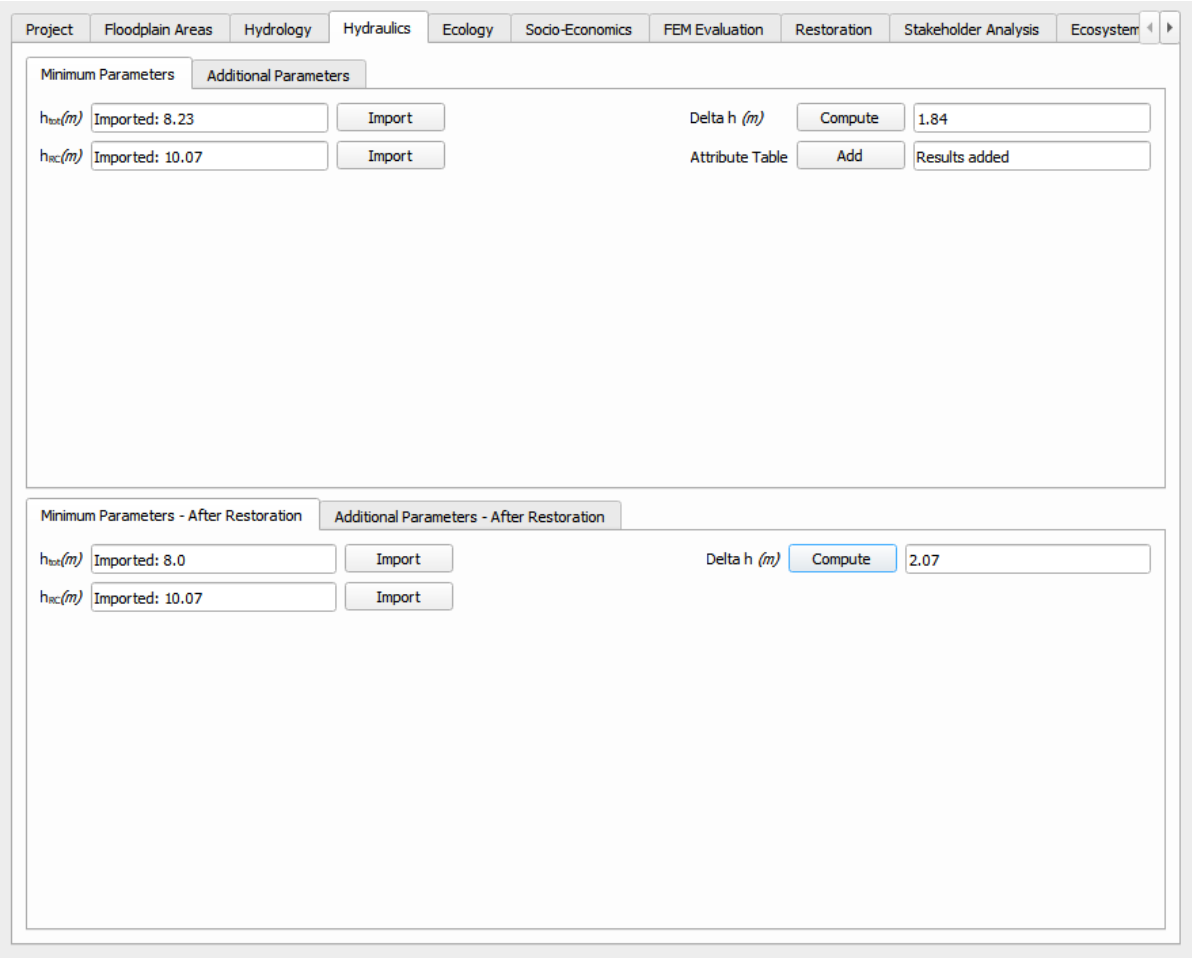


*Figure 21: Option "Hydraulics" for "Minimum Parameters" with imported water levels $h_{tot}$ and $h_{RC}$ for the current status and after a restoration project and the calculated water level changes (Δh) for both scenarios.*

Additionally, in the tab "Additional Parameters" the flow velocity (Δv) and the bottom shear stress change (Δτ) can be calculated after $v_{RC}$ and $v_{tot}$ and $\tau_{tot}$ and $\tau_{RC}$ were determined accordingly to the FEM-handbook for additional parameters (see Appendix B). All the mentioned parameters can also be determined after implementing a restoration measure to see the effects on the hydraulic FEM-parameters (Figure 22).

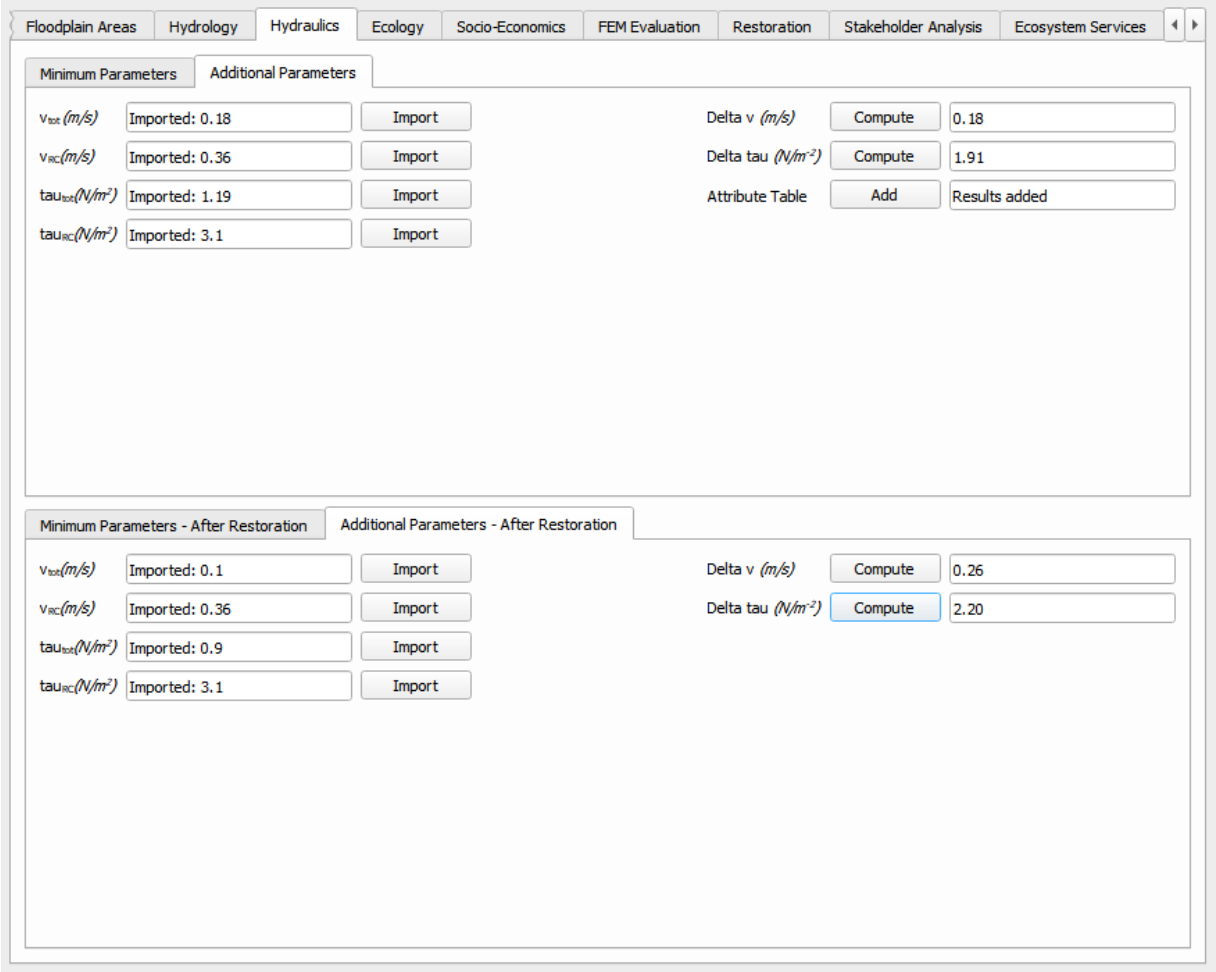


*Figure 22: Option "Hydraulics" for "Additional Parameters" with imported $v_{RC}$ and $v_{tot}$ and $\tau_{tot}$ and $\tau_{RC}$ for the current status and after a restoration project and the calculated flow velocity ($\Delta v$) and the bottom shear stress change ($\Delta \tau$) for both scenarios.*

### 3.3.5 "Ecology": Calculation of ecological FEM-parameters

With the option "Ecology", we store the results of the ecological minimum and additional FEM-parameters for the current situation and after an implemented restoration measure. The minimum parameters are the protected species and the connectivity of floodplain water bodies, which have to be calculated according to the methods described in the FEM-handbook for minimum FEM-parameters (see Appendix A). In our example, 20 protected species currently occur at the floodplain. After restoration, this number increases to 26 protected species. The connectivity of floodplain water bodies is evaluated with a low performance (1) at the current floodplain. After restoration, the connectivity of the floodplain water bodies improves to a medium performance (3). In Figure 23, you see the imported results for the minimum ecological FEM-parameters. By clicking on "Add", the stored values for the current status are added to the attribute table.

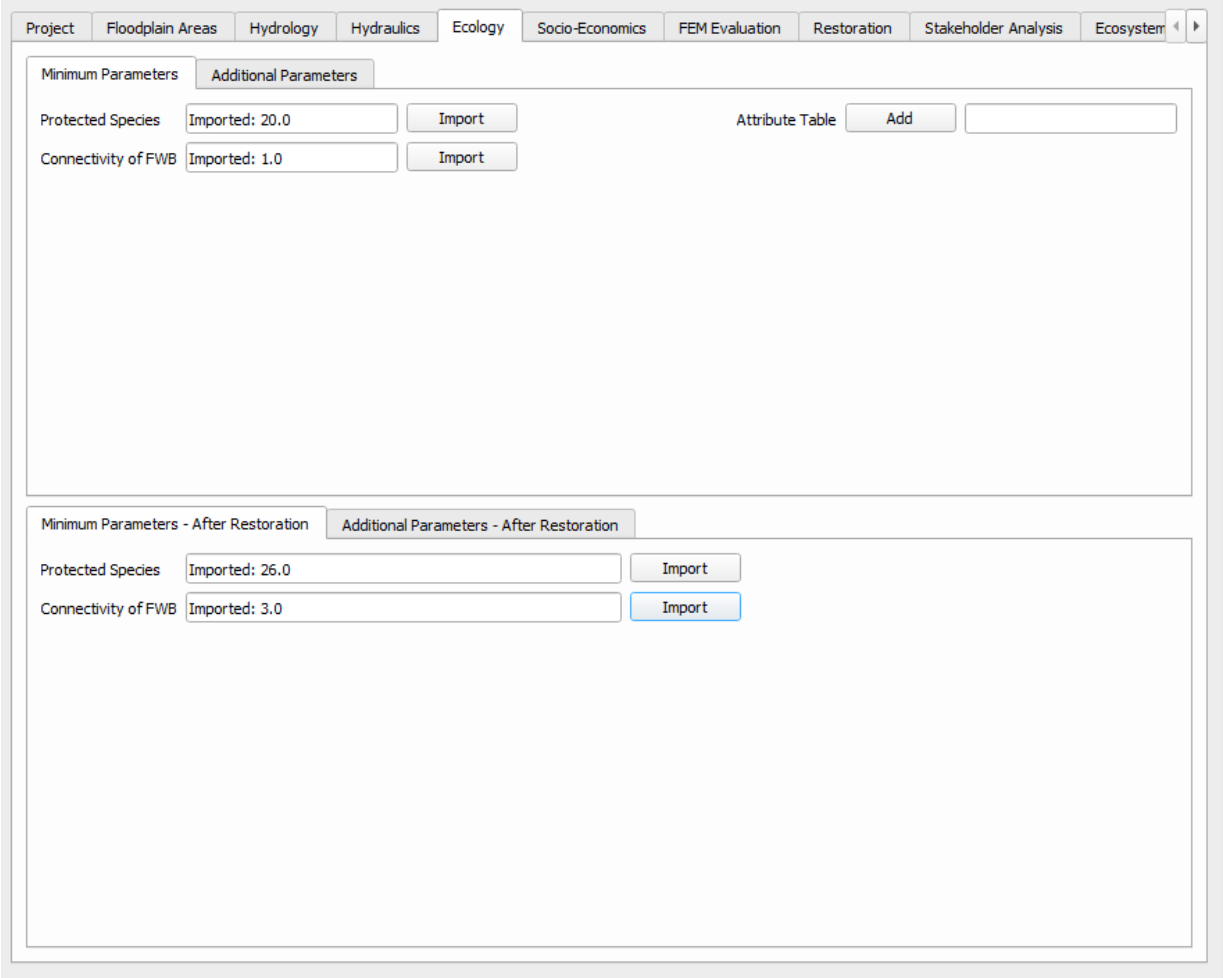


*Figure 23: Option "Ecology" for "Minimum Parameters" with imported results for "protected species" and "connectivity of FWB" for the current status and after the implementation of a restoration measure/project.*

The additional parameters include: Protected Habitats; Vegetation Naturalness; Water Level Dynamics; Potential for Typical Habitats; Ecological Water Body Status, Invasive Species and can be calculated following the described methods in the Appendix B. The protected habitat parameter shows what part of the floodplain area is defined as a protected area according to Natura 2000 or other documents about protected species or habitats like the Emerald Network. Therefore, the area of the floodplain has to defined in the option "Floodplain Area" and the area of the protected habitat has to be imported in the option "Ecology → Additional Parameters" under "$Area_{protected}$" then the parameter "Protected Habitat" can be calculated in the tool. In Figure 24, the results for all additional ecological parameters for the current status and after the implementation of a restoration measure/project are shown. By clicking on "Add", the calculated values are added to the attribute table.

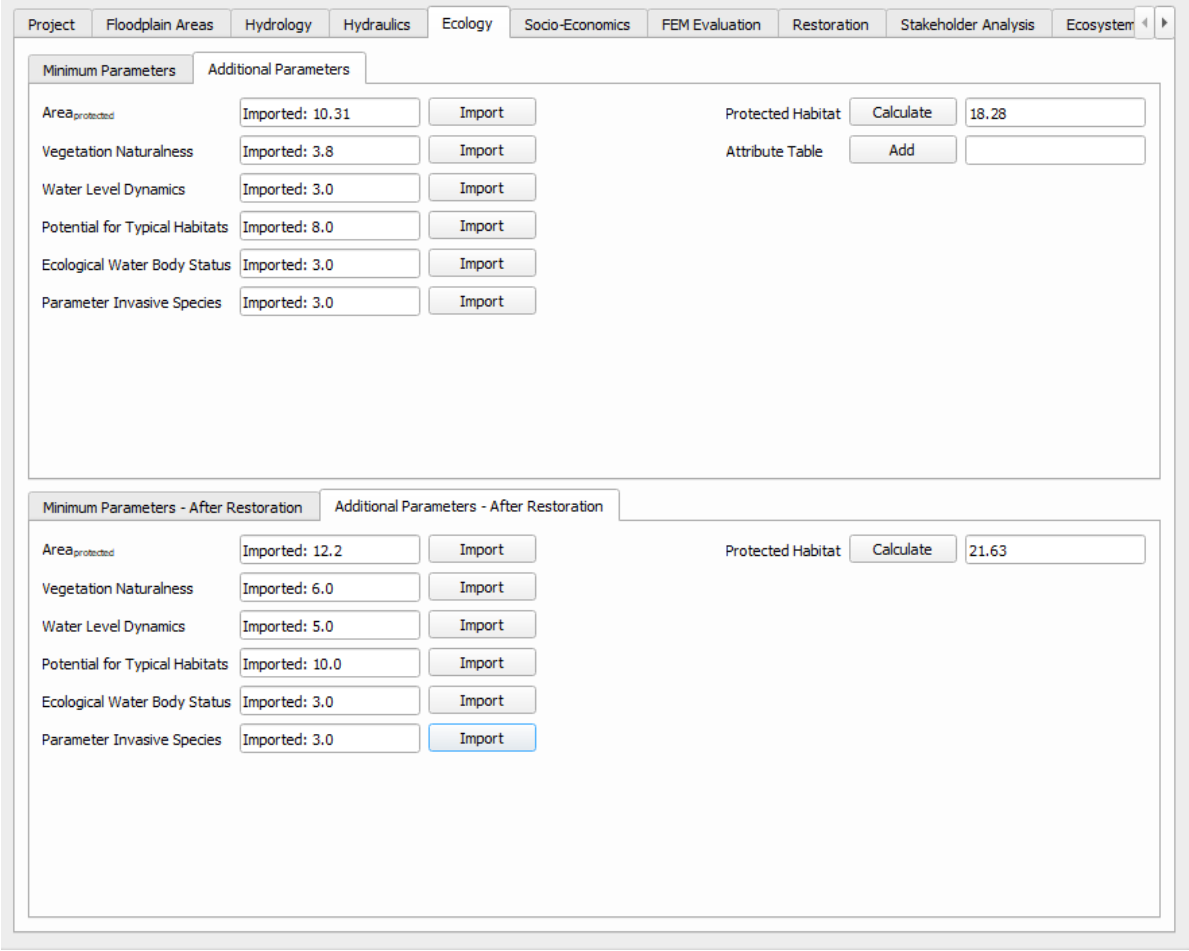


*Figure 24: Option "Ecology" for "Additional Parameters" with imported results for all additional ecological parameters for the current status and after the implementation of a restoration measure/project.*

### 3.3.6 "Socio-Economics": Calculation of socio-economic FEM-parameters

With the option "Socio-Economics", we store the results of the socio-economic minimum and additional FEM-parameters for the current situation and after an implemented restoration measure. The minimum parameters are the number of affected buildings per km$^2$ and the land use, which have to be calculated according to the methods described in the FEM-handbook for minimum FEM-parameters (see Appendix A). In our example, the number of affected buildings per km$^2$ is 19.63 for the current status and after the restoration. The land use parameter proves from a medium performance (3) at the current status to a high performance (5) after the restoration. In Figure 25, you see the imported results for the minimum ecological FEM-parameters. By clicking on "Add", the calculated values for the current status are added to the attribute table.

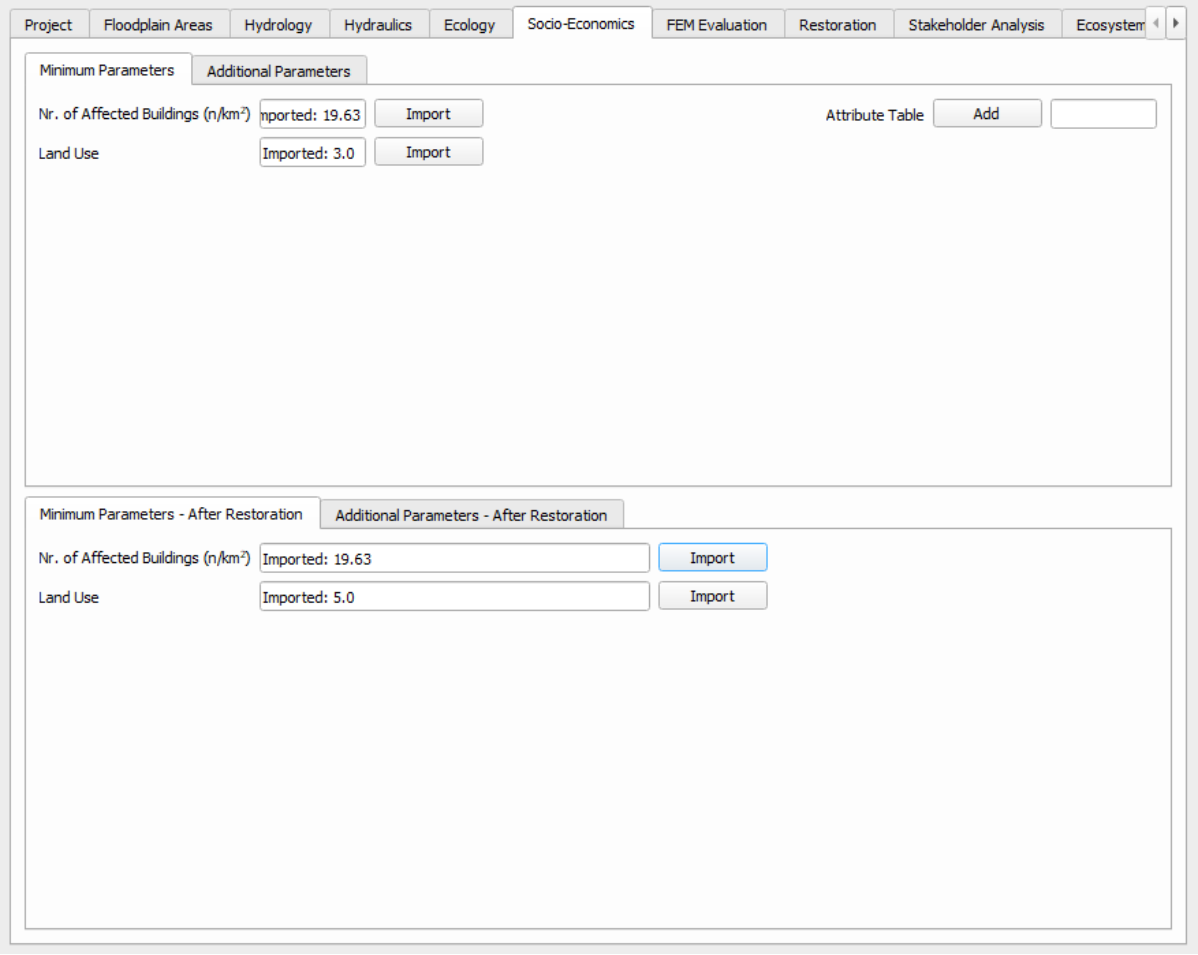


*Figure 25: Option "Socio-Economics" for "Minimum Parameters" with imported results for "Nr. of affected buildings" and "land use" for the current status and after the implementation of a restoration measure/project.*

For the option "Socio-Economics", the only additional parameter for the current status is the "Presence of documented planning Interests". For the after restoration state, there is also the "Extended Cost-Benefit Factor" (Figure 26). The "Presence of documented planning Interests" was evaluated for both scenarios with a medium performance. The "Extended Cost-Benefit Factor" was calculated for the restoration project with 0.9. In D4.3.1 (Danube Floodplain, 2021b), it is described how to apply the extended CBA. Besides the cost-benefit parameter. By clicking on "Add", the calculated values are added to the attribute table.

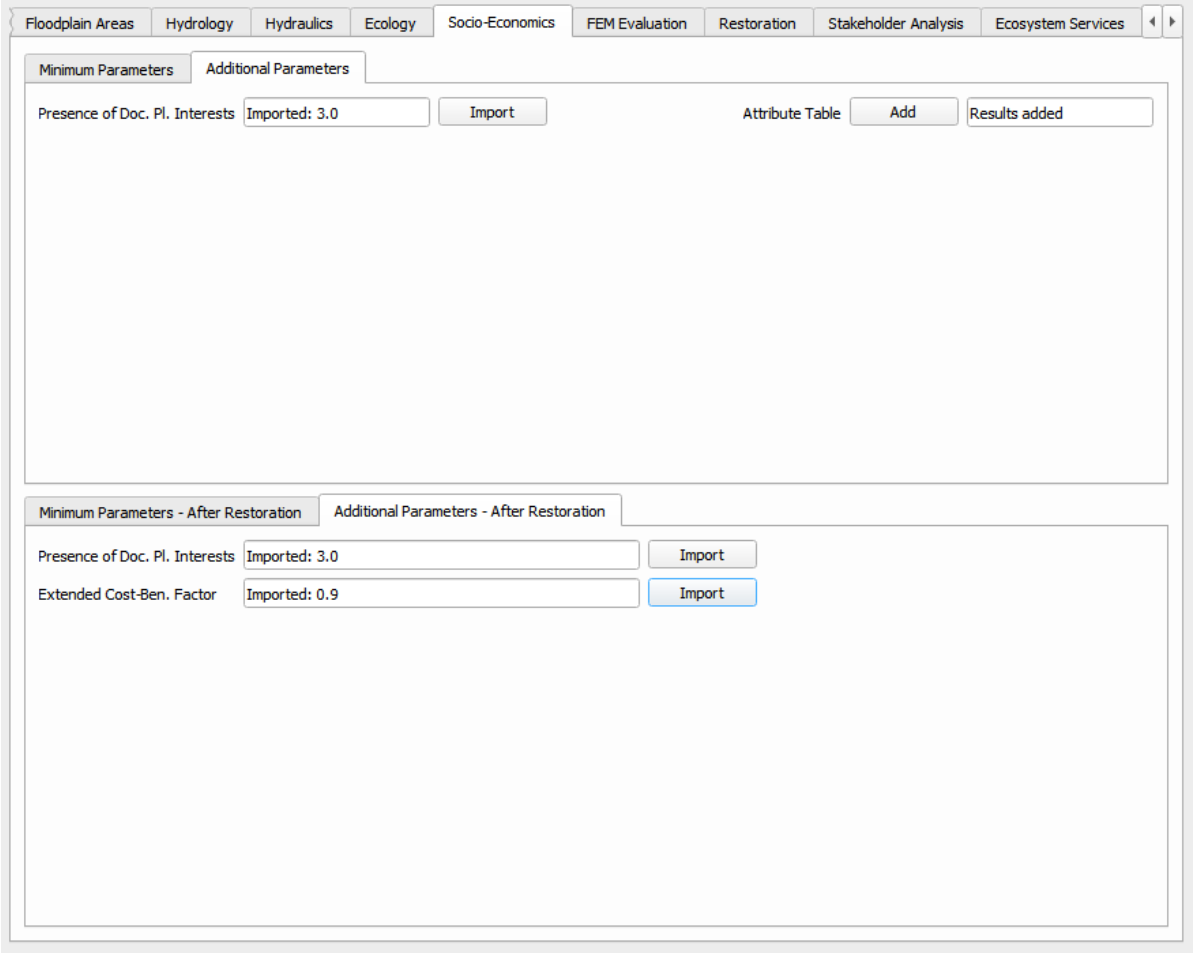


*Figure 26: Option "Socio-Economics" for "Additional Parameters" with imported results for "Presence of documented planning interests" for the current status and after the implementation of a restoration measure/project. The parameter "Extended Cost-Benefit Factor" is also shown for the restoration project.*

### 3.3.7 "FEM Evaluation": Defining thresholds and applying the FEM Evaluation

With the option "FEM Evaluation", it is possible to define the thresholds for the minimum/additional FEM-parameters and perform the FEM-Evaluation for the current status and after implementing a restoration measure or project. First, the thresholds are defined. It is possible to load default values for the minimum and additional parameters ("FEM Evaluation" → "Thresholds" or "Threshold (additional)" → Load Default Values "Apply"), but the thresholds can also be defined by the user manually. In Figure 27, the default values for the thresholds of the minimum FEM-parameters are shown. Figure 28 presents the default values of the thresholds for the additional FEM-parameters.

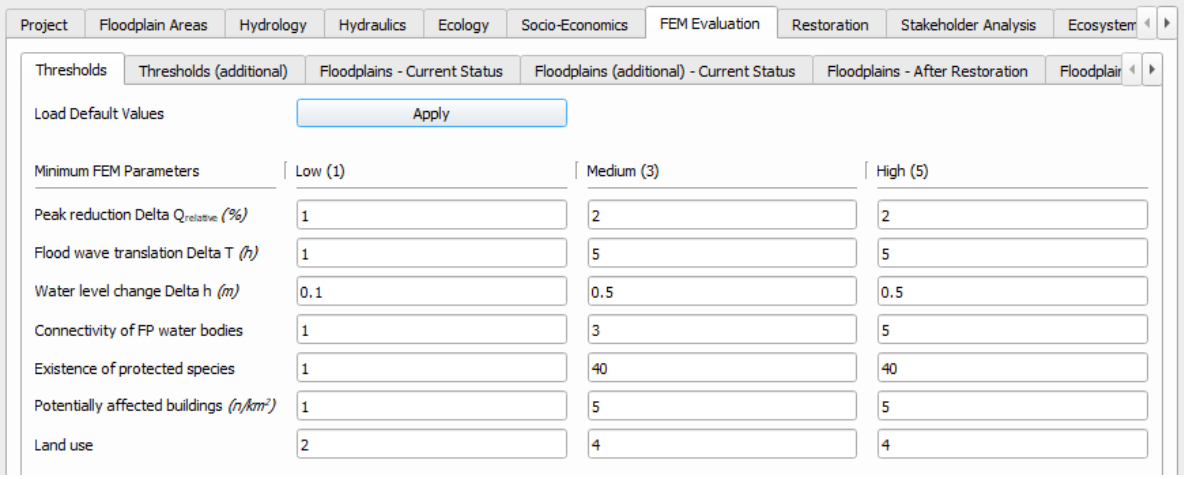


*Figure 27: Option "FEM Evaluation" → "Thresholds" defines the thresholds for the minimum FEM-parameters. Here the default values for the thresholds are shown.*

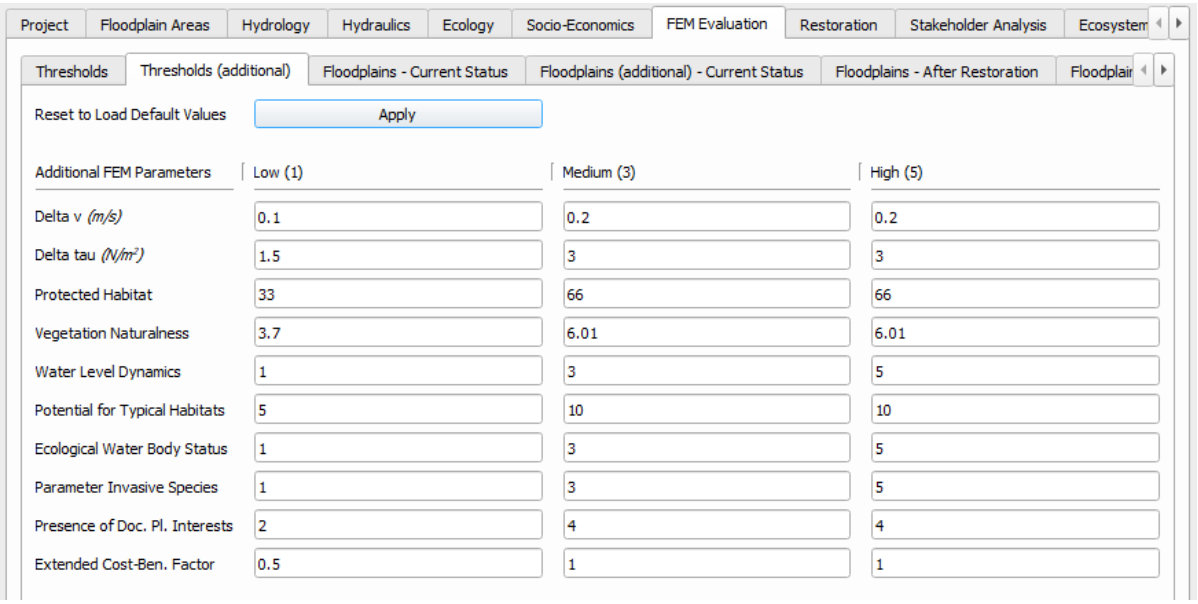


*Figure 28: Option "FEM Evaluation" → "Thresholds (additional)" defines the thresholds for the additional FEM-parameters. Here the default values for the thresholds are shown.*

In the option "FEM Evaluation" → "Floodplains – Current Status", you can load the results of the minimum FEM-parameters by clicking "Confirm values" and applying the FEM-Evaluation by clicking "Calculate FEM". Based on the FEM-Evaluation and the total sum of points, the restoration demand and the need for restoration are defined (for more details on the method see D3.2.1 Danube Floodplain, 2021a). The results can be added to the attribute table by clicking "Add". In Figure 29, the results of the FEM-Evaluation for the current status of an Austrian floodplain along the Danube River are presented. The hydrological parameter "relative peak reduction" and "flood

wave translation" are evaluated with a high performance (5) in the FEM-Evaluation. The "water level change", "connectivity of FP water bodies", "existence of protected species" and the "land use" parameters are showing a medium performance (3). Only the parameter "potentially affected buildings" was evaluated with a low performance (1). Based on these results, a medium demand for restoration and a need for preservation were determined for this floodplain.

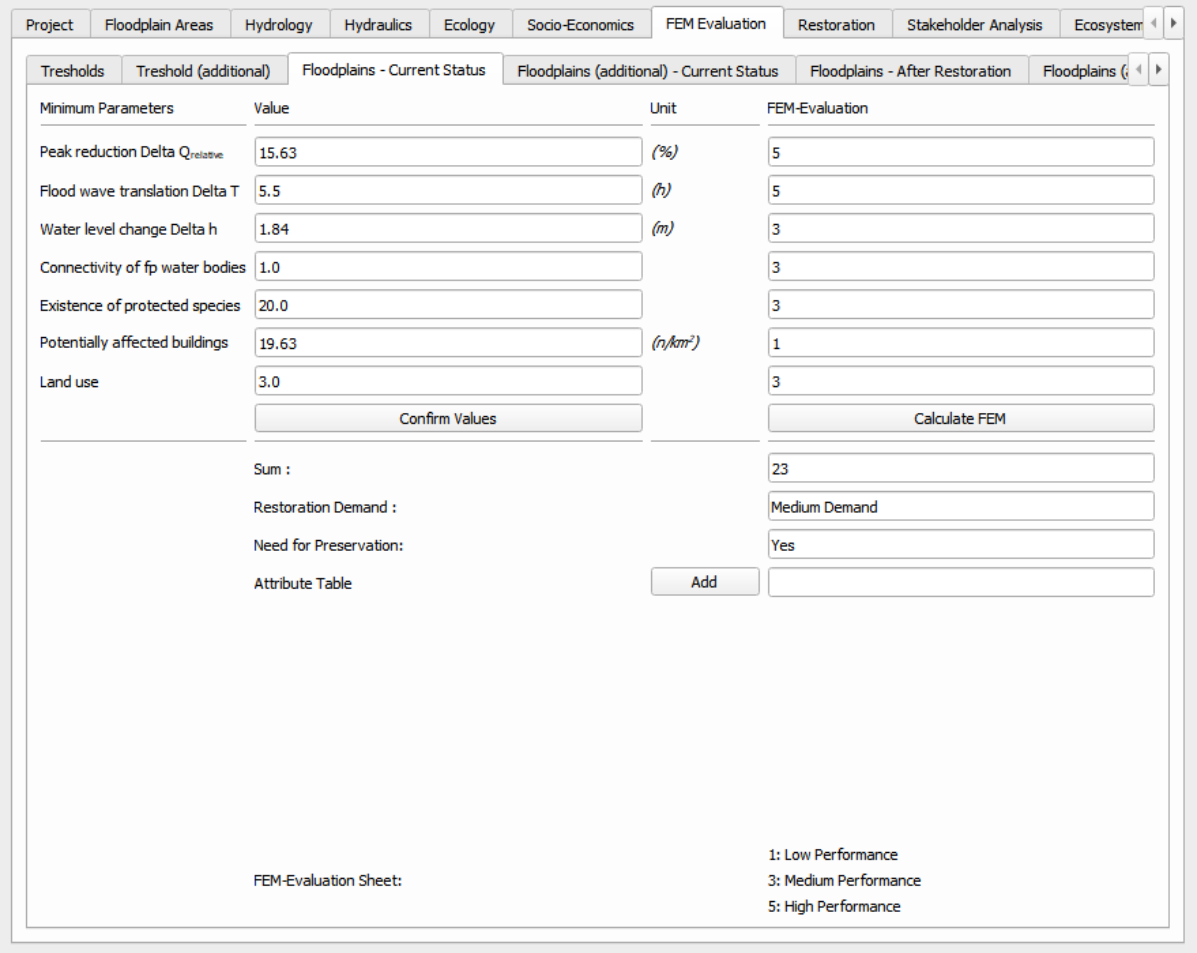


*Figure 29: Option "FEM Evaluation" → "Floodplains – Current Status" allows applying the FEM-Evaluation for the current status by clicking "Calculate FEM". Based on the FEM-Evaluation and the sum of the points, the restoration demand and the need for preservation are defined. Here you can see the results for an Austrian floodplain along the Danube River.*

In the option "FEM Evaluation" → "Floodplains – After Restoration", you can load the results of the minimum FEM-parameters by clicking "Confirm values" and applying the FEM-Evaluation by clicking "Calculate FEM" after implementing a restoration measure or project. The results of the FEM-Evaluation are then used in the option "Restoration" to give a recommendation concerning the restoration measure or project. In Figure 30, the results of the FEM-Evaluation after implementing the restoration measure at an Austrian floodplain along the Danube River are

presented. The hydrological parameter "relative peak reduction" and "flood wave translation" and the "land use" are evaluated with a high performance (5) in the FEM-Evaluation. The "water level change", "connectivity of FP water bodies" and "existence of protected species" parameters are showing a medium performance (3). Only the parameter "potentially affected buildings" was evaluated with a low performance (1). These results are used in the option "Restoration" to give a recommendation about the implementation of the restoration measure or project.

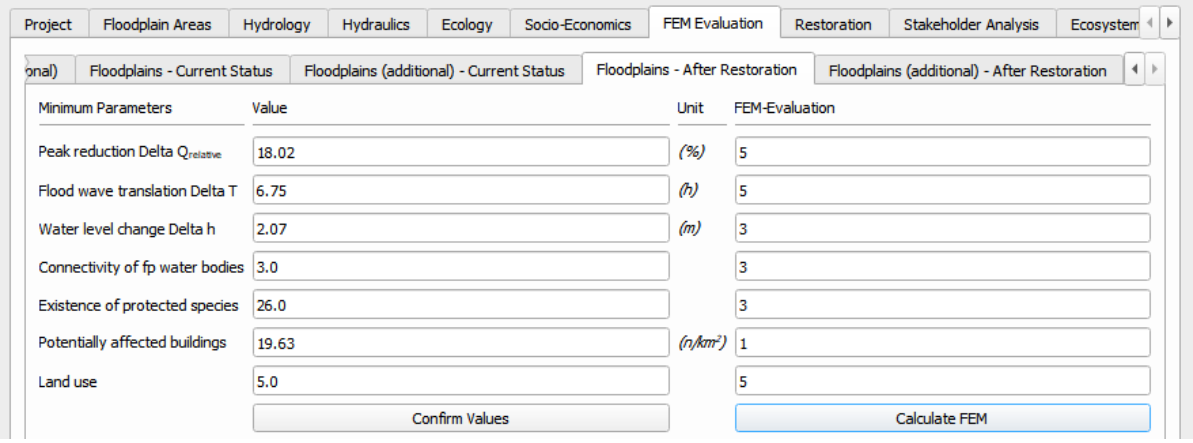


*Figure 30: Option "FEM Evaluation" → "Floodplains – After Restoration" allows applying the FEM-Evaluation after implementing a restoration measure or project by clicking "Calculate FEM". Here you can see the results for an Austrian floodplain along the Danube River after implementing a restoration measure.*

### 3.3.8 "Restoration": Giving a recommendation about the implementation of an investigated restoration measure or project

The option "Restoration" allows determining if a restoration measure or project is recommended or not, considering and comparing the results of the FEM-evaluation for the current status and the situation after the implemented restoration. In Figure 31, the FEM-performances of the minimum FEM-parameters for the current status and after the restoration are shown. By clicking "Calculate" the results are loaded and a restoration decision is made based on them. Supposing one of the minimum FEM-parameters is evaluated with a higher performance after the restoration as in the current status. In that case, the implementation is recommended by showing in the field "Restoration Decision" "Yes". The recommended additional analyses (stakeholder analysis, additional parameters, ecosystem services, habitat modelling) can lead to a change of the recommendation, but if these additional analyses also favor the restoration measure or project, it is recommended to implement it.

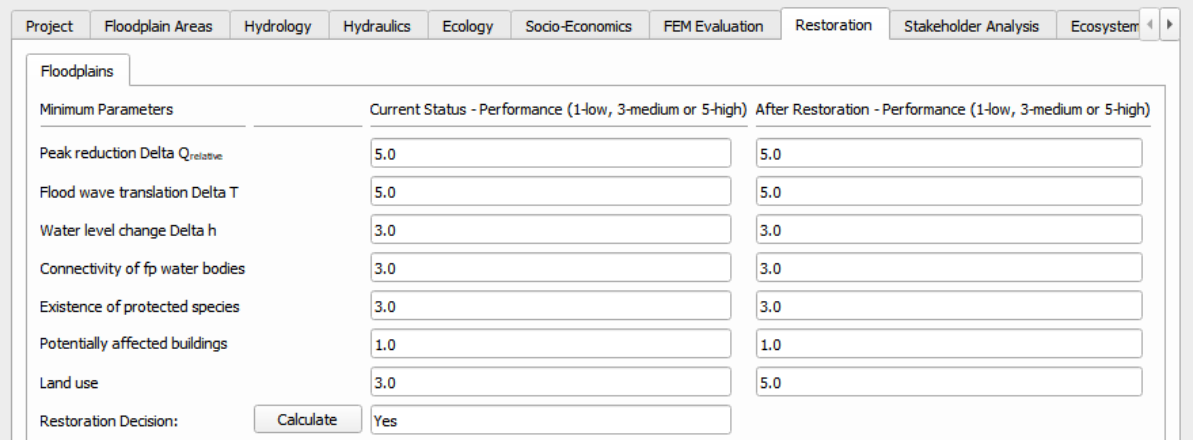


*Figure 31: Option "Restoration" allows recommending the implementation of the investigated restoration project or not based on the FEM. If one of the minimum FEM-parameters is evaluated with a higher performance after the restoration as in the current status, the implementation is recommended.*

### 3.3.9 "Stakeholder Analysis": Conducting a simple stakeholder analysis

The option "Stakeholder Analysis" allows listing all affected stakeholders their interests and power (high, medium, low). Planned measures for stakeholder involvement can be described as well. In our example, six stakeholders were identified, ranging from the general public to national authorities. Their powers and interests were assessed and planned measures for stakeholder involvement (online stakeholder workshop and on-site inception) were defined (Figure 32).

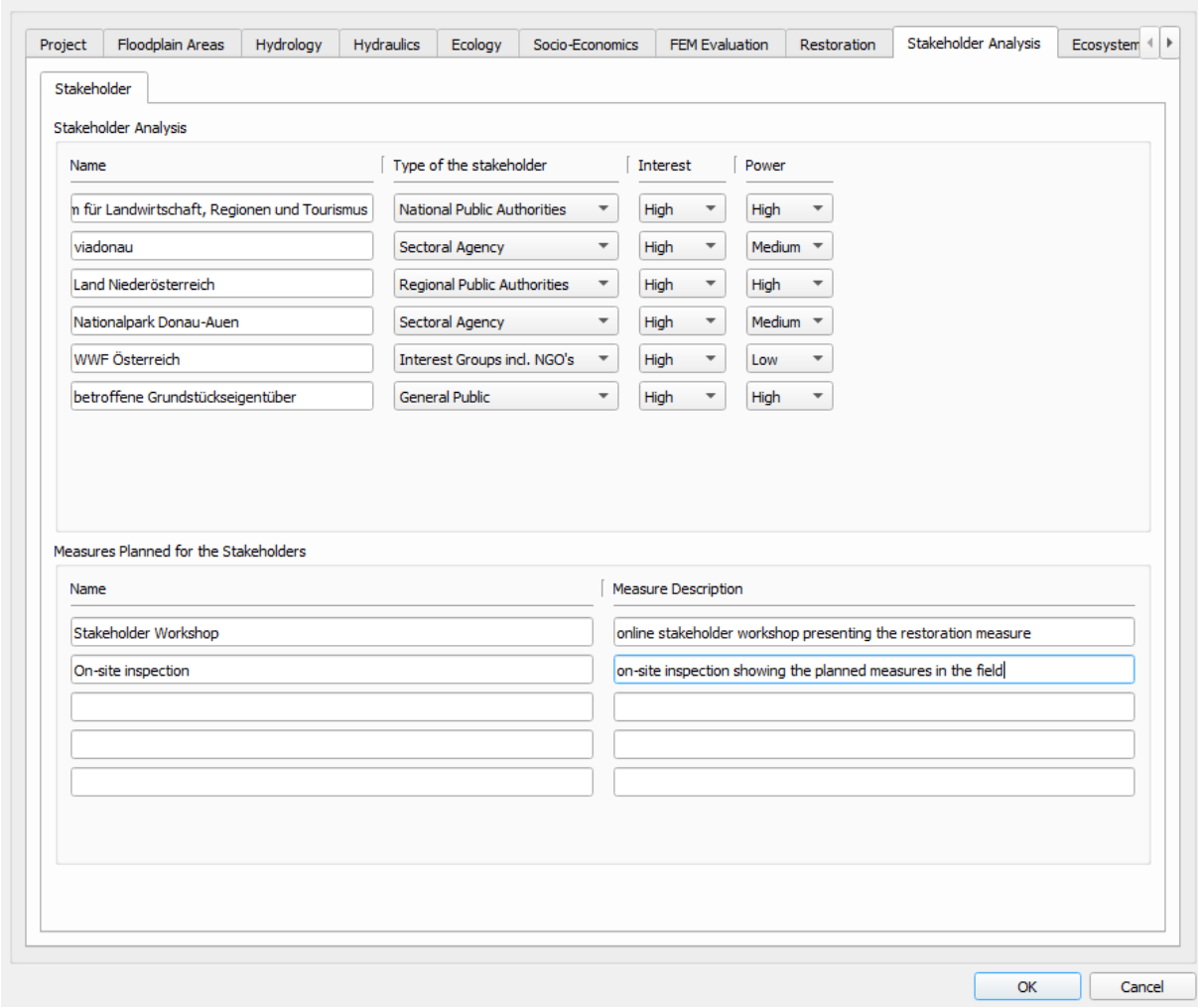


*Figure 32: Option "Stakeholder Analysis" where all affected stakeholders their interests and power can be listed. Planned measures for stakeholder involvement can also be described.*

### 3.3.10 "Ecosystem Services": Assessing the ecosystem services of a floodplain

With the option "Ecosystem Services", the floodplain's ecosystem services can be assessed and stored in the FEM-Tool (Figure 33). The assessment can be done for the current status as well as after a restoration measure or project. For the example that we used for the handbook so far, the ecosystems services were not assessed. Hence we do not have here data to fill into the FEM-Tool. For more details on ecosystem services, please look at the D4.2.2 (Danube Floodplain, 2020a), where the applied methods and results are described.

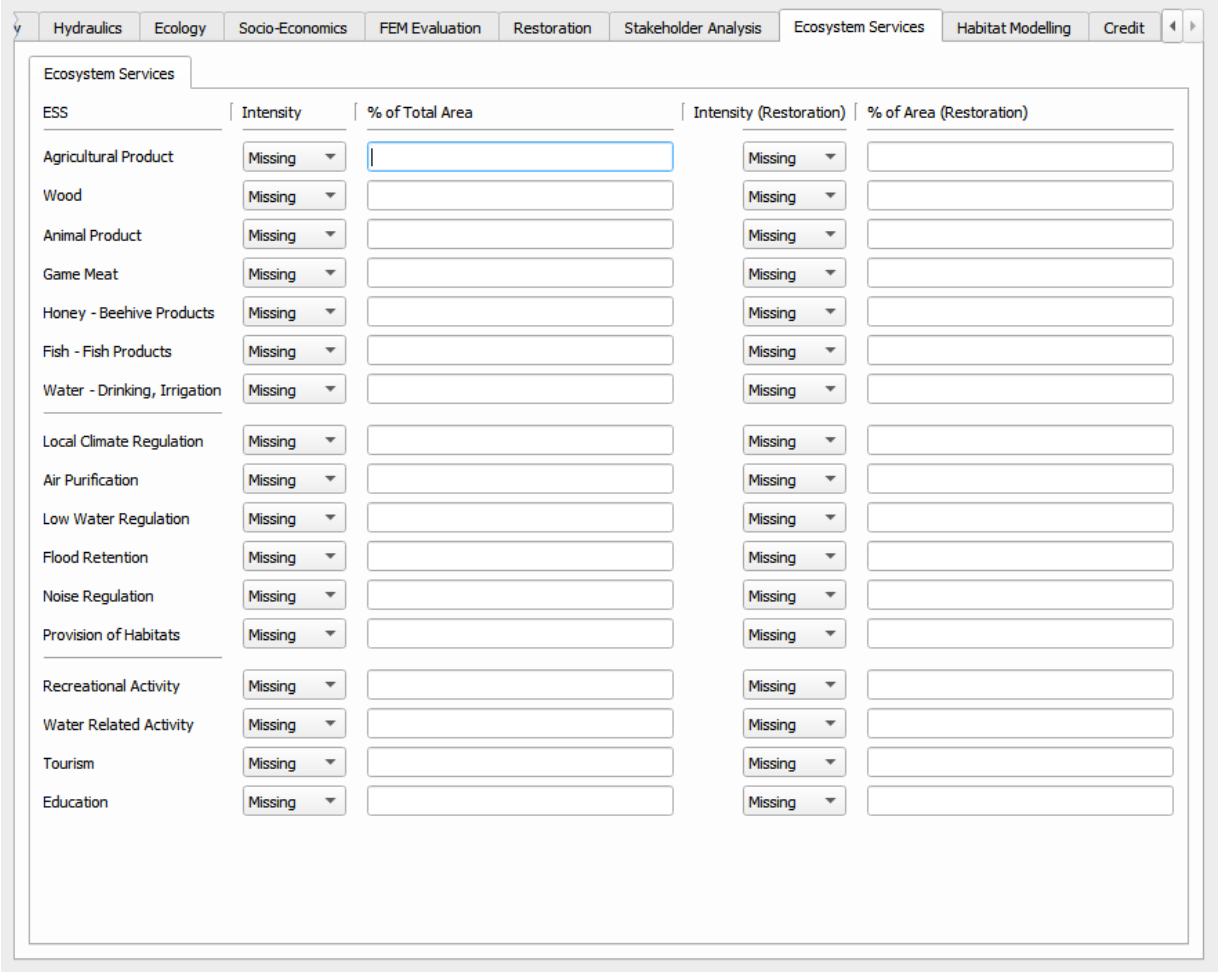


*Figure 33: Option "Ecosystem Services" allows storing the results of an analysis of the ecosystem services of a floodplain.*

### 3.3.11 "Habitat Modelling": Storing the results of habitat modelling

The option "Habitat Modelling" allows storing the information about the lateral connectivity during a $HQ_{2\text{-}5}$ for the current and the restoration state. The area of different habitat types (floodplain, backwater, channel) and the occurred flow velocities can be stored as well (Figure 34). For the example that we used for the handbook so far, a habitat model was not applied. Hence, we do not have here data to fill into the FEM-Tool. For more details on habitat modelling, please look at the D4.2.3 (Danube Floodplain, 2020b), where the habitat modelling at pilot sites in the Danube region is summarized and described.

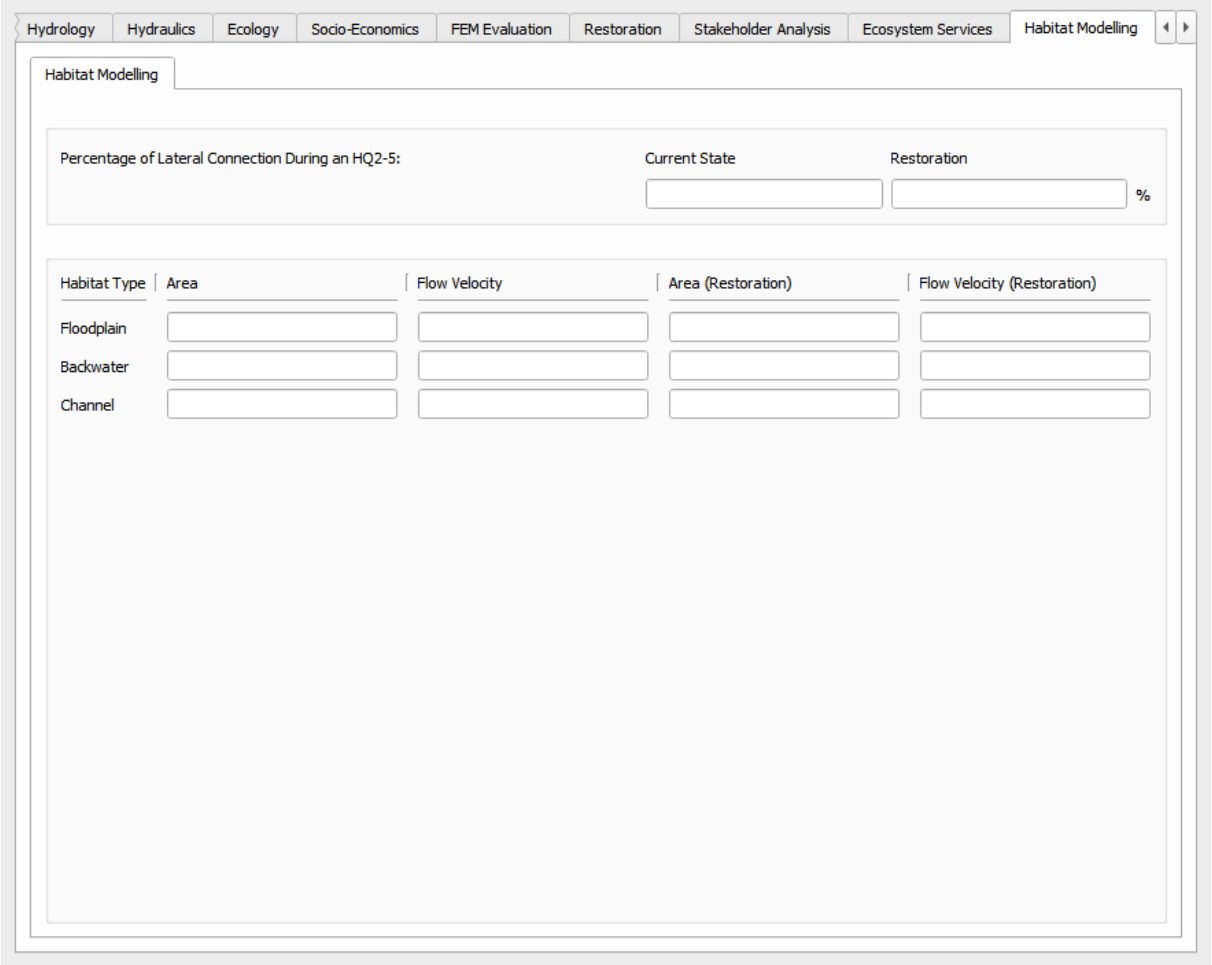


*Figure 34: Option "Habitat Modelling" allows storing the information about the lateral connectivity during a $HQ_{2-5}$ for the current and the restoration state. The area of different habitat types (floodplain, backwater, channel) and the occurred flow velocities can be stored as well.*

### 3.3.12 Preparing input data for FEM-Tool Applications: Tips

Rigorous preparation of the input data set is key to apply the FEM-Tool successfully. It starts with the preparation of the centerline of the river and the inundation area. Each of these shape files has to be one continuous file. If one of the shape files consists of two or more separated lines, merge them. In **Fehler! Verweisquelle konnte nicht gefunden werden.** presents the recommended folder structure for the input data used in the FEM-Tool. For each option in the FEM-Tool, a folder including the necessary input data should be created. How the input data for the FEM-parameters should be prepared is found in the minimum and additional FEM-parameters handbooks (Appendix A and B). In the deliverables D4.2.2 (Danube Floodplain, 2020a) and D4.2.3 (Danube Floodplain, 2020b), all the necessary information about the Ecosystem Services and habitat modelling is found.

# 4. Conclusion/Outlook

With the integration of the FEM (Floodplain Evaluation Matrix)-Tool into the open-source software QGIS, an important step was done to ensure the further dissemination of the outputs of the Danube Floodplain project. The upgraded tool accelerates and simplifies the application of the Floodplain Evaluation Matrix (FEM) and allows assessing floodplain restoration measures/projects. The tool gives the opportunity to assemble all relevant data from hydraulic modelling, ecosystem services, ecological assessments, habitat modelling, stakeholder and extended cost-benefit analysis creating a basis for the decision-making on floodplain preservation and restoration.

The tool was tested with data from pilot sites (Bistret and Suhaia-Zimnicea – RO, Middle Tisza – HU). The users received this handbook and a video tutorial before using the FEM-Tool for the first time. Both are showing how to use the tool and the users were available to use the tool on their own using the handbook and the video tutorial. The application at the pilot sites has shown that the tool processes the input data without bugs, handling and the concept are understood by the end-users. The current version of the tool fulfills the requirements for the project. Ideas and plans for the further development and improvement of the tool at the University of Natural Resources and Life Sciences, Vienna (BOKU) are already there. For example, it is planned to calculate further minimum and additional FEM-parameters (e.g. Number of affected buildings per $km^2$; Land use etc.) directly in the FEM-Tool. A layout template for the factsheets is also planned and will be implemented into the tool. The automatic delineation process will also be further developed and improved to ensure the application in different rivers, in particular the rivers changing mostly towards Y coordinate such as at the Hungarian Danube, precisely calculated.

A further improvement on the automatic identification of the selection of the floodplain can be completed by implementing a logic that considers the changes of the coordinate system of the river along QgsPoint(Y) direction. This will improve the overall logic about distance computation between the centerline of the river and the inundation areas. In addition to that, non-linear regression models available in Python can also be considered as a further step to improve data acquisition and manipulation.

# 5. References

Danube Floodplain. D 3.2.1. Report on the evaluation of floodplains along the Danube River. Deliverable title: Priority list with potential preservation and restoration areas (based on FEM-tool); 2021a.

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

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

Danube Floodplain. D 4.2.3. Report on the assessment of biodiversity in the pilot areas including a database and maps of pilot areas' biodiversity and habitat modeling as input for 4.4.1 and part of output 4.1; 2020b.

Danube Floodplain. D 3.2.2. Report on data included within database; 2020c.

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# 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 [$m^3/s$] for the investigated floodplain. The retention effect of the river channel has to be considered as well. Therefore, the peak reduction $\Delta Q_{RC}$ 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 $\Delta Q_{RC}$ 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[1]. Concerning the hydrological input data of the tributaries, you have some options:

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

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 $HQ_{100}$, 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 $\Delta Q_{tot}$**

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 $\Delta Q_{tot}$ it is necessary to calculate the difference between the peak of the input and the output flood wave.

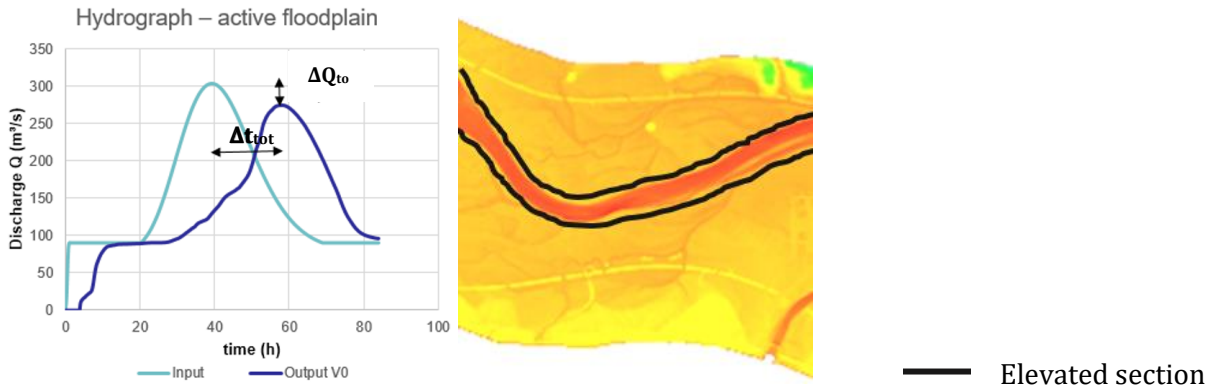



*Figure A 1: FEM-parameter flood peak reduction ΔQtot for active floodplains*

**Step 3: Calculating $\Delta Q_{RC}$ 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 $\Delta Q_{RC}$ (Figure A 2).

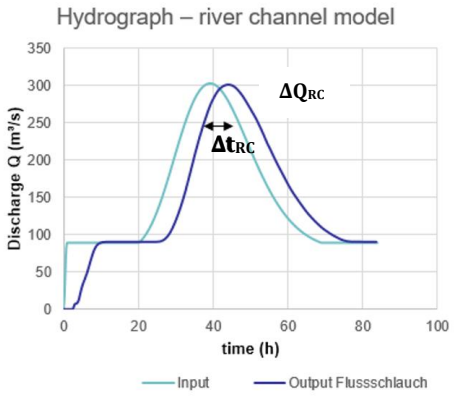



*Figure A 2: FEM-parameter flood peak reduction $\Delta Q_{RC}$ for the river channel*

**Step 4: Calculating ΔQ and $\Delta Q_{rel}$**

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

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

Additionally, the relative peak reduction $\Delta Q_{rel}$ [%] 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.

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

**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 $\Delta Q_{obs}$ (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 $\Delta Q_{obs}$, 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 $\Delta Q_{obs}$.

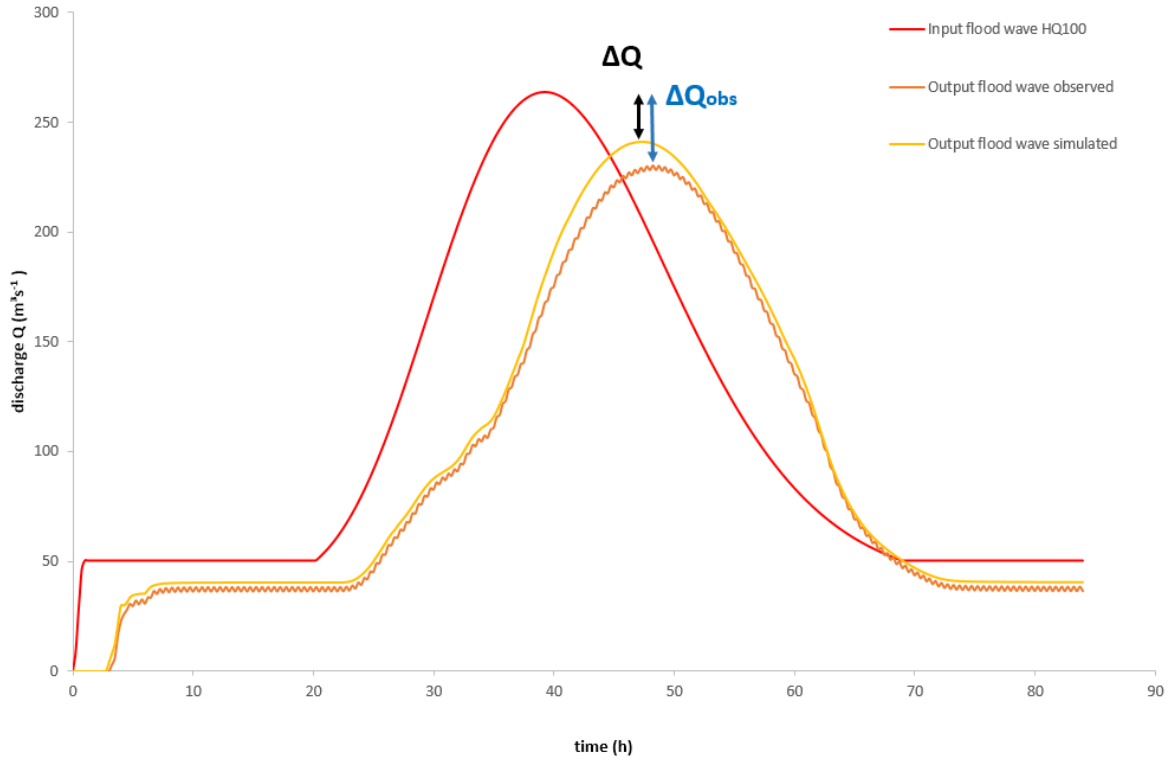
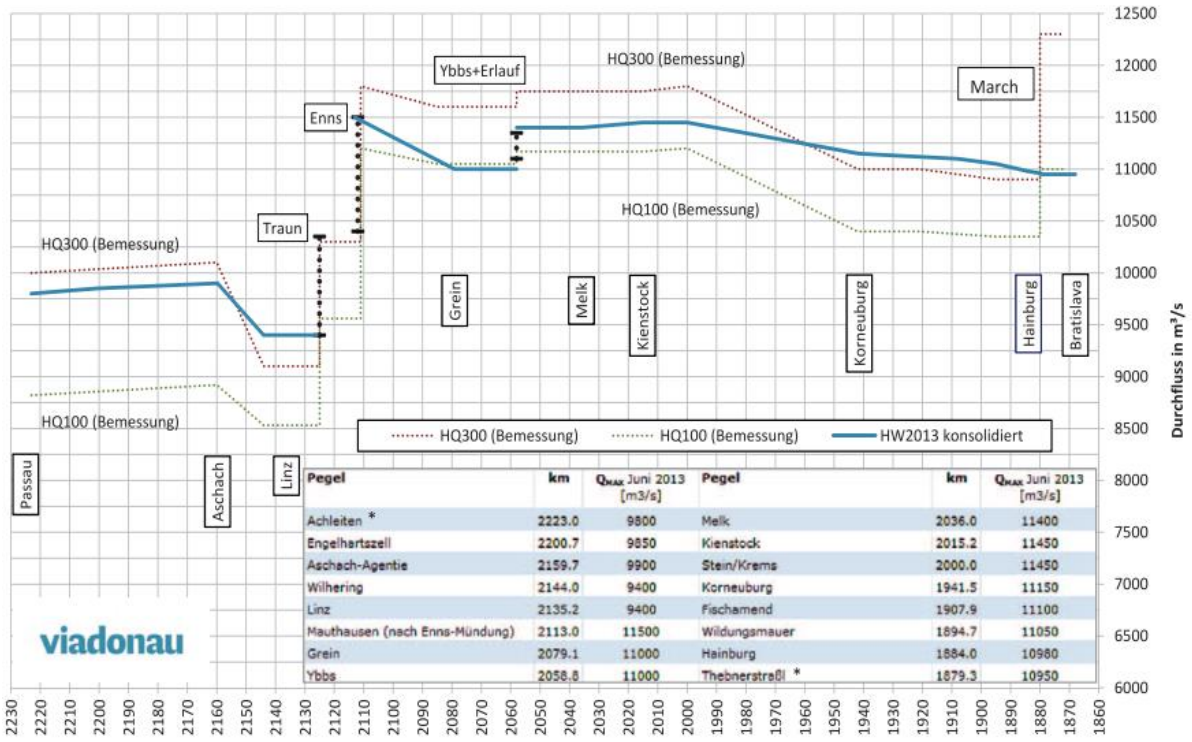



*Figure A 3:Comparison of the observed ΔQobs with the calculated ΔQ with the help of the observed and simulated output hydrographs*

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




| Pegel | km | $Q_{MAX}$ Juni 2013 [m3/s] | Pegel | km | $Q_{MAX}$ Juni 2013 [m3/s] |
|---|---|---|---|---|---|
| Achleiten * | 2223.0 | 9800 | Melk | 2036.0 | 11400 |
| Engelhartszell | 2200.7 | 9850 | Kienstock | 2015.2 | 11450 |
| Aschach-Agentie | 2159.7 | 9900 | Stein/Krems | 2000.0 | 11450 |
| Wilhering | 2144.0 | 9400 | Korneuburg | 1941.5 | 11150 |
| Linz | 2135.2 | 9400 | Fischamend | 1907.9 | 11100 |
| Mauthausen (nach Enns-Mündung) | 2113.0 | 11500 | Wildungsmauer | 1894.7 | 11050 |
| Grein | 2079.1 | 11000 | Hainburg | 1884.0 | 10980 |
| Ybbs | 2058.8 | 11000 | Thebnerstraßl * | 1879.3 | 10950 |

*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 $\Delta Q_{RC}$ of the river channel model is then subtracted.

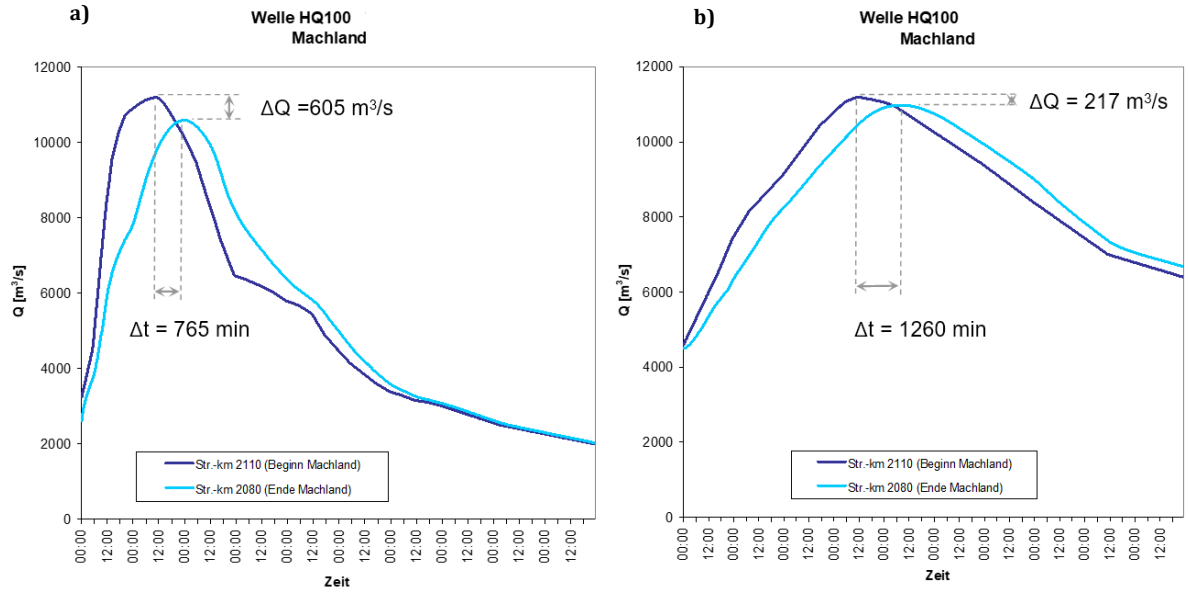



*Figure A 5: Flood peak reduction - example Austria (Machland)*

In the last step the $\Delta Q_{rel}$ was calculated by using the flood peak of the inflow wave (11.203 $m^3/s$).

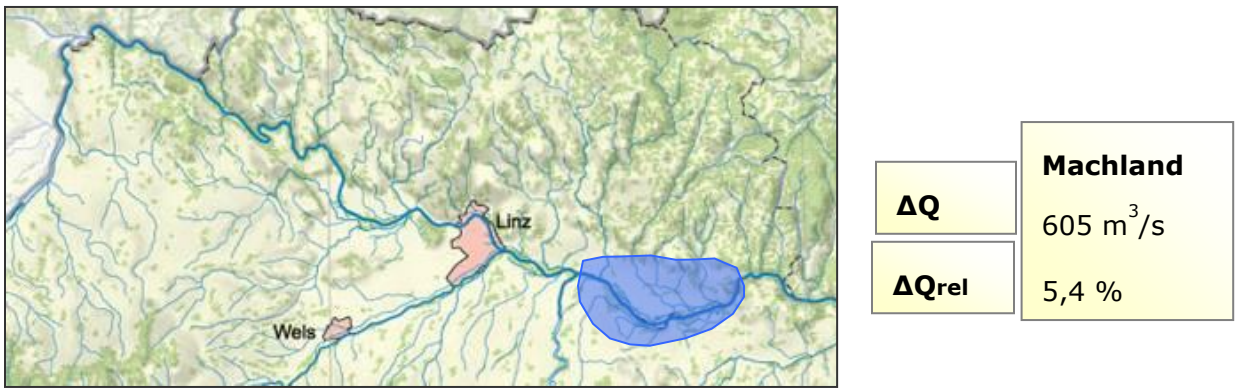



*Figure A 6: Flood peak reduction relative for a steep flood wave (2002) - example Austria (Machland)*

### 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 ($\Delta Q_{rel}$) 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 $\Delta t_{tot}$**

You can use the same output hydrograph for calculating the flood wave translation $\Delta t_{tot}$ 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 $\Delta t_{tot}$, it is necessary to determine the time when the peak of the flood waves (input/output) occur and calculate the difference between them.

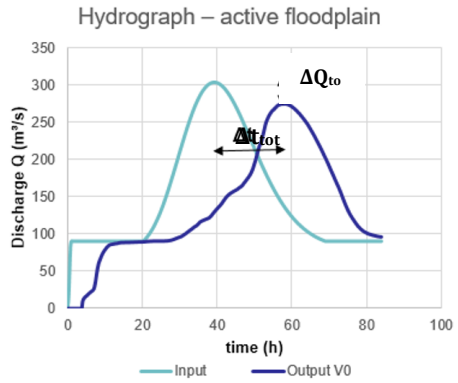



*Figure A 7: FEM-parameter flood wave translation $\Delta t_{tot}$ for active floodplains*

**Step 2: Calculating the $\Delta t_{RC}$ for the river channel**

You can use the output hydrograph from the modelling of $\Delta Q_{RC}$ for calculating the flood wave translation $\Delta t_{RC}$ for the river channel. In order to compute $\Delta t_{RC,}$ 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).

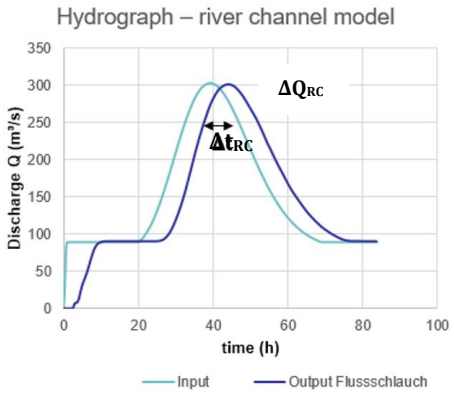



*Figure A 8: FEM-parameter flood wave translation $\Delta t_{RC}$ for the river channel*

**Step 3: Calculating Δt**

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

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

**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 $\Delta t_{obs}$, 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 $\Delta t_{obs}$, 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 $\Delta t_{obs}$ (Figure A 9).

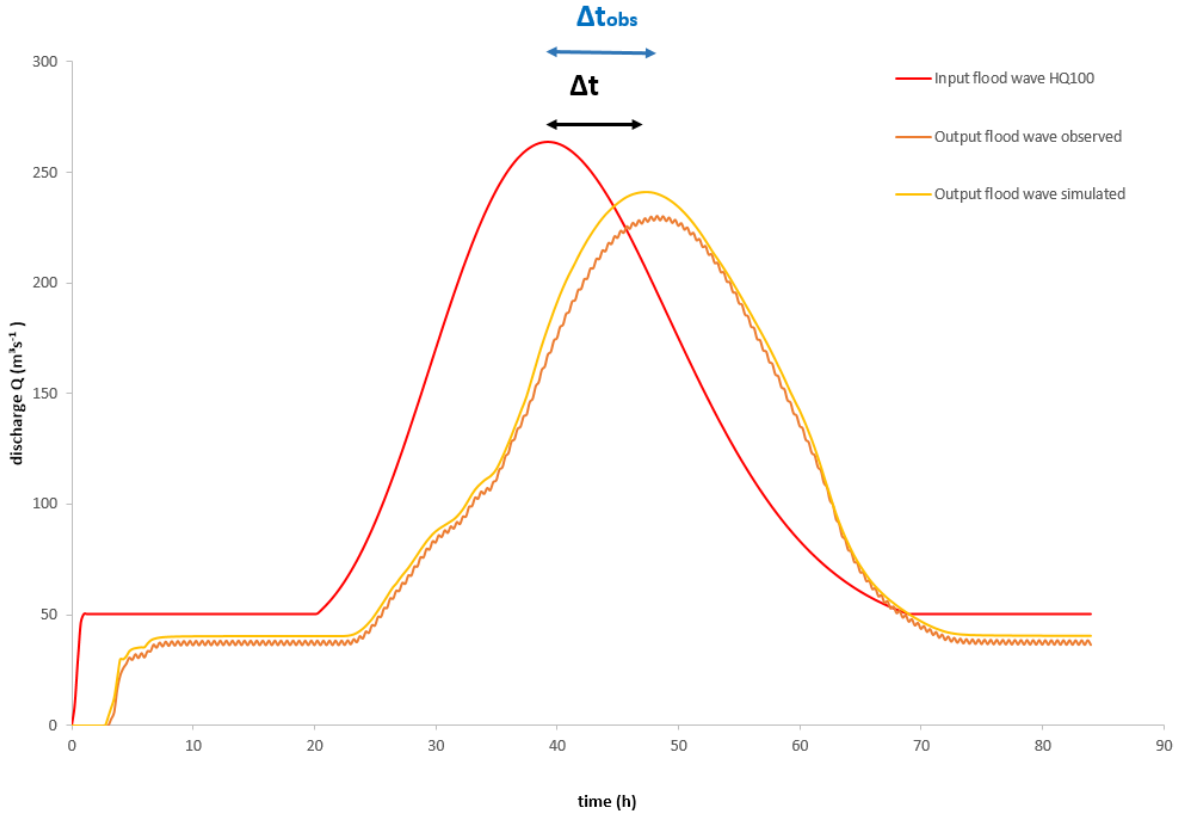



*Figure A 9: Comparison of the observed $\Delta t_{obs}$ with the calculated Δt with the help of the observed and simulated output hydrographs*

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 $\Delta t_{RC}$ of the river channel model is then subtracted (Figure A 10).

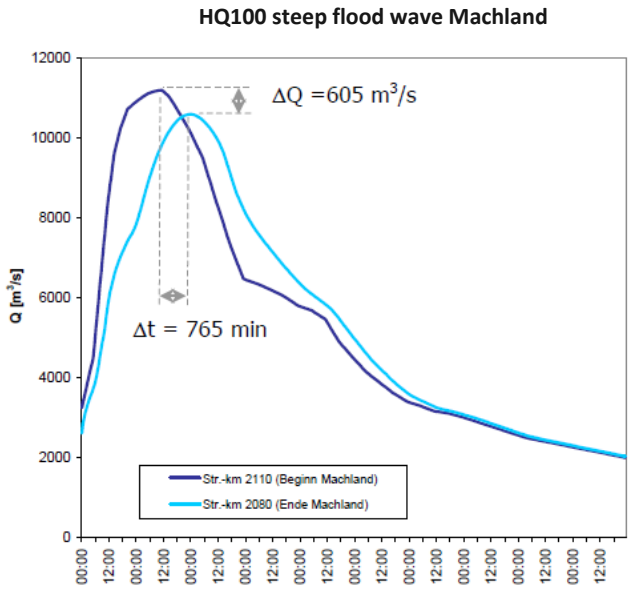



*Figure A 10: Flood wave translation - example Austria (Machland)*

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 |

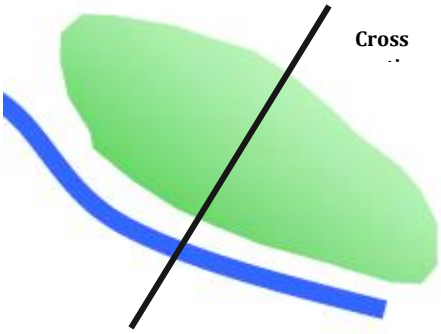
# 2. Hydraulics

## 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 $\Delta Q_{RC}$ and $\Delta t_{RC}$ 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 ($\Delta Q_{tot}$ and $\Delta t_{tot}$). 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 ($\Delta Q_{RC}$ and $\Delta t_{RC}$) 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.

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

### 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).

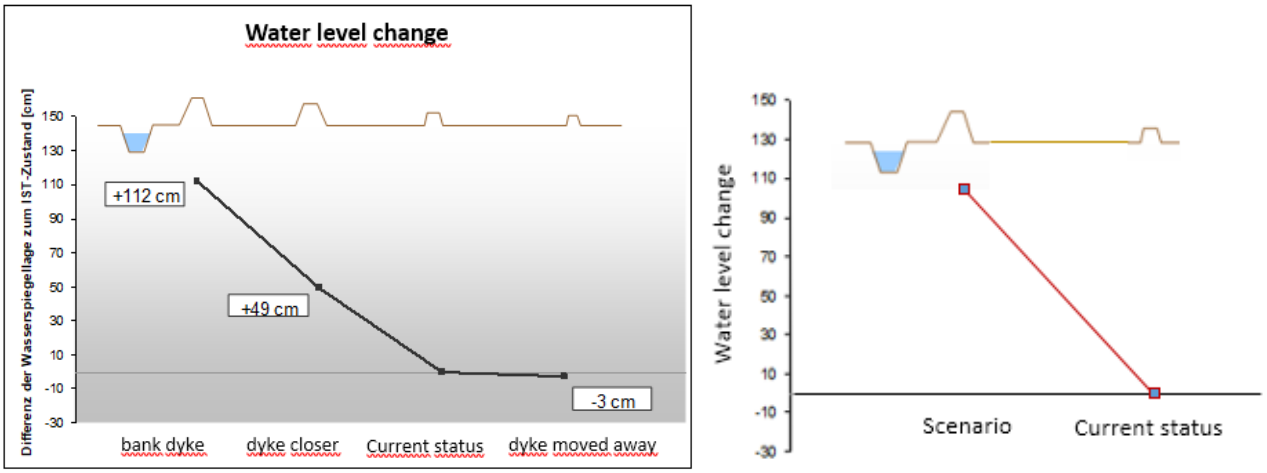



*Figure A 11: water level change - example Austria (Machland)*

### 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:

1. mean water level (from gauging stations)
2. bankfull flow (1D/2D modeling)
3. 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[2] 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"

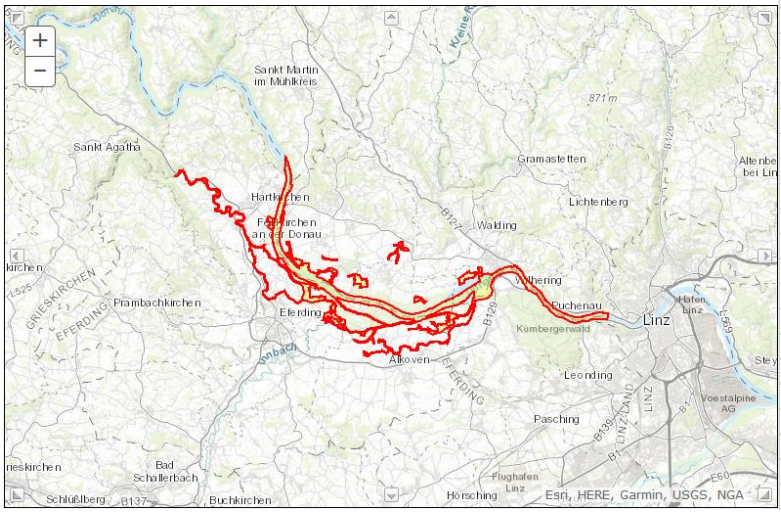
**Step 3: Summarizing all protected species**

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

[2] 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 $km^2$ large and there are 1044 buildings on the floodplain. After dividing the amount by the area, it gives 19.63 buildings/$km^2$.

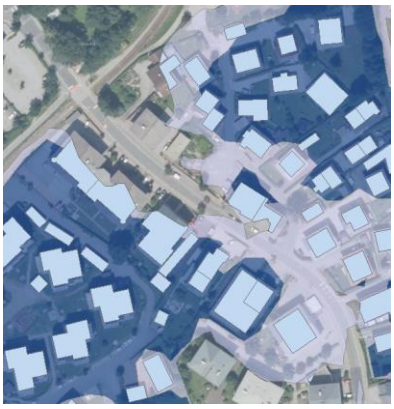


*Figure A 13: potentially affected buildings - example Austria (Feldbach)*

### 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).

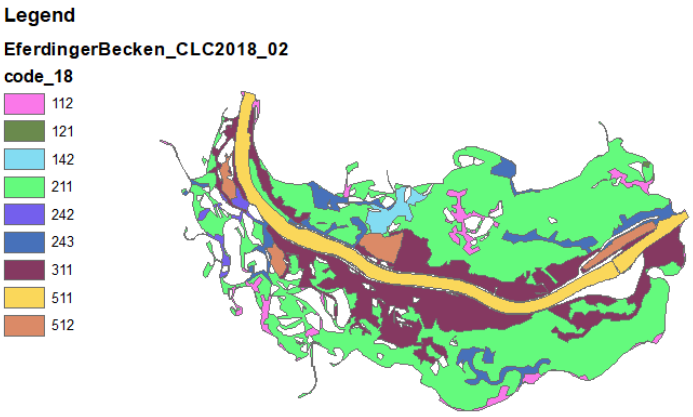



*Figure A 14: land use - example Austria (Eferdinger Becken)*

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 |

# Annex B – FEM-Handbook: additional parameters

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# 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 $HQ_{1000}$[3]. 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).

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

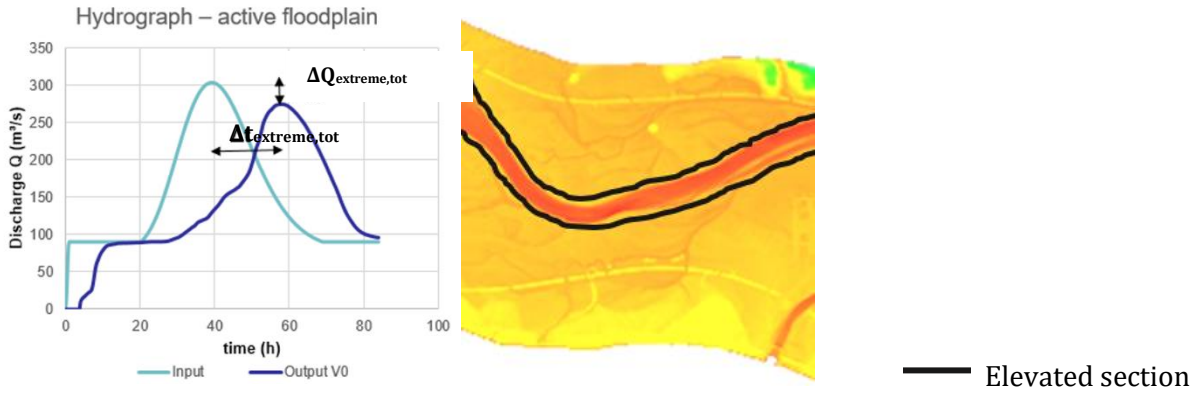



*Figure B 1: FEM-parameter flood peak reduction ΔQextreme,tot for active floodplains*

**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).

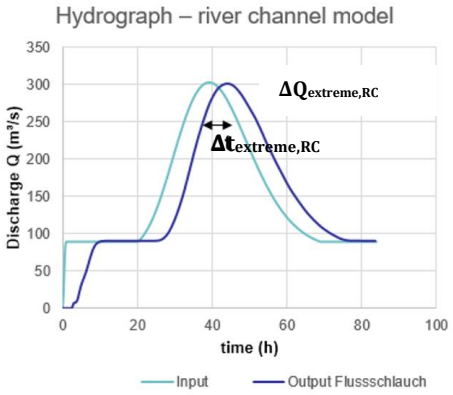



*Figure B 2: FEM-parameter flood peak reduction $\Delta Q_{extreme,RC}$ for the river channel*

**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 $\Delta Q$ 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).

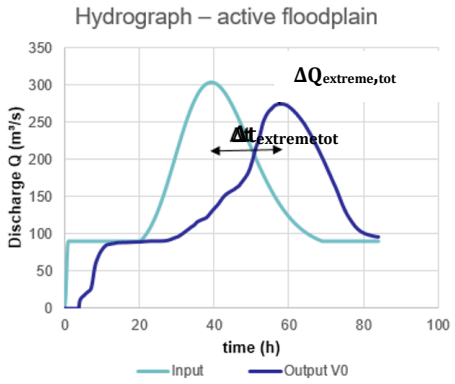



*Figure B 3: FEM-parameter flood wave translation $\Delta t_{extreme,tot}$ for active floodplains*

**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).

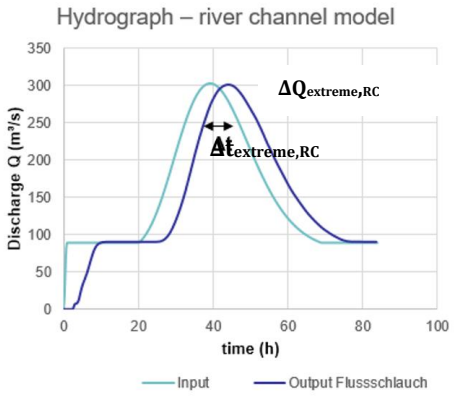



*Figure B 4: FEM-parameter flood wave translation $\Delta t_{extreme,RC}$ for the river channel*

**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 $\Delta Q_{rel}$ with $\Delta Q_{extreme,rel}$ and $\Delta t$ with $\Delta t_{extreme}$**

Now you calculate the relation between the $\Delta Q_{rel}$ 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 $\Delta t$ 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.

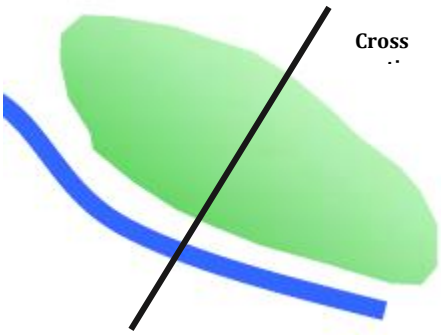
# 2. Hydraulics

## 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 $\Delta Q_{RC}$ and $\Delta t_{RC}$. 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 ($\Delta Q_{tot}$ and $\Delta t_{tot}$). 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 ($\Delta Q_{RC}$ and $\Delta t_{RC}$) 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).

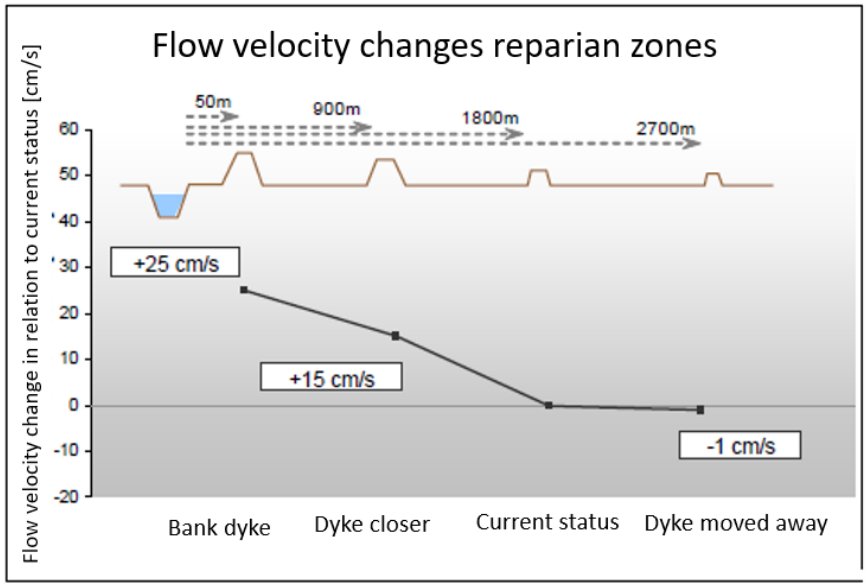



*Figure B 5: flow velocity change – example Austria (Machland)*

### 2.1.5 Thresholds

In **Fehler! Verweisquelle konnte nicht gefunden werden.**, 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 $\Delta Q_{RC}$ and $\Delta t_{RC}$ 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 ($\tau_{tot}$)**

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

**Step 2: Calculating bottom shear stress for a $HQ_{100}$ without floodplain ($\tau_{RC}$)**

In the next step, you use the same hydrodynamic-numerical calculation, which was used to determine the hydrological parameters ($\Delta Q_{RC}$ and $\Delta t_{RC}$) and you determine the calculated bottom shear stress ($\tau_{RC}$) 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 ($\tau_{RC}$) from the bottom shear stress ($\tau_{tot}$) with active floodplain. The bottom shear stress change Δτ demonstrates the increase of the bottom shear stress due to a loss of the floodplain.

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

### 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 $N/m^2$ (Figure B 6). In general, only one scenario has to be calculated where the floodplain is disconnected.

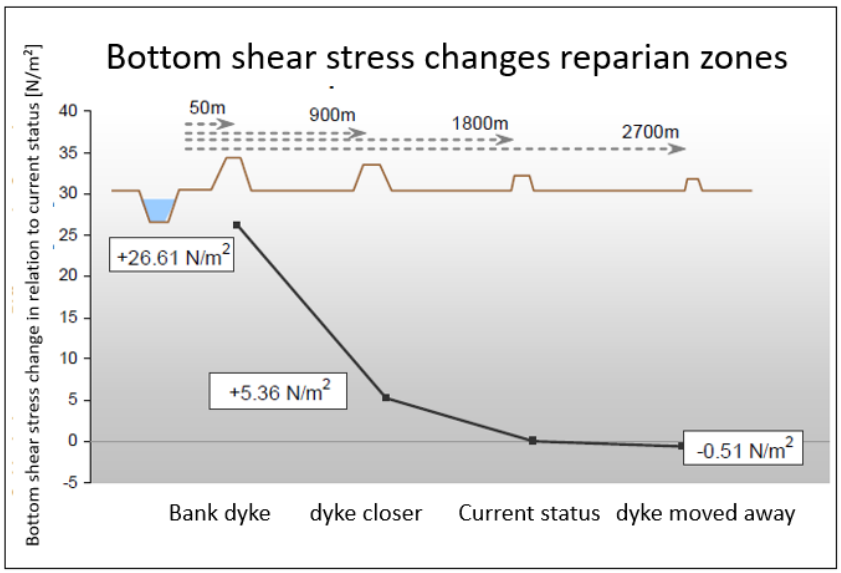



*Figure B 6: bottom shear stress change – example Austria (Machland)*

### 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 ($\Delta\tau$) is smaller than 1.5 N/m$^2$, the performance of the floodplain is low. Between 1.5-3 N/m$^2$, the performance is medium. All floodplains with a bottom shear stress change above 3 N/m$^2$ perform high.

*Table B 2: Thresholds to determine the performance of the bottom shear stress change $\Delta\tau$ in the FEM-Evaluation*

| Thresholds $\tau$ | |
|---|---|
| 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).

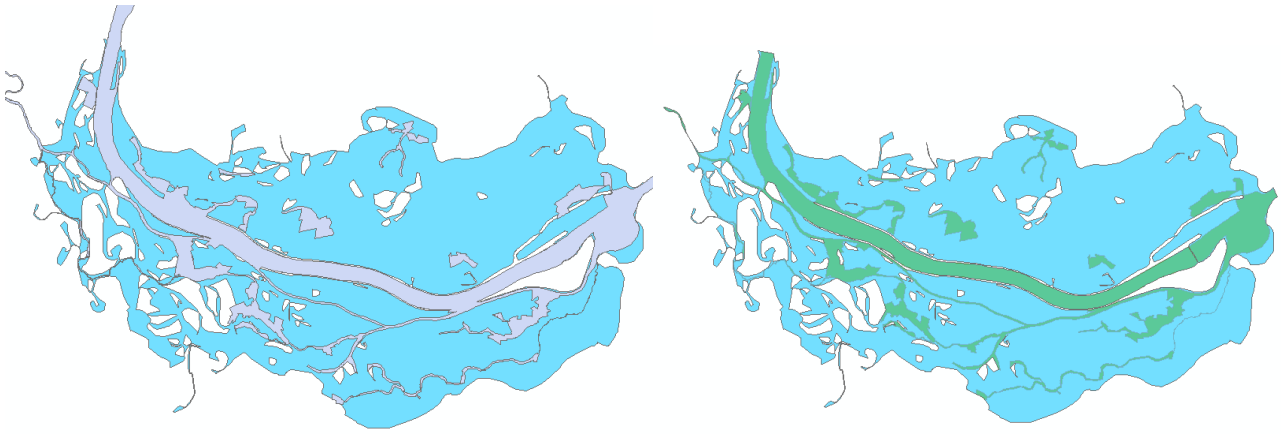


*Figure B 7: Natura 2000 area at Eferdinger Becken*

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).

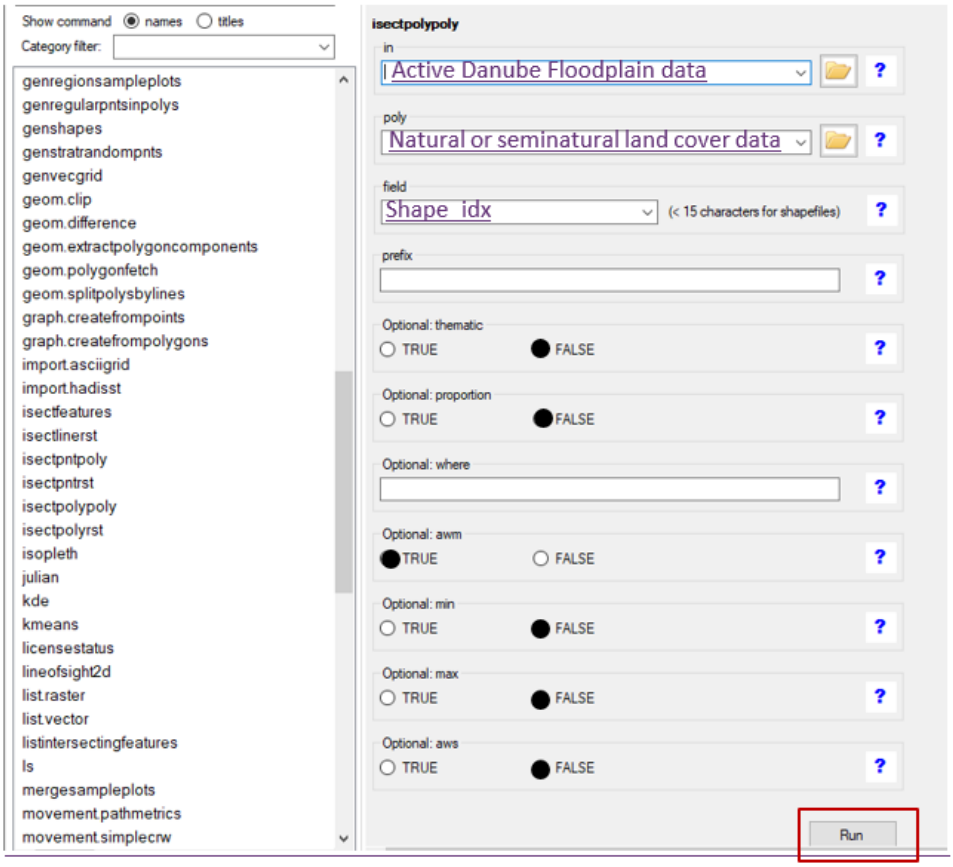



*Figure B 8: Input mask of the GIS tool to calculate the landscape metrics*

**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).

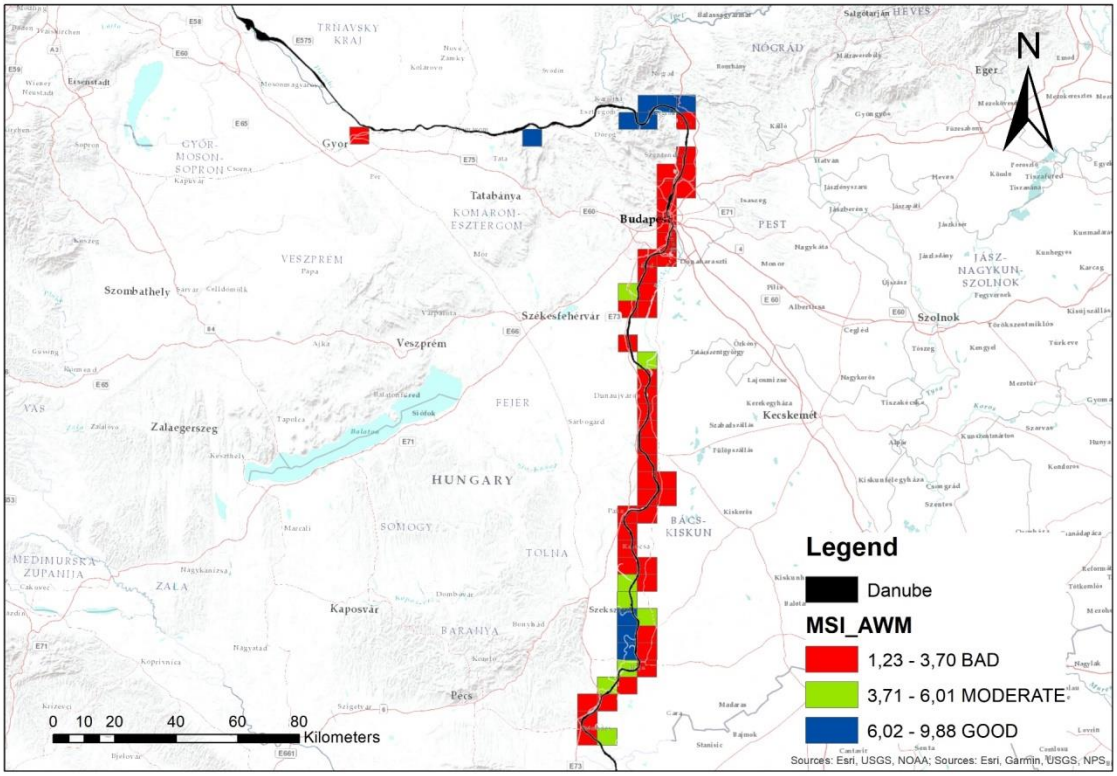



*Figure B 9: Vegetation naturalness - example Hungary*

### 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 o | 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 |

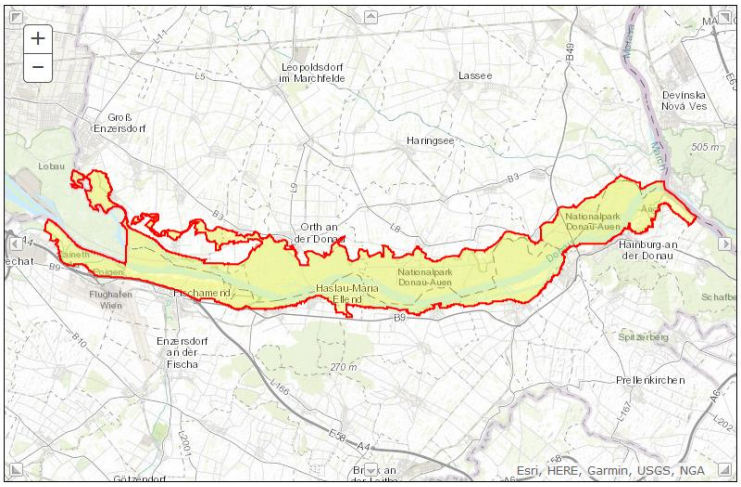



*Figure B 11: protected Habitat types - NP Donauauen*

### 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.

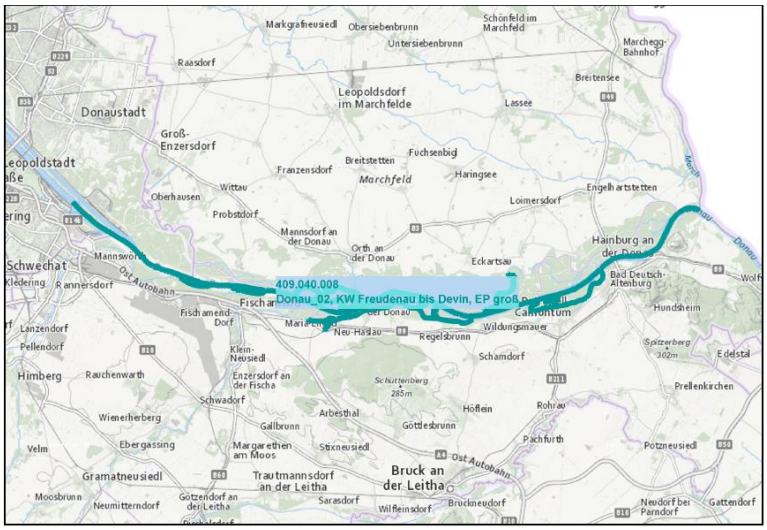
### 3.5.3 Workflow

**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 |

## 3.6 Invasive Species

### 3.6.1 Description

Any living organism can be invasive species that is not native to an ecosystem and causes harm, such as a plant, insect, fish, fungus, bacteria. They can have negative consequences for the biodiversity, the economy, flood risk and even human health. Invasive species are those that grow and reproduce quickly and spread aggressively. Knowing the extent of invasive infection is key issue to successful floodplain rehabilitation. There is freely available occurrence (point) data of invasive fauna and plants species which suitable to work with them in a GIS software like QGIS or ArcGIS. Richness and

Shannon Diversity Indices are good indicators to represent the density and species richness of invasive species inside active floodplain units.

### 3.6.2 Source

The fauna and plants datasets are available for the whole world on the gbif.org website. The freely downloadable data was collected by scientist and citizen scientist. https://www.gbif.org/

### 3.6.3 Workflow

**Step 1: Downloading and preparing fauna and plants datasets**

On gbif.org, the search by species and filter by countries is available. Date of field observation, location of occurrence with coordinates and validation status are available options. After all the options and filters (such as country and name of given invasive species) have been set go to the download tab and choose the Simple download option. It will be downloadable as a .csv file from this website: https://www.gbif.org/occurrence/search

To select the invasive species from the gbif database, we used the species lists from the following publications:

*Paunović, Momir ; Csányi, Béla ; Stanković, Igor & Wolfram, Graf & Leitner, Patrick & V, Bammer & Huber, Thomas & Szekeres, József & Borza, Péter. (2015). In book: Joint Danube Survey 3 – Chapter: Invasive Species - A Comprehensive Analyses of Danube Water QualityChapter: Invasive SpeciesPublisher: The International Commission for the Protection of the Danube River, ViennaEditors: Liška I., Wagner F., Sengl M., Deutsch K., Slobodník J.*

this chapter is downloadable from this website:
https://www.researchgate.net/publication/284168907_Invasive_Species

**Step 2: Open the downloaded datasets in GIS environment**

After downloading the geotagged spatial attribute .csv files of all invasive species, open the .csv files in ArcMap desktop. Go to the Catalog menu and select one of the .csv file, right click on it and select the Create feature class tab -> From XY table. Here, set the columns which contain the X and Y coordinates (set the WGS 1984 coordinate below) and save the point based shape file. Repeat this method with all of the downloaded dataset.

Also open the polygon shape file which contains the active Danube floodplain units.

**Step 3: 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:

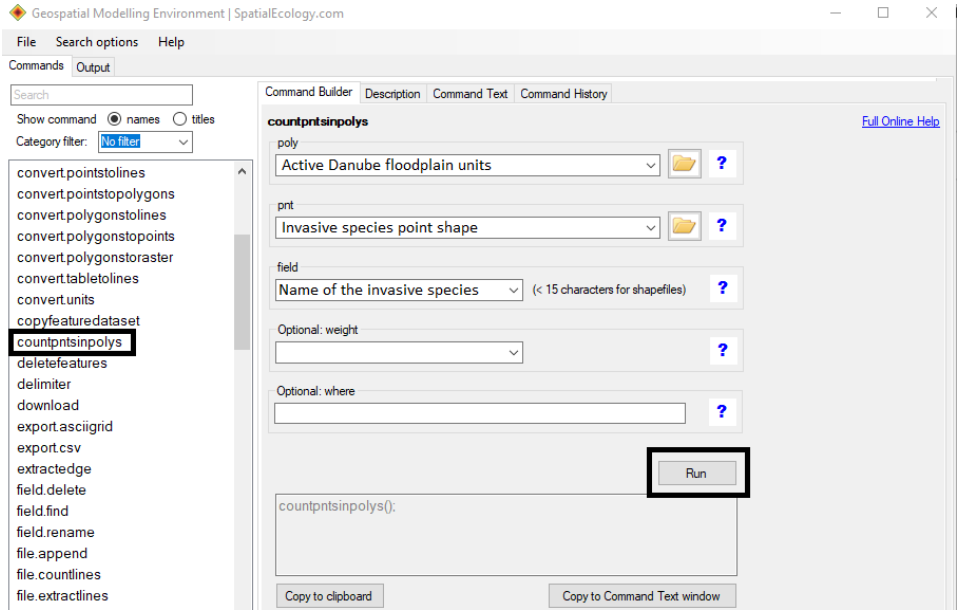
http://www.spatialecology.com/gme/images/SpatialEcologyGME.pdf

**Step 4: Count the species occurrence points inside the active Danube floodplain units**

Open the Geospatial Modelling Environment (GME). In the command list (left side) choose the *countpntsinpolys* command. It counts the number of points that overlap each polygon, and writes the result to a field in the polygon attribute table.

Set the *poly* as the active floodplain units' shape, *pnt* filed as the invasive species point shape and to the *field* write the name of the invasive species. Click on Run!

Repeat this step for all invasive species point shape.




**Step 5: Calculate the diversity indices inside Active Danube floodplain units**

Open the Danube floodplain shape file's attribute table in ArcMap, all of the species have an own column. In the attribute table top-left corner select the *Table options* and click on the *Export* tab. Export our table as an dBase table. Open this table in Microsoft Excel. Download the following Excel add-in: http://www.geo.u-szeged.hu/~toto/Excel_Diversity_add-in/. Double click on the add-in file, it installs new functions to our MS Excel.

Create new columns in the Excel for the species diversity indices, SDI (Shannon Diversity Index) and RI (Richness Index). In Excel, top menu bar, click on *Formulas* and *Insert function* tab and select the *User defined* category. Find and click on the Numspec (Number of species) function, set the range, which is the all invasive species columns at the first floodplain unit. Do the same method with the *Shannon* (Shannon's diversity index) function. This Excel add-in offer more diversity functions like Shannon Evenness Index, Simpson's diversity index and etc. Save the file as .csv file.

**Step 6: Join the calculated diversity indices back to the floodplain units**

Go back to the ArcMap and right click on the floodplain units' shape file, choose the *Join and Relates* tab than *Join*. In the 1. point choose the DFGIS_ID field, in the 2. point select the .csv file, which contains the diversity indices. In the 3. point select the DFGIS_ID field. Click OK!

Now, the invasive species diversity indices are available in the Active Danube floodplain shape's attribute table.

**Step 7: Visualisation of the results**

Open the Layer properties of the Danube floodplain shape file, go to the *Symbology* tab and select the *Quantities* on the left. Select the SDI at the *Value* field and set 5 classes. Click on the *Classify* and set the *Natural breaks (Jenks)*. Set a green to red colour ramp and click OK!

Put a base map under this layer if necessary and design the map in Layout view.

### 3.6.4 Example

USZ collected 42 invasive species occurrence data through the Danube river inside the active floodplain units. Based on these datasets, Shannon Diversity and Richness Index were calculated inside each floodplain polygon. The indices were analysed separately by non-native plants, macroinvertebrates and fishes.

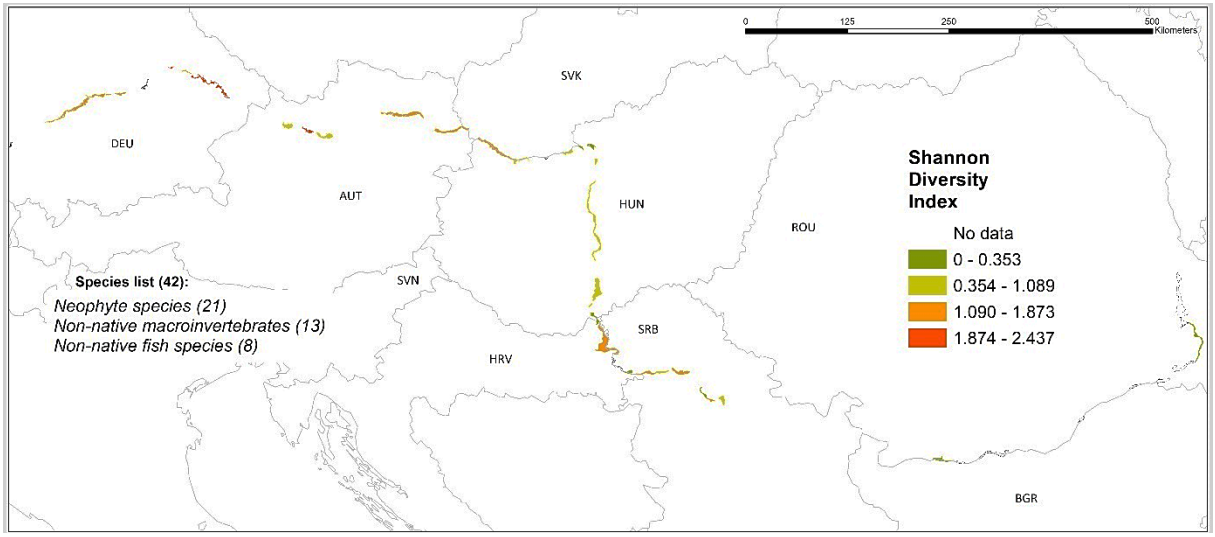



*Figure B 133: Shannon Diversity Index of invasive species through the Danube River*

### 3.6.5 Thresholds

We calculated the category thresholds of the SDI values based on the whole active floodplains of the Danube River. In case the smaller and other study areas (especially the tributaries of Danube) these

classification is not adaptable, but the Natural break based classification is useful tool to make three categories.

In Table B 8, the thresholds are shown, which are used to determine the performance of the floodplain for the parameter of invasive plant species infection. If the Shannon Diversity Index of invasive species is smaller than 0.353, the infection of the floodplain with invasive species is low. Between 0.354-1.873, the infection is medium. All active floodplains with a Shannon Diversity Index above 1.874 show high infection of invasive species.

*Table B 8: Thresholds to determine invasive species infection in the FEM-Evaluation*

| Thresholds Invasive Species | |
|---|---|
| 1 | >1.874 |
| 3 | 0.354-1.873 |
| 5 | <0.353 |

# 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