The Danube River Basin Floodplain Restoration and Preservation Manual

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Danube Floodplain

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Authors:
F. Perosa[1], M. Disse[1], V. Zwirglmaier[1], M. Gelhaus[2], F. Betz[2], B. Cyffka[2]
H. Habersack[3], M. Eder[3]
M. Comaj[4], D. Vesely[4]
K. Mravcova[5], M. Studeny[5],
J. Krajčič[6], M. Jarnjak[6], L. Gosar[6]
B. van Leeuwen[7], Z. Tobak[7], D. Vizi[8], T. Pravetz[8], A. Samu[9], T. Gruber[9],
D. Ninković[10], M. Marjanović[10], N. Stošić[10], Ll. Marjanović[10], L. Galambos[10], T. Bošnjak[10],
C. Ionescu[11], A. Galie[12], Roman A.[13], E. Tuchiu[14], C. Rusu[14], P. Mazilu[14], S. Rindasu[14]

Affiliations:
[1]Technical University of Munich, [2]Catholic University of Eichstätt-Ingolstadt
[3]University of Natural Resources and Life Sciences, Vienna
[4]Morava River Basin Agency
[5]Water Research Institute
[6]Slovenian Water Agency
[7]University of Szeged, [8]Middle-Tisza District Water Directorate, [9]WWF Hungary
[10]Jaroslav Černi Water Institute
[11]WWF Romania, [12]National Institute of Hydrology and Water Management, [13]Ministry of Environment, Waters and Forests, [14]National Administration "Romanian Waters"

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Part A – Introduction and background

A.1. Introduction

Why floods are important?

Floods can cause damages and loss of life, significant economic and social costs, can affect environment and cultural assets. The last decades show that severe floods have become more and more frequent in Europe, especially in the Danube River Basin.

However, floods are natural events and high probability floods could provide positive effects on the ecosystems. They supply floodplains and connected wetlands with water, ensuring fish reproduction, nutrient reduction and contributing to groundwater recharge. The combination of flooding with compatible land use leads to a range of positive effects for the well–being of the society.

In response to the increasing occurrence of floods, at the level of European Union the Directive 2007/60/EC on the assessment and management of flood risks (FD[1]) was adopted in 2007, establishing through Flood Risk Management Plans (FRMPs), a framework for flood prevention, protection and preparedness (including forecasting) at European level.

Article 7 of the Floods Directive (chapter IV -Flood Risk Management Plans), stipulates that *"Flood risk management plans shall take into account relevant aspects such as costs and benefits, flood extent and flood conveyance routes and areas which have the potential to retain flood water, such as natural floodplains, the environmental objectives of Article 4 of Directive 2000/60/EC, soil and water management, spatial planning, land use, nature conservation, navigation and port infrastructure".*

Why water status is important?

Europe's waters are affected by nutrient, organic and chemical pollution as well as by hydromorphological pressures/alterations including the flood protection infrastructure. The Water Framework Directive 2000/60/EC[2] (WFD) introduces the River Basin Management Plan (RBMP) as a key implementation tool, having as main objective the achievement of good status[3] by 2015 for surface water bodies and groundwater bodies.

[1] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32007L0060&from=EN
[2] https://eur-lex.europa.eu/resource.html?uri=cellar:5c835afb-2ec6-4577-bdf8-756d3d694eeb.0004.02/DOC_1&format=PDF
[3] Note: good status/good potential for surface water body means the status achieved when both its ecological status/ecological potential and its chemical status are at least "good"; good groundwater status means the status achieved by a groundwater body when both its quantitative status and its chemical status are at least good.

Under Article 4, the Directive also allows exemptions for time extensions (till 2027- Article 4.4) as well as less stringent environmental objectives (Article 4.5) regarding the water status under certain conditions. Temporary deterioration of the status in case of natural causes or "major forces" which are exceptional or could not reasonably have been foreseen, in particular extreme floods and prolonged droughts, is allowed as well, through the Article. 4.6. Article 4.7 clearly defines the terms of failing the environmental objectives as the result of new modifications to the physical characteristics of a surface water body.

The environmental objectives applicable to water bodies established under WFD Article 4 should be taken into account in the FRMPs as the relevant aspects as required by Article 7 of FD, enforcing the interlinkages between WFD and FD and their compliance.

Why the integration between the WFD and the FD is important?

The integration between the WFD and the FD offers the opportunity to optimize the mutual synergies and minimize potential conflicts between them, being required by Article 9 of Flood Directive that *appropriate steps shall be taken at the level of Member States in order to coordinate the application of both Directives,* focusing on opportunities for improving efficiency, information exchange and for achieving common synergies and benefits having regard to the environmental objectives of WFD laid down in Article 4 of Directive 2000/60/EC.

The conservation and the restoration of the natural functions of wetlands and floodplains, with their ability to retain floodwaters and reduce the flood pulse, allow important opportunities for synergies with WFD implementation from a water status prospective. Also, the coordination of measures under FD, especially ones regarding the new infrastructure projects, with the environmental objectives of the Water Framework Directive, is an essential issue in the integration process.

Why floodplains are important?

The floodplains are natural land-areas alongside the river course which are being flooded regularly - in case of high river flow exceeding the river bed capacity. Providing additional space for the increased water flow, floodplains accommodate the flood-waters, reducing the flood peaks and slowing the flow velocity and this way reduce the flood risk downstream. Besides their function as a natural flood protection, the floodplains provide additional important environmental benefits. Slowing the flow velocity, they facilitate the deposition and absorption of sediments, nutrients and other pollution, improving of the water quality. The river-water temporary stored in the floodplains during the flood's periods recharges the groundwater aquifers, regulating the availability of water during drier periods. The natural floodplains play important role for the wildlife and plants. They are rich and biologically diverse environments, which provide favorable habitat conditions and support an abundance of plants, birds, fish, and other species. The floodplains are valuable natural systems, providing multiple environmental and social benefits and their preservation is essential for ensuring the synergy between the objectives of the FD, WFD and BHD.

The understanding of the functions and importance of the floodplains is at the heart of the concept of the Danube floodplain project, which aims to reduce flood risk through floodplain restoration along the Danube River and its tributaries. The main objective of the project is improving transnational water management and flood risk prevention as required by the Floods Directive while maximizing benefits for biodiversity conservation in line with the WFD and BHD objectives.

Why a Danube Floodplain Manual?

During the last decades, Europe suffered major catastrophic floods along the Danube. Major flood events in the Danube River Basin of the recent past occurred in 2002, 2005, 2006, 2009, 2010, 2013 and 2014.

In 2006, for example, a major flood event occurred simultaneously on the Tisza, Sava and Velika Morava. *The flooding stretched from the Morava mouth to the southern tip of the Csepel Island in Hungary, downstream of the Tisza mouth in Serbia and along the whole Romanian section of the Danube where highest historical flows and water levels were recorded. The extent of flooding in Romania was the largest in the last hundred years.*[4]

In 2013 major flood events have been registered almost simultaneously in Germany, Austria, Slovakia, Hungary, Croatia, Serbia, Romania and Bulgaria. The return periods corresponding to the measured flood discharges reached 100 years in most Danube countries, but several gauging stations registered 200 even 500 years[5].

Therefore, coordinated measures to reduce flood risk, improving transnational water management and flood risk prevention are imperative. The traditional "way" like grey solutions (dykes, and regulation of river stretches) maybe still necessary, especially in urban areas, or in combination with green infrastructure. But restoring floodplains has multiple benefits, as flood protection measure gives rivers more room to respond to large floods bringing benefits such as maintaining and improving ecology and biodiversity, surface water quality, recreation options and fish and wildlife habitat protection, and contribute to drought mitigation as well.

As a main output of the project, the Danube Floodplain Manual addresses practitioners showing the technical details of key restoration approaches, potential win-win measures to mitigate flood risk through floodplain restoration and conservation actions, but also steps on how to plan and

[4] Flood Risk Management Plan for the Danube River Basin District
[5] Floods in June 2013 in the Danube River Basin
https://www.icpdr.org/main/sites/default/files/nodes/documents/icpdr_floods-report-web_0.pdf

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implement future restoration projects, how to solve potential conflicts in an integrated way and how to involve and engage key stakeholders.

There are a significant number of publications, reports, research studies and websites related to floodplain restoration. The Danube Floodplain Manual's purpose is to comprise the results of the project contributing to the knowledge improvement among the countries located within the Danube River Basin, leading to integrative water management including floodplain restoration. These results were obtained through a broad participative process, with all relevant stakeholders such as representatives from local administrations, water and flood risk management, NGOs and the scientific community.

A.2. Legal background information

A.2.1 Floods Directive and floodplain restoration/preservation

Flood risk management represents the application of policies, procedures and practices aimed at identifying risks, analysing and evaluating those risks in order to reduce them, so that human communities can live, work and satisfy needs and aspirations in a sustainable physical and social environment.

Flood risk management includes (inter alia) planning and implementation of different types of measures (preventive measures and actions before the occurrence of the phenomenon, operational measures during the floods and restoration measures carried out after the flood event).

The main objective of the FD is the assessment and the management of flood risks.

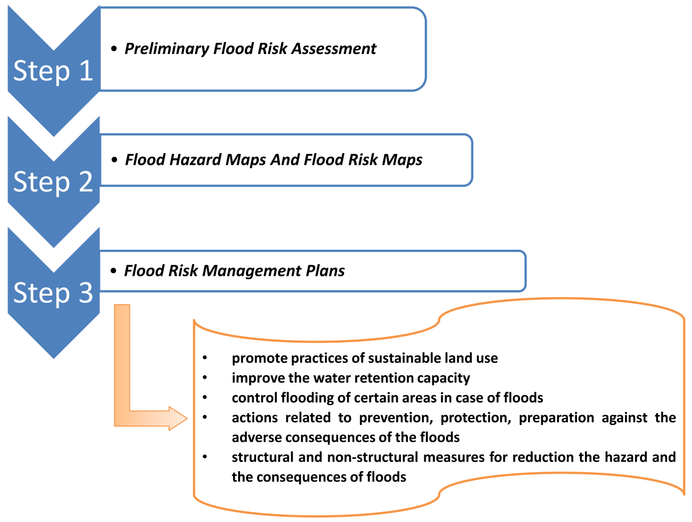

Figure 1 - Steps on flood risk management

The aim is to reduce the risk of (adverse) consequences for human health and life, ecology, cultural heritage and economic activities. The implementation is done in planning cycles. Three steps comprise the process of flood risk management: preliminary flood risk assessment, flood hazard and flood risk maps and FRMP *(Figure 1)*

Step 1. Preliminary Flood Risk Assessment

The *preliminary flood risk assessment* involves the identification at national level of the significant historical floods (especially from the point of view of the recorded damage, but also from the point of view of the hazard) and the delimitation of the areas with potentially significant flood risk.

The main stages for the elaboration of *preliminary flood risk assessment* are the followings:

- Collecting information regarding historical floods namely identifying historical events and selecting significant events. In this regard, an inventory of major floods that have appeared in the past has been made, based on information gathered from different sources. This inventory identifies significant floods, either from a hazard or impact point of view (recorded damage);
- Mapping the areas affected by historical floods (using GIS), carried out at the river basin authority;
- Identification of areas with potentially significant flood risk.

Step 2. Flood Hazard Maps and Flood Risk Maps

Flood hazard maps provide information about water depth, extent of flooded areas and, as the case may be, water velocity, for floods that can occur over a certain period of time (for example: once every 1000 years, every 100 years, every 10 years). The elaboration of these type of maps is made using different techniques, such as hydrological and hydraulic modelling, based on a detailed mapping of the river and the floodplain. They are generally used to indicate areas of land or properties that may be flooded in case of events with a certain return period.

Flood risk maps are developed based on flood hazard maps, analysing the data on the elements exposed to the hazard and their vulnerability. These indicate the potential negative effects associated with the flood scenarios according to: population, economic activity, environment and cultural heritage.

Step 3. Flood Risk Management Plans

Flood Risk Management Plans are prepared for all areas identified with potentially significant flood risk and for which hazard and flood risk maps have been developed.

Thus, flood risk management objectives are set, focusing on reducing the potential negative effects of floods on human health, economic activity, the environment and cultural heritage.

Flood risk management plans should:

- promote practices of sustainable land use;
- improve the water retention capacity;
- flood control of certain areas in case of floods;
- actions related to prevention, protection, preparation against the adverse consequences of the floods;
- structural and non-structural measures for reduction the hazard and the consequences of floods.

Floods Directive promotes natural water retention measures, especially when these are a viable alternative to more classic, grey measures.

A.2.2 Water Framework Directive and floodplain restoration and preservation Floodplains and environmental objectives of WFD

The areas next to rivers, which are only covered by water during floods, are also part of the river system. Known as floodplains, in their natural condition they secure flood protection and are an important ecological part of this system they filter and store water, secure the healthy functioning of river ecosystems, and help sustain the high biological diversity present there[6].

Man-made structures built for various water uses (e.g., flood protection, navigation, hydropower generation) generate hydromorphological pressures which might generate the alteration of river hydrology and river morphology, having an impact on the aquatic fauna and flora and can henceforth impact the water status.

For the surface waters, WFD sets the environmental objective of Good water status to be achieved till 2015 and preventing further deterioration.

From the perspective of the coordination between WFD and FD, it has to be emphasized that the environmental objectives applicable to water bodies established under WFD Article 4, should been taken into account in the FRMPs as the relevant aspects as it is required by Article 7 of FD, enforcing in this way the interlinkages between WFD and FD.

In relation to ecological status classification of water bodies, the hydromorphological quality elements provided in the WFD are represented by: hydrological regime, river continuity and morphological conditions.

Even if the term „floodplain” is not explicitly mentioned in the WFD, Annex V includes as it was previously mentioned, **the river continuity** in the list of hydromorphological quality elements supporting the biological elements. River continuity incorporates **lateral connectivity** of rivers which refers to the connection of river with its floodplain, but also longitudinal connectivity and the river connection to ground water bodies *(Figure 2).*

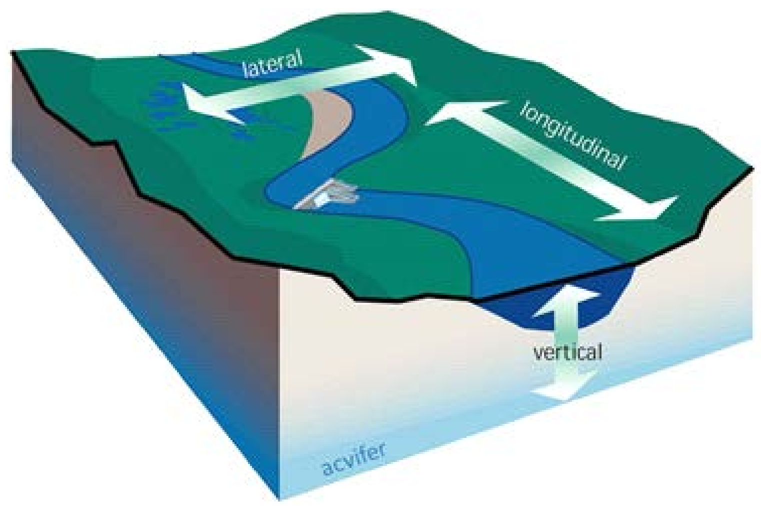

Figure 2 - The three dimensions of river Continuity
(source: https://www.therrc.co.uk/why-restore)

[6] Adapted from https://www.eea.europa.eu/themes/water/european-waters/why-should-we-care-about-floodplains

In some cases, as a result of the alterations of hydromorphological characteristics, including ones referring to the lateral connectivity, a surface water body (WB) may be designated as heavily modified or artificial water body according to the provisions of Article 4.3 of WFD. When these alterations are not significant/do not lead to the substantial changes in the character of a water body[7], those water bodies are classified as natural WBs/non-heavily modified water bodies.
In terms of ecological status, the river and floodplain connectivity are reflected in the assessment status of the hydromorphological quality elements (QEs) for high status and in relevant biological quality elements' (BQEs) ecological status. In the case of good, moderate, poor or bad ecological status/potential classes, the river and floodplain connectivity alteration should be reflected in relevant BQEs ecological status[8].

Also, there might be cases, where for the conservation status of water-dependent habitats and species protected under the Birds and Habitats Directives, the flow requirements in natural water bodies are different or go beyond the one required for the achievement of Good Ecological Status or maintenance of High Ecological Status and therefore should be considered as additional objectives[9].

In the context of the RBMPs under the WFD, a specific key type of measures refers to natural water retention measures. This key type of measure has been reported for addressing significant hydromorphological pressures in about one-third of the Member States[10]. More details on these types of measures are provided in Chapter Catalogue of *"win-win" restoration and preservation measures for reaching flood protection, environmental and biodiversity objectives.*

A.2.3. Nature Protection Directives: Habitats Directive 92/43/EEC and Birds Directive 2009/147/EC and floodplain restoration and preservation

The European Union has been committed to the protection of nature since the adoption of the Birds Directive in 1979[11], which provides comprehensive protection to all wild bird species naturally occurring in the European Union area.

The Habitats Directive[12] was adopted in 1992 to help maintain biodiversity. It protects over 1000 animals and plant species and over 200 types of habitat. It also established the EU-wide Natura 2000 network of protected areas.

[7] Note: the water body can meet the "good ecological status" (GES)
[8] Common Implementation Strategy (CIS) Guidance Document No. 13
[9] Common Implementation Strategy (CIS), Guidance document No. 31
[10] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52015SC0050&from=EN
[11] DIRECTIVE 2009/147/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL
[12] COUNCIL DIRECTIVE 92 /43 /EEC of 21 May 1992; https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31992L0043&from=EN on the conservation of natural habitats and of wild fauna and flora

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Both Directives represent the central tool for bringing protected species and habitats into a favorable conservation status besides other existing tool.

"Floodplains have an important role in flood risk management, by modifying the river discharge and protecting societies and economic activities from damage. Floodplains are also very heterogeneous habitats that create favorable conditions for many species and thus have a high environmental value. Under natural conditions, floodplains can contain a wide range of freshwater ecosystems, including permanently flowing and temporal channels, oxbow lakes, spring brooks, tributaries and temporary wetlands, being found along a gradient of decreasing hydrological connectivity from permanent to temporary links with the main bed of the river."[13]

Therefore, considering the terms of Nature Protection Directives, **floodplain restoration** and **preservation** address to multiple benefits related to **habitats and species:** create aquatic, riparian and terrestrial habitats; - fish stocks (better management); biodiversity preservation and prevention of biodiversity loss; protection of important habitats (community habitats, priority habitats)[14].

What conservation status means?

According to Habitats Directive provisions, **conservation** *means a series of measures required to maintain or restore the natural habitats and the populations of species of wild fauna and flora at a favorable* ***status* (…).**

Conservation status of a natural habitat *means the sum of the influences acting on a natural habitat and its typical species that may affect its long-term natural distribution, structure and functions as well as the long-term survival of its typical species* (Habitat Directive, *Art.1*).

The **increase of the floodplain area** is for sure one of the milestones on European Union **policies,** considering the implementation process of Birds and Habitat Directives, policy needs being as follows[15]:

- **increased area of natural floodplains** is likely to improve **conservation status** assessments of **listed habitats and species.**
- floodplains are highly **valuable habitats** and form an important part of the Natura 2000 network. Several Habitats Directive Annex I habitat types and Annex II species types are found on natural **floodplains,** as are many birds covered by the Birds Directive.

[13] Flood risks and environmental vulnerability-EEA Report No 1/2006
[14] Paillex et al., 2007
[15] https://www.eea.europa.eu/themes/water/european-waters/why-should-we-care-about-floodplains#tab-interactive-charts

As the milestone of Europe's green infrastructure, Natura 2000 network[16] acts as an important foundation for healthy ecosystems, which delivers multiple ecosystem services to society, like:

- maintenance of habitats and species;
- soil formation and composition;
- spreading of seeds and small animals.

The Habitat Directive defines the **natural habitats** as "terrestrial or *aquatic areas distinguished by geographic, abiotic and biotic features, whether entirely natural or semi-natural*" and list these habitat types in Annex I and refers also to the **habitat of a species** which is" an environment defined by specific abiotic and biotic factors, in which the species lives at any stage of its biological cycle" and these species are listed in Annex II and/or Annex IV or V of the directive.

The most relevant habitat type listed in the Annex I of the Habitat Directive and related to the water and the floodplains are the **Freshwater Habitats** which includes standing water habitats and running water habitats (sections of water courses with natural or seminatural dynamics where the water quality shows no significant deterioration.

As regard natural species, the Habitats and Birds Directives annexes provides a wide range of taxon related to water and floodplain, e.g.: Amphibians, Fish, some of Invertebrates, Mammals and Plants.

Regarding the bird species, considering that at least one stage of their life (passage, rest, reproduction, nesting, food, etc.) is connected with water, it is considered that all taxa are potentially related with water and floodplain.

A.3. Synergies between FD, WFD, BHD in floodplain restoration and preservation process

The WFD, FD, BHD are not stand-alone documents of European legal regulations, but in many ways generates interrelations, synergies as same as conflicts *(Figure 3).* Reaching and preventing deterioration of good ecological status through WFD, ensuring biodiversity through the conservation of natural habitats and of wild fauna and flora through BHD, reducing the flood risk by giving more space to the rivers represent the key actions to the success of several sustainable development goals in the EU.

Dimensions of sustainable development such as environmental, economic and social aspects are covered to different degrees in the above three Directives. The environmental aspect is the main one covered by the WFD and B&H D, whereas for the FD social aspect prevails.

[16] https://natura2000.eea.europa.eu/

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There are some reasons for a better coordination between the WFD and the FD comparing to BHD (e.g., alignment of planning cycles for WFD and FD), but this not exclude other aspects which can offers the opportunity to optimize the synergies also with BHD, (e.g., coordination of measures in the context of integrated planning to achieve the WFD and BHD objectives).

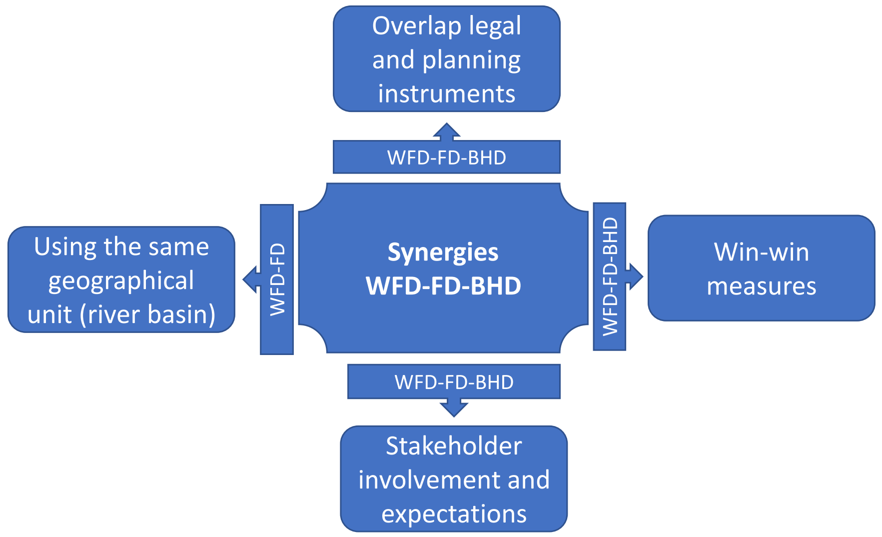

Figure 3 - Synergies WFD, FD, BHD

Moreover, both the nature directives and the WFD aim at ensuring healthy aquatic ecosystems while at the same time ensuring a balance between water/nature protection and the sustainable use of nature's natural resources.

"The FD planning cycle is aligned with the WFD planning cycle. There are a series of references to the WFD set out by the FD to support coordination and possible integration between the two Directives. Hence, Article 9 of the FD explicitly states that Member States shall take appropriate steps to coordinate the application of the FD and WFD, focusing on opportunities for improving efficiency, information exchange and for achieving common synergies and benefits with respect to the environmental objectives in Article 4 of the WFD in particular such that:

- *Flood hazard and risk maps contain information that is consistent with relevant information in the WFD (in particular from WFD Article 5 analysis);*
- *Development of FRMPs should be carried out in coordination with and may be integrated into reviews of RBMPs".*[17]

Planning and management under FD and WFD address to the same geographical unit - *the river basin* - which acts as natural "reference area" for both water quality and flood risk management.

[17] Links between the Floods Directive (FD 2007/60/EC) and Water Framework Directive (WFD 2000/60/EC), accessed on https://circabc.europa.eu/sd/a/949f3206-9ed4-4293-9817-816b82a936b1/links%20between%20the%20Floods%20Dierective%20and%20Water%20Framework%20Directive%20-%20Resource%20Document

Each of the above Directives deals with measures. Prioritisation of these measures instead often deals with each Directive specific criteria, or different effectiveness and benefit indicators. Including synergy effects criteria between directives in the prioritisation process could minimise conflicts between them.

For example, the prioritisation of measures for flood risk management could comprise of different criteria such as flood prevention, economic feasibility, practicability, as well as effects to the WFD. It is important to note that, the 3-rd management cycle for WFD, as the 2-nd management cycle for FD will start in 2021. In the same time in 2020 the measures undertaken in relation with Natura 2000 will be updated. All these timelines lead to the conclusion that the planning phase in terms of identification win-win measures is the key point in successful implementation of these EU Directives. On the other side measures needed to reach WFD goals will also benefit maintaining/reaching favourable conservation status.

Although not explicitly mentioned in the Water Framework Directive, the link with ecosystem services (e.g. as a benefit indicator) appears to be a promising concept to help its implementation, on the basis that there is a connection between the aims and objectives between WFD and BHD, respectively the good ecological status objective and achievement of conservation objectives.

The same approach could be also valid in the case of FD, where the ecosystem services approach could be a key aspect in the assessment process of the natural water retention measures, like floodplain restoration. Commonly applied cost-benefit-analysis (CBA) for flood protection measures regularly include the construction costs and the benefits from reduced flood risk for property. This approach does not take into account benefits from improved biodiversity and ecosystem services, which are major advantages of floodplain restoration projects compared to traditional technical measures.

To overcome this, the Danube Floodplain project propose an extension of traditional CBA by integrating ESS. In this way a complete picture of the entire benefits, economic, social and environmental, will be available.

Nevertheless, the coordination of stakeholder's involvement and engagement even from the planning stage could have many benefits in terms of implementation. By ensuring a close cooperation between all stakeholder at an early stage of the process, each related approach will stand a better chance of success.

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Part B – Floodplain restoration in the Danube River Basin

B.1. Danube River Basin District Flood Risk Management and River Basin Management Plans

During the 19th century and especially in the second half of 20th century significant anthropogenic actions determined a substantial loss of floodplains in the Danube River Basin. Flood protection, agriculture, navigation, hydropower are the main drivers which leads to disconnection and loss of floodplains.

Originally Danube floodplains covered an area of approximately 41,605 sq km[18], which is equal to about 3.3% of the total Danube catchment area. The total floodplain area for the Danube was reduced by 68% (80% for all assessed rivers) with differences for upper (75%), middle (79%) and lower (73%) Danube stretches[19].

As consequence protecting and restoring wetlands along the Danube and its tributaries, reconnecting the river to its natural flooding areas, reducing the risks of major flooding in areas with human settlements and offering benefits both for local economies (e.g., fisheries, tourism), but also for the ecosystems makes the subject of Flood Risk Management Plan for the Danube River Basin District (DFRMP)[20] and Danube River Basin District Management Plan 2009 and 2015 updated one (DRBMP)[21].

Drivers, pressures analysis, impact on the aquatic ecosystems but also measures related to disconnection of floodplains have been considered in DRBMP. The DRBMP underlines that wetlands/floodplains and their connection to river water bodies play a key role in the functioning of aquatic ecosystems and have a positive effect on water status[22]. At the same time, activities on the implementation of the FD in the Danube River Basin deals with flood risk reduction and floodplain use. Development of the DFRMP is significantly contributing to the identification of connected, disconnected wetlands/floodplains and to the reconnection potential.

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[18] Danube River Basin District Management Plan, ICPDR, 2009, accessed on http://www.icpdr.org/main/activities-projects/danube-river-basin-management-plan-2009
[19] WWF, May 2010 - Assessment of the restoration potential along the Danube and main tributaries, accessed on http://awsassets.panda.org/downloads/wwf_restoration_potential_danube.pdf
[20] Flood Risk Management Plan for the Danube River Basin District, ICPDR, 2015, accessed on https://www.icpdr.org/main/sites/default/files/nodes/documents/1stdfrmp-final.pdf
[21] Danube River Basin District Management Plan, ICPDR, 2015, accessed on https://www.icpdr.org/main/activities-projects/river-basin-management-plan-update-2015
[22] Note: In this context water status refers to ecological status (natural water bodies), ecological potential (heavily modified and artificial water bodies) and chemical status.

The updated DRBMP addresses *"those wetlands/floodplains considered to have a definite re-connection potential, which can be difficult to be assessed e.g., due to different land uses taking place on the former wetlands/floodplains.* Hence a total 193,475 ha of wetlands/floodplains have been identified to have a reconnection potential. *"Out of these and as part of the JPM implementation 2009-2015, 5,715 ha are totally and 40,920 ha are partly reconnected where some of the required measures were already completed but further measures are planned, having* positive effects on water status and flood *mitigation. The remaining wetlands/floodplains, covering an area of 146,840 ha, have a remaining potential to be re-connected to the Danube River and its tributaries in the next WFD cycles".*

Considering the multi-functional characteristics, to protect and manage water resources, to restore or maintain ecosystems as well as natural features and characteristics of water bodies using natural means and processes, Natural Water Retention Measures (NWRM) represent the key connecting component of both FRMP and RBMP. Moreover, NWRM contributes to integrated goals dealing with nature and biodiversity conservation and restoration. As part of NWRM, floodplain and wetland restoration and preservation, re-meandering, reconnection of oxbow lakes, reallocation on elimination of river bank protection are few of win-win solutions for a sustainable water management and included in both Danube or national FP and RBMP related program of measures.

B.2. Drivers and pressures in relation with floodplain disconnection

As an overall mechanism for analysing environmental problems and responses with regards to sustainable development, the 'Drivers-Pressures-State-Impact-Response (DPSIR[23]) concept, allows for a better understanding of the cause-effect correlation in relation to floodplain disconection.

Using the DPSIR conceptual framework, by considering significant pressures which acts on floodplain disconnection will help the restoration and preserrvation decision making process to identify feasible actions.

The DPSIR approach is a cyclic, iterative and complex process, considering the (continuous) changes of significant pressures generated by different driving forces, the (continuous) changing of water status, corresponding impact and related measures. Implementing into practice such a conceptual framework on floodplain issue implies a in-depth analysis of the relations between natural systems and human systems.

[23] The DPSIR framework used by the EEA: http://ia2dec.ew.eea.europa.eu/knowledge_base/Frameworks/doc101182

Driving forces such as social and economic needs will lead to activities which exert pressures on the environment and, as a result, the state of the environment will be subjected to change. For instance the continuously development of grey flood infrastructure will have an impact on natural dynamic of the rivers flow and biodiversity. Finally, those consequences will lead to Impacts on ecosystems and societies that may induce a response that feeds back on the driving forces, pressures, states, or impacts directly, through adaptation or curative actions.

Therefore, the DPSIR framework can be used to get a handle on the all different floodplain disconnection- related terms necessary to be considered in the pressuress and impact analysis process *(Figure 4).*

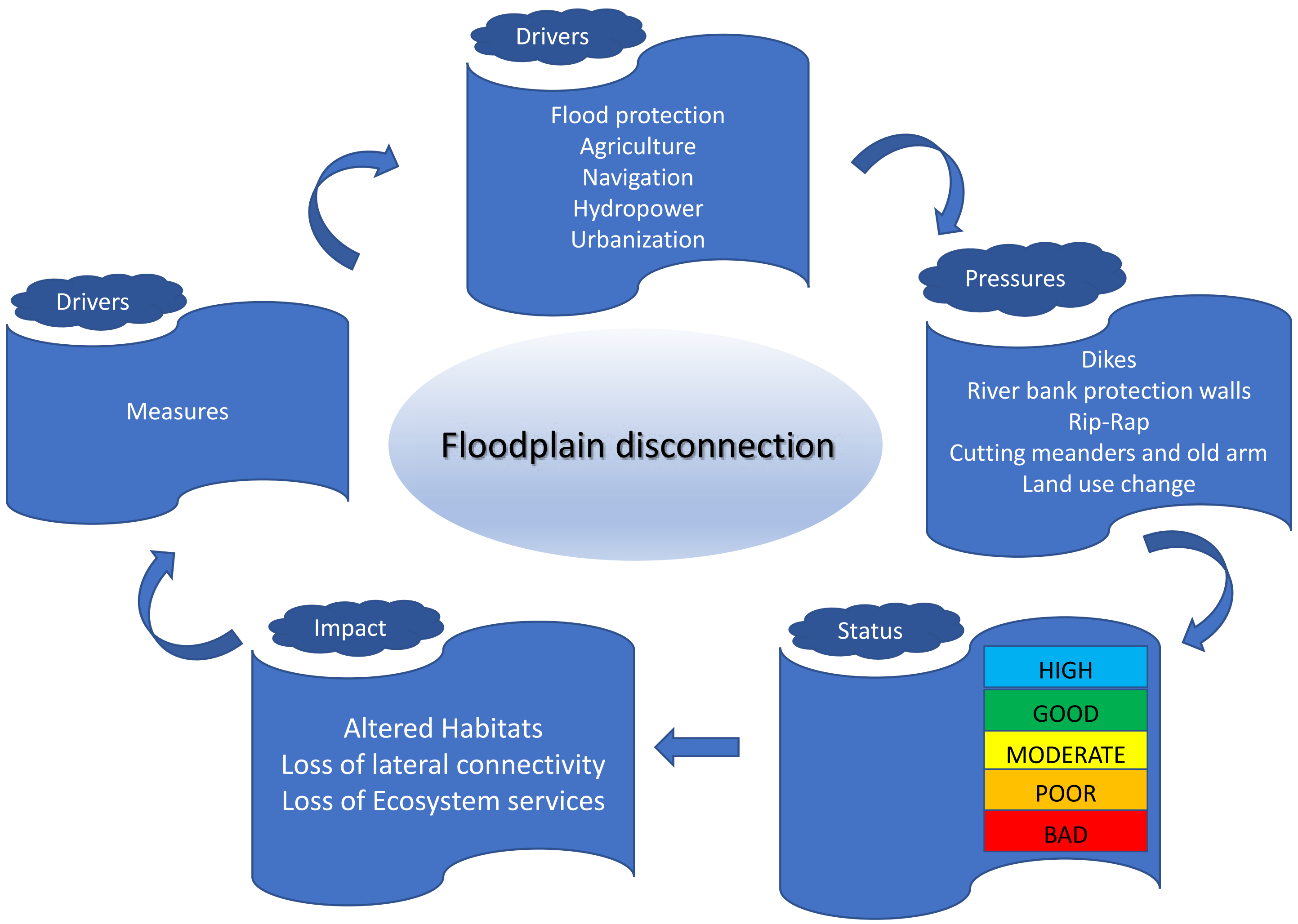

Figure 4 - DPSIR Framework for floodplain disconnection

Danube River Basin's floodplains covered in the past wide stretches and had high ecological importance. Cleared for agriculture and significantly changed through urban development and flood control engineering works, only fractions of floodplains remain. To improve navigation, river channels are often straightened and dredged. Hydropower and water supply projects caused significant changes in hydrological regime and geomorphological processes influencing floodplains preservation. No less important increasing the land cover change, e.g., conversion into arable lands, deforestation in the catchment area led to increasing of the flood risk.

As consequence, at the Danube wide-level, the disconnection of adjacent wetlands and floodplains is among the categories of significant basin-wide hydromorphological alterations[24].

Engineering works for river regulation (e.g., rip rap, river bank protection walls, cut off meanders, and old arms), dykes and embankments are the key pressures causing lost or reduction of the floodplains. Referring only to the Danube River 7807 km of dykes[25] were identified on the Danube River causing interruption of lateral connectivity.

Considering the above pressures, floodplain disconnection has a negative impact on water status, on the functioning of aquatic ecosystems. Reducing the lateral connectivity between a river and its floodplain and implicitly the water retention and sediment transfer, degradation of river morphology, increasing nutrients, loss of spawning, nursery and feeding grounds areas, decreasing in aquifers recharges are the key impacts of floodplain disconnection which influence the deterioration the water status carried out under the Water Framework Directive. Loss of floodplains is also reflected in assessments of conservation status (Birds and Habitat Directives). According to European Environmental Agency (EEA), only 17 % of floodplain habitats and species have good conservation status, reflecting the high degree of disturbance to floodplain systems[26].

Having in view the multiple benefits provided by natural floodplains, EU policies encourage restoration based on natural water retention measures, as well as conservation of existing natural floodplains, to be adopted in the river basin or flood risk management plans, conservation plans or climate change adaptation plans. As a consequence, either national RBMP and FRMP but also both DRBMP and DFRMP refers to floodplain restoration measures. According to DRBMP update 2015, in total 193,475 ha of wetlands/floodplains have been identified to have a reconnection potential, out of which 40,920 ha are partly reconnected in the Danube River basin. At the same time restoration of floodplains, combination of classical and green infrastructure, natural retention measures, are subject of flood risk management.

The updates of RBMP and FRMP but also of DRBMP and DFRMP in 2021 will reinforce the restoration and preservation of the floodplains as a sustainable way considering the environmental and flood risk objectives.

[24] Danube River Basin District Management Plan, ICPDR, 2015, accessed on https://www.icpdr.org/main/activities-projects/river-basin-management-plan-update-2015
[25] Report Interactions of Key Drivers and Pressures on the Morphodynamics of the Danube (from Danube Sediment Project), 2019, accessed on http://www.interreg-danube.eu/uploads/media/approved_project_output/0001/30/83e787f3ecfba590b0be8665722bdbd7e7424768.pdf
[26] European Environment Agency: Floodplains: a natural system to preserve and restore - EEA Report No 24/2019, accessed on https://www.eea.europa.eu/publications/floodplains-a-natural-system-to-preserve-and-restore

B.3. Active and potential floodplains - identification and evaluation

Note: this chapter was adapted from the following sources: Danube Floodplain. Deliverable D 3.2.1. Priority list with potential preservation and restoration areas (based on FEM-tool), 2021.

Active, Potential and Former Floodplains

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This section presents the methods for identifying and evaluating active and potential floodplains along the Danube River. Active floodplains are defined as all areas that are still flooded during a HQ_{100} flood event. Potential floodplains are currently not inundated in the case of a HQ_{100}, but with restoration measures, these areas can be reconnected to the river system leading to inundation during a HQ_{100} event. For the evaluation of the identified floodplains, the Floodplain Evaluation Matrix (FEM)[27] was further developed and adapted with the contribution of all project partners to serve the project's needs best.

The workflow related to methodological steps and results performed in the frame of the project is presented in the *Figure 5.*

[27] Habersack et al. 2015

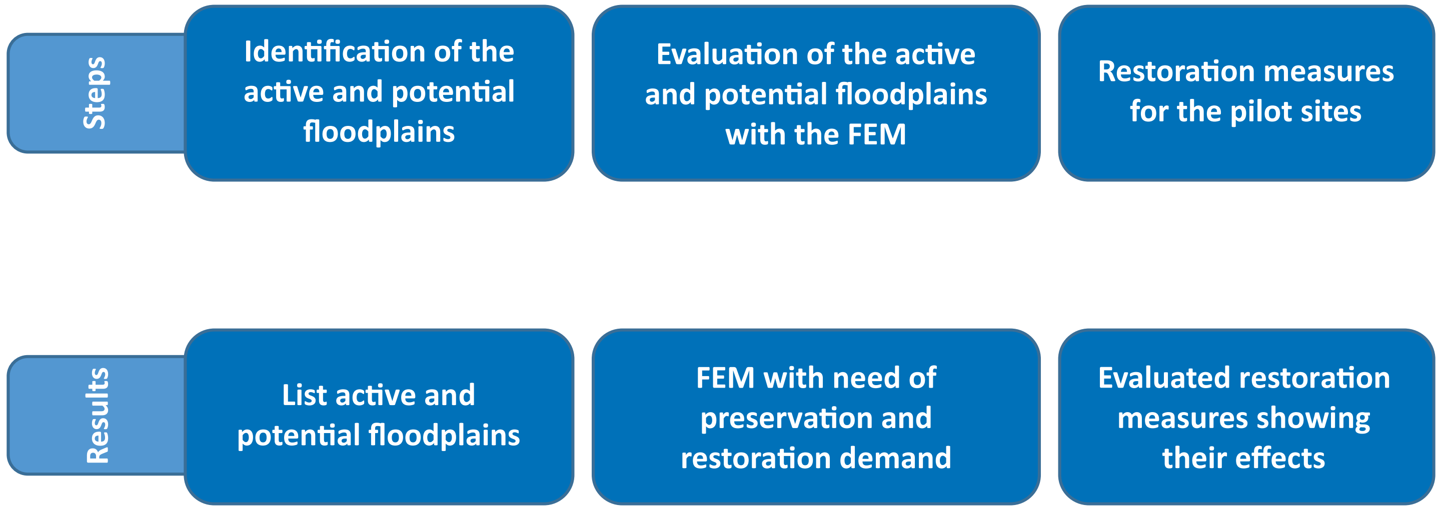

Figure 5 - Methodological steps for active and potential floodplains identification and assessment processes (in the frame of the project)

B.3.1.1. Identification of active and potential floodplains

➢ ***Active floodplains***

Within the project, a method was developed to identify and delineate active floodplains resulting in a Danube Floodplain Inventory (DFInv) of hydraulically predefined floodplain sections.

According to the Danube FLOODRISK project, a flood event with a return period of 100 years is widely accepted as the design discharge for flood protection measures along the Danube River[28]. Therefore, these inundation outlines were chosen as the data basis for the identification of the active floodplains in the Danube Floodplain project. If the countries could offer better national flood risk maps (e.g., more accurate, more recently developed), these maps were used for the identification.

> ⓘ **Additional info:**
>
> In 2012 the **Danube FLOODRISK project** created hazard and risk maps for three different scenarios (frequent event HQ_{30}, medium event HQ_{100}, extreme event HQ_{1000}) for the whole Danube and published the results in the Danube Atlas. The hydrological processing was performed at different degrees of complexity, depending on the future utilization of the results. Synthetical hydrographs were generated, under the volume conservation hypothesis. For hydraulic simulations in steady state either a unique value of the maximum discharge corresponding to a probability of exceedance P% or an uncertainty interval of the maximum discharges was obtained if taking into account the hydrologic uncertainty. For unsteady state simulations, a family of hydrographs corresponding to the same probability of exceedance P% are obtained. The floods corresponding to the maximum discharges which could lead to the dyke overtopping was considered for hydraulic simulations. (Danube FLOODRISK 2012)

[28] Danube FloodRisk Project, ICPDR, 2012, accessed on http://www.icpdr.org/main/activities-projects/danube-floodrisk-project

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

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

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

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

This methodology was developed to identify floodplains at the Danube, which should be evaluated with the Floodplain Evaluation Matrix (FEM) and displayed in the Danube GIS and Danube Floodplain GIS. In general, the thresholds can be selected for each river individually under consideration of specific characteristics of the river and its floodplains. For the Danube River the following values were selected:

- **1st group:** floodplains identified according to the methodology described before, larger than 500 ha, which will be evaluated and ranked by the FEM;
- **2nd group:** floodplains smaller than 500 ha but with a floodplain width bigger than the width of the river;
- **3rd group:** riparian zones with a width smaller than the river width. These riparian zones are not be displayed or evaluated as the effect for flood risk management is minor, but are nevertheless important for the ecology and morphology.

➢ *Potential floodplains*

After the identification of all active floodplains along the Danube, a methodology was developed for the identification of potential floodplains. Potential floodplains are currently not inundated in the case of HQ_{100}, but with restoration measures, these areas can be reconnected to the river system leading to inundation during various HQ events (at least HQ_{100}), depending on the sites' character and the reconnection design. Historical maps and/or inundation outlines of a $HQ_{extreme}$ e.g. HQ_{300} or HQ_{1000} are used to identify former/historical floodplain first. If settlements, critical infrastructures and streets are located in the historical/former floodplain, each country decides on its own if they want to identify this area as a potential floodplain (settlements, streets and critical infrastructures had to be protected by complementary local flood defence measures – e.g. protective walls, earth deposits/dikes).

The detailed analysis and identification of former floodplains were not part of the original Danube Floodplain project and will be presented with the results of the project's extension (Deliverable 6.2.3: Identified and analyzed historical floodplains implemented into Danube GIS and Danube Floodplain GIS). In each country, the former/historical floodplain was delineated based on the available data. Therefore, the applied methodology differs per geography region and were not complete at the time of this document

If the historical/former floodplain is currently used by agriculture, each country decides on their own if a compensation is possible or not or adapting landuse for permanent water retention is possible via adjusted financial incentives for farmers. If the partners decide that a compensation for the land or adjusted landuse is not possible, no potential floodplain will be identified. The Danube FLOODRISK project also provides inundation outlines for extreme flood events along the entire Danube River. The assumption was that during a $HQ_{extreme}$, the dykes would overtop, and the potential floodplains beyond the dykes would be visible. Some partners also used historical maps to identify the former/historical floodplains. Additionally, historical conditions could be analysed by modelling a historic scenario of the river section without dams, dikes and power plants.

If a partner wanted to reconnect a certain area beyond the dyke, modifications in the hydrodynamic-numerical model were necessary to ensure that the potential floodplain is reconnected during a HQ_{100} before evaluating the effects of the additional area. One example of such a modification is removing the entire or part of dyke in the model. The connection of the potential floodplain at a HQ_{100} is necessary since the FEM-parameters are evaluated for such an event.
In the context of the project, it was decided to differentiate between two types of potential floodplains, namely potential and "operational" potential floodplains. The difference between these two types is that the "operational" potential floodplains are identified and discussed with stakeholders, technical experts and decision makers.

In the following it is described how the identification of potential floodplains is working:

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

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

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

Step 4: Define the Danube Floodplain scenario for this potential floodplain. The scenario for the reconnection (e.g., cut of dikes, removal of dikes, land use change) will then be used for the modelling of the potential floodplains.

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

The methodology was accepted by all partners and applied in each country individually[29]. *Table 1* presents the Delineated potential floodplains along the Danube.

[29] Danube Floodplain Project: Summary of used complex methodology and process description on hydraulic 1D and 2D, CBA, ESS, ecological assessment and stakeholder analysis (Deliverable D 4.3.4 from WP4: Flood prevention pilots) accessed on http://www.interreg-danube.eu/uploads/media/approved_project_output/0001/46/74485a6e25d48c946a4f7af3a313d1a946c3184d.pdf

Table 1 - Delineated potential floodplains along the Danube and gauges, where the 1D model results are handed over to the next downstream partner

No.	Potential Floodplain Code	Country	Location	Floodplain area (km2)
1	DE_DU_PFP01	DE	Oberelchingen-Lech	167
2	DE_DU_PFP02	DE	Lech-Neuburg	37.4
3	DE_DU_PFP03	DE	Großmehring	4.9
4	DE_DU_PFP04	DE	Katzau	3.1
5	DE_DU_PFP05	DE	Geisling/Gmünd	25
6	AT_DU_PFP01	AT	Krems-Wien	160.7
7	AT_DU_PFP02	AT	Wien-Devin	121.4
8	HU_DU_PFP01	HU	Szigetköz	157.1
9	HU_DU_PFP02	HU	Paks	22.1
10	HU_DU_PFP03	HU	Veránka-sziget	161.7
11	HU_DU_PFP04	HU	Béda-Karapancsa	54.7
12	RS_DU_PFP01	RS	Siga-Kazuk	60.6
13	RS_DU_PFP02	RS	Vajska	59.9
14	RS_DU_PFP03	RS	Kamarište	100.7
15	BG_RO_DU_PFP01	BG/RO	Slivata-Orsoia area/Desa area	82.8
16	BG_RO_DU_PFP02	BG/RO	Dolni Tibar-Oreahovo area/Bistret-Bechet area	279.7
17	BG_RO_DU_PFP03	BG/RO	Oreahovo-Cerkovita area/ Bechet-Turnu Magurele area	309.7
18	BG_RO_DU_PFP04	BG/RO	Deagas Voivoda-Svistov area/ Traian-Zimnicea area	204.5
19	BG_RO_DU_PFP05	BG/RO	Novgrad area/Nasturelu area	31.7
20	RO_DU_PFP01	RO	Borcea Buliga	8.6
21	RO_DU_PFP02	RO	Bentu	0.7
22	RO_DU_PFP03	RO	Garliciu	10.8
23	RO_DU_PFP04	RO	Tichilesti	318.1
24	RO_DU_PFP05	RO	Cotu Pisicii	11.6

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B.3.1.2. Evaluation of active and potential floodplains - Floodplain Evaluation Matrix (FEM)

Background

The Floodplain Evaluation Matrix (FEM) developed by the Institute of Hydraulic Engineering and River Research at the University of Natural Resources and Life Sciences, Vienna (BOKU) is a holistic tool to evaluate river floodplains by considering multiple parameters that affect/influence and determined the processes within these floodplains[30]. The project PRO Floodplain was carried out in ERA-NET CRUE[31] in order to develop an evaluation method for the effectiveness of floodplains in hydrological/hydraulic, ecological and sociological terms, which was until then not available. The FEM should also serve as a tool for decision support for relevant stakeholders.

The FEM was already applied in different case studies in Austria and Germany and numerable parameters were identified and included based on literature research and questionnaires. Parameters for hydrology (e.g., peak reduction, flood wave translation) and hydraulics (e.g., water level change, flow velocity change) were calculated using hydrodynamic-numerical models. 2D-models are recommended for the application of the FEM. If no calibrated 2D-model is available, calibrated 1D-models can be used for the calculation too.

With this methodology, a valuable decision support tool is available for relevant stakeholders to assess the multiple benefits that floodplain restoration and preservation as a sustainable non-technical measure can offer as it is demanded by the EU Floods Directive (2007/60/EC). In general, it allows the evaluation of various river reaches by setting up a priority ranking, which indicates where efforts of floodplain preservation / restoration should be spent first to obtain maximum benefits. The preservation of whole floodplains would stop the ongoing floodplain losses, which were obtained over the last centuries.

FEM-parameters

For the Danube Floodplain project, the original FEM method was further developed to serve the project needs. Therefore, all possible parameters from the previous applications of the FEM were collected and explained to the partners. Additional parameters could also be suggested by partners and this list was then discussed with all partners. From the list of parameters, the partners then selected which ones they see as important for the evaluation of the floodplains and they would see possible and meaningful to calculate. Also, was suggested a minimum set of parameters, which is mandatory for all partners to be calculated. All other parameters are additional ones, which can be evaluated and serve as additional information in the Danube Floodplain GIS but will not be considered for the ranking list. Nevertheless, the results will be valuable

[30] Habersack, Schober & Hauer 2015
[31] Habersack et al. 2008

information for decision makers and, as such, be shown in the factsheet of each floodplain. The matrix itself consists of four categories: hydrology, hydraulics, ecology and socio-economics. For each category, one or two parameters were selected for the minimum set.
The *Figure 6* presents the Floodplain Evaluation Matrix developed in Danube Floodplain project for assessment active and potential floodplains.

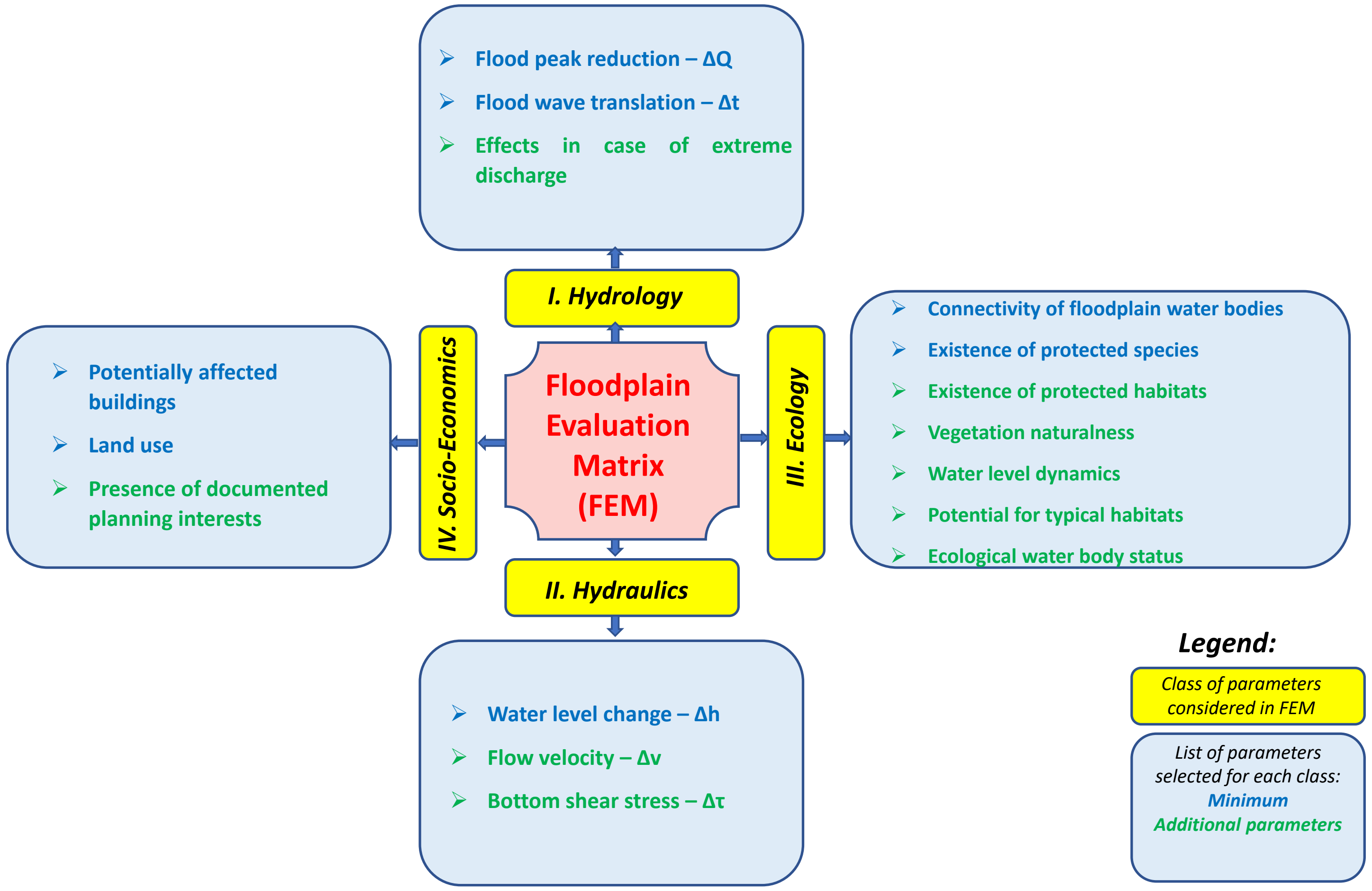

Figure 6 - Floodplain Evaluation Matrix developed in Danube Floodplain project for assessment active and potential floodplains

In the following paragraphs, the selected FEM-parameters are shortly described. A detailed description can be found in the FEM-Handbook (see Deliverable 3.2.1 – annex A and B)[32].

[32] Danube Floodplain Project: Priority list with potential preservation and restoration areas (based on FEM-tool) (Deliverable D 3.2.1 from WP3: Floodplain evaluation) accessed on http://www.interreg-danube.eu/approved-projects/danube-floodplain/outputs

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Hydrology:

Flood peak reduction – ΔQ: The flood peak reduction considers the effect of a floodplain on the peak of a flood wave. To evaluate the peak reduction for a floodplain, the peak of an input hydrograph (e.g. HQ_{100}) at the beginning of the floodplain and the peak of the output hydrograph at the end of the floodplain will be determined. The difference between the peaks is the peak reduction ΔQ [m^3/s] for the investigated floodplain.

Flood wave translation – Δt: 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 similary as the peak reduction, namely by calculating the time difference Δt [h] between the occurrence of the output/input hydrograph peak.

Effects in case of extreme discharge: 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 are also incorporated in the FEM to account for remaining risk (higher discharges due to climate change). Hydrodynamic-numerical modelling of the higher discharge (HQ_{1000}) can highlight additional capacities of floodplains or increased risks for settlements behind the dykes (e.g., by overtopping of existing dykes). The evaluation considers the effects on peak reduction and flood wave translation in each floodplain for this higher discharge compared to HQ_{100}.

Hydraulics:

Water level change – Δh: 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. Hence, we compare the water levels of the two scenarios (with and without floodplain) in the river channel at the middle of the floodplain.

Flow velocity – Δv: 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. Hence, we compare the velocities of the two scenarios (with and without floodplain) in the river channel at the middle of the floodplain.

Bottom shear stress – Δτ: 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. Hence, we compare the bottom shear stresses of the two scenarios (with and without floodplain) in the river channel at the middle of the floodplain.

Ecology:

Connectivity of floodplain water bodies: Connectivity is crucial for the functionality 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 groundwater 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 three scenarios (mean water level, bankfull, above bankfull)

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

Existence of protected habitats: This parameter shows what part of the floodplain area is designated as a 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.

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

Water level dynamics: In order to restore floodplain habitats, rivers and floodplains must have a water level dynamic, almost like the one that exists in the natural floodplains. For this reason, the water level dynamics are used as a FEM parameter. If significant changes have been made on the river, floodplain areas may have completely different water level dynamics. This can result in permanently (excessive) high water levels in dammed-up parts of the river or in dry floodplain areas in deepened river segments. 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. The parameters water level duration, frequency of the flood and amplitude of the water levels are summarized to describe the possible water level dynamics. The historical state before the development of the river serves as a point of reference.

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

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

Socio-Economics:

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

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

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

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

- High performance (5 points, colour code: blue)
- Additional performance (3 points, colour code: green)

Based on selected thresholds, the performance of the floodplain for each parameter can be determined. The thresholds can be selected for each river individually under consideration of specific characteristics of the river and its floodplains. The selected thresholds can be found in Deliverable 3.2.1[33]. It is recommended to start with the thresholds used at the Danube River and if necessary, adaptation can be made. At the selected tributaries in the Danube Floodplain project, the same thresholds were used. After determining the performance, the need for preservation and the demand for floodplain restoration can be evaluated. First, the need for preservation is determined. A floodplain has to be preserved if at least one parameter of the minimum set is evaluated with a 5 (high performance). After that, the restoration demand is defined. Based on the minimum parameter evaluation, each floodplain is assigned to one of three groups (low, medium, high demand for restoration) depending on the achieved points in the FEM-evaluation. The thresholds can be selected for each river individually.

The results of identification of active floodplains and related restoration demand, also of identification of the potential floodplains on Danube are presented in the following set of maps[34].

[33] Danube Floodplain Project: section 2.2.2 from Priority list with potential preservation and restoration areas (based on FEM-tool) report (Deliverable D 3.2.1 from WP3: Floodplain evaluation) accessed on http://www.interreg-danube.eu/approved-projects/danube-floodplain/outputs
[34] Based on GIS shapefiles collected and processed within Danube Floodplain Project (under WP3 coordination - USZ)

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Active Floodplains

DFGIS_ID	Location	Area [ha]	Rest.dem.
DE_DU_AFP01	Donaueschingen	973.3	
DE_DU_AFP02	Riedlingen	634.1	
DE_DU_AFP03	Oberelchingen - Lech	15554.4	medium
DE_DU_AFP04	Lech - Neuburg	3229.3	medium
DE_DU_AFP05	Bergheim – Ingolstadt	2192	high
DE_DU_AFP06	Neustadt – Weltenburg	1644.6	high
DE_DU_AFP07	Regensburg	745.3	high
DE_DU_AFP08	Geisling/Gmünd	1061.5	high
DE_DU_AFP09	Straubing - Isar	6716.4	medium
DE_DU_AFP10	Isar - Vilshofen	4531.1	medium

Restoration demand

high

medium

low

no information

Potential floodplain

N W E S

0 30 km

Potential Floodplains

DFGIS_ID	Location	Area [ha]
DE_DU_PFP01	Oberelchingen - Lech	16697.8
DE_DU_PFP02	Lech - Neuburg	3735.8
DE_DU_PFP03	Großmehring	493.5
DE_DU_PFP04	Katzau	308.6
DE_DU_PFP05	Geisling/Gmünd	2502.1

Legend: *Danube River* · *Danube River Basin District* · *National borders* · *100000 - 250000 inhabitants* · *250000 - 2000000 inhabitants* · *Urban areas*

Danube Active and Potential Floodplains - Austria

Interreg
Danube Transnational Programme
Danube Floodplain

Active Floodplains

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

Restoration demand

high
medium
low
no information

Potential floodplain

N W E S

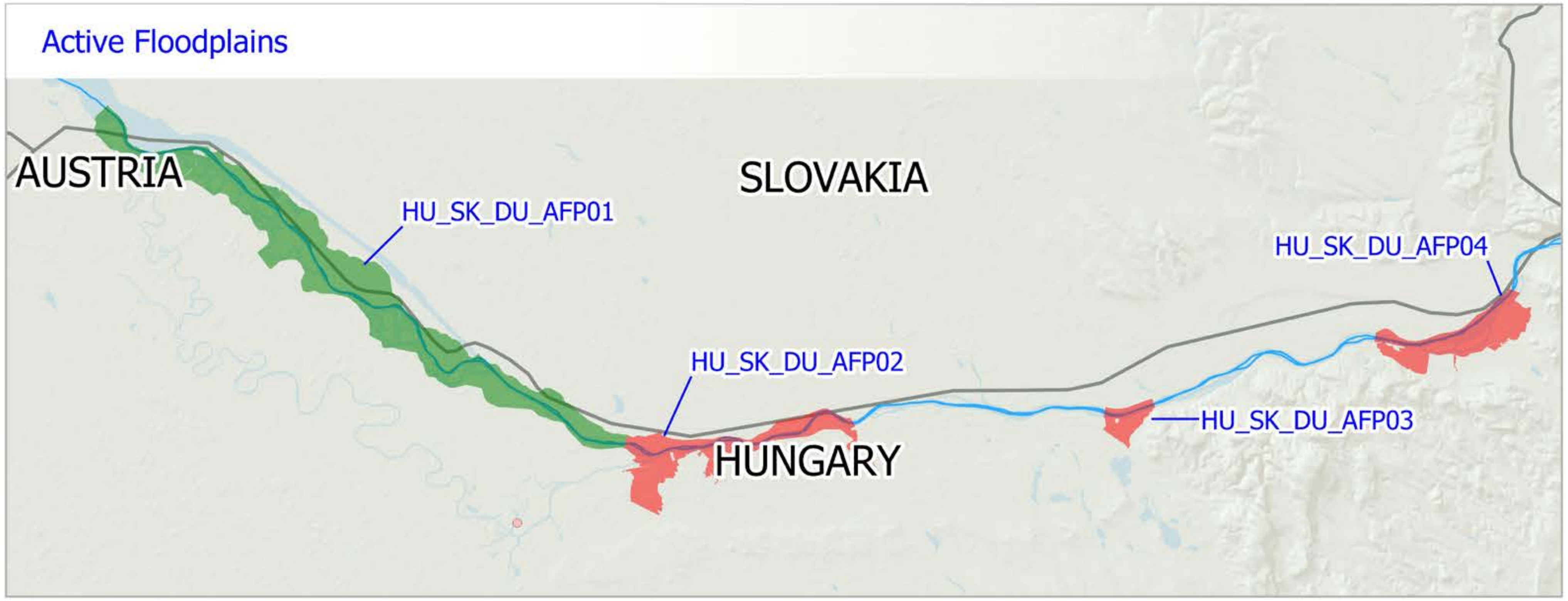
0 30 km

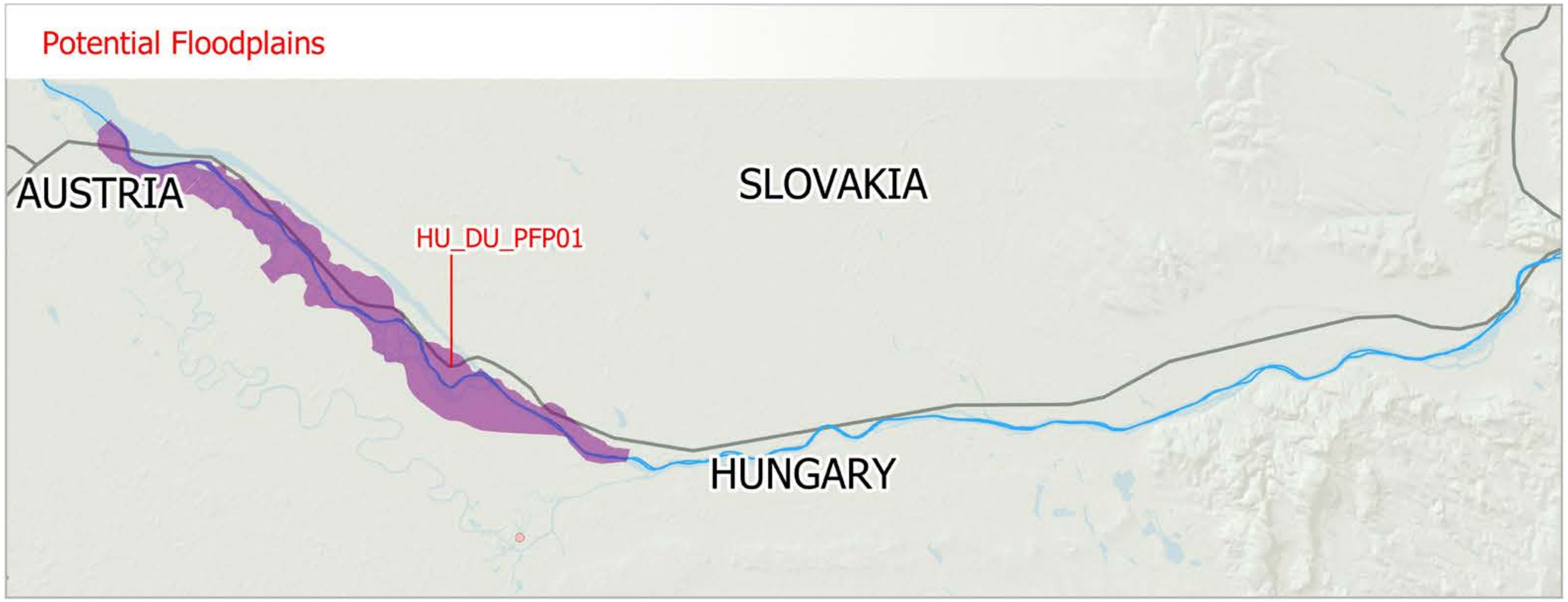
Potential Floodplains

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

Legend *Danube River* *Danube River Basin District* *National borders* *100000 - 250000 inhabitants* *250000 - 2000000 inhabitants* *Urban areas*

Danube Active and Potential Floodplains - Slovakia / Hungary





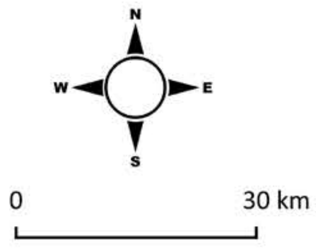
Active Floodplains

DFGIS_ID	Location	Area [ha]	Rest.dem.
HU_SK_DU_AFP01	Szigetköz	14024.6	low
HU_SK_DU_AFP02	Gönyű	4059.2	high
HU_SK_DU_AFP03	Almásfüzitő	827.1	high
HU_SK_DU_AFP04	Esztergom	3118.2	high

Restoration demand

- *high*
- *medium*
- *low*
- *no information*

- *Potential floodplain*



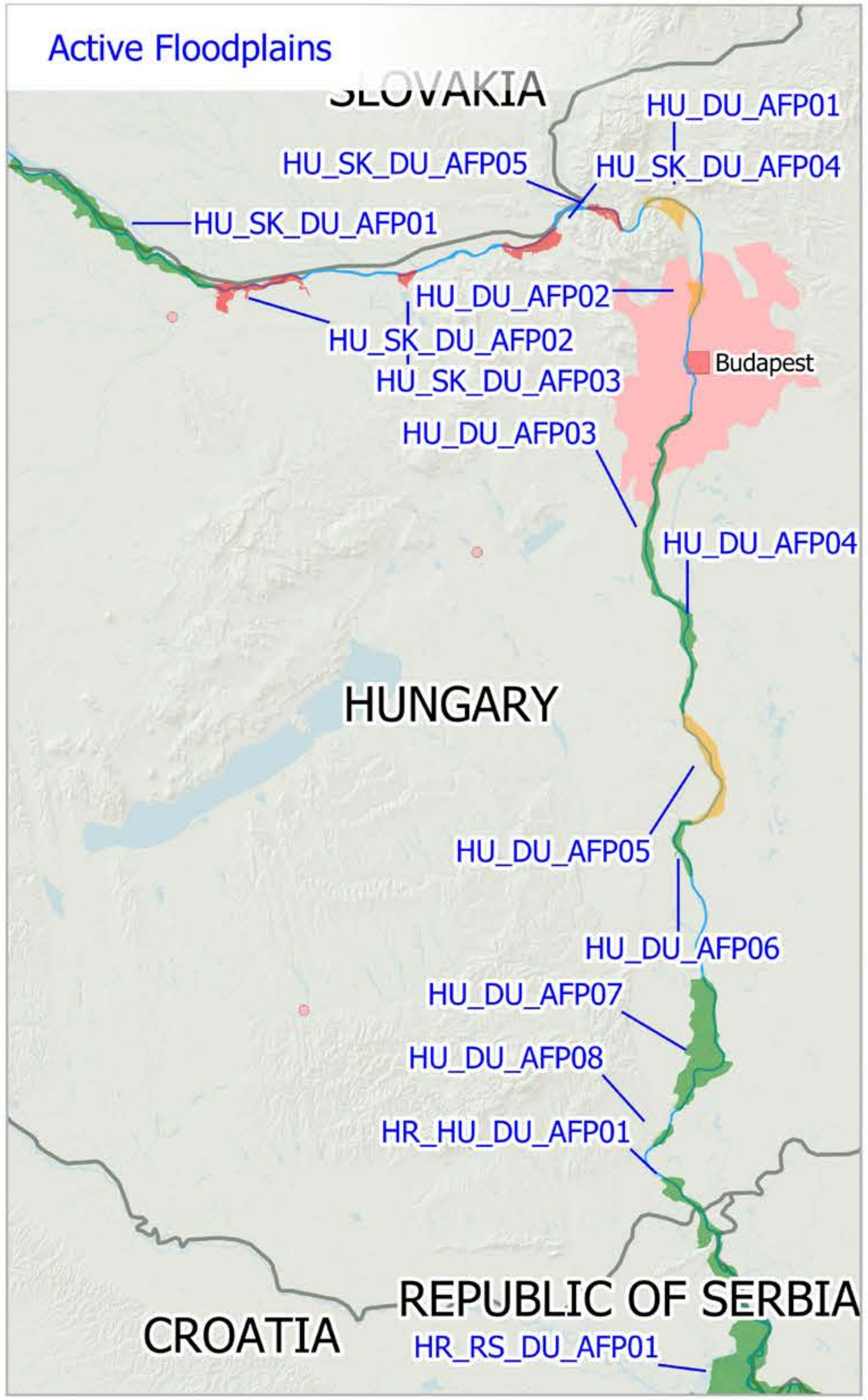
Potential Floodplains

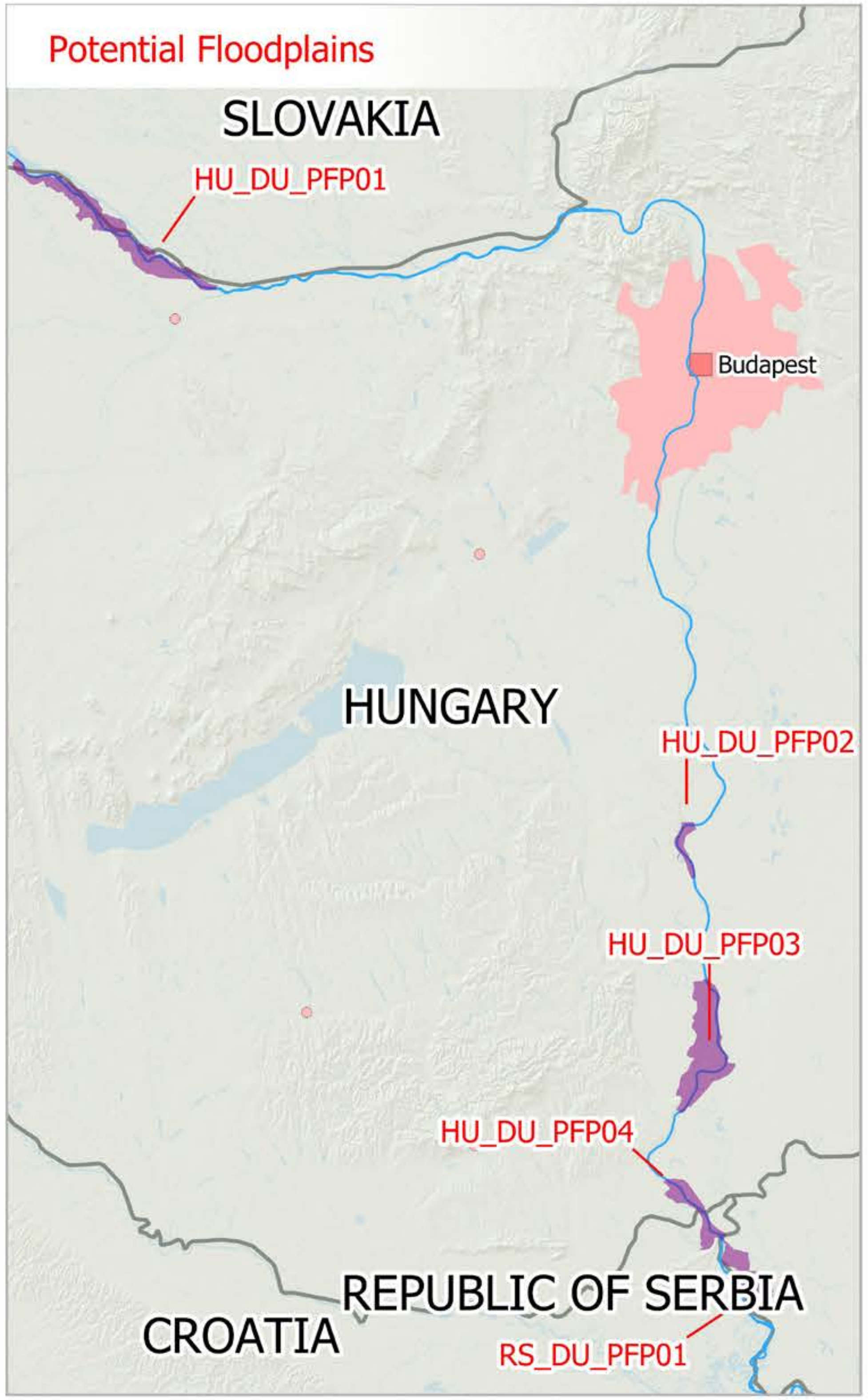
DFGIS_ID	Location	Area [ha]
HU_DU_PFP01	Szigetköz	15711.3

Legend — *Danube River* — *Danube River Basin District* — *National borders* — *100000 - 250000 inhabitants* — *250000 - 2000000 inhabitants* — *Urban areas*

Danube Active and Potential Floodplains - Hungary

Interreg
Danube Transnational Programme
Danube Floodplain





Active Floodplains

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

Restoration demand

high
medium
low
no information

N W E S
0 30 km

Potential Floodplains

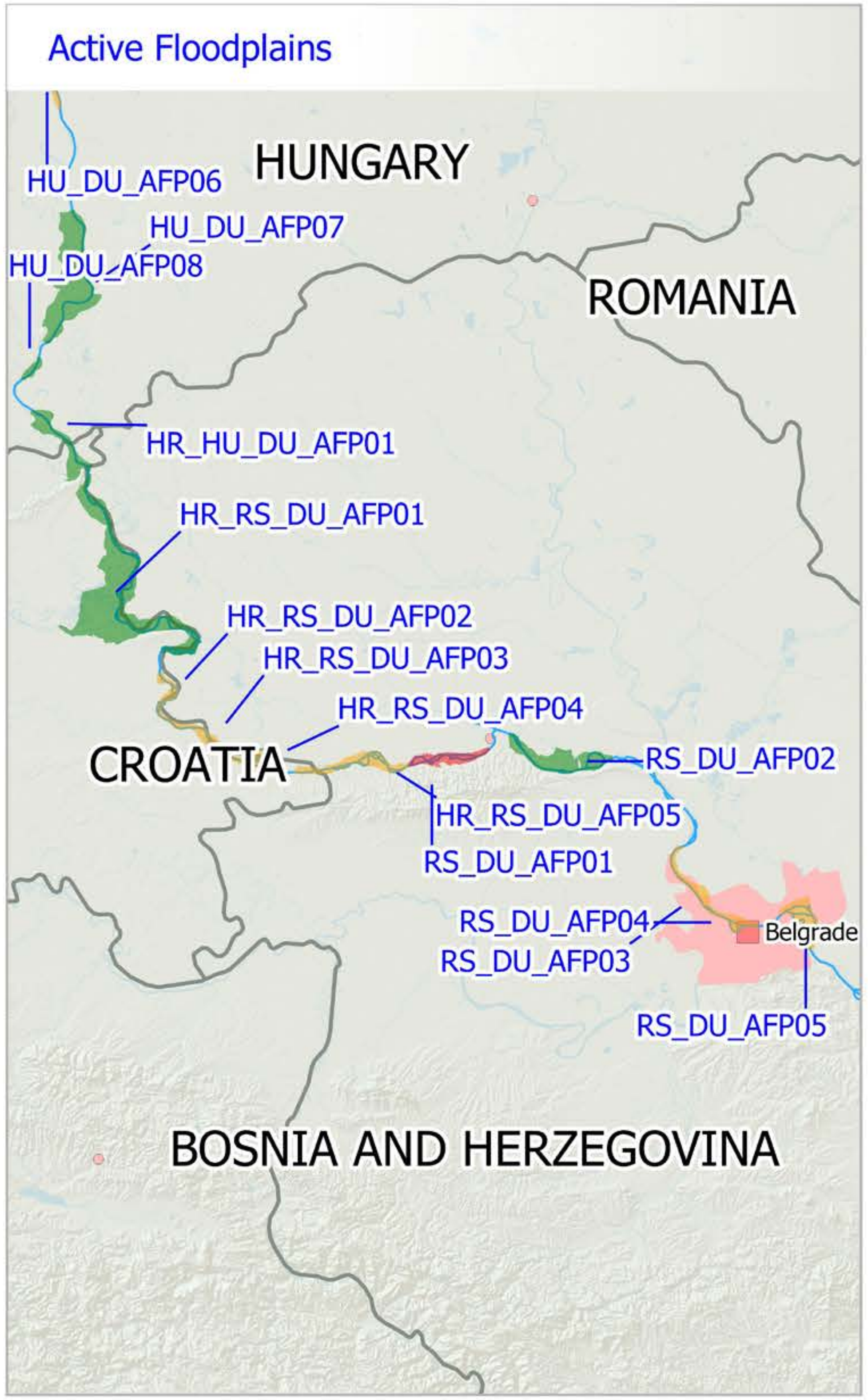
DFGIS_ID	Location	Area [ha]
HU_DU_PFP01	Szigetköz	15711.3
HU_DU_PFP02	Paks	2214.2
HU_DU_PFP03	Veránka-sziget	16171.6
HU_DU_PFP04	Béda-Karapnacsa	5470.6
RS_DU_PFP01	Siga - Kazuk	6057.5

Legend

Danube River
Danube River Basin District
National borders
Urban areas
100000 - 250000 inhabitants
250000 - 2000000 inhabitants
Potential floodplain

Danube Active and Potential Floodplains - Hungary / Croatia / Serbia

Interreg
Danube Transnational Programme
Danube Floodplain



Active Floodplains

DFGIS_ID	Location	Area [ha]	Rest.dem.
HR_HU_DU_AFP01	Béda-Karapnacsa	4822.1	low
HR_RS_DU_AFP01	Kopački rit / Gornje Podunavlje	27994.1	low
HR_RS_DU_AFP02	Borovo / Vajska	1958.5	medium
HR_RS_DU_AFP03	Vukovar / Bačko Novo Selo	2462.3	medium
HR_RS_DU_AFP04	Mohovo / Karađorđevo	3001.2	medium
HR_RS_DU_AFP05	Ilok / Bačka Palanka	4922.2	medium
HU_DU_AFP05	Dunaföldvár	6377.7	high
HU_DU_AFP06	Paks	2034.8	medium
HU_DU_AFP07	Veránka-sziget	15904	low
HU_DU_AFP08	Bezerédy-sziget	901.1	low
RS_DU_AFP01	Futog-Beočin	3481.3	high
RS_DU_AFP02	Koviljsko-petrovaradi rit	7480.7	low
RS_DU_AFP03	Novi Banovci	2765.8	medium
RS_DU_AFP04	Beograd	1838.4	medium
RS_DU_AFP05	Pančevo	4323.5	medium

N W E S

0 30 km

Restoration demand

- *high*
- *medium*
- *low*
- *no information*

Potential Floodplains

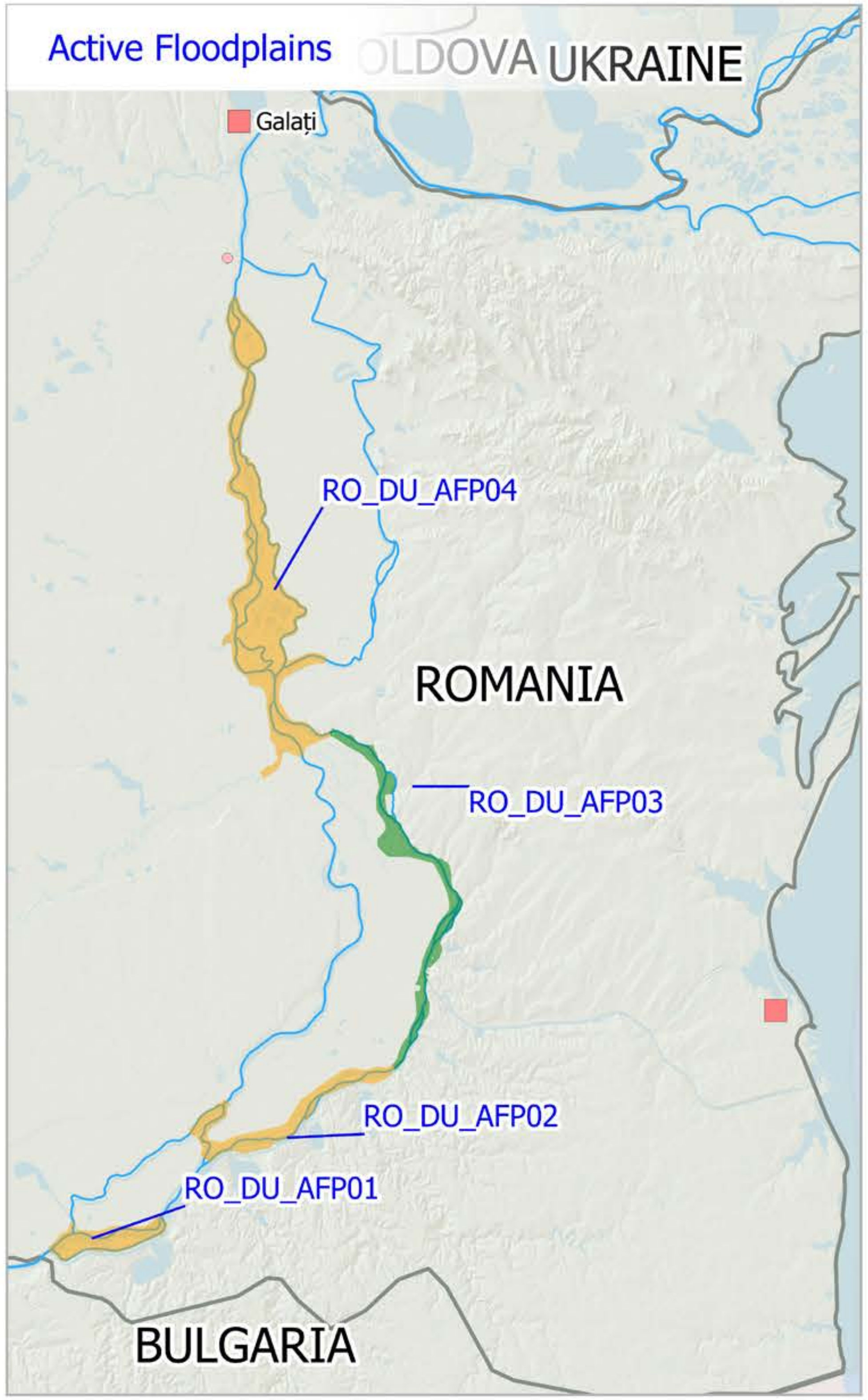
DFGIS_ID	Location	Area [ha]
HU_DU_PFP02	Paks	2214.2
HU_DU_PFP03	Veránka-sziget	16171.6
HU_DU_PFP04	Béda-Karapnacsa	5470.6
RS_DU_PFP01	Siga - Kazuk	6057.5
RS_DU_PFP02	Vajska	5986.2
RS_DU_PFP03	Kamarište	10069.1

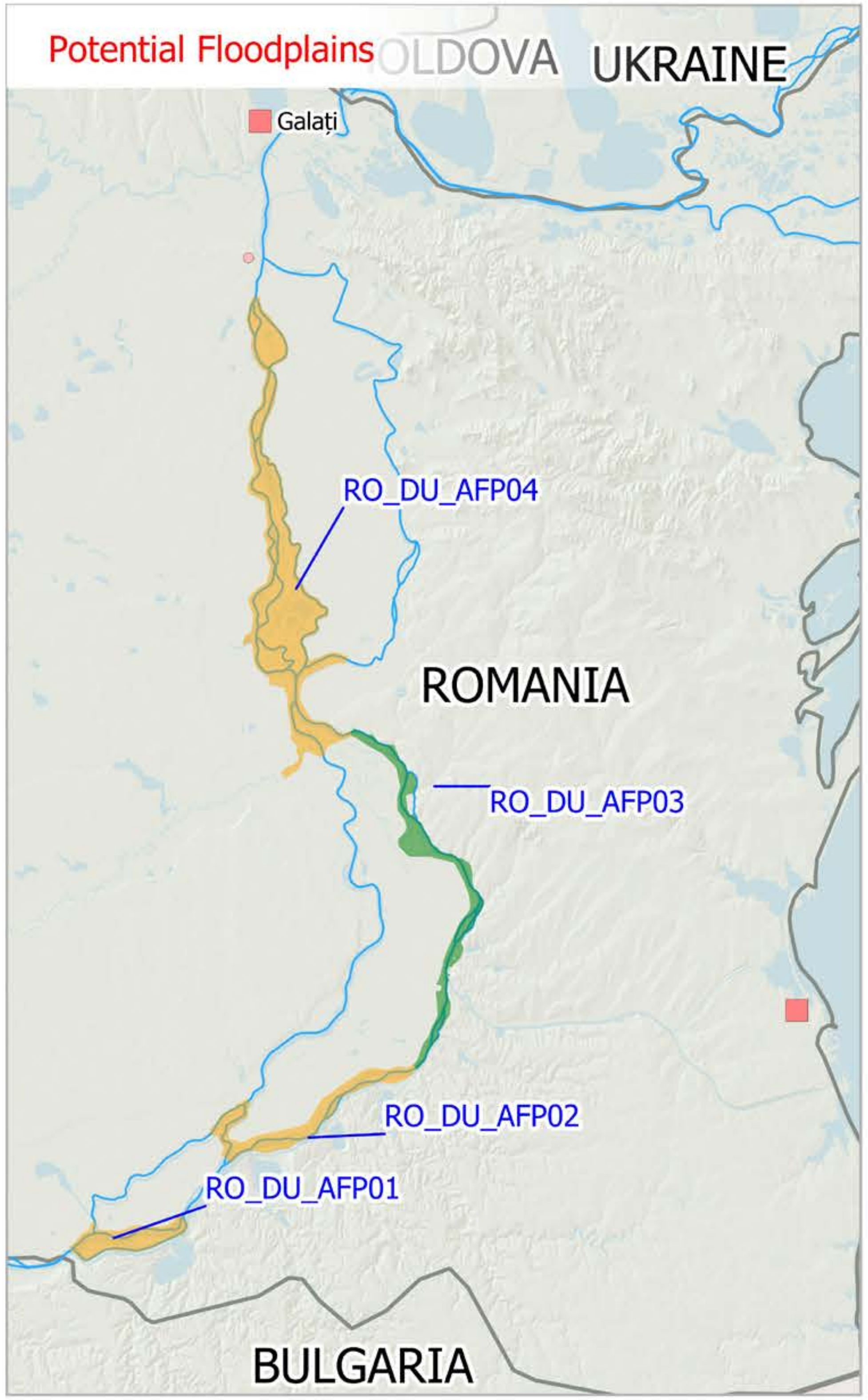
Legend

Danube River — *Danube River Basin District* — *National borders* — *Urban areas* — *100000 - 250000 inhabitants* — *250000 - 2000000 inhabitants* — *Potential floodplain*

Danube Active and Potential Floodplains - Romania

Interreg
Danube Transnational Programme
Danube Floodplain





Active Floodplains

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

N W E S

0 30 km

Restoration demand

high
medium
low
no information

Potential Floodplains

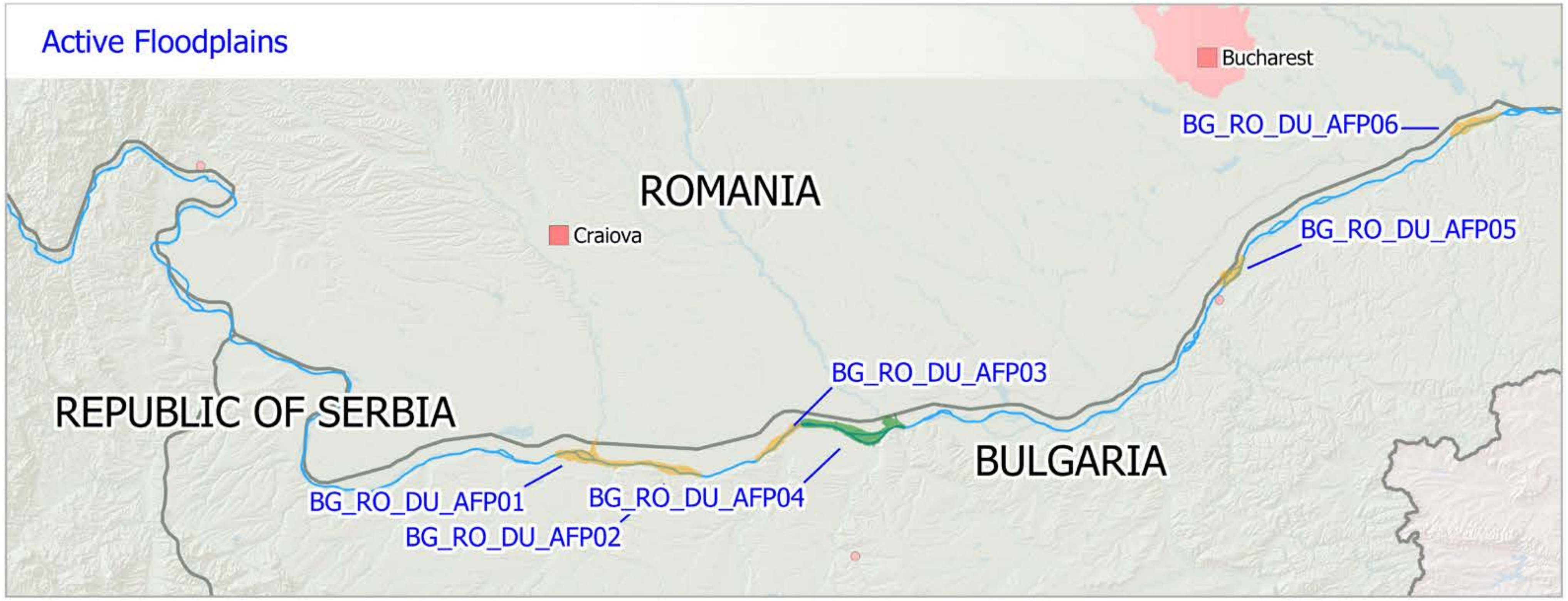
DFGIS_ID	Location	Area
RO_DU_PFP01	Borcea Buliga	857.9
RO_DU_PFP02	Bentu	68.6
RO_DU_PFP03	Garliciu	1083.8
RO_DU_PFP04	Tichilesti	31808.3
RO_DU_PFP05	Cotu Pisicii	1163.5

Legend

Danube River
Danube River Basin District
National borders
Urban areas
100000 - 250000 inhabitants
250000 - 2000000 inhabitants
Potential floodplain

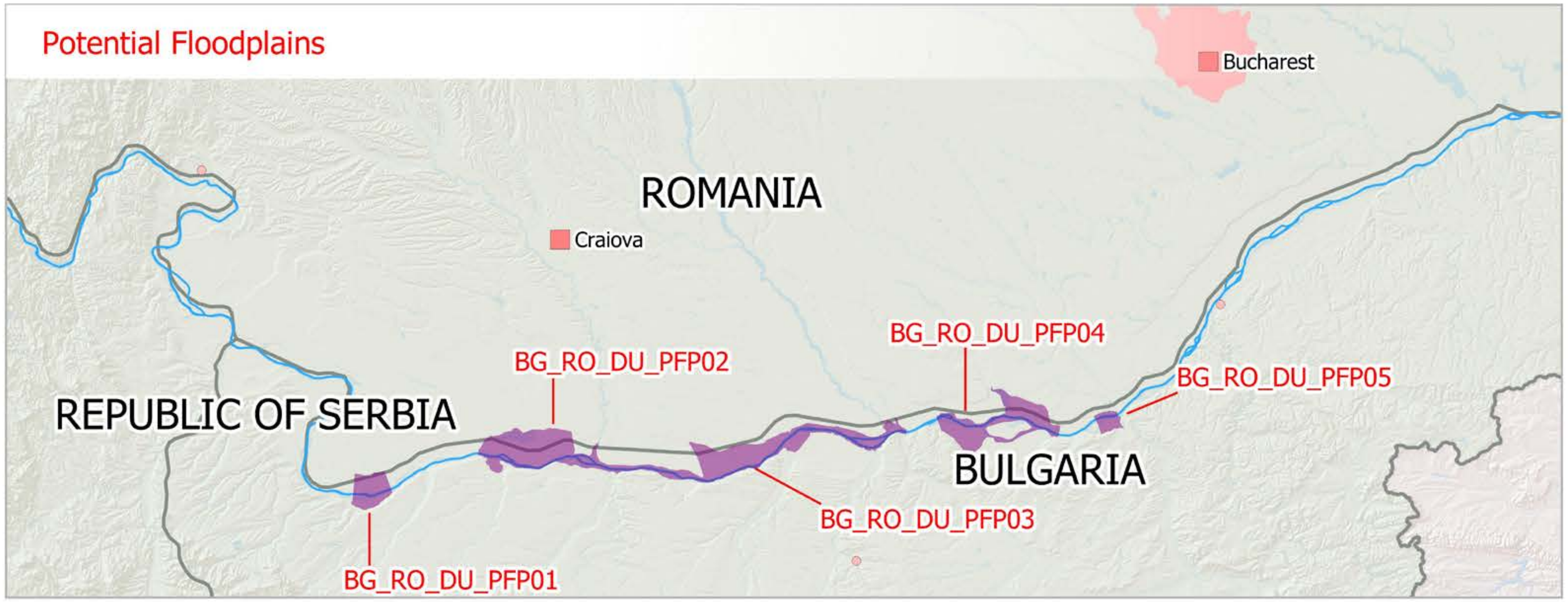
Danube Active and Potential Floodplains - Romania / Bulgaria

Interreg
Danube Transnational Programme
Danube Floodplain



Active Floodplains

DFGIS_ID	Location	Area [ha]	Rest.dem.
BG_RO_DU_AFP01	RO: Ostroveni - Bistret; BG: Kozlodui - Oreahovo	6009.3	medium
BG_RO_DU_AFP02	RO: Dabuleni; BG:Leskovet - Ostrov	3227.4	medium
BG_RO_DU_AFP03	RO: upstream from Corabia; BG: Baikal - Ghighen	2932.6	medium
BG_RO_DU_AFP04	RO: downstream from Corabia - Islaz; BG: Zagrajden - Somovit	8162.3	low
BG_RO_DU_AFP05	RO: Giurgiu; BG: Marten	2534.8	medium
BG_RO_DU_AFP06	RO: Chiselet-Dorobantu; BG: Popina	3357.8	medium



Potential Floodplains

DFGIS_ID	Location	Area [ha]
BG_RO_DU_PFP01	RO: Desa; BG: Slivata - Orsoia	8276.8
BG_RO_DU_PFP02	RO: Bistret - Bechet; BG: Dolni Tibar - Oreahovo	27972.8
BG_RO_DU_PFP03	RO: Bechet - Turnu Magurele; BG: Oreahovo - Cerkovita	30972
BG_RO_DU_PFP04	RO: Traian - Zimnicea; BG: Deagas Voivoda - Svistov	20450
BG_RO_DU_PFP05	RO: Nasturelu; BG: Novgrad	3169.1

B.4. Scenarios for restoration and preservation

In Deliverable 4.1.2 of work package 4 ("Technical document concerning the homogenization of different models, as well as the basin wide assessment of the strategy measures' impact and efficiency"), one-dimensional (1D) modeling investigations at the Danube and three tributaries (Morava, Tisza, and Sava) were conducted. For this, a model chain approach was applied, where project partners simulated in a river section the current state (CS), i.e. including all active floodplains, and the restoration scenario (RS), i.e. activating the potential floodplains (PFP) delineated in Activity 3.1 (See B.3. Active and potential floodplains - identification and evaluation). This was implemented for different hydrological scenarios or actual flood events. The results of the simulated flood peak reduction (ΔQ) and the translation of the flood wave (temporal displacement of the peak, Δt) were analyzed quantitatively and compared for each hydrological event for both scenarios. This analysis is described in Subchapter B.4.1 "Hydrodynamic Modeling of Active and Potential Floodplains".

In all other deliverables of work package 4, three restoration scenarios were investigated in five pilot areas, shown in Figure 7 (Begecka Jama, Bistret, Krka, Middle Tisza, and Morava). The scenarios are a current state scenario (CS) and two different restoration scenarios (RS1 – realistic and RS2 – optimistic). The restoration measures included e.g. dike relocation to reactivate floodplains, land use change and topographical variations in the river bed, and floodplain expansion (e.g. by reactivating old oxbows). This analysis is described in Subchapters B.4.2 (Restoration Scenarios in the Pilot Areas) and B.4.3 (Hydrodynamic Modeling in the Pilot Areas).

B.4.1. Hydrodynamic Modeling of Active and Potential Floodplains

> ⓘ **Additional info:**
>
> Deliverable D 4.1.2: Technical document concerning the homogenization of different models, as well as the basin wide assessment of the strategy measures' impact and efficiency as input for D 4.3.4 and D 4.3.2.;
>
> Deliverable D 4.3.4: Summary of used complex methodology and process description on hydraulic 1D and 2D, CBA, ESS, ecological assessment and stakeholder analysis.
>
> Deliverable D 4.4.3: Summary of general recommendations for a successful realization process, communicated to local, national, and international stakeholders in workshop activities and publications as input for D 5.2.1 and D 5.2.2.

Within the Danube Floodplain Project, a continuous one-dimensional (1D) hydrodynamic model chain was created from Neu-Ulm (Germany) to Calarasi (Romania) to assess the transboundary effect of restoration measures on the peak discharge and the wave translation during a flood event in the Danube River Basin (DRB). The continuous model along the Danube not only allows assessing local effects but also enables assessing transnational and potential superposition of effects. For the implementation of the model chain, each country along the Danube River created an individual 1D hydrodynamic model, respectively. To connect the individual models, the output of the previous upstream model was used as an input for the downstream model. Different hydrological scenarios were simulated in two scenarios for each model: first, representing a current state scenario, i.e. with all currently active floodplains; second, including potential additional floodplains identified in Activity 3.1. Additionally, the effects of restoring floodplains along the tributaries Morava, Tisza, and Sava were evaluated.

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

In the 1D model chain, the same predefined floodplains investigated by the FEM were investigated, however not separately, but in a continuous simulation along the whole river for one flood event. This means that the project did not evaluate an HQ100 peak runoff upstream of each floodplain (like in the FEM evaluation), but used a long-distance approach, with continuous varying flood magnitudes along the rivers.

All countries developed two 1D hydrodynamic models for their respective parts of the Danube River. The current state (CS) model includes all active floodplains and was calibrated with data from local authorities. The second model represents a restoration state (RS) and was developed based on the calibrated CS model. In the RS model, the determined additional potential floodplains were included. For the Austrian stretch, an already existing 2D model was applied. It also has to be mentioned that the section between the Iron Gate I and Iron Gate II was not considered within this project. The hydraulic conditions differ significantly before and after the structures and thus do not require a connection of the Serbian Danube section and the Romanian Danube section. To create one continuous model, the output hydrograph of the upstream model was used as input for the next downstream model. Similarly, a CS model and an RS model were created for the investigated tributaries. The Tisza tributary model was implemented by two countries (Hungary and Serbia). As no potential floodplains were determined in Serbia, the results from the Hungarian partner were transferred downstream in one model, i.e. CS and RS models match.

To assess the effects of additional floodplains on the peak reduction (ΔQ[35]) and the temporal displacement (Δt[36]) of the flood wave, several simulations were compared. Along the Danube model chain, nine simulations were compared (three hydrological scenarios applied to the CS and the RS models). For each of the three tributaries, six simulations were performed (three different hydrological scenarios applied to the CS and the RS model).

For the hydrological scenarios, it was decided to commonly examine the three past flood events of 2006, 2010, and 2013 with data of the respective gauges in the DRB. The three selected events have different magnitudes (HQ of flood peaks) in each Danube section, ranging from HQ_2 to larger than HQ_{100} events. The timeframe of the events was set so that the flood wave could reach Calarasi and then the peak could also decline. For tributary models (Morava, Sava, and Tisza), gauging data for different flood magnitudes (HQ_{2-5}, HQ_{10-30} and ca. HQ_{100}) were chosen by the national partners. The three HQs represent three different flood magnitudes (and corresponding return periods) and thus three different hydrological scenarios: a low, medium, and high flood event, respectively. The input for these hydrological scenarios was derived from past real events at the tributaries. In some cases, the observed flood waves are up- or down-scaled to generate the appropriate return period. The necessary input data for the model start and all lateral tributaries were obtained from national hydrological authorities.

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

Figure 7 shows an example of the modeling section analyses. In the CS model, existing active floodplains were included in the 1D model, while in the RS 1D model, the potential floodplains were additionally implemented. At the downstream border of the modeled section, the output hydrographs of the CS and RS were compared for each flood event. The difference in maximum runoff (ΔQ) and the difference in time (Δt) between the two hydrographs downstream of each potential floodplain were analyzed. Additionally, model output hydrographs of the current and the restored state at the downstream model border were compared.

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

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Danube Floodplain
www.interreg-danube.eu/danube-floodplain

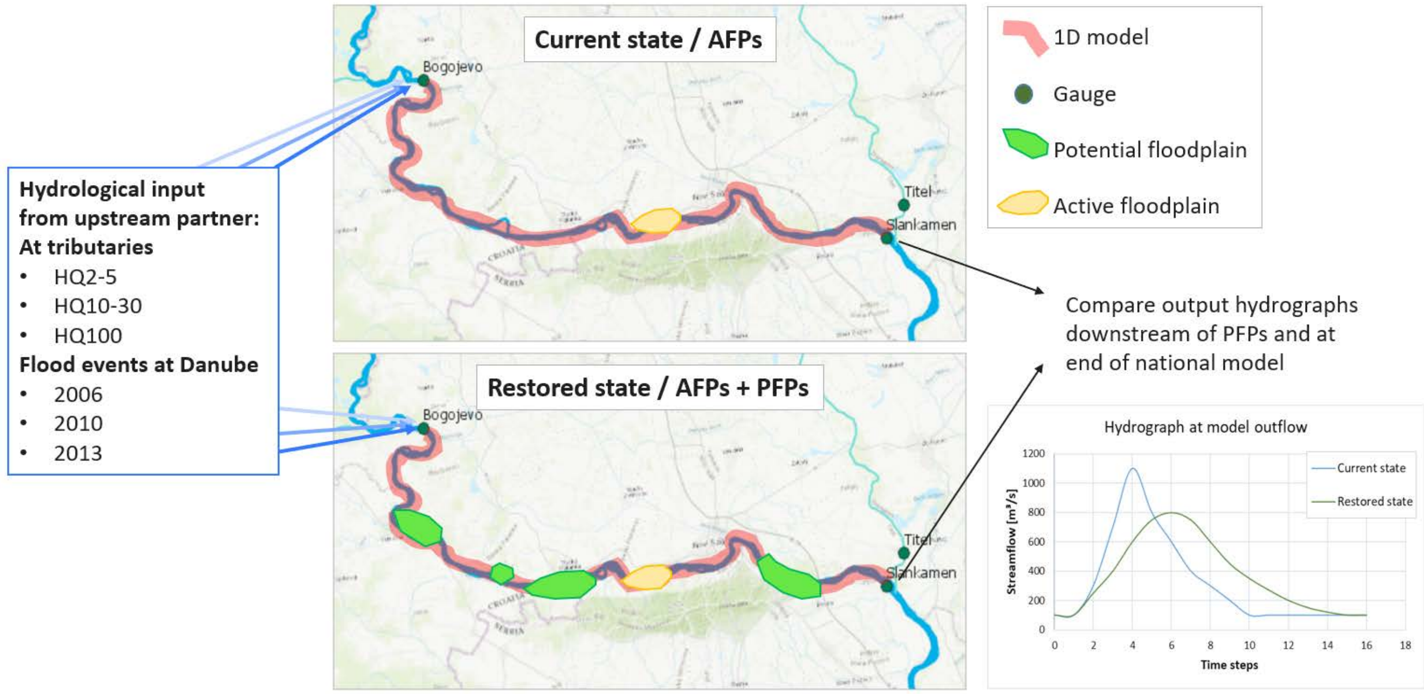

Figure 7 - Example of the current state and restored state 1D models in the sections with input and output analysis

B.4.2. Restoration Scenarios in the Pilot Areas.

1. Current State (CS)

The first scenario represents the current state of the area (CS).

2. Realistic restoration scenario 1 (RS1)

In the second scenario **(realistic restoration scenario 1; RS1)**, all planned measures are implemented, e.g., dike relocation, modification of land cover, and river geometry.

> ⓘ **Additional info:**
> In cooperation with national authorities, as well as the identified stakeholders two restoration scenarios were developed, specific for each pilot area. The planned restoration measures were discussed with relevant stakeholders on a stakeholder workshop in each of the pilot areas, including discussions on various domains like fishery, agriculture, shipping, municipal authorities, nature protection, residents, etc.

3. Optimistic restoration scenario 2 (RS2)

Furthermore, an optimistic scenario **(restoration scenario 2; RS2)** is developed, which includes more extensive measures. With this approach, the maximum capacity of flood protection obtained by restoration measures in the pilot areas without consideration of real limitations is shown.

To quantify the effects of the two restoration scenarios, simulations were conducted. A description of these is included in the next sections.

B.4.3. Hydrodynamic Modeling in the Pilot Areas

Additional info:

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

Deliverable D 4.3.4: Summary of used complex methodology and process description on hydraulic 1D and 2D, CBA, ESS, ecological assessment and stakeholder analysis.

Deliverable D 4.4.3: Summary of general recommendations for a successful realization process, communicated to local, national, and international stakeholders in workshop activities and publications as input for D 5.2.1 and D 5.2.2.

Within the framework of the “Report on the technical realization scenarios taken into consideration for modelling, the implementation in a 2D model and assessment of the impact” (Deliverable D 4.1.1), a two-dimensional (2D) hydrodynamic model has been set up for the current state scenario and the two restoration scenarios in each pilot area. The first model has been run for the current state of the area (CS) and was set up based on a recent high-resolution DEM and up-to-date ground survey data; it is the base model for the restoration scenarios models. The second 2D model has been set up for realistic restoration scenario 1 (RS1), in which all planned measures are implemented. The development of the optimistic scenario model (restoration scenario 2; RS2) includes more extensive measures. The project partners along the DRB were responsible for the creation of the 2D models for each pilot area. First, the current state model was set up, calibrated, and validated with input data requested from local authorities. After calibrating and validating the current state model, the measures of both restoration scenarios were implemented. This was done e.g., by adjusting the digital elevation model (DEM), the channel geometries, and the roughness coefficients of the models according to the planned measures. After an agreement on the explicit restoration measures in each scenario with the stakeholders, the project partners set up the three 2D models for the pilot areas[37]:

Despite the high data requirements and the high demand on computational power, hydraulic modelling is a widely applied tool to achieve spatially detailed representations of river floodplain interactions (Stone et al., 2017). To assess the effects of floodplain restoration measures on the flood hazard, hydraulic 2D-models are well suited.

For each model, three hydrological scenarios were tested. A frequent flood event (HQ2-5), a medium flood event ($HQ_{10\text{-}30}$) and a 100-year flood event (HQ_{100}) were simulated by the project partners in their pilot area models. The input data for these events were mainly taken from observed past events in the pilot areas at nearby gauging stations or up- or downscaled hydrographs of these events to fit to the selected HQ values. National hydrological authorities provided the data. The combination of the hydrological scenarios with the three restoration scenarios gives a total of nine scenarios simulated for each pilot area. The transient time series were added as input to the model in hourly time steps at the upper model boundary in the main channel. Major tributaries were considered and implemented with a steady runoff value or unsteady observed runoff time series where data were available. The lateral inflow of small magnitude was added punctually at several locations.

All investigated scenarios were analyzed with a non-steady input hydrograph, to determine the differences in the flood peak discharge, the flood wave translation, and several spatial hydraulic components. In previous studies of floodplain assessment, mostly steady-state simulations were applied, which are less demanding in terms of computational performance but do not reveal the important procedure of water expansion and retreat during a flood event[38].

The results obtained from the model runs were then evaluated regarding several hydraulic components (water depth, flow velocity, flooded area, peak discharge, stored volume, temporal displacement of the flood wave). These parameters were used to assess the impact of the restoration scenarios of the flood hazard. The complete methodology and results description can be found in the deliverable’s report “D 4.1.1: Report on the technical realization scenarios taken into consideration for modelling, the implementation in a 2D model and assessment of the impact” of the Danube Floodplain project.

[37] Danube Floodplain Project: section 4.2 from Summary of used complex methodology and process description on hydraulic 1D and 2D, CBA, ESS, ecological assessment and stakeholder analysis (Deliverable D 4.3.4 from WP4: Flood prevention pilots) accessed on http://www.interreg-danube.eu/uploads/media/approved_project_output/0001/46/74485a6e25d48c946a4f7af3a313d1a946c3184d.pdf

[38] Stone et al., 2017

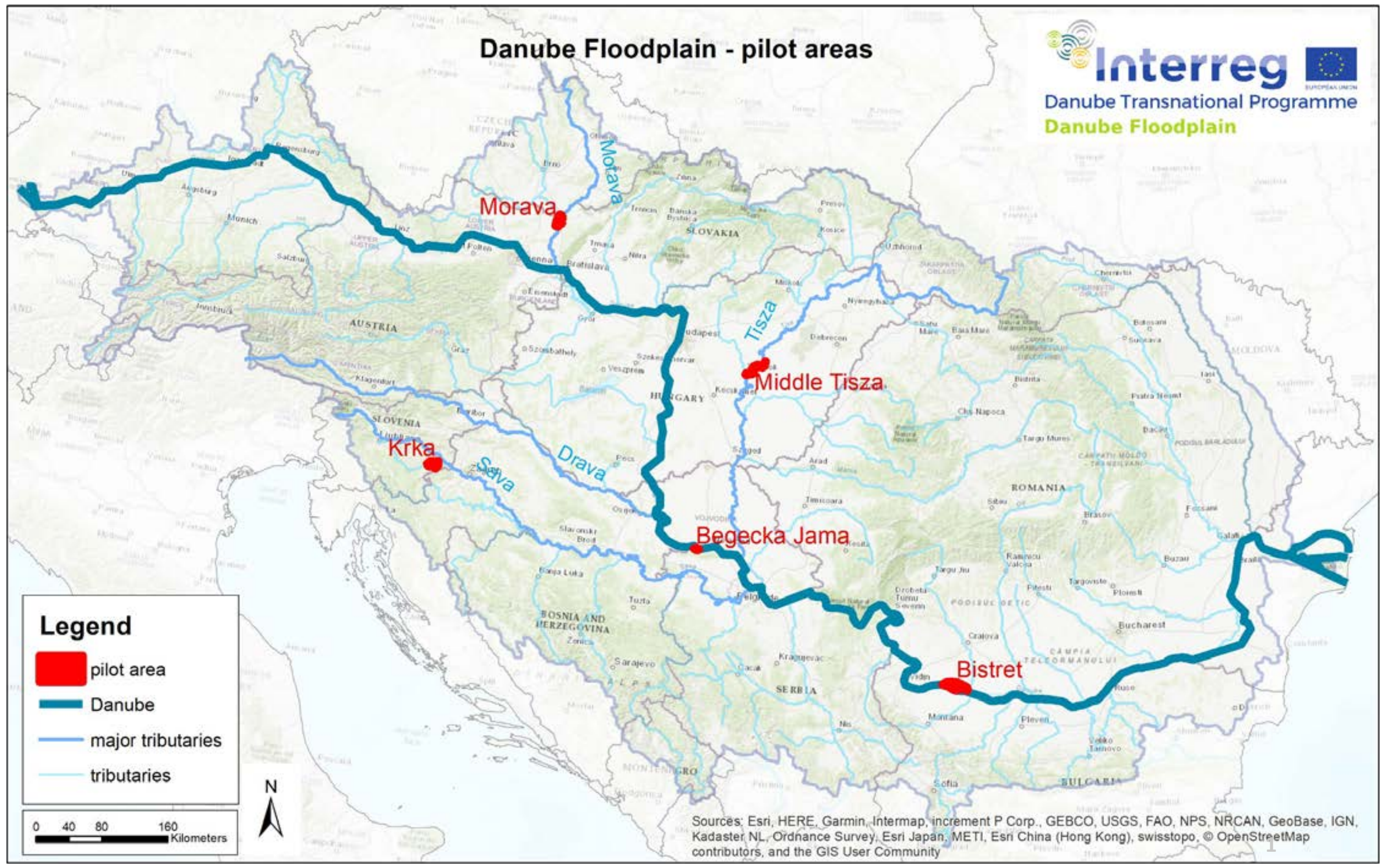

Figure 8 - The pilot areas in the frame of the Danube Floodplain project[39]

In the table below (Table 2), a summary of all restoration measures in the pilot areas for both scenarios is given. Different kinds of restoration measures, e.g., in-stream measures which change the roughness and the shape of the riverbed, alterations in the floodplain size (through e.g., dike relocation), as well as morphological and/or land cover changes in the floodplain were determined. The main purpose of the restoration measures is to re-establish natural floodplain conditions and to achieve a win-win situation for both the environment and flood protection. These measures can be also extended to other potential floodplain areas where the parameters considered in the 2D modeling are similar. Restoration measures determined (following the approach presented in the project) are not exclusives, but analyzed in the frame of specific characteristics from pilot areas, as realistic implementation scenario or/and optimistic implementation scenario.

[39] Danube Floodplain Project: thematic maps hosted on web-portal www.geo.u-szeged.hu/dfgis/

Details regarding restoration measures determined and implemented for RS1 and RS2 for the five pilot areas can be found in report *Summary of used complex methodology and process description on hydraulic 1D and 2D, CBA, ESS, ecological assessment and stakeholder analysis* from Danube Floodplain project (see section 4.2 from this Manual)[40] and *Report on the technical realization scenarios taken into consideration for modelling, the implementation in a 2D model and assessment of the impact* (see section 4.1 from this Manual)[41]. Table 2 presents a synthesis of restoration measures in the pilot area determined and implemented for RS1 and RS2.

Table 2 - Restoration measures for the pilot areas (RS1 = realistic implementation scenario; RS2 = optimistic implementation scenario)

Implementation scenarios:	**Which measures are implemented in the pilot areas? - examples -***			
	Technical works (constructions):	**Floodplain morphology restoration (land cover and lateral branches):**	**River morphology restoration (river channel geometry alteration):**	**Support measures:**
realistic implementation scenario (RS1)	- dike relocation; - controlled dike overtopping/ gaps in dike.	- modify floodplain DTM; - create and connect new lateral branches or pools / new water regime; - increase floodplain area; - increasing the roughness of floodplain (afforestation).	- increase the diversity of the river morphology/ diversity of cross profiles of the river.	- research e.g. on the role of floodplains for flood risk resilience especially under climate and land use change; - administrative and legislative measures are re-designed and barriers are replaced by incentives.
optimistic implementation scenario (RS2)	- dike relocation; - dike removal.	- modify floodplain DTM; - create and connect new lateral branches or pools / new water regime; - increasing the roughness of floodplain (afforestation); - increase floodplain area; -reconnect old oxbow.	- create fish spawning areas; - change course of river (meandering).	- research e.g. on the role of floodplains for flood risk resilience especially under climate and land use change; - administrative and legislative measures are re-designed and barriers are replaced by incentives.

* for details and other examples see *"Catalogue with "win-win" restoration and preservation measures for reaching flood protection, environmental and biodiversity objectives"* (annexed to the present Manual).

[40] Danube Floodplain Project: section 4.2 from Summary of used complex methodology and process description on hydraulic 1D and 2D, CBA, ESS, ecological assessment and stakeholder analysis (Deliverable D 4.3.4 from WP4: Flood prevention pilots) accessed on http://www.interreg-danube.eu/approved-projects/danube-floodplain/outputs

[41] Danube Floodplain Project: section 3.3 : Priority list with potential preservation and restoration areas (based on FEM-tool) from Deliverable D.3.2.1 from WP3: Floodplain evaluation, accessed on http://www.interreg-danube.eu/approved-projects/danube-floodplain/outputs

For example:

- The measure **"dike relocation"**, as technical works acting in the embankment sector, representing shifting the current dike away from its' current location (spatial translation of the location of a dike at an increased distance from the current one). In terms of an effect on river hydro-morphology it means:

  – improving the lateral and vertical (groundwater) connectivity;

  – enlarging floodplain area where sediment erosion / deposition can take place;

  – improving the lateral sediment and nutrient exchange between floodplain and river.

This restoration measure is implemented for both realistic and optimistic implementation scenarios.

- The measure **"increasing the roughness of floodplain (afforestation)"**, acts as a floodplain morphology restoration (land cover and lateral branches) measure, representing introducing trees and tree seedlings to a floodplain area. The main effect leads to increase the forest cover area in the floodplain in order to improve the water retention capabilities and to manage water velocity during high flows and sediment transportation. Afforestation implies using various native tree species in order to create a suitable habitat for species. Increasing the roughness of the floodplain helps to manage the water velocity during high flows, but also to retain the sediment. In terms of an effect on river hydro-morphology it means:

  – improving the vertical (groundwater) connectivity;

  – improving morphological condition for riparian area.

As mentioned before, further details and examples are presented in the *"Catalogue with "win-win" restoration and preservation measures for reaching flood protection, environmental and biodiversity objectives"* (annexed to the present Manual).

B.5. Cost Benefit Analyses and ecosystem services approach

Overview

ⓘ **Additional info:**

Output 4.1: Flood Prevention Measures tested in pilot areas

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

Deliverable D 4.3.4: Summary of used complex methodology and process description on hydraulic 1D and 2D, CBA, ESS, ecological assessment and stakeholder analysis.

Deliverable D 4.4.3: Summary of general recommendations for a successful realization process, communicated to local, national, and international stakeholders in workshop activities and publications as input for D 5.2.1 and D 5.2.2.

Cost-benefit-analysis (CBA) methods are useful instruments in the decision-making process and estimate the economic efficiency of alternative options, by comparing the benefits derived from an option with the associated costs[42].

The basic principle of CBA requires that a project results in an increase of societal welfare, i.e., the societal benefits generated by the project should exceed the costs of it. However, in most of the cases the benefits rely on the consideration of tangible monetary effects. The benefits include for example the decreasing of damage costs, which are often subdivided in direct costs (repair of buildings and interior damage), costs of economic activities affected (loss of crops) and indirect costs outside the flooded area (mainly due to economic activities interruption).

Among other challenges, e.g., developing and implementing a common agreed methodology for floodplain delineation, the Danube Floodplain Project faces the challenge of developing a common methodology for conducting a cost-benefit-analysis (CBA), improved with ecosystem services (ESS) assessment and evaluation. The extended CBA is the more appropriate method for evaluating public policies than a simple financial CBA, since government interventions are often related to the provision of public goods and ecosystem services[43].

This section of the Manual synthesizes the key outputs of the activities performed on the pilot areas in the framework of the Danube Floodplain Project. The key elements of this subchapter are ESS assessment and CBA including the ESS evaluations, which we will call from now on "extended CBA".

[42] ICPDR, 2015
[43] ICPDR, 2015a

For a better understanding of the process, the *Figure 9* synthesizes the workflow of the extended CBA for floodplain restoration measures in the Danube Floodplain Project. As the figure shows, three kinds of input data, which came from previous tasks, were required for conducting the extended CBA (ESS analysis and mapping, hydrodynamic modeling, and stakeholder analysis). As in a standard CBA, the costs and the flood risk were estimated. The extension of the standard CBA consisted then in the quantitative assessment and evaluation of other four ESS groups, besides flood mitigation (greenhouse gases sequestration, nutrients retention, cultivated goods, and nature-based recreation).

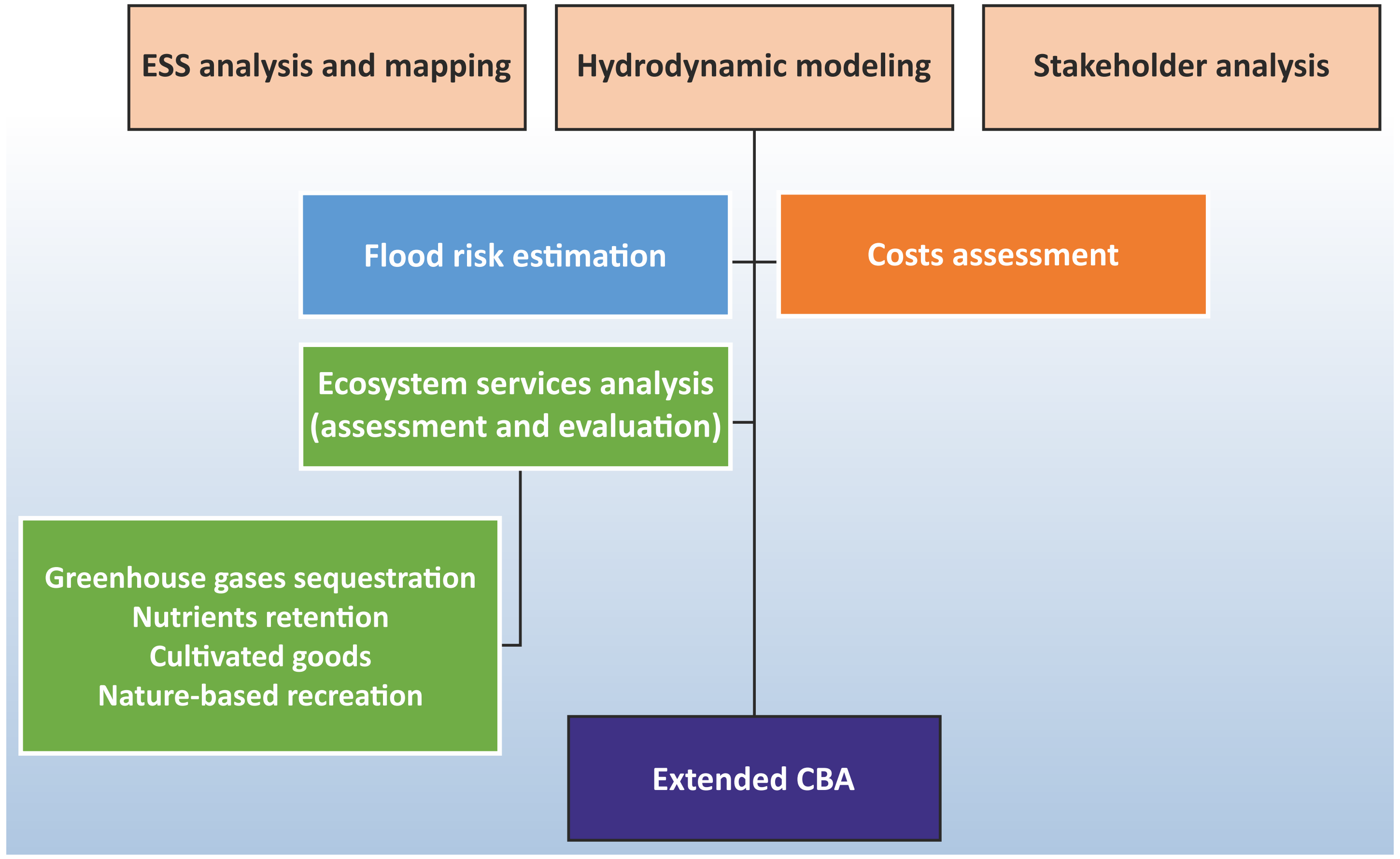

Figure 9 - Workflow of the extended CBA for floodplain restoration measures in the Danube Floodplain Project

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B.5.1. Ecosystem services. Concept, analysis and mapping

Additional info:

Deliverable 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; 2020b.

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

This section summarizes all the aspects related to ecosystem services from concept and types to estimation, mapping and assessment. One of the purposes was to find appropriate tools to integrate the ecosystem services in water management practices. It is important to distinguish between used ecosystem services on which many stakeholders rely and potential ones. At the same time, the assessment of biodiversity plays a major role as the basis for other ecosystem services.

Concept of Ecosystem Services

Ecosystems are defined as "a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit" (Convention on Biological Diversity) and are multi-functional.

The ecosystem services concept appeared during the last decades of the 20th century, being relatively new in the global context and evolving from „environmental services" concept.

The basic idea behind the ecosystem services approach is connecting humans and nature. Man, and nature mutually influence each other. Human activities have a direct or indirect impact on nature. Conversely, natural events affect society and its well-being. Thus, ecosystem services (ESS) bring direct or indirect economic, material, health or psychological benefit to people. For raising awareness in society, the most eloquent definition of ecosystem services is "the benefits people obtain from ecosystems".

The aim of using the ESS approach in the Danube Floodplain Project was to show the benefits and value of ecosystems to society and to improve the conditions for sustainable management of nature and ecosystems at the Danube River Basin.

To be able to measure, map or value these benefits, the ecosystem services are classified in: provisioning (e.g., fresh/drinking water), regulating (e.g., flood prevention and water purification), cultural (e.g., recreation or sports in the landscape) and supporting[44] *(Figure 10).*

[44] Morris and Camino, 2011

The supporting ecosystem services represent processes and functions that underpin the other three services; for this reason, they are not taken into account in the Danube Floodplain Project's approach.

PROVISIONING	REGULATING	CULTURAL
Products obtained from ecosystems, such as food, timber, clean water, energy	services provided by ecosystems that regulate our environment, such as flood prevention, water purification, crop pollination	non-material benefits obtained from ecosystems, such as recreation, sports, learning, spiritual
		

SUPPORTING
services necessary for the production of all other ecosystem services, such as soil formation, nutrient recycle

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Figure 10 - Examples of ecosystem services

Analyzing and mapping the ecosystem services

Analyzing and mapping the ecosystem services was considered in the frame of Danube Floodplain project.

The visualization of ecosystem services maps can be used by decision-makers for a wide scale of situations (land use planning, environmental impact assessment, river basin management and flood risk planning, nature protection, restoration projects, etc.).

At the same time, a coherent description and assessment of ecosystem services are mainly based on their location and extent in space and on the status of the source ecosystems, both at local, national and transboundary level.

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In most cases, local stakeholders and communities play an essential role in ESS assessment and can provide key information even potential ESS, given zonal characteristics of a certain area. Further, this knowledge is used to identify the loss and degradation of ecosystem and their services, the possible socio-economic impacts, and the measures to a sustainable development for their restoration and maintenance. This was in fact the approach of ESS assessment in the Danube Floodplain project. Stakeholders were involved from the beginning in the project. An initial list of ESS was reviewed by local stakeholders, the presence of the ESS in their pilot areas and, where appropriate, added other ESS relevant to the area.

A growing need to value and to map the provision and demand of ecosystem services appeared in the frame of Biodiversity Strategy where the European Commission stated that Member States "…will map and assess the state of ecosystems and their services in their national territory…"

Ecosystem services can be assessed in many ways: from software tools to enquiring of stakeholders using questionnaires or choice experiments, to ask residents about which ecosystem services are used in the study area or to hold the survey in the form of discussion rounds.

In the Danube Floodplain Project, ecosystem services were firstly analyzed based on stakeholders' feedbacks in pilot areas enriched with analyses on land cover/land use data from Copernicus (European Environment Agency, 2012) and additional CORINE land cover data (European Environment Agency, 2018) with the help of responsible project partners of the pilot areas (and some external experts not related to the project).

These analyses and data were georeferenced, which played a significant role in understanding ecosystem services processes and identifying the potential ecosystem services hotspots and low spots for restoration projects. For a consistent approach, the project team developed and used a scale of intensity for provisioning and regulating ecosystem services.

The intensity of services was derived from the level of details for individual ecosystems in each pilot area and the values of all ecosystem services were divided in classes using 2 approaches:

Analysis of stakeholders: the stakeholders ranked the value of used ecosystem services after restoration from 0 to 5 *(Figure 11)*. Since the measures can also result in one of the ESS no longer being provided, the benefits must be ranked zero (no benefit).

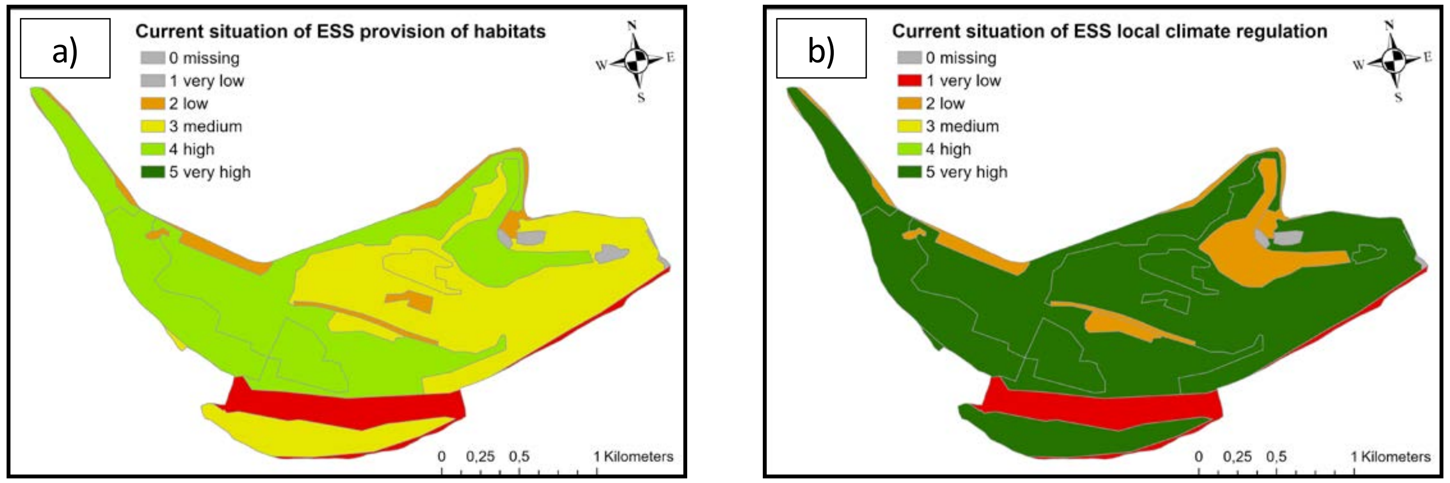
Class	0	1	2	3	4	5
Intensity	Missing	Very low	Low	Medium	High	Very high

Figure 11 - Class intensity-assessment by stakeholders

[45] Note: ESS identified in the RESI project

Several examples from Danube Floodplain project related to assessment of ecosystem services are provided bellow

In Begecka Jama pilot area ESS were assessed by the Serbian project partners with the help of local researchers and the results indicated 3 provisioning ecosystem services, 5 regulating ecosystem services and 5 cultural ecosystem services. The most complex occurrence of intensity classes is represented by the following maps:



Intensity of the ecosystem services provision Intensity of the ecosystem services local climate habitat in the pilot area Begecka Jama regulation in the pilot area Begecka Jama

Mapping by using land cover/land use data: gives an overview of all considered ESS and their definitions. By jointly classifying all provisioning and regulating ESS, areas with a particularly high provision of ESS (so-called hot spots) and also areas with a very low provision of ecosystem services (so-called cold spots) can be easily identified. The ranking values was established from 1 to 5 *(Figure 12)*.

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

Figure 12 - Class intensity using land cover/land use data

To allow comparability between the two approaches the bellow examples cover also the Begecka Jama pilot area.

According to land cover/land use types represented in the below map, the Begecka Jama pilot area is characterized by large forest areas, water bodies (part of the Danube river, lake Begec, small lake in the western part and old oxbows), with no agriculturally used areas.

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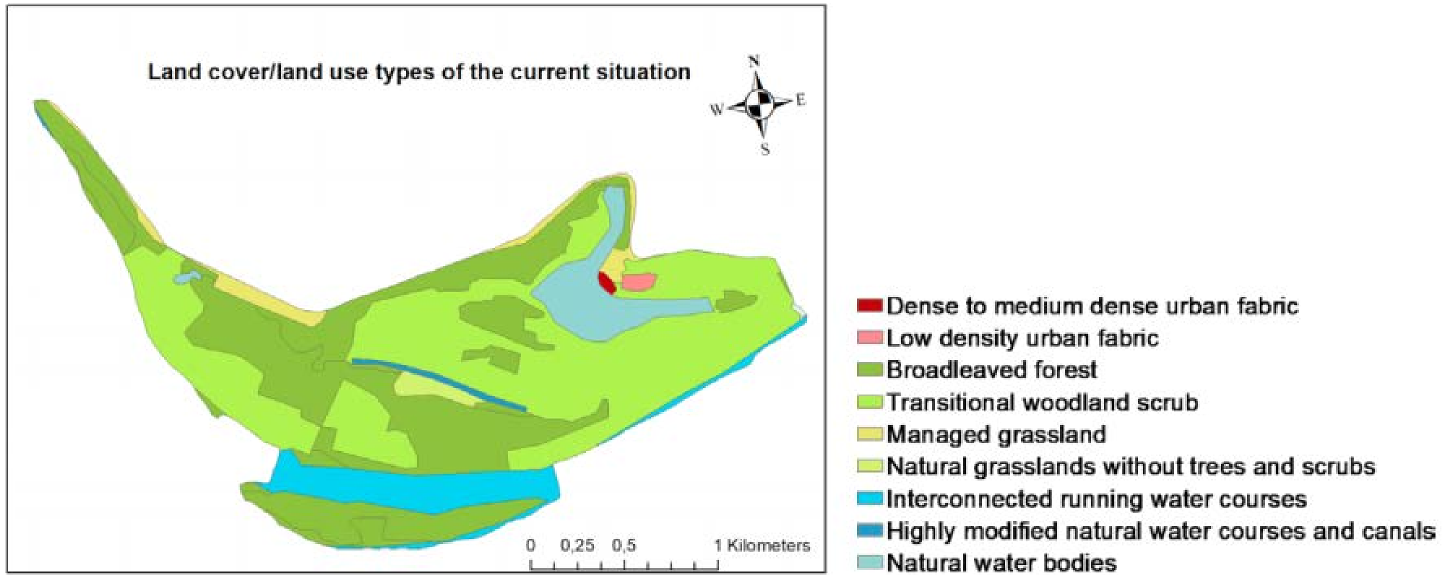
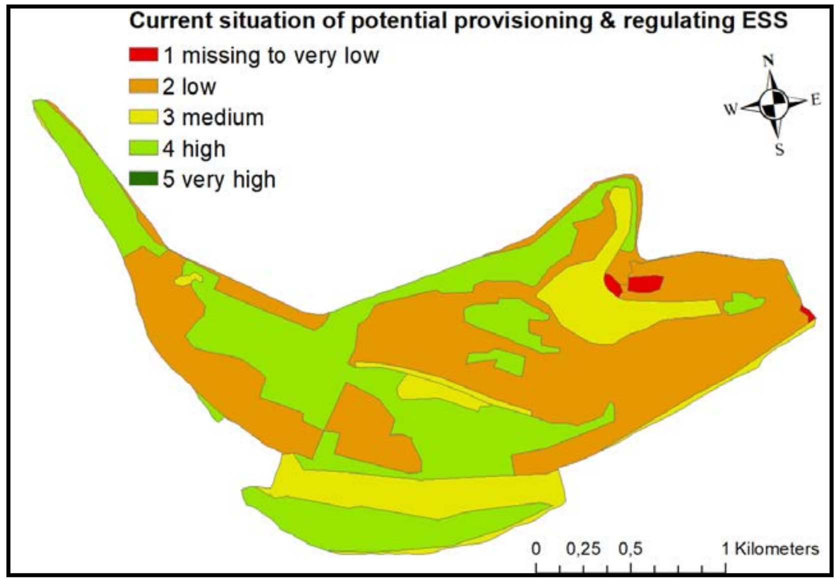


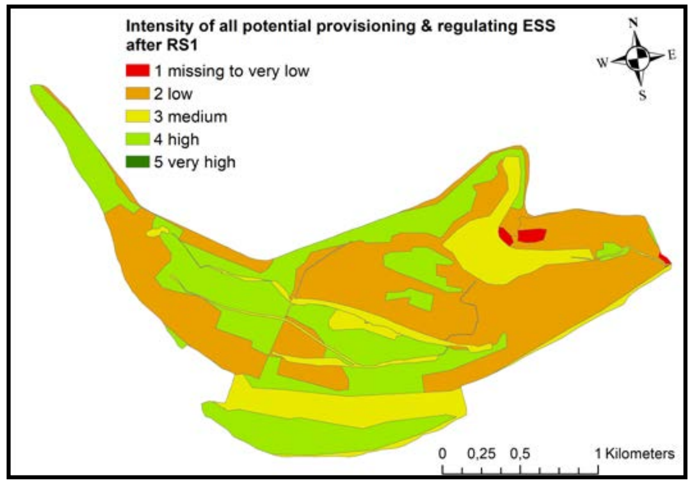
Land cover/land use types of the current situation of the pilot area Begecka Jama

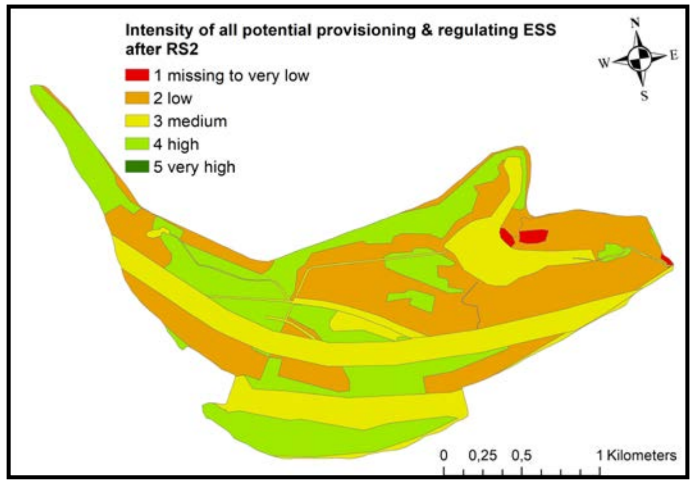
Applying the intensity scale of provisioning and regulating ESS together, in the following map it is noticeable that especially the broadleaved forest areas show a high intensity of the ESS provisioning. The land cover/land use 'Transitional woodland and shrub' or rather the hybrid poplar plantations provide only ESS on a low level. Urban areas are very poor in the supply of provisioning and regulating ESS and the different water bodies have a medium intensity



Current situation of the intensity of potential provisioning ESS and regulating ESS in pilot area Begecka Jama

After the identification of the potential provisioning and regulating ESS, the following maps present the situation after restoration scenarios RS1 (widening and cleaning of lateral branches and oxbows) and RS2 (creation of a new river channel, the widening and the reconnecting of lateral branches and oxbows):





Intensity of potential provisioning and regulating Intensity of potential provisioning and ESS after implementation of restoration measures regulating ESS after implementation of restoration of RS1 of RS2

All the ecosystem services including their definition, considered in the process of stakeholder's consultations on ecosystem services are presented in Table 3:

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ESS class	ESS	Definition
Provisioning ESS	agricultural product	All plant foods produced by agricultural cultivation
	wood	Wood for heating or creating wood products (furniture, roof trusses)
	animal product	Meat, cold cuts, milk, butter, wool, etc.
	game meat	Game meat obtained by hunting and offered for sale, like groose, duck, deer, boar, etc.
	honey	Honey and other products from the beehive
	fish	Fish or fish products offered for sale, produced by professional fishing or aquaculture
	water	Water for drinking or irrigation from surface water bodies or groundwater bodies
Regulating ESS	local climate regulation	The ability of forests and water bodies to influence local temperatures by evaporation or storing of heat under tree crown or in water bodies. In the summer months the air is cooled by evaporation, in autumn and spring the heat is stored and slowly released into the environment.
	air purification	The ability of plants to purify air by assimilation of particulates or harmful gases
	low water regulation	The ability of rivers and floodplains to reduce the risk of a river drying out due to the inflow from aquifers in floodplains or by stabilising the river water level through the roughness of the river
	flood retention	The ability of rivers and floodplains to retain or flatten flood waves. The retention volume is used by overflow/flooting.
	nutrient retention	The ability of floodplains to store nutrients (N,P,C) by uptake into stationary biomass, by deposition as sediments or to decimate nutrients by microbial degradation or respiration (in case of C).
	noise regulation	Availability of forests with undergrowth to reduce noise by reflaction of acoustic noise
	provision of habitats	Availability of habitats in typical functional and structural quality, which may be used by typical biotic communities of rivers and floodplains, which may then partially be used by humans.
Cultural ESS	recreational activity	All activities that take place in the area and lead to recreation or are carried out as a hobby, such as hiking, cycling, jogging, photography, mushroom picking, bird watching, hunting, etc.
	water related activity	All activities that are carried out in or on water bodies and are done as a hobby or for recreation, like swimming, canoeing, stand up paddling, sport fishing, etc.
	tourism	This can be special places that are visited by tourists or activities that are done by tourists, for example, hunting or fishing tourism, ports for cruise ships, hotels, summer cottages, thermal baths, historical places, etc.
	education	All activities that lead to further education for oneself or for others, for example scientific research, cultural heritage, archaelogical sites, information evants, etc.

Table 3 - Ecosystem services identified in the pilot area

Different factors were used to identify and evaluate the individual ecosystem services.

The *ESS agricultural products* was identified by means of land cover/land use classes indicating the cultivation of crops, vegetables, fruit trees, berries or wine.

Different grasslands and forest types but also water bodies were used to define the *ESS animal products.*

Grassland and forest types were used to identify and assess the ESS game meat, in some pilot areas also different water bodies.

The provision of the *ESS honey* for example was mainly assigned to grassland habitats.

Water bodies indicate the *ESS fish.* Water bodies which, due to their temporary connection with the river, only serve as spawning habitats but are nevertheless essential for fish production were also taken into account. It was assumed that rivers and lakes can be used for water supply (ESS water as drinking water or for irrigation).

Regarding the estimating the *ESS local climate* regulation of different land cover/land use types, the evaporation function was the main factor in the assessment process.

The ESS air purification was estimated according to the research of Vieira et al. (2017), where the natural structured forests with tree, shrub and herb layers generates a higher value comparing to artificial forest plantations or grasslands[46].

Groundwater recharge and evaporation rate was used for assessing the *ESS low water regulation.*

To assess the *ESS flood retention,* special attention was paid to the level of roughness of a land cover/land use type and, in the case of water bodies, to the absorption capacity of an increased runoff.

Regarding *the ESS nutrient retention* it was considered that the higher value is in natural floodplain-type habitats than in heavily fertilized or sealed areas (according to the results of the RESI project[47])

When assigning the value of the ESS *provision of habitats* to a specific habitat type, it was taken into account to which extent the habitat type is typical of floodplain and to which extent the habitat type is close to nature.

[46] C. Vieira et al. / Molecular Phylogenetics and Evolution 110 (2017) 81–92

[47] Podschun et al. 2018

B.5.2. Extended Cost Benefit Analysis

> ⓘ **Additional info:**
>
> Deliverable D 4.3.1. Report on assessment results of the CBA applied to the pre-selected pilot areas including ESS, stakeholders and biodiversity as input for 4.4.1 and therefore part of the feasibility studies in output 4.1; 2021a.
>
> Deliverable D 4.3.2. Method documentation describing the implementation of ESS and biodiversity to traditional CBA as input for D 4.3.4 and therefore of output 5.1; 2021b.
>
> Deliverable D 4.3.4: Summary of used complex methodology and process description on hydraulic 1D and 2D, CBA, ESS, ecological assessment and stakeholder analysis.
>
> Deliverable D 4.4.3: Summary of general recommendations for a successful realization process, communicated to local, national, and international stakeholders in workshop activities and publications as input for D 5.2.1 and D 5.2.2.

Overview

As it was specified in the beginning of this subchapter, CBA is a useful tool in the decision-making to estimate the profitability of different flood protection measures (alternative options), by comparing the corresponding costs and benefits.

A classical or standard CBA in flood risk management considers as benefits the avoided flood risk. Therefore, in the frame of assessing the flood risk, it is essential to estimate the potential damage that can be caused by flood events. In other words, the risk assessment creates the ground for applying a CBA, to measure whether the pay-off of investments in flood protection has a positive or negative value. This will lead to the possibility to differentiate between different flood protection measures.

Considering the flood management, a standard CBA aims at comparing the costs of measures for increasing the safety against flooding (for example dike reallocation or removal, reconnecting old arms, or even change of land use) with the estimated decrease in expected annual flood damage. Different types of costs are taken into account: investment costs, e.g., the initial costs used to implement the main changes from current to alternative state, and operation and maintenance costs, e.g., the regular costs needed to keep the desired state in good and effective quality.

In addition, for demonstrating the profitability of the floodplain restoration measures for flood risk mitigation, an extended cost-benefit analysis (extended CBA) can be used to include other ecosystem services of floodplains in the decision-making process and show their additional value. In other words, the avoided flood risk benefit as a result of the floodplain restoration measure is completed with ESS benefits as result of the same measure.

Assessment of the investment costs, net present value, and Benefits-Costs-Ratio

The water authorities estimated the costs of the investments for the realization of the potential floodplain restoration measures. The costs were divided into investment costs and maintenance costs.

In order to determine the present value, the investment costs related to restoration and the benefits of the preservation measures need to be discounted. In the CBA related to the flood context, there is a range of discount rates values recommended by different sources and in general there is a lack of consensus on the discount rate to use in ecosystem services valuation studies[48]. The European Commission for example recommends that for the social discount rate 5% is used for major projects in Cohesion countries and 3% for the other Member States[49].

However, the Danube Floodplain approach considered a 4 % rate of discount. Together with investment project life (e.g., a dike), considered to be 50 years in the Danube Floodplain Project, these parameters have been used to derive present value (PV) of the costs and benefits. The discounted values were then used in this project to estimate the benefits-costs difference and the benefits-costs-ratio (BCR), which represents the ratio between present value of benefit expected from the project and the present value of the cost of the project.

$$\mathbf{BCR=}\ \frac{\textit{PV Benefits expected from the Project}}{\textit{PV Costs of the Project}}$$

Extended Cost Benefit Analysis

The lack of information in CBA on interactions in the ecological system leads to limited results, due to the high complexity of ecosystems[50]. As a consequence, CBA needs to be completed and monetary assessment of ecosystem services represents the key input which comes to confer a higher confidence in this process. In practice, this faces several challenges, the most important being the monetization of the ESS so that they can be compared with standard costs and benefits of the floodplain restoration measure.

Evaluation of ESS

Several steps were done for the monetary evaluation of ecosystem services in the Danube Floodplain project *(Figure 13).*

[48] Hein et al., 2016 accessed on https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0164460

[49] Sartori et al., 2015

[50] Feuillette et al., 2016

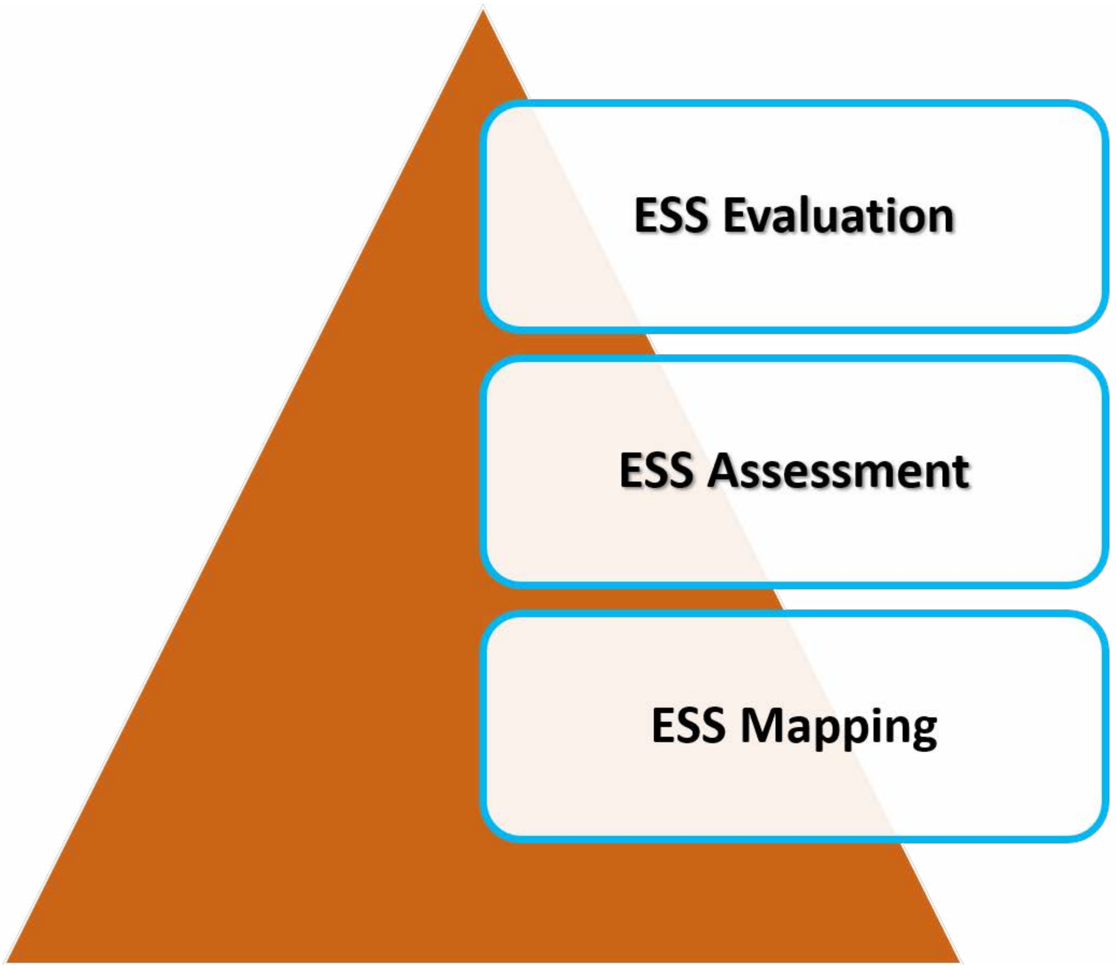

Figure 13 - Steps for evaluation of ecosystem services in Danube Floodplain project

ESS Analysis and Mapping were previously described in the *Analysis and mapping the ecosystem services* Subchapter. It is important to reinforce those local stakeholders were very helpful in determining the current provision and corresponding benefits of different ecosystem services for each the respective pilot area. *ESS Assessment and Evaluation process* is the way to show the importance of ecosystems in human life to the society. From the perspective of regional planners, it is a supporting instrument for planning the use of an area.

Several monetization instruments and techniques could be used for ESS evaluation.

Total economic value (TEV), is a concept that refers to the value derived from a natural resource. Two types of values define the TEV: 'use' and 'non-use'. 'Use values' refer to the fact that a community for example use currently or will use the environmental goods (e.g., fish, timber). Direct use values are the easiest ones to estimate, as they usually stem from products that can be traded in a market as entrants into a production process or final products. Regarding 'non-use' values, some of the benefits are not associated with any direct use but exist due to individual value, for example water quality and biodiversity in a lake[51].

Different methods can be used to assess ESS. Varying from assumptions used for different evaluation paths i.e., field survey or interviews, these methods offer a reliable support in terms of ecosystem services/benefits monetization. In general, to estimate the value of ESS, four categories of approaches exist[52]: cost-based: e.g., replacement costs; revealed preferences: e.g., travel costs; stated preferences: e.g., willingness to pay; benefit-transfer, e.g., meta-analytic value transfer functions. A detailed description of these methods can be seen in deliverable D 4.3.2[53].

In the Danube Floodplain Project, five pilot areas were subject of the extended CBA, of which four were estimated with a common methodology, allowing a comparison among the four analyses, also in terms of implemented restoration measures. In order to include the stakeholders' points of view and the results of the consultations within each pilot area a *local scale application tool – Toolkit for Ecosystem Services Site-based Assessment (TESSA)* has been used in the frame of ecosystem services assessment. A standardized GIS version of the TESSA models was created to improve the ecosystem services assessment at local level with clear advantages both for mapping of the floodplain's services and over other more time demanding software[54].

The TESSA Toolkit[55] was used as theoretical background for the ESS estimation and evaluation. In order to make it more efficient, the assessment steps were reproduced in a python code for QGIS3[56]. The expected output of ESS evaluation with TESSA *(Figure 14)* consists of singular ESS monetary values and for each scenario (Current Situation-CS, Realistic Scenario-RS1, Optimistic Scenario-RS2) and each ESS group (flood protection, global climate regulation, cultivated goods, nutrients retention, nature-based recreation). ESS maps are available for each restoration scenario, to represent the total ESS win in comparison to the current state scenario, i.e. to represent the spatial difference of the ESS sums between RS and CS. Details about each method are included in *Deliverable D 4.3.4 Summary of used complex methodology and process description on hydraulic 1D and 2D, CBA, ESS, ecological assessment and stakeholder analysis as input of D 4.4.2 and therefore of output 5.1,* whereas the results are available in *Deliverable D 4.3.1. Report on assessment results of the CBA applied to the pre-selected pilot areas including ESS, stakeholders and biodiversity as input for 4.4.1 and therefore part of the feasibility studies in output 4.1* and in *Output 4.1: Flood prevention measures tested in pilot areas*

[51] adapted from Guidance document no. 1 Economics and the environment, EC 2003
[52] Grizzetti et al., 2016
[53] Danube Floodplain. Deliverable 4.3.2. Method documentation describing the implementation of ESS and biodiversity to traditional CBA as input for D 4.3.4 and therefore of output 5.1; 2021.
[54] Perosa et al., 2021
[55] Peh et al., 2013
[56] Note: QGIS3 is a free and open-source cross-platform desktop geographic information system (GIS) application that supports viewing, editing, and analysis of geospatial data available on GitHub (GitHub, 2020).

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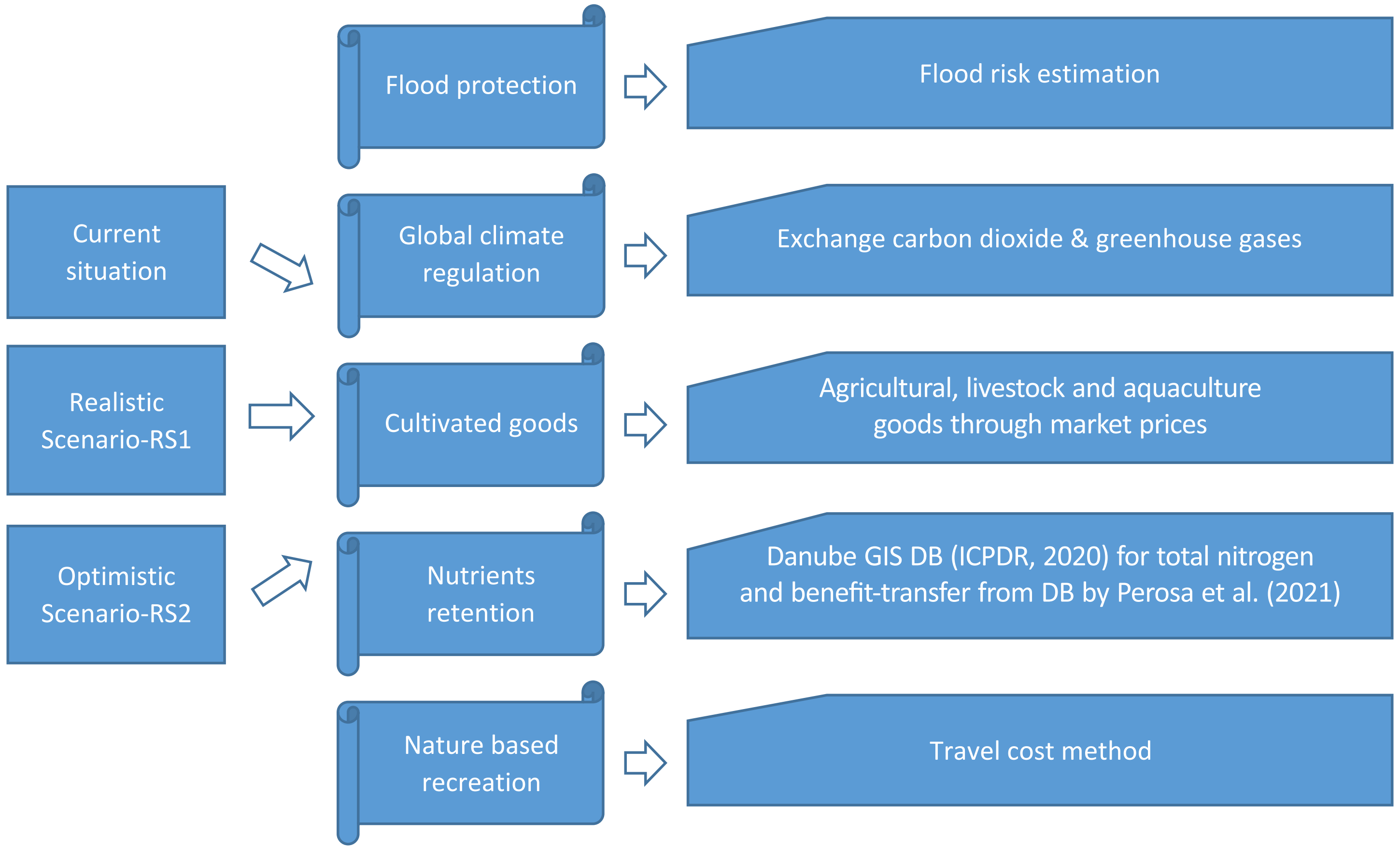

Figure 14 - ESS Evaluation through TESSA and alternative methodologies

Flood Mitigation ESS.
The *flood mitigation ESS* was estimated through flood risk estimation. The water depth maps for each pilot area resulted from the 2D hydrodynamic modeling of the three return period groups of high probability (2 to 5 years), medium probability (10 to 20 years), and low probability (100 years). A flood-caused damage has been estimated based on Joint Research Centre (JRC) damage functions[57] and applied to six land use types (residential buildings, industrial or commercial buildings, agriculture, infrastructure, transport, other), derived for the pilot areas from the CORINE land use land cover dataset[58]. In the end, the trapezoidal method for flood risk (expected annual damage) estimation[59].

Global Climate Regulation:
Carbon Storage ESS. In the context of the TESSA toolkit, the ecosystem service of "global climate regulation" refers to the exchange of carbon dioxide and other greenhouse gases between the atmosphere and the plants, the animals, and soil within ecosystems. Two blocks: the *"Carbon storage"* package and the *"Greenhouse gases"* package was subject of global climate regulation ESS in the Danube

[57] Huizinga et al., 2017
[58] EEA, 2019, accessed on https://land.copernicus.eu/pan-european/corine-land-cover/clc2018?tab=metadata
[59] Olsen et al., 2015

Floodplain Project. The carbon stocks estimation is done following the Tier 1 methodology of the IPPC reports[60].

Global Climate Regulation:
Greenhouse Gases Flux ESS. The assumption used was that the change of *carbon stocks* takes place in the tree-dominated area only. To calculate the growth of carbon stocks, the growing rates of planted trees (Mean Annual Increment, MAI, expressed in m^3/ha/yr.) were taken from the Planted Forests Database (PFDB)[61]. After obtaining the MAI, the Carbon Fraction (CF) to dry matter of wood was read (in tons carbon/tons dry matter) from table 4.3 of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories[62]. The *carbon losses* due to disturbances in the pilot area according to the suggestions of the TESSA Toolkit[63] was based on IPCC's default Tier 1 methods[64]. The procedure assumes that the change of carbon stock takes place in the tree-dominated area only. Disturbances can come from wood removals, fuelwood collection and charcoal removals, or other disturbances (e.g., illnesses, fires, etc.). Based on the previous assessments, the *net carbon sequestration* is calculated for the existing scenario (whether it is the current state scenario or any other restoration scenario). For the *Greenhouse Gases Emission and Sequestration*, the procedure for estimating the quantity of greenhouse gases (GHGs) sequestered from the atmosphere in the floodplain areas follows the steps suggested by the second part of the section on "global climate regulation" ESS in the TESSA Toolkit[65]. In the case of *drained soils,* input data used for CO2 emissions are those found in Table 2.1 of Chapter 2 of IPCC (2014)[66], which gives the appropriate default emissions factors as the annual flux of carbon as CO2 from on-site oxidation or sequestration (expressed in tons CO2 ha-1 y-1). To estimate the *emissions of CH4 due to the presence of grazing* animals in the pilot area, the procedure is divided into two sections: one for the domestic animals, and one for the wild grazers. In this case, also a reliable estimate of the number of domestic animals present and/or a population estimate for wild grazers is necessary. Therefore, the Eurostat database on was used to extract the information on the heads of domestic animals counted per hectare[67] in the NUTS2 regions[68]. Otherwise, the information was provided by the pilot area owners. Related to *CH4 emissions from wetlands,* the assessment was based on the type of wetland that characterizes the pilot area. A *shapefile* containing habitat class, wetland categories (Natural inland; Managed drained; Managed not drained), characteristics of the category (e.g., Position of the water table), presents of shunts in the wetland was created to support the assessment. The estimation of emitted CH4 from natural wetlands requires the table of the emission factors taken from the TESSA Toolkit[69], and from the IPCC reports[70].

[60] IPCC, 2006
[61] FAO, 2003
[62] IPCC, 2014
[63] Peh et al., 2013
[64] IPCC, 2014
[65] Peh et al., 2013
[66] IPCC, 2014
[67] Eurostat, 2020a
[68] Eurostat, 2019
[69] Peh et al., 2013
[70] IPCC, 2014

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The estimation of N2O *emissions from agriculture* FAO estimated data that were found on the FAOSTAT data portal[71] and on information on the agricultural land area which was extracted from the CORINE 2018[72].

The estimation of CO2 *equivalent and overall GHG flux,* all annual greenhouse gas fluxes for each separate habitat at the site was expressed in a single figure. This process was done in three steps:

1. considering the carbon sequestration from trees;

2. calculation the overall greenhouse gas flux;

3. Getting a singular value from summing all values. The corresponding monetary value of the *stored carbon and the GHGs flux* was by multiplying the estimated CO2 equivalents times the values of the CO2 emissions taxation systems documented in the report of the World Bank[73].

Cultivated goods ESS.
The estimation of *cultivated goods* ESS was divided into three parts, based on the most important (and possible to estimate) provided goods: agricultural, livestock, and aquaculture goods. In the analysis, we tried to follow the TESSA guidelines[74] as much as possible, according to the data availability. Input data for agriculture and livestock ESS provisioning come from FAOSTAT tables and for aquaculture ESS provisioning come from Eurostat tables. The basic knowledge of the *crop types* present in the pilot area was provided by the local authorities. The spatial extension of the agricultural production areas was given instead by the stakeholder ESS maps on cultivated goods. From the list of crop types, two maps per crop type published by EarthStat[75] was used. The ESS value of crop production was then estimated with the market-based valuation methodology of market prices. The necessary data are found in the "Trade - Crops and livestock products" section of the FAOSTAT database[76], which provides the producer prices per unit [USD/ton]. The estimation of *Livestock products* was based on the national data from the FAOSTAT database[77] that are then scaled according to the size of the area recognized by the stakeholders. The ESS value of livestock products is estimated with the market-based valuation methodology of market prices. The necessary data are found in the "Trade - Crops and livestock products" section of the FAOSTAT database[78], which provides the producer prices per unit [USD/ton]. The estimation of *fish species cultivated in aquaculture* was based on the national data from the Eurostat database that were then scaled according to the size of the area recognized by the ESS map.

[71] FAO, 2019
[72] EEA, 2019
[73] World Bank, 2020b
[74] Peh et al., 2013
[75] Monfreda et al., 2008
[76] FAO, 2019
[77] FAO, 2019
[78] FAO, 2019
[79] Eurostat, 2020b
[80] ICPDR, 2020

Nutrient's retention.

The estimation of nutrients retention was based on the data from the DanubeGIS[80] of total nitrogen (TN) measurements at the Danube and its tributaries and combined them with our knowledge on the presence of active floodplains in the DRB (Danube Transnational Programme, 2020). Knowledge of volume of water filtered by the floodplain per year is needed to assess nutrient retention. The approach consists of simulation of the extreme floods (HQ_2 to HQ_5, HQ_{10} to HQ_{20}, and HQ_{100}) on the related floodplain and calculation of the expected annual retention volume (EARV) with the trapezoid method.

Nature-based Recreation.

The individual travel cost method (ITCM) was applied to assess the nature-based recreation (e.g., exercising, experiencing nature, etc.) provided by the floodplain areas and their restoration. Due to COVID-19 pandemic, the method was based on interviews that were conducted online through LimeSurvey (LimeSurvey GmbH). To retrieve data on the restoration scenarios, the interviews included a section in which the respondents described their potential reaction to the hypothetical floodplain restorations.

As an example of the results of ecosystem services evaluation in the Danube Floodplain project, we present Figure 15 for the pilot area of Begecka Jama. From both maps, we observe that the regions with the highest increase in ESS value per unit area are the ones directly affected by the floodplain restoration.

As a consequence of the ESS evaluation, the extended CBA justifies the implementation of at least one restoration measure of three out of four pilot areas in the Danube Floodplain Project. All these scenarios would not be categorized as profitable if evaluated with a standard CBA. With an extended CBA, we brought further evidence in favor of floodplain restoration measures to be implemented for the general benefit of the communities.

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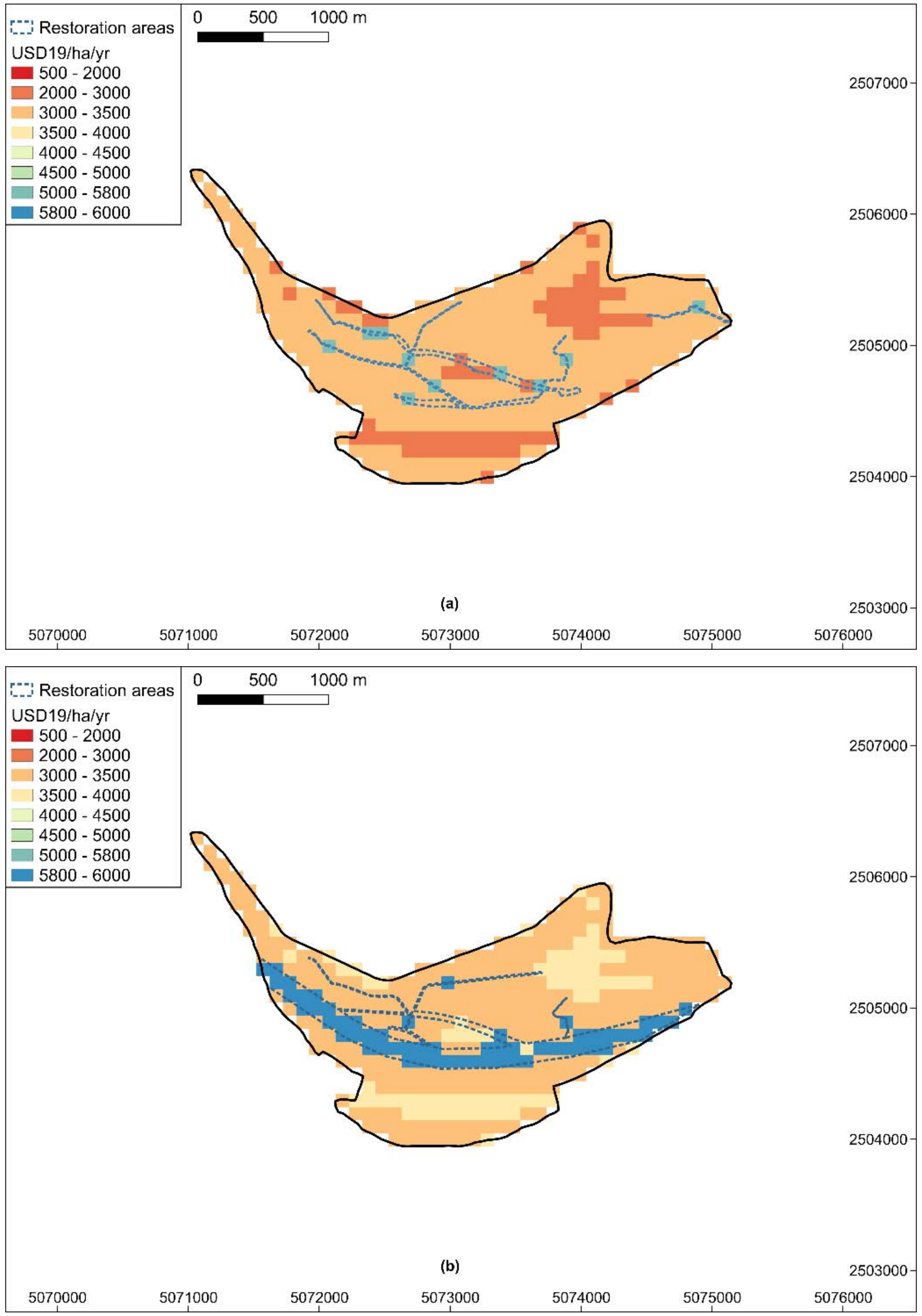

Figure 15 - Map of the sum of ESS added value (excluding carbon storage) of the floodplain restoration measure by unit area (homogenized to USD2019/ha/yr) in Begecka Jama for RS1 (a) and RS2 (b) restoration scenarios. Adapted from Perosa et al. (2021b).

Regarding the modeling of ecosystem services, it can be concluded that researchers should develop new methodologies, by including and evaluating other ESS which are not subject of the commonly used ESS assessment guidelines (TESSA) or software (InVEST, ARIES, etc.), such as groundwater recharge or noise regulation. Furthermore, a better interpretation of the results might be given by analyzing the ESS uncertainties. In this respect, monitoring of the implemented restoration measures could confirm or discard the ESS assessment results.

B.6 Habitat modeling

ⓘ **Additional info:**

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; 2020c.

Deliverable D 4.3.4: Summary of used complex methodology and process description on hydraulic 1D and 2D, CBA, ESS, ecological assessment and stakeholder analysis.

Deliverable D 4.4.3: Summary of general recommendations for a successful realization process, communicated to local, national, and international stakeholders in workshop activities and publications as input for D 5.2.1 and D 5.2.2.

The general aim of the habitat modeling work within the Danube Floodplain Project was to evaluate whether a certain floodplain restoration measure is capable of improving typical floodplain habitats. Such prediction was made based on environmental co-variables, like water depth, flood duration, flow velocity[81,82], etc. At the basis of the method, there is a conceptual understanding of how these environmental factors influence habitats and the species living in them. Therefore, quantitative formulations were made to link habitats and environmental variables[83].

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

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

Floodplain meso-habitat	Habitat characteristic
Channel	Patch with permanent inundation and high depth and flow velocity even during minor
Laterally connected oxbows and oxbows	Patches formed by former meanders and laterally connected to the recent main channel from at least one side
Ponds and only vertically connected backwaters	Patches formed by depressions filled with water without direct surface connection to the river channel
Laterally connected floodplain	Patches of the floodplain flooded by surface water during minor flood events (HQ2-5)
Aquatic-terrestrial transition zones	Patches at the interface of channel and floodplain with low slope and high flood duration during minor flood events (HQ2-5)

As an output of the analysis, we learned that reducing the connectivity between channel and floodplain is the major threat of floodplain ecosystems in the Danube Basin. The approaches to achieve lateral connectivity in pilot areas are different. The most common measure is the relocation of dykes, others are the creation of connection channels or the modification of channel planform.

The results of meso-scale biodiversity assessment in the pilot areas showed that floodplain habitats, and thus biodiversity, can benefit from increasing the lateral connectivity, as intended by the majority of restoration scenarios. However, while the assessment on the meso-scale shows the general tendency for the development of habitats, a microscale analysis could have given insights on the level of species or specific communities. Still, this requires in-depth knowledge of the setting and cannot be obtained without extensive fieldwork.

[81] Guisan and Zimmermann, 2000
[82] Maddock et al., 2013
[83] Danube Floodplain Project. DANUBE FLOODPLAIN OUTPUT 4.1: FLOOD PREVENTION MEASURES TESTED IN PILOT AREAS; 2021

B.7. Tools for assessing restoration projects

> ⓘ **Additional info:**
>
> Danube Floodplain. D 4.4.2. General evaluation tool based on table calculation or GIS software for possible later assessment of other restoration projects ensuring a simplified and standardized assessment of such projects, which is described in the manual (output 5.1), 2021

A general evaluation tool for assessing floodplain restoration projects was developed in the Danube Floodplain project. This chapter gives an overview about the FEM-Tool in its basic form as a Microsoft Excel Tool working with Macros. The FEM-Tool has been be further developed in the additional Work Package 6 of the Danube Floodplain project and integrated in a *QGIS software* as plug in. It is recommended to use the upgraded FEM-Tool, which is described in Deliverable D.6.1.1. and can be downloaded using this link:

https://github.com/boku-iwa/Floodplain-Evaluation-Matrix-Tool.

The upgraded FEM-Tool allows to: automatically delineate active floodplains; calculate some FEM-parameters; store the results of the FEM, stakeholder analysis, ecosystem services, habitat modelling; determine if a restoration project/measure is recommended based on the FEM-results and create factsheets for each floodplain. For the basic and the upgraded version, the overarching principles are the same and described in this chapter. In the D 6.1.1, you find a detailed manual for the upgraded FEM-Tool. The overarching principles of the tool are the same in the basic as well in the upgraded version and described in this chapter.
The FEM-Tool (D.4.4.2) uses 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. *Figure 16* shows an overview about all possible input data that can be included in the FEM-Tool.

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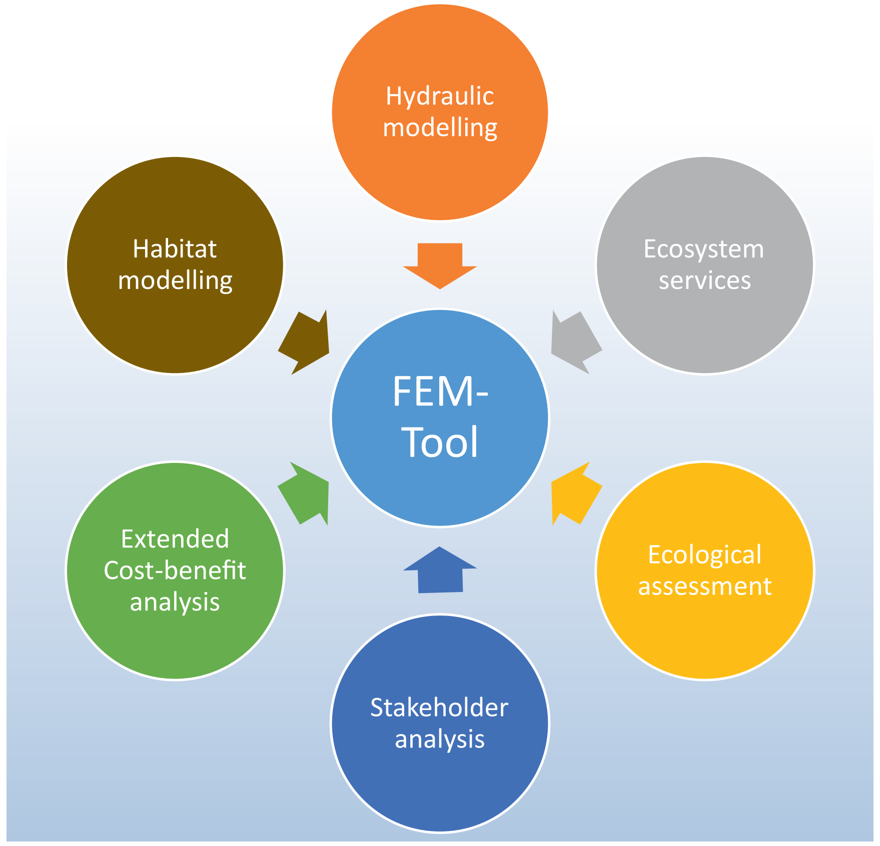

Figure 16 - Overview about possible input data in the FEM-Tool

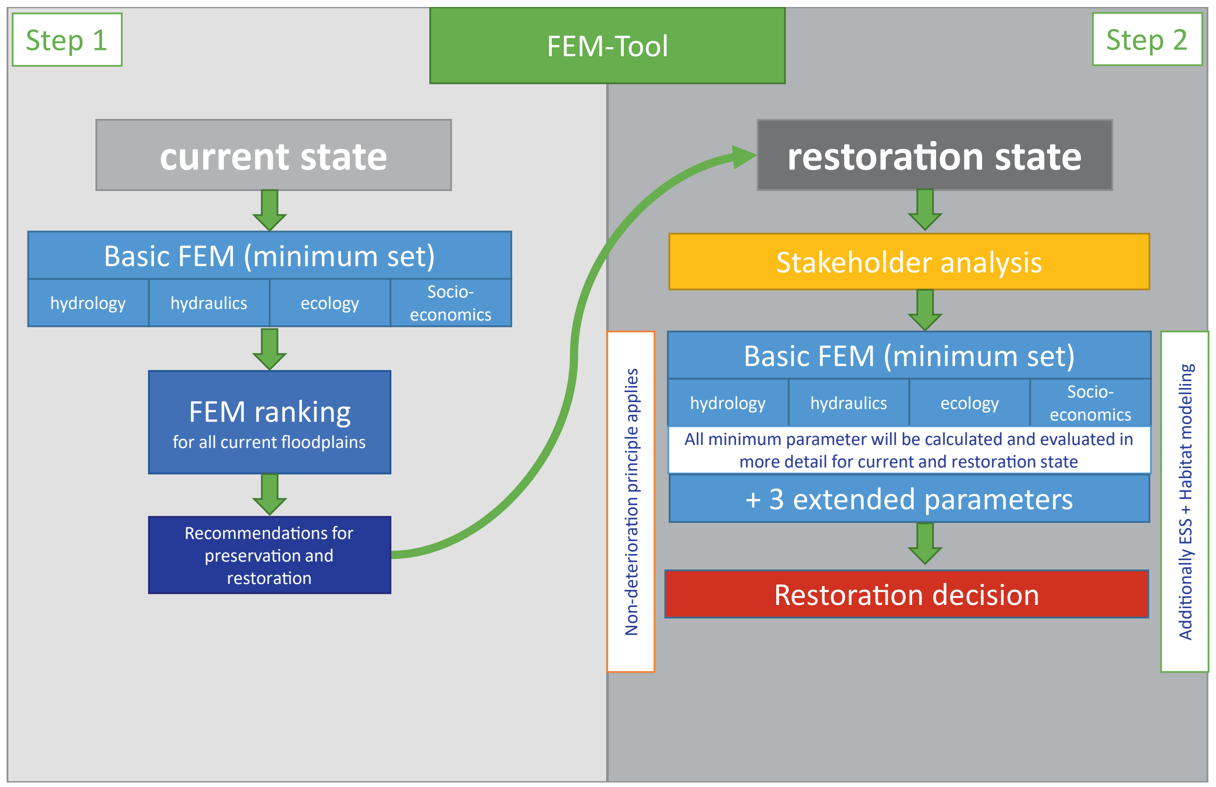

Figure 17 - Steps for evaluation of a restoration project with the FEM-Tool

The FEM-Tool offers the possibility to enter all relevant input data and proceed the FEM results leading to a recommendation if a restoration project should implement or not. The basic form of the FEM-Tool was created in Microsoft Excel. Macros are used to proceed the entered input data automatically.

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 17* a schematic overview including the workflow of the FEM-Tool is shown.

The first step of the FEM-Tool is assessing the current state of an active floodplain with the FEM method. In B3, the FEM method and the methodology for the identification of active/potential floodplains are shortly described. In D.3.2.1[84], a more comprehensive description is presented.

The current FEM-Tool is based on Microsoft Excel and works with Macros proceeding the entered input data automatically. In the general settings, the river name, country, editor and date of the analysis can be entered. Next, it is noted that all active floodplains along the river should be identified using the method described in D.3.2.1 *(Table 6)*. The number of identified floodplains has to be entered and then additional floodplain sheets are created automatically according to the number of floodplains. In the created floodplain sheets, the floodplain code, name and results for the FEM analysis of the current state can be entered *(Table 5)*.

[84] Danube Floodplain Project: Priority list with potential preservation and restoration areas (based on FEM-tool) - Deliverable D 3.2.1 from WP3: Floodplain evaluation, 2019, accessed on http://www.interreg-danube.eu/approved-projects/danube-floodplain/outputs

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Table 5 - Input mask of the floodplain sheets for the FEM results of the current state (the FEM results are only exemplary)

FEM TOOL			
Floodplain Evaluation Matrix Tool			
Floodplain 1			
Code: DU_AFP_01		**Name:**	
Minimum Parameters			
Parameter	***Value***	***Unit***	***FEM-Evaluation***
Hydrology			
relative peak reduction ΔQrel:	3.00	%	5
flood wave translation Δt:	250	min	3
Hydraulics			
water level change Δh:	64	cm	5
Ecology			
connectivity of floodplain water bodies:	3	-	3
Existence of protected species:	36	Nr	3
Socio-economics			
Potentially affected buildings:	2	Nr/km²	3
Land use:	4.1	-	5
Restoration project	No		

It is possible to choose a floodplain ranking and restoration project in two drop-down lists (Table 6). If a floodplain ranking (Table 8) is desired, an additional sheet called “Ranking” will automatically be created. If a restoration project is evaluated, the additional input masks for a description of the restoration project (Table 9), stakeholder analysis (Table 10), restoration project evaluation (Table 11), ecosystem services (Table 12), and habitat modelling (Table 13) are displayed in each floodplain sheet. The different input masks will be explained in detail in this chapter.

Table 6 - Input mask for the general and specific settings of the FEM-Tool

FEM TOOL Floodplain Evaluation Matrix Tool	
Settings	
General	
River:	
Countries:	
Editor:	
Date of Analysis:	
Please identify all active floodplains at the river by using GIS software or maps. Decide wether you want to do a ranking and/or restoration projects at the floodplains. Please change the FEM parameter thresholds if necessary. For a detailed FEM parameter description please have a look at the FEM Handbook.	
Specific	
Number of identified floodplains:	10
Floodplain ranking:	Yes
Restoration projects:	Yes

For assessing the current state and the performance of an active floodplain, the minimum set of FEM-parameters is used. The thresholds can be selected for each river individually under consideration of specific characteristics of the river and its floodplains. In Table 7, the selected thresholds for the Danube River and the input mask in the FEM-Tool are shown as an example. The FEM-Tool allows the user to set these thresholds on its own (Table 4).

Table 7 - Input mask in the FEM-Tool and the used thresholds in Danube Floodplain for the Danube River to determine the performance (low, medium, high) of the minimum FEM-parameters

Thresholds			
FEM Parameter	***Low (1)***	***Medium (3)***	***High (5)***
peak reduction ΔQrel:	< 1.00 %	1% - 2%	> 2.00 %
flood wave translation Δt:	< 1 h	1 - 5 h	> 5 h
water level change Δh:	< 10 cm	10 cm - 50 cm	> 50 cm
connectivity of floodplain water bodies:	1	3	5
Existence of protected species:	< 1	20	> 40
Potentially affected buildings:	> 5.0 n/km²	5 - 1 n/km²	< 1.0 n/km²
Land use:	< 2	2 - 4	> 4

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After determining the performance, the need for preservation and the demand for floodplain restoration can be evaluated (see B3 and D3.2.1[85] from Danube Floodplain project). The FEM-Tool allows the user to set the thresholds for the restoration demand on its own. Based on the selected thresholds and the FEM results the active floodplains are ranked. In the tool, the need for preservation as well as the restoration demand are automatically determined in the Ranking sheet (Table 8), which is created if a ranking is desired and chosen in the general settings (Table 6).

Table 8 - FEM ranking including need for preservation and restoration demand

FEM TOOL Floodplain Evaluation Matrix Tool										
		Hydrology		Hydraulics	Ecology		Socio-Economics			
	Floodplain	peak reduction ΔQrel	flood wave translation Δt	water level change Δh	connectivity of floodplain water bodies	Existence of protected species	Potentially affected buildings	land use	Need for Preservation	Restoration Demand
1	DU_AFP_01	5	3	5	3	3	3	5	Yes	Medium
2	DU_AFP_02	1	1	1	3	5	5	5	Yes	high
3	DU_AFP_03	3	5	5	1	3	3	5	Yes	Medium
4	DU_AFP_04	5	5	5	5	5	3	3	Yes	low
5	DU_AFP_05	1	1	1	3	5	5	5	Yes	high

Followed by the evaluation of the current state of the floodplain and the ranking with the FEM method, the restoration project and its effects are assessed. First, the restoration project and the selected measure can be described (Table 9).

Table 9 - Input mask for the description of the restoration project including the selected measure

Restoration project	
Description of restoration project:	
Selected measures:	

After the description, the stakeholder analysis starts, where all the affected stakeholders should be listed and their interest and power (high, medium, low) determined. Planned measures for the stakeholder involvement should be described as well.

[85] Danube Floodplain Project: Priority list with potential preservation and restoration areas (based on FEM-tool) - Deliverable D 3.2.1 from WP3: Floodplain evaluation, 2019, accessed on http://www.interreg-danube.eu/approved-projects/danube-floodplain/outputs

Table 10 - Input mask for the stakeholder analysis in the FEM-Tool

Stakeholder analysis			
Name of organisation	(General) Type of stakeholder	Interest	Power
	National public authorities Regional public authority Local public authority Sectoral agency Interest groups including NGOs Higher education and research International organisation General public		

Measures planned for the Stakeholders	
Name of organisation	Measure description

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. Besides the cost-benefit parameter, in this example, the sediment balance as a hydraulic parameter and the water level dynamics as an ecological parameter were chosen as additional parameters. The FEM results, assessed with the more detailed data sets after the restoration, are compared with the FEM results of the current state (Table 11). 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.

Table 11 - Input mask for comparing the current FEM results with the results after the implementation of the restoration project (the FEM results are only exemplary)

Restoration Project evaluation					
Parameter	*Value Current State*	*Value Restoration State*	*Unit*	*FEM Current State*	*FEM Restoration State*
Hydrology					
peak reduction ΔQrel:	3	4	%	5	5
flood wave translation Δt:	250	330	min	3	5
Hydraulics					
water level change Δh:	64	54	cm	5	5
Sediment balance:	0.4	0.5	-	3	3
Ecology					
connectivity of floodplain water bodies:	40	42	%	3	3
	6	8	days		
Existence of protected species:	36	47	Nr	3	5
Water level dynamics:	3	3	-	3	3
Socio-economics					
Potentially affected buildings:	2	3	Nr/km²	3	3
Land use:	4.1	4.2	-	5	5
Cost-Benefit-Ratio:		0.6	-		3
List of non-monetarised benefits:					
Restoration recommendation:			**Yes**		

The floodplain's ecosystem services can also be assessed and entered into the FEM-Tool (Table 12). It should be assumed for this analysis that the restoration project is implemented. In Deliverable D.4.2.2[86], the results of the ecosystem services assessment in the Danube Floodplain project are presented and the methodology is described.

Table 12 - Input mask for the ecosystem services in the FEM-Tool

Ecosystemservices					
Category	ESS	Intensity	Percentage of total Area	Intensity (Restoration)	% of area (Restoration)
Provisioning ESS	agricultural product				
	wood				
	animal product				
	game meat				
	honey; beehive products				
	fish or fish products				
	water (drinking, irrigation)				
Regulating ESS	local climate regulation				
	air purification				
	low water regulation				
	flood retention				
	nutrient retention				
	noise regulation				
	provision of habitats				
Cultural ESS	recreational activity				
	water related activity				
	tourism				
	education				

The results of a habitat modelling can also be summarized in the FEM-Tool, as shown in Table 13. In Deliverable D.4.2.3[87], the habitat modelling at pilot sites along in the Danube region is summarized and described.

[86] 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; 2020
[87] 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; 2020

Table 13 - Input mask in the FEM-Tool for results from a habitat model

Habitat Modelling					
Percentage of lateral connection during an HQ2-5:			**Curent State**	**Restoration**	
					%
Habitat type	**Area [ha]**	**Flow velocities**		**Area [ha] (Restoration)**	**Flow velocities (Restoration)**
Floodplain					
Backwater					
Channel					

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.

B.8 Key stakeholders' involvement their role and contribution

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

An efficient and sufficient communication between project partners on one side, and stakeholders from the area of the considered floodplains (especially on the pilot sites) on the other side, proved to be essential for the positive outcome of the Danube Floodplain project. Through the preparation phase of the pilots and their feasibility works and also in any other similar projects, that is the way to gain as much as possible opinions, remarks, and suggestions about the circumstances, open issues and obstacles on the local level. Not to discuss them timely can cause postponing or even prevent the implementation of any projects and their measures for flood risk reduction, prevention of the habitats, and water protection.

The planned measures affect a wide range of stakeholders, including landowners and residents. Therefore, their interest in the project's pilots was particularly high and it was important to get these stakeholders enthusiastic about the measures. In addition, the knowledge of the stakeholders was used to record and evaluate the ecological, economic, and cultural values of the pilot areas with the aid of the ecosystem services approach.

Identification of Stakeholders

- Who benefits from the pilot area?
- Who is active ion the pilot area or is familiar with the pilot area?
- Who benefits from the pilot area?
- Who has knowledge of the ecological situation of the pilot area?

Among stakeholders, we could find for example, local residents, water authorities, nature conservation authorities and associations, and representatives of agriculture, fishery, and tourism. Residents often have a good knowledge of the area and their traditions, and could thus give an overview of the economic, environmental, and cultural situation. To identify other stakeholders, the experience from the "River Ecosystem Service Index (RESI)" Project was used[88].

Figure 18 - Stakeholder target groups

Within this project, a list of 25 relevant ecosystem services of German rivers and floodplains were generated along with the identification of relevant stakeholders associated with these services. The identified stakeholders were finally assigned to eight target groups *(Figure 18)*

Stakeholder Engagement

The workshops conducted at the level of the pilot areas enabled everyone to expand their knowledge of the pilot areas and their understanding of different uses. The acquired knowledge and understanding of other sectors can help in the later planning and implementation of flood protection and restoration measures. Nevertheless, not only authorities benefitted from the events. The community representatives were also able to discuss their concerns with those involved in the pilot site projects and who will later implement the measures. This, in turn, is of great interest to the project planners. The participants of the workshops benefitted in several ways, e.g., by receiving knowledge from other areas, by expressing their interests, by having the opportunity to expand their network, and by getting in contact with the authorities implementing the measures.

[88] Podschun et al., 2018

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The assessment of ecosystem services supported the stakeholders to engage with topics outside of their interest fields. For example, representatives from the different water authorities also dealt with the forestry use of the riparian forests bordering the river or with the cultural offerings of the region. Such an approach contributes decision-makers and stakeholders alike to understand that the management of flood waters can alter the various processes which drive functions and subsequent ecosystem service delivery.

Restoration and preservation measures was also a subject of discussions with the relevant stakeholders. In this way it was possible to derive and implement sustainable solutions to flood risk management options. By involving as many stakeholders as possible, restoration measures can be evaluated from a wide range of perspectives. This allows to identify and address issues that might not have even been recognized in advance.

The stakeholder engagement needs to have its own strategy in all separate projects. Different tools and different level of involvement could be necessary, which highly depends among others on the scale of the restoration, the number of stakeholders and on the level how they are affected. This approach was started during the implementation of the pilot sites' actions of the Danube Floodplain project, but the full list of necessary actions has not been implemented yet. The further steps could be done during the finalization of the works on the pilot areas, since many of the stakeholder involvement activities are to be implemented continuously.

As a conclusion it is undoubtable that floodplain restoration affects a wide range of stakeholders and interests[89], making it potentially highly controversial. Ensuring an optimal balance between the multiple services a floodplain can provide as a result of restoration measures, to humans and the wider natural environment, requires agreement between many actor groups spanning a variety of policy fields.

[89] Adams and Perrow 1999:94-95; Adams et al. 2004; Turner et al. 2000:13-14; Adger and Luttrell 2000:78

Part C – Catalogue of "win-win" restoration and preservation measures for reaching flood protection, environmental and biodiversity objectives

General considerations

Floods are best dealt with at river basin level, with a range/combination of measures limiting run-off, slowing river flow, allowing case-by-case floods to expand into natural and agricultural land and protecting vulnerable assets.

The traditional engineering solutions (like dams, channelization, protection walls, dikes etc.) related to flood risk management may deliver the expected results in terms of flood protection but on the other side have a significant negative effect on aquatic ecosystems and biodiversity. Traditional engineering solutions (grey measures) are resilient and sustainable to some extent. Grey infrastructure solutions, i.e., hard engineering structures, deal with the flood risk problem in an isolated and unilateral manner commonly neglecting ecological aspects. However, these structures are inevitable flood defense solution especially in case of urban areas. At the other hand, floodplain restoration and preservation can significantly contribute to the flood protection bringing benefits from the floodplain related ecosystem services as well.

Natural Water Retention Measures (NWRM) are measures that aim to safeguard and enhance the water storage potential of landscape, soil, and aquifers, by restoring ecosystems, natural features and characteristics of water courses and using natural processes[90]. Implementing these measures will support green infrastructure[91], improve the status of water bodies, and reduce the vulnerability to floods and droughts.

There are a wide range of advantages of NWRM, through using green infrastructure over traditional, grey infrastructure, like functioning in the long run without too much maintenance, the ability to simultaneously deliver multiple benefits and higher resilience to natural hazards (flood or seismic risks). Green Infrastructure consists of land management or engineering measures which use vegetation, soils, and other natural materials to restore the natural water retention capacity of the landscape.

Floodplain restoration and preservation measures are among the most well-known NWRM. They have multiple benefits such as: increasing the water storage, flood peak reduction, recycling of nutrients and habitat enhancement for aquatic species, and other species found in the floodplain, such as floodplain-typical plant species (reed bed, softwood tree species, ...improving the biodiversity. Activities such as fishing and recreation will increase and therefore the well-being of peoples from and nearby the floodplain area.

[90] https://ec.europa.eu/environment/water/adaptation/ecosystemstorage.htm
[91] https://ec.europa.eu/environment/nature/ecosystems/strategy/index_en.htm

Of course, there are a significant number of specific literature and websites related to floodplain restoration and preservation measures. Therefore, the Catalogue does not propose to address in the same way or formats to what is already available, but to comprise the key activities and results of Danube Floodplain project. The Catalogue is a living document, the restoration measures are not addressed in an exhaustive way and could be updated based on a variety of stakeholder's experience.

About the Catalogue

The Catalogue of "win-win" floodplain restoration and preservation measures proposed a variety of key structural measures addressed to restoration and preservation of the natural function of the river that will reduce flooding, improve water status and biodiversity, and revitalize social and economic conditions of the communities. It is mainly addressed to the specific measures identified in the restoration's scenarios from pilots' areas, but at the same time includes relevant measures considering the project partners experience.

The structure of the Catalogue covers four main sections *(Figure 19)*

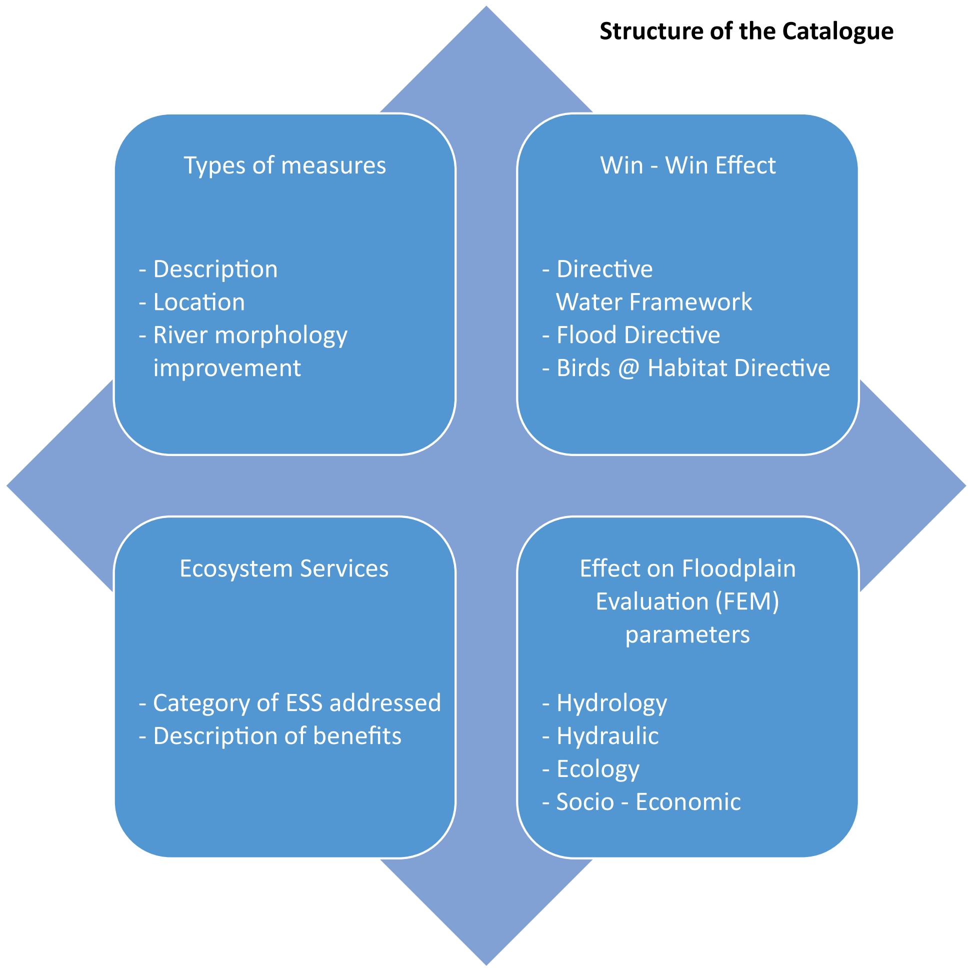

Figure 19 - Structure of the Catalogue

Types of measures

A wide range of restoration and preservation measures with the aim of re-establishing natural floodplain conditions and achieving a win-win situation for both, the environment and for flood protection, were the subject of restoration scenarios *(see Ch. B.4.1. Restoration Scenarios in the Pilot Areas. Hydrodynamic Modeling* from this Manual) used in the Danube Floodplain project pilot areas.

The planned restoration measures were discussed with relevant stakeholders in each of the pilot areas, including various domains like fishery, agriculture, shipping, municipal authorities, nature protection, residents. Thus, different kinds of restoration measures, e.g., in-stream measures which change the roughness and the shape of the riverbed, increasing in the floodplain size (through e.g., dike relocation), as well as morphological and/or land cover changes in the floodplain were determined.

Considering the current status of the floodplains, the measures were addressed either to restoration but also to preservation of existing floodplains. Of course, floodplain preservation and restoration are complementary and flood management must envisage both actions, the present proposal trying to point out the key role of each measure in relation with the existing or potential floodplain.

The restoration and preservation measures were addressed to four main categories: *technical works (constructions); floodplain morphology restoration (land cover and lateral branches); River morphology restoration (river channel); support (administrative actions)*

The technical works *(constructions)* includes the measures addressed to the existing flood protection constructions or infrastructure i.e., dykes or flood protection river dams or weirs. They involve engineering works of high complexity and in some situations very high costs.

The measures addressed to *floodplain morphology restoration (land cover and lateral branches)* aimed at the existing or former features of floodplain area, i.e., former meanders, oxbows. Due to the important role of large-scale land use changes and land-use practices in reducing of the conveyance capacity of the channels and river arms thus increasing the likelihood of flooding, related measures are also addressed.

Morphological changes (i.e., modification of the river flow section, rip raps, riverbanks protection walls) in riverbeds determine the risk for soil erosion within floodplain areas. As consequence, a set of measures are addressed to the *river channel morphology* restoration in order to improve lateral connectivity and hydrological regime closer its natural dynamics.

It is well recognized that environmental scientists contributed significantly to the development of water and floodplain management policy. Areas of research in this field vary widely from studying the process pattern dynamics and transfer of the sediment to floodplain area, to hydrologic and hydraulic studies for an accurately modelling of the floodplain behaviour, to quantifying floodplain ecological process and ecosystem services. Besides the legal instruments on the European level (FD) other legislative tools but also administrative ones could be developed and implemented

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i.e., related to land use planning in the floodplain preservation actions. A coherent and legal- based approach of spatial planning instruments on the other hand, and water management on the other hand is a successful way forward in the floodplain's preservation process. All these measures or rather instruments are considered as necessary *support measures* in the floodplain restoration and preservation policy.

A synthesis of floodplain restoration and preservation measures is presented in *Figure 20*

Technical works (constructions)	*Floodplain morphology restoration (land cover and lateral branches)*	*River morphology restoration (river channel geometry alteration)*	*Support measures*
-Dike relocation -Dike removal -Dike slitting -Implementing culverts/inlet sluices into the dike -Lowering dikes in different locations -Removal of weirs -Operational mode changing of dams /hydropower plant -Adequately designed and positioned culverts.	-Land use conversion towards natural conditions -Creating retention ponds -Increasing the roughness of floodplain (afforestation) -Creating flood control channels -Re-connection of lateral branches/ oxbows -Deepening lateral branches/ oxbows	-River widening by construction of new lateral channels -Increasing the roughness in the river channel. Restoration of natural substrate -Removing parts or the entire bank stabilizations/embankments -River bank re-vegetation -Initiate meandering of river course by using river engineering structures -Reconstruction of groynes	-Research, studies, scientific projects -Administrative and legislative measures

Win-Win Effect

The win-win effect is defined by the measure that can deliver on the objectives of Flood Directive, Water Framework Directive and Natura 2000 policies, namely reducing the flood risk, the contribution to reaching the environmental objectives, and conservation status for birds and habitats. As noted, before, NWRM can address to a reduction in the risk of floods and also better water replenishment of groundwater and surface water bodies in dry conditions, to major causes of not achieving good water status and major threats to biodiversity, mainly by natural flow regulation. NWRM are not exhaustive as being a win-win solution. Land use practices or engineer works at the present dykes, i.e., slitting entire dykes or several sections could also complete the list of win-win measures.

Ecosystem Services

There is a clear need to embed the ecosystem services concept addressing floodplain restoration and preservation win–win solutions. Ecosystem services (ESS) bring direct or indirect economic, material, health or psychological benefit to people. The ESS aims approach is to identify adequate solutions to improve the conditions for sustainable management of nature and ecosystems. With the help of the ecosystem service approach trade-offs between different sectoral uses can be identified. ESS can help to mediate between science and society or between different stakeholders. In addition, they are a good tool to estimate and present the impact of management measures on the ecosystem, but also on other benefits.

Due to a large variability in terms of features of a certain restoration measure (e.g. reconnection at mean water or high-water level, entire area flooded or just individual channels, width of the additional floodplain as result of dike reallocation), it is very difficult to quantify the effect when dealing with a certain measure in general. Therefore, in the frame of the Catalogue it is only possible to say which ecosystem services are affected by the measures, but not to what extent.

Effect on Floodplain Evaluation Matrix (FEM) Parameters

The Floodplain Evaluation Matrix (FEM) allows assessing effects of restoration measures with a set of parameters covering Hydrology, Hydraulics, Ecology and Socio-Economics (see B3). For each parameter a level of performance (high, medium, low) is determined. The best-case scenario is that each parameter shows a high performance. Since the FEM covers hydrological, hydraulic, ecological and socio-economic parameters, it might be possible to see the win-win effect of the proposed measure in the evaluation. In the catalogue, a qualitative and pragmatic approach was chosen to estimate the effect (improvement, worsening, uncertain) of the proposed measure on the FEM parameters. Color codes are used for each set of parameters to differentiate the effects.

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Part D – Planning and implementing floodplain restoration and conservation projects

General considerations

Sustainable river development is a complex issue. Clear restoration objectives and steps must be defined, different interests must be balanced and various legal requirements must be taken into account. This section intends to present general floodplain restoration and preservation steps aiming at creating the prerequisites for a balanced solution and an efficient and successful implementation of measures.

Planning and implementing floodplain restoration and conservation projects of the Floodplain Management Manual refers to the restoration sites (potential floodplain areas) already selected within the river basin according to the methodology presented in section B.3.

D.1. Conceptual framework – steps for planning and implementing floodplain restoration and conservation projects

The design of an efficient restoration project should include clear goals and objectives, sufficient baseline data and historical information, integrated planning and comprehensive design, and long-term monitoring.

The general steps *(Figure 21)* used in practice for planning and implementing the restoration and preservation projects are the following: (1) conceptual planning; (2) planning; (3) implementation; (4) post-implementation action (monitoring and maintenance); and (5) evaluation of the project objective achievements.

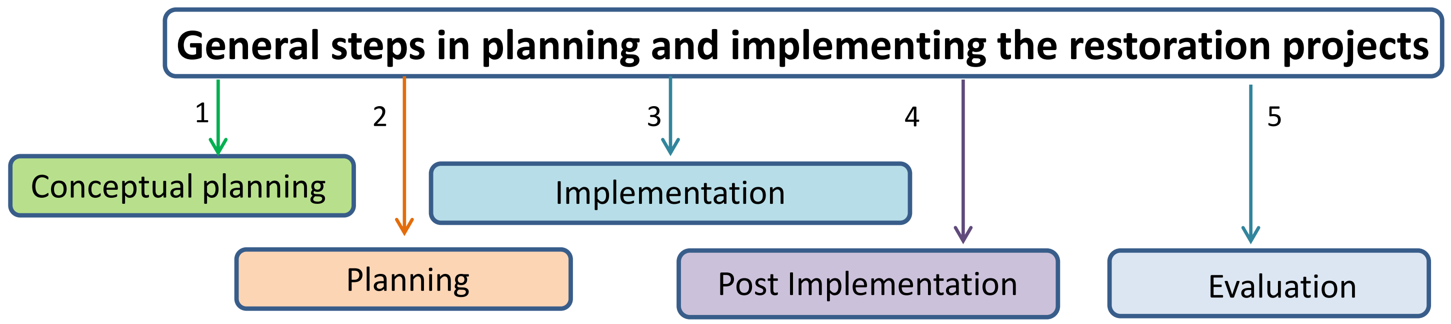

Figure 21 - General steps for planning and implementing the restoration projects

In the case of floodplain restoration and preservation projects the goal (or desired future condition) is to restore floodplain dynamics by reconnecting to the river. So, the desired future condition is that the ecosystem looks and functions as it did before it was damaged or degraded. In practice, the exact replication of past conditions is rarely possible. Therefore, a realistic or at most an optimistic approach is preferable.

To be sustainable, the policy objectives of floodplain restoration and conservation projects *(Figure 19)* should be related to the objectives of water key legal provisions: good ecological status underlined by WFD; reducing the flood risk - FD and protection and conservation of habitats and species - BHD.

Five main steps are proposed in the process of floodplain restoration and preservation: Conceptual planning; Planning; Implementation; Post-implementation; Evaluation. *Figure 23* illustrates the steps for planning and implementing the floodplain restoration and conservation projects which are presented in detail within the following paragraphs.

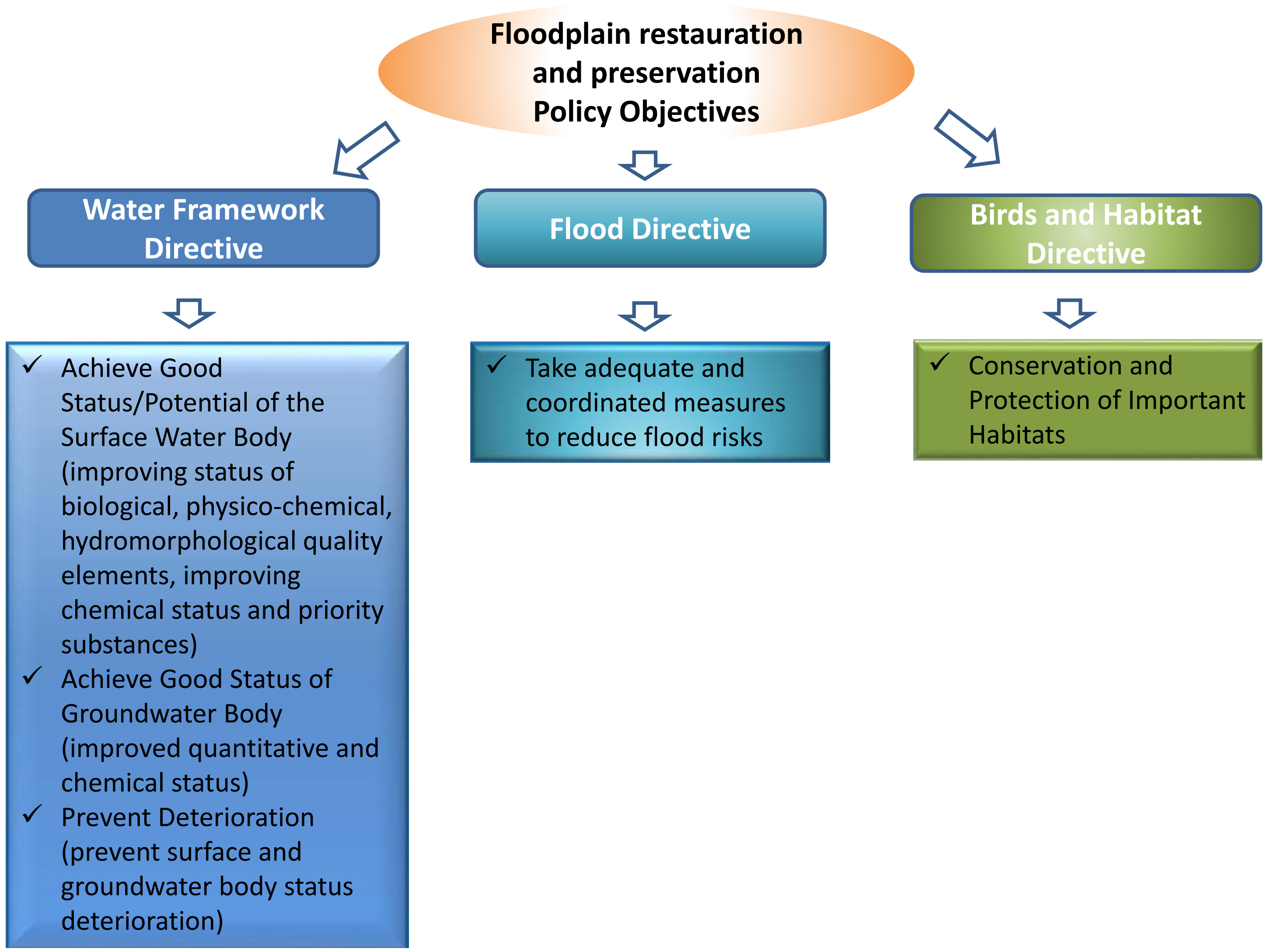

Figure 22 - Policy objectives for floodplain restoration and preservation

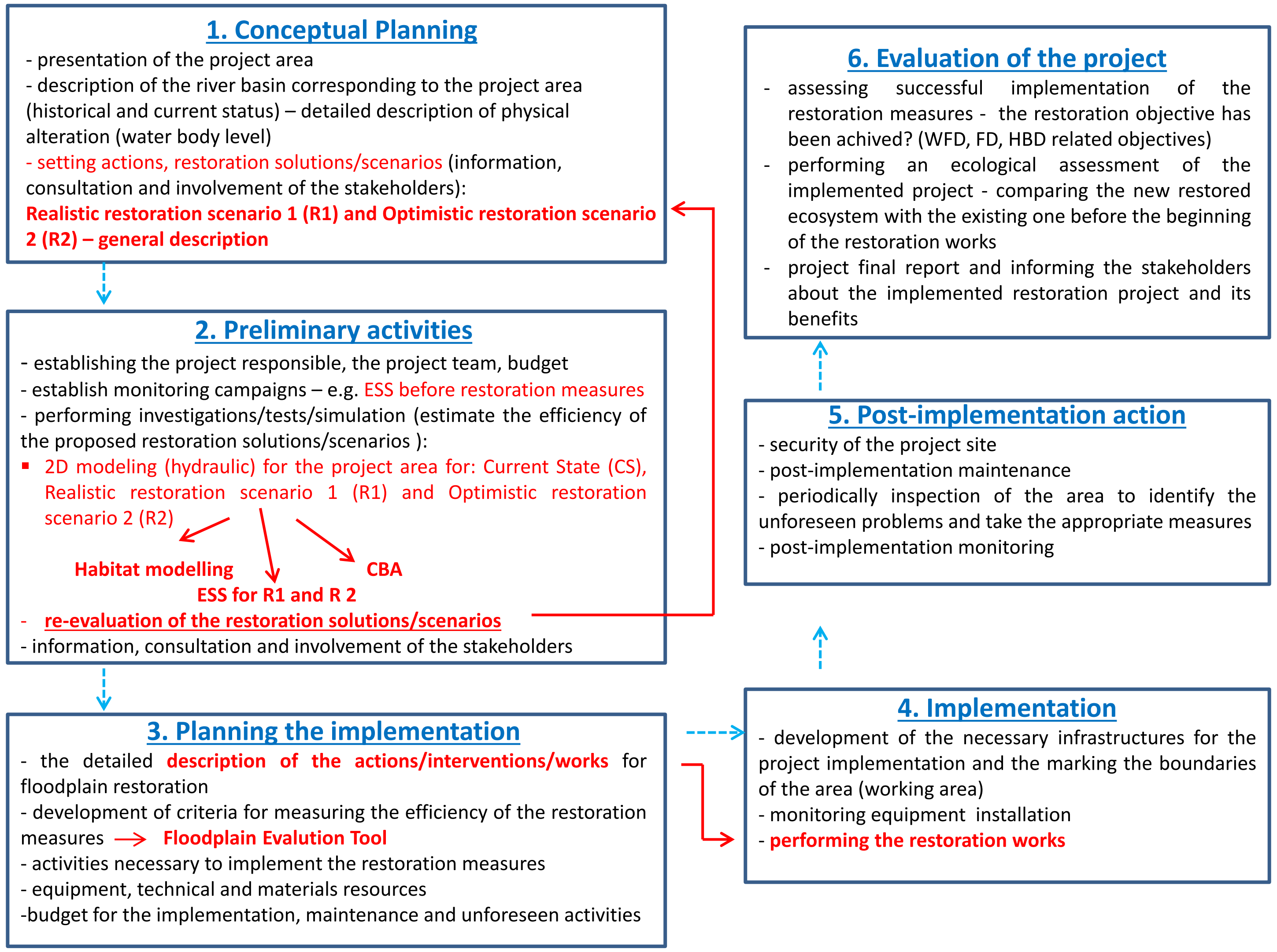

Figure 23 - Steps for planning and implementing the floodplain restoration and conservation projects.

Step 1: Conceptual Planning

Conceptual planning (planning and design) is a stage prior to a decision making related to a certain restoration and preservation option. It represents a preliminary study in order to understand the former and actual situation of the river basin/sub-basin/river sector/waterbody.

Conceptual planning of the floodplain restoration project refers to the general description of the river basin/river sub-basin/river sector/waterbody (historical and current status), identification, localization and delimitation of the potential floodplain area/areas, possible administrative, social or legal restrictions, establishing the project team and the budget, monitoring campaigns, stakeholders consultation, which in total provides relevant background information.

D.1.1 The description of the river basin/river sub-basin/river sector/waterbody

River basin planning is the most sustainable way for developing, protecting and harnessing the water resources of the basin in order to achieve objectives related to the environment, social or safety of the river itself. Since the adoption of WFD and FD, all EU countries are using the basin planning approach for water management.
The river basin (or sub-basin/river sector/waterbody) is described in terms of historical and current status.

Current status

The current status is referring to the description of the river basin/river sub-basin/river sector/waterbody in terms of physic and geographical, ecological and hydrological and geomorphological characteristics.
Description (including topographic maps) of the land features, river network, hydromorphological pressures (i.e., dykes, cutting off meanders, or old arms, changes in land use), recent flood events, protected areas (species and habitats) come to complete the current status assessment. Considering the integrated approach in water management, information on surface and groundwater water status could provide useful inputs in the process of identification win-win restoration and preservation solutions.

Current status

The description of historical status is based on historical maps/orthophotos in order to describe chronologically the anthropogenic intervention/modifications (e.g., water related engineer works), historical flood events, and water quality within the river basin/river sub-basin/river sector/waterbody.
Both current and historical status described in a general way will offer a possibility of comparison between what was in the past and what has changed and can thus support the process of identifying the most appropriate restoration solutions.

D.1.2 Identification, localization and delimitation of the potential floodplain area/areas within the river basin/sub-basin/river sector/waterbody

The potential floodplain/floodplains areas already identified (according the delineation criteria presented in section B.3 from this Manual) should be evaluated and ranked by using Floodplain Evaluation Matrix (minimum set of parameters which is mandatory) in order to identify the demand for restoration (the priority for restoration measures) (see the section B3.1.2 from this Manual). The results of FEM application will include the potential floodplains in one of the three groups:

- Lower demand - potential floodplains in this group have the lowest priority for restoration measures
- Medium demand - potential floodplains in this group have a medium priority for restoration measures
- High demand - potential floodplains in this group have the highest priority for restoration measures

The information from section D1.1 from this Manual (current situation) should provide useful inputs for FEM application. FEM will provide those potential floodplain areas that should be restored.

The following steps are referred to the potential floodplain areas that should be restored according to FEM final ranking.

D.1.3. Stakeholders involvement

The identification and the involvement of the relevant stakeholders are very important from the beginning of the project (see section B.7 from this Manual).

D.1.4 Identification of landowners and social-economic and legal context

The project area (in terms of the Chapter B.3.1 it is a potential floodplain) is located and delineated within maps (topographic maps including the project boundaries showing the river basin and man-made and natural features on the ground such as roads, railways, power transmission lines, contours, elevations, rivers, lakes, etc.). After the project area is delineated, the further step is to identify the land ownership and also relevant aspects regarding the social-economic and legal context. An example is the legal context in terms of identification of legal or administrative restrictions (e.g., urban regulations) and the necessary permits. The following aspects should be considered:

- *legal restrictions of the access to the property* can restrict the implementation of the restoration activities, and in this case, it is necessary to obtain an authorization or derogation by the law;
- *identification of existing infrastructure* within the study area, i.e., sewerage networks, water supply networks, gas and oil pipes networks, high voltage lines, etc.;
- *checking the area regarding the presence of archaeological sites and/or historical objectives;* an authorization is required to perform activities in the immediate vicinity of these areas;
- the *presence of high importance national security facilities* near the sites (e.g., military base);
- *location of the study area within a nature protected area;* some works cannot be performed within the nature protected areas, and it is necessary to obtain special authorizations;
- *location of the study area in the transboundary context* e.g., how the project will affect neighbouring country in case being in the vicinity of or sharing the state border with another country.

D.1.5 Establishing the surveillance and monitoring campaigns

Considering the needs of the precise DTM[92] information as a prerequisite for 2D hydraulic modelling, a detailed geodetic surveillance (e.g., LiDAR) must be done. Field observation may complete the existing data on existing infrastructure/hydromorphological alterations for example, recent changes in land use. Data on groundwater quality can be updated through monitoring campaigns, thus providing a starting point in identifying appropriate solutions

D.1.6 Establishing the project team and the budget

The profile of the technical experts should consider all range of possible activities in the restoration process, focusing but not limiting to flood protection, environmental, spatial planning and economic expertise.
Establishing the budget for the implementation, maintenance and unforeseen activities, includes the concrete restoration activities, but also updating stakeholders (and their further involvement if necessary) and communication activities.

Step 2: Planning

D.2.1 Setting floodplain restoration scenarios

The next step is to identify the floodplain restoration scenarios which are strongly related to the aspects described in this Manual in sections D1.1 (e.g., existing infrastructure, hydromorphological alterations), water status, land use practices) and D1.4. Administrative or/and legislative constrains described within D1.4 including the transboundary aspect (if any) should be also considered. Two restoration scenarios are recommended, a realistic (RS1) and an optimistic (RS2) one (see section B.4.1) and a baseline scenario is also recommended, which is the business-as-usual approach. The realistic and optimistic scenarios should be developed and agreed upon in cooperation with relevant stakeholders (local and national). The realistic scenario offers a higher degree of practicability compared to the extended one, reduced limitations or constraints, pragmatic and acceptable technical solutions. The optimistic scenario offers an extension of restoration measures and can lead to significant additional costs and possible constraints that require further resolution, but might have bigger impact.
The development of the two restoration scenarios individually should be done in cooperation with national authorities as well as the identified relevant stakeholders (e.g. fishery, agriculture, shipping, municipal authorities, nature protection, residents) within the project area.

[92] Note: Digital Terrain Model

D.2.2 ESS assessment

Ecosystem services assessment and mapping is described within section B.5.1 from this Manual. The assessment of ecosystem services should be done with the input of the relevant stakeholders for current situation and also in case of application of the two scenarios.

D.2.3 Habitat modelling

The general aim of the habitat modeling is to evaluate whether a certain floodplain restoration measure is capable to improve typical floodplain habitats. Such prediction is made based on environmental co-variables like water depth, flood duration, flow velocity (Subchapter B7 from this Manual)

D.2.4 Re-evaluation of the restoration solutions/scenarios

The results of ESS assessment and habitat modelling should be the base for re-evaluation of the restoration solutions/scenarios (are they realistic ones or are needed to be modified?).
Setting realistic scenarios is essential. The possibility of achieving the expected results identified during the planning (step D2.1) may appear to be unrealistic in light of the detailed information that appeared later (possible as a result of CBA).
At this point, the project team should reconsider the restoration solutions/scenarios identified in step D 2.1, and can make changes if justified (other restoration solutions/actions could be added).

D.2.5 Detailed description of the restoration solutions/scenarios

After the re-evaluation of the restoration solutions/scenarios the following steps should be done:

- A *detailed description of the restoration solutions/scenarios.*
- *Setting up the roadmap for the planning of the activities* necessary to implement the restoration measures.
- *Establishing the budget for the implementation, maintenance and unforeseen activities.*

Step 3: Implementation

Within the implementation phase, the following actions are recommended:

- *Development of the necessary infrastructures (i.e., access roads) delineation of working area.*
- *Installation of the monitoring equipment* (new gouging stations etc.) and *their location by GPS coordinates.*

- *Performing the restoration works* (described in detailed in step D2.5) and approval of operational plan (approval of the new status by the relevant authorities are necessary).
- Compile a baseline assessment (status of habitats and species) before the field works start and biomonitoring during the years of the implementation.
- Give regular update to the stakeholders and to do communication activities.

Step 4: Post implementation

The restoration and preservation of a floodplain are strongly related to the post-implementation actions, as follows:

- *Performing the post-implementation maintenance.*
- *Periodically surveillance of the area* to identify the unforeseen problems and take the appropriate measures.
- *Performing the post-implementation monitoring;* it is ideal for the project to monitor the dynamics of the parameters over several years (the literature indicates most often 6 years).
- *Defining the corrective and adaptation measures.*

Step 5: Evaluation

The evaluation of the project is the final step in planning and implementing floodplain restoration and conservation projects and are conducted to ensure the satisfaction of project objectives (related to the Water Framework Directive - e.g., good ecological status/potential; Floods Directives - reduce flood risk; and Habitats and Birds Directives - protection and conservation of habitats and species). It is based on:

- *Interpretation of the data* (e.g., monitoring data) in order to evaluate the successful implementation of the restoration measures.
- *Performing an ecological assessment of the implemented project* with the purpose of comparing the newly restored ecosystem with the one before the beginning of the restoration works.
- *Elaboration of the project's final report and informing the stakeholders* about the implemented restoration project and its benefits, *including the publication* in technical journals, specialized magazines, etc.

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