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D.1.1 – Detailed Analysis of Demonstrators Ecosystems

DALIA DANUBE REGION WATER LIGHTHOUSE ACTION

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EXECUTIVE SUMMARY

Water resources in the Danube River Basin, including rivers, lakes and groundwater, are vital for various purposes but face pollution and challenges. The countries of the basin described here cooperate under frameworks such as the Danube River Basin Convention and the EU Water Framework Directive to ensure sustainable management. Coordination spans international, sub-basin and local levels within this vast and interconnected basin.

In the 19th century, the Danube underwent profound changes due to human intervention, which today have far-reaching negative effects on the environment. Industrialization and the expansion of navigation led to a change in the course of the river, destroying numerous floodplains and wetlands. Regulation of the river to prevent flooding has led to a loss of the natural dynamics of the ecosystem. In addition, industrial waste and sewage polluted the river, leading to a significant deterioration in water quality. These human interventions have had serious consequences for the biodiversity and ecological balance of the region. Today, comprehensive measures and solutions are needed to preserve and restore nature along the Danube. These include renaturation projects, habitat restoration and the reduction of pollutants. In this context, nine pilot areas are working intensively on these challenges as part of the DALIA project. The project aims to develop innovative approaches to the protection and revitalization of the Danube and its surroundings. Only through such efforts can we restore the ecological stability of this important river system and leave an intact environment for future generations.

The nine designated pilot sites (DPS), scattered throughout the vast Danube basin, are thus "light-houses" for targeted efforts to address the various environmental problems. They span regions as diverse as Hungary, Germany, the Czech Republic, Slovakia, Serbia and Romania, and represent different initiatives tailored to the specific problems of each ecosystem.

In Hungary's DPS1, for example, the focus is on rejuvenating the Szigetköz region by addressing the impacts of river engineering and hydropower development. This includes addressing the alteration of the river system and its subsequent impact on ecological conditions and increased flood events in the area.

In the German DPS2, efforts are focused on restoring connectivity in the Upper Danube floodplain. This is in response to the negative impacts of hydropower barriers and dams, which have significantly reduced floodplain areas and endangered habitats due to rising groundwater levels.

The Czech Republic's DPS3 focuses on addressing the consequences of artificial damming along the Dyje River, mitigating the resulting water scarcity and fragmentation of native vegetation, especially the vital floodplain forests.

Slovakia's DPS4, known as "Springs Reborn," focuses on the upper Vah River catchment and aims to address flash floods, erosion, biodiversity loss, and declining groundwater levels through strategic rehydration strategies.

In Serbia's DPS5, restoration initiatives target the Begečka jama wetland, addressing pollution and sediment inputs that degrade water quality and disrupt the hydrological regime.

Romania's DPS6 focuses on sustainable sturgeon migration routes within the Danube basin, using dedicated bypasses at Iron Gates I and II to facilitate uninterrupted migration routes.

In addition, within the Romanian Danube Delta, DPS7 focuses on improving sediment flow monitoring to enhance sediment transport in the Black Sea, supporting ecological health and coastal resilience.

Hungary's DPS8 contributes to monitoring and mitigating plastic pollution in the Bodrog River, addressing persistent littering of floodplains and protecting aquatic habitats.

Finally, DPS9 in Romania aims to implement, at a hydrographic basin scale, 3 Litter Traps to efficiently retrieve plastic bottles and other artificial floating materials from Barcau, Crisul Repede and Crisul Negru watercourses, in the



transboundary sector of Romania and Hungary, in order to maintain the good ecological potential of the rivers and landscape of the area and beyond.

Taken together, these designated pilot sites represent a concerted effort to counteract human-induced changes, promote sustainable water management, and restore ecological harmony within the Danube basin.

The DALIA project aims to use this document as a foundational guide, setting the stage for its overarching goal. By transferring knowledge from existing pilot regions to new areas within the Danube River Basin, the project demonstrates the scalability of solutions. By funding implementation projects in specific regions, the initiative supports the Ocean Water Mission by demonstrating replicable solutions and implementing innovative, sustainable approaches. DALIA acts as a central platform and uses this framework to develop, demonstrate and deploy transformative solutions that are essential for the protection and restoration of marine and freshwater ecosystems, as well as for tackling pollution in our oceans, seas and waters.



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INTRODUCTION

Water is an essential natural capital for life, citizens' well-being and societal prosperity. After decades of intensive and damaging use, pollution and hydrological pressure, Europe's freshwaters and oceans are at critical risk of losing their health and the ecosystems that surround them. This is not only a dramatic loss in economic terms, but also entails unforeseen environmental, social and cultural damage. The Danube River Basin (DRB) covers more than 800,000 square kilometres, or 10% of continental Europe and is home to 79 million people. According to the Danube River Management Plan, the majority (52%) of all rivers do not meet the criteria for good chemical status and all monitored indicators are deteriorating. The Danube is an artery of the ecosystems of the whole DRB and the region with significant environmental impacts. The river also has an important economic use, supporting SMEs and creating jobs for local people, as well as a cultural importance. To properly manage this complex and fragile ecosystem, we need to think in terms of a river basin and harmonise our actions from the Black Forest to the Black Sea.

This is where the DALIA project (Danube Region Water Lighthouse Innovation Action) steps in to improve the negative effects in the Danube region. The project is comprised of 22 expert organizations – including universities, authorities, SMEs and NGOs – from 8 different Danube EU and Associated countries accumulating an outstanding set of knowledge, covering not only the basin geographically but all different fields of expertise necessary to deal with the multidisciplinary issues. DALIA innovation actions are supported by 9 Demonstration Pilot Sites (DPS), located throughout the Danube River Basin, which serve as examples of targeted initiatives that address various environmental challenges. These sites tackle issues such as river engineering, floodplain disconnection, water scarcity, pollution, and habitat degradation. Each designated pilot site represents a unique effort, ranging from revitalizing ecological systems and restoring natural water flows to enhancing monitoring systems and rehabilitating wetlands.

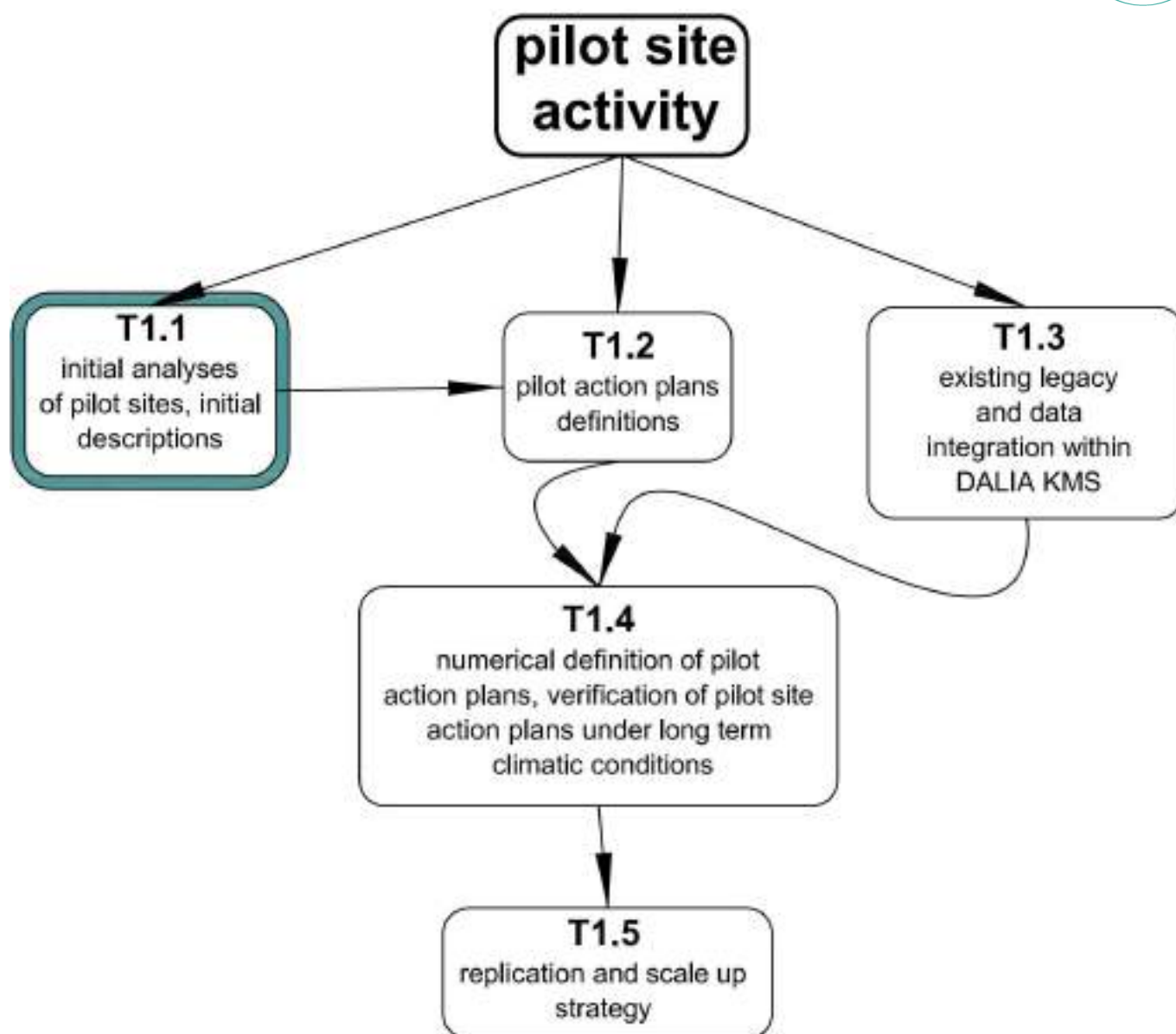
The aim of Task and Deliverable 1.1 “Detailed analysis of demonstrators’ ecosystems” is to analyse the ecosystems of all pilot sites to inform possible stakeholders about the individual measures and achievements and to serve the overall objectives of the project through the activities in the 9 DPS. The main outcome of this Deliverable are fact sheets for each DPS, which describe a general overview of the area, the history of human alterations, and actions taken to address the resulting problems. This is followed by a description of the expected or already known environmental impacts, and finally a conclusion and possible recommendations for actions.

The description and analysis of the ecosystems of the individual pilot areas should also serve as a basis for the actions in other tasks and work packages:

- WP1: The results of analysing and describing the individual pilot areas can be used as a basis for Deliverable 1.2 “Action plans co-design, schedule, execution and validation”
- WP2: Work Package 2 can benefit from the results of Deliverable 1.1 to find associated regions with similar conditions as the pilot sites (Task 2.1.). In addition, Deliverable 1.1. provides examples of possible measures in the pilot sites that could be replicated in the associated regions (Task 2.2.)
- WP4: Work Package can use the information of the pilot sites to publish them in the KMS and provide potential associated regions a detailed overview of the pilot sites.
- WP5: Work Package 5 can use the information on the pilot sites to produce flyers, posters and website material to promote the project and in particular the open call.

CONNECTION OF THE INDIVIDUAL TASKS IN WP1

D.1.1 – Detailed Analysis of Demonstrators Ecosystems



1. POLICY INTEGRATION AND DANUBE RIVER BASIN MANAGEMENT PLAN

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General context

Water resources such as rivers, lakes, transitional water bodies and groundwater in the Danube basin are vital for drinking water, biodiversity, industry, agriculture, transport, energy and recreation. However, these resources face pollution and other damaging pressures. The countries of the Danube River basin (DRB) are therefore cooperating to protect and improve the aquatic environment. The Danube River Basin Convention (DRBC) and the EU Water Framework Directive are important instruments for the sustainable management of these resources. The Water Framework Directive (WFD) develops comprehensive principles and a river basin planning cycle to ensure the sustainable use of water resources.

The EU Water Framework Directive proposes an integrated approach to water management at the hydrographic basin scale. For river basins spanning several countries, an international river basin area has to be managed to coordinate all activities. The Danube River basin is such an area and includes the Danube and its tributaries, transitional waters, lakes, coastal waters and groundwater.

The Danube River basin management is based on three levels of coordination: international level for the whole basin (Part A), national or international level for sub-basin coordination (Part B) for selected sub-basins (Tisa, Sava, Prut and Danube Delta), and sub-unit level defined as an administrative unit on national territory (Part C).

The Danube River basin is one of the largest and most international river basins in the world, covering the territories of 19 countries and with an area of 803,260 km². This basin has a great diversity of habitats, including glaciated mountains, forested mountains, high plateaus, plains and wet lowlands such as the Danube Delta (ICPDR, 2021).

In order to assess the condition of the water bodies in the Danube River basin, a specific typology of the Danube River was developed, dividing the river into ten types of sections with specific morphological and habitat characteristics. This allows a harmonized and comparable assessment of the status of water bodies in all countries of the basin.

For the risk analysis, the length of river water bodies has been taken into account in relation to the environmental objective of the Water Framework Directive for rivers, lakes, transitional and coastal waters. The analysis focused on current and potential pressures that could affect the status of water bodies by 2027. For some countries, data on risks are not yet available.

Within the Danube River Management Plan (DRBMP) a total of 29,127 km of river water bodies were analysed, and the results indicate that about 28.7% of them do not pose major risks in achieving good or potentially good ecological status, and 46.3% do not pose major risks in achieving good chemical status by 2027. However, there are areas for which no data are available for risk assessment, which may require further monitoring and investigation. These assessments and analyses are essential for the management of the Danube River basin and for the implementation of appropriate measures to protect and improve water quality throughout the basin (ICPDR, 2021).

Since the adoption of the Danube River Basin District Management in 2009, intensive activities and investigations have been carried out to identify new relevant and important issues throughout the Danube River Basin. These include sediment quality, invasive alien species and the sturgeon issue.

In addition, new activities were launched and work continued to strengthen cross-sectoral cooperation in the areas of inland navigation, sustainable water power and agriculture, as well as the links between the Water Framework Directive and flood risk management and the marine environment. These sectoral policies are closely interlinked and have an impact on different important aspects of water management.

Infrastructure projects such as navigation, hydropower and flood protection measures are relevant to significant water management issues under the heading "Hydromorphological changes". In particular, agricultural activity affects significant water management issues such as organic pollution, nutrient pollution and pollution by hazardous substances. Basin-wide measures to reduce nutrient pollution and pollution by hazardous substances contribute also to improving the state of the Black Sea.

Another key policy initiative is the EU Green Deal and the EU Biodiversity Strategy. Under these strategies, water management efforts will be stepped up to halt the decline of European biodiversity and implement measures to restore it. In this respect the significant water management issues will consider the connectivity of transboundary ecosystems and ecological corridors for aquatic species to enhance the resilience of aquatic ecosystems in the Danube basin and ensure a coherent approach in maintaining and enhancing ecosystem connectivity across national borders in the next update of the significant water management issues.

The updated Danube River Basin Management Plan 2021 has nine chapters, which follow the requirements of the Water Framework Directive and are structured according to the significant water management issues in the Danube River Basin District and the European Environment Agency's (EEA) Diverse-Pressures-Status-Impact-Response (DPSIR) framework. The DPSIR framework analyses environmental drivers, pressures, status and impacts in the context of sustainable development.

Close cooperation between the Danube countries provides a framework for long-term sustainable solutions, addressing new and emerging water-related challenges such as the impact of climate change. The updated Danube River Basin Management Plan 2021 supports the activities of the International Commission for the Protection of the Danube River (ICPDR) and provides updated scientific support. Emphasis is placed on the need for a holistic and integrated approach to transboundary water resources management.

Sturgeons are emblematic species in the sustainable management of the Danube River basin, representing symbols for the conservation of this aquatic ecosystem. Relevant determinants, such as human activities, leading to pressures on sturgeon populations are identified. Pollution, physical changes to the river system and illegal fishing are examples of such pressures affecting the state of the environment and having a negative impact on sturgeons.

Multiple actions are being considered to protect sturgeons, such as reducing pollution, restoring habitats and promoting the sustainability of infrastructure such as water power and inland navigation. In the context of climate change, opening up the migration corridor through the construction of through dams is an important issue for sturgeon protection.

With the Update of the Danube River Basin Management Plan in 2021 it builds on previous structures and assessments, updating relevant information. In addition, particular attention is paid to integration with other sectoral policies, such as flood risk management, nature protection, sustainable water power and agriculture, and the link with the marine environment (ICPDR, 2021).



Significant pressures

Agriculture, transportation, energy generation, and urban growth all put a strain on the aquatic environment. These pressures must be examined as part of long-term river basin management and as a basis for deciding effective methods to address and minimize them. The WFD mandates that information on the kind and magnitude of anthropogenic pressures be collected and updated regularly. Cumulative impacts may emerge while addressing DRB pressures at the basin-wide scale. A particular pressure can have downstream (e.g., pollution concentrations) and/or upstream (e.g., river continuity) effects. Addressing these concerns effectively a basin-wide approach and international cooperation are needed.

At the river basin scale, the urban wastewater sector discharges approximately 190,000 tons of Biochemical Oxygen Demand (BOD) and 440,000 tons of Chemical Oxygen Demand (COD) into the DRB's surface water bodies each year (reference year: 2018). For the reference year (2018), direct industrial emissions of organic compounds totalled approximately 65,000 tons of COD. Since the reference year of the DRBMP 2009 (2005/2006) and the DRBMP Update 2015 (2011/2012), a significant reduction in BOD emissions from urban wastewater has been observed. Because of the significant improvement of wastewater infrastructure over the last decades, the most recent statistics are approximately 61% and 27% fewer than those of the DRBMP 2009 and DRBMP Update 2015 (ICPDR, 2021).

For organic pollution, a significant decrease in nutrient emissions from point sources in the Danube River basin is evident. Recently reported point source nutrient emissions are significantly lower than in the 2009 DRBMP and 2015 DRBMP updates, N emissions are reduced by 44% and 18%, respectively, and P emissions are reduced also by 56% and 22%, respectively. Diffuse emissions have also decreased due to low agricultural intensity in many countries and the measures taken. Diffuse emission dominates the total emission pattern (N:87%, P:78%), transporting nutrients from agricultural and urban areas to water bodies. Regarding sources, agriculture (N:44%, P:37%) and urban water management (N:30%, P:43%) are responsible for most nutrient emissions indicating the need to take appropriate measures in these areas. Analysis of historical trends in nutrient intake in rivers over the past decades shows that the amount of nutrients transported to the Black Sea has decreased significantly. However, over the past 5-10 years, the measured loads have been quite low and close to the Black Sea targets, indicating that water quality has improved significantly.

Hydrological change has a significant impact on water bodies in the DRBD and often impedes the achievement of environmental goals. There are 269 bodies of water out of 975 (28%) affected by significant reservoirs, 62 bodies of water (6%) due to significant withdrawal, 51 bodies of water (5%) due to significant mountain peaks, 357 areas water (37%) due to significant continuity (including 264 bodies of water (27%) affected by impassable discontinuity), 552 bodies of water (57%) due to significant morphological change (including categories 2 -5 in a 2-layer reporting system) and 19 water bodies (2%) significantly affected disconnecting wetlands/flood plains (with obvious reconnection). Based on these results, the main hydromorphological changes of DRBD are significant morphological, continuum, and reservoir discontinuities (ICPDR, 2021).

Additional steps are being developed for the years 2021-2027. There are 204 metrics connected to impoundment improvements, 46 to water abstractions, 32 to hydropeaking, 424 to continuity disruptions, and 222 to water bodies influenced by morphological changes. An additional 23,399 ha of floodplains/wetlands are expected to be reconnected. In several situations, considerable hydromorphological adjustments were reported to have attained GES/GEP, implying that no actions to improve hydromorphological conditions were required.

Over the past fifteen years, the Danube countries have invested approximately 28 billion euro in wastewater infrastructure by the Urban Waste Water Treatment Directive (UWWTD) and WFD requirements. Nearly 180 operating industrial facilities with direct emissions to surface water are certified to update technology standards by the Industrial Emissions Directive (IED) regulations. Since 2006, the proportion of cities and industrial facilities connected

to the sewer network and full treatment plants, or individual treatment facilities also increased significantly (to almost 80% at the DRB level), showing a significant improvement.

Another important issue in the Danube River Basin is plastic pollution. A wide variety of animals consume plastic particles, and the transfer of these particles to aquatic food webs is a rising concern. Plastics' potential harm to freshwater organisms is poorly understood. There is also a scarcity of information on the presence of microplastics in the Danube River Basin. The level of awareness of riverine trash differs throughout Danube countries, but in most cases, it is regarded as an increasing concern. It is also worth noting that in several Danube countries, riverine litter management is not treated as a separate topic, but rather as part of a national waste management strategy. There is no difference in knowledge or action in most Danube countries. Most Danube countries have no difference in awareness or interest in microplastics (plastic particles less than 5mm in diameter) versus larger-sized litter, even though attention to the damage of microplastics to the environment, people, and animals has grown in recent years, owing to growing research-based evidence on both the national and international levels. A good example is the Tid(y)Up project that aimed to minimize plastic pollution in the Tisza River and examine plastic pollution's impact on the Danube and the Black Sea. The project partners create and implement a set of coordinated initiatives, consult, and give tools to key stakeholders, and establish long-term transboundary and intersectoral collaboration to monitor and eliminate plastic pollution.

As a result, we must all do more to conserve this lovely Danube Basin, which is shared by 19 countries, making it the most international river basin on the planet. The Danube Basin is home to 79 million people of many cultures and languages. For ages, they have been interconnected by the Danube's vast water system.

Ecosystems assessment and integration issues

According to the Water Framework Directive (WFD), exemptions from achieving the environmental objectives can be granted if specific conditions stated in WFD are met. Necessary Future Infrastructure Projects (FIP) may necessitate an exemption under WFD if they are expected to unavoidably deteriorate water status. It's important to understand that while applying WFD permits certain modifications to surface water bodies under certain circumstances (e.g., improving inland navigation conditions), any exemption must always ensure that "all practicable steps are taken to mitigate the adverse impact on the status of the body of water."

Thus, it becomes crucial to incorporate measures in the planning of FIP to align with the Significant Water Management Issues (SWMI) objectives, such as avoiding negative impacts on critical fish habitats (e.g., sturgeon spawning sites), adjacent protected areas, and riverbed erosion.

In the Danube River Basin, the integration with other sector policies is of paramount importance to foster synergies and prevent potential conflicts. Ongoing efforts are being made to implement and enhance exchanges with various sectors like inland navigation, hydropower, agriculture, and nature protection, which includes sturgeon conservation activities. Identifying and pursuing basin-wide opportunities for exchange among these sectors is also a priority.

Flood events are natural occurrences in all river systems, but recent years in the Danube Basin have shown that they can result in devastating social, economic, and environmental consequences.



Future climate change is anticipated to escalate the magnitude and frequency of flood events, posing a higher flood risk in Europe in the coming decades. While it's impossible to completely prevent flooding, adopting measures to preserve and restore rivers and floodplains to a more natural state, along with implementing sustainable practices across the basin, can significantly decrease the likelihood of flood events and the damage they cause.

Encouraging changes in land use along rivers and promoting practices that consider water retention can help mitigate the increasing overall damage caused by floods.

Water-related protected areas have been established to safeguard habitats or species with a focus on maintaining or improving ecosystem status (including Natura 2000 sites). Out of the total of 1,737 protected areas, 1,017 (59%) have been designated under the EU Habitats Directive, and 358 (21%) fall under the EU Birds Directive. Forty areas (2%) are protected under both the Habitat and Birds Directives, all being Natura 2000 sites designated in EU Member States. There are 322 (19%) protected area types reported by non-EU Member States, mainly comprising nature reserves and Biosphere Reserves. A significant proportion of designated Natura 2000 sites is situated along the Danube River (ICPDR, 2021).

In several Danube countries, the water supply networks suffer from poor conditions primarily due to a significant lack of long-term funding, inadequate maintenance, and ineffective operation in some areas.

High levels of leakage are prevalent, with water losses reaching as much as 30-50% in certain cases. For instance, Hungary experiences losses of 27.3%, while the Czech Republic faces losses of 15.8%. Disparities in piped drinking water supplies between urban and rural regions occur, with rural populations in some countries being less well-served. The percentage of the population connected to public water supply systems varies across the region, ranging from less than 13% in rural Republic of Moldova to over 99% in countries like Bulgaria and Germany, and generally follows an increasing trend.

Austria stands out with the largest percentage of electricity generated from hydropower, accounting for 60% of its total electricity production. Ukraine and Montenegro also have a significant share of hydropower in their energy mix, ranging between 50% and 60%. Croatia, Slovenia, Romania, and Serbia maintain around 30% of their national electricity generation from hydropower, which increases to nearly 60% when considering the Danube River Basin (DRB) as a whole. Germany, on the other hand, has a lower proportion of hydropower, but a substantial amount is produced within the DRB, making it a significant contributor to the country's overall hydropower production.

In countries like Slovakia, Bulgaria, and Bosnia and Herzegovina, hydropower continues to play a vital role in their electricity systems. However, in most Danube countries (excluding DE, HU, and MD), hydropower currently represents the most crucial component of their total renewable energy production.

Joint programmes of measures

The quality of river water depends on human activities that generate large amounts of pollutants. For this reason, it is necessary to implement measures at the national and international level to prevent or reduce pollution.

The measures stipulated in the Danube River Basin Management Plan (DRBMP) aim to identify certain strategic projects and activities of importance at the level of the river basin to be carried out jointly by the Danube riparian states. The principles and measures set out in the document are widely recognized and applied throughout the DRB area and are included in the new EU strategy on adaptation to climate change.

The program of measures is structured based on the results of the analyzes and evaluation of the water condition and includes a set of measures at the basin level, and they target the main management objectives for the year 2027. These objectives also take into account the measures provided in the national programs. Also, these objectives integrate the expected results regarding the improvement of the water status of the Danube until 2027.

The reference documents for national strategies and activities are National Management Plans. Within them, there can be found detailed information about the stage of implementation of these measures. In these plans, the guiding principles regarding the measures to be adopted for national and international RBMP are stipulated, outlining the framework conditions necessary for compliance with the requirements and norms in force.

The established measures are aimed at preventing negative effects on water (pollution with organic, nutrient and dangerous substances, hydromorphological changes and the effects of climate change (drought, water scarcity, extreme hydrological phenomena and other impacts), as well as the protection of important groundwater bodies at the basin level.

Organic pollution is produced by the discharge of wastewater from point and/or diffuse sources. Organic materials are found in untreated municipal wastewater and in agricultural sources and food processing industries.

In the previous management cycles, significant investments were attracted in the field of organic pollution control in the Danube River Basin District (DRBD) and a considerable reduction of organic pollution was recorded. In the future, additional measures must be instituted in addition to the investments made in the wastewater infrastructure. At the Danube River Basin level, it was found that most of the wastewater in the region is managed correctly. However, there are many large industrial facilities that release significant pollutant emissions into surface waters. Therefore, this objective must be taken into account and even improved (ICPDR, 2021).

Nutrient pollution is caused by point sources, including untreated or inadequately treated wastewater discharges from urban, industrial, agricultural and diffuse sources. The hazardous substances discharged into the Danube River are pesticides, ammonia, other organic micropollutants, heavy metals and petroleum products.

Regarding the objectives for the Danube River Basin, a key factor for achieving them is reducing the ammonium and nitrate contamination. Within these management objectives, the elimination or reduction of the amount of ammonium and nitrates entering the groundwater bodies in the DRBD is essential. At the basin-wide level, emissions of nitrates, other nutrients and relevant hazardous substances must be effectively controlled to prevent deterioration of groundwater quality in the DRBD. If the groundwater is already polluted, it is essential to restore good quality. This can be achieved through rigorous implementation of EU legislation.

Large-scale hydromorphological changes in the Danube basin are caused by hydraulic structures such as dams or other flood protection works/river regulation and navigation on the Danube and its main tributaries. Other causes identified could be: gravel and water capture, outdoor recreation and fishing are considered to be of minor or local importance.

Regarding the future development scenarios regarding the urban wastewater sector, they differ depending on several factors. One refers to EU membership. Thus, for the EU member states, the basic scenario assumes the establishment of public sewage systems in all urban agglomerations with a population greater than 2,000 inhabitants and the connection of these agglomerations to the Urban Waste Water Treatment Plan (UWWTP) with appropriate technology.



Even if in some countries there are delays regarding the implementation of the current measures, it is recommended, that all EU Member States comply with the obligations stipulated in the legislation in force and implement the corresponding measures. For the other countries that are not part of the EU, in the scenarios, is foreseen the construction/modernization of a certain number of wastewater collection systems and UWWTP (with the specified treatment technology).

Among the necessary measures are the preventive ones needed to mitigate the impact of climate change and to minimize the effects of this phenomenon, thus reducing the vulnerability of aquatic and water-related ecosystems to these changes.

Also in the scientific field, significant progress has been made and, therefore, there has been an increase in awareness and support for governments. Several projects have contributed to broadening the knowledge base in different research areas and regions, providing monitoring tools and management guidelines for decision makers and water managers, e.g. regarding droughts: DROGHT-R&SPI, DEWFORA, PESETA and regional cooperation programs such as EUROCLIMA.

The measures applied so far have contributed substantially to the reduction of nutrient inputs to surface water and groundwater in the DRBD, but further efforts are still needed. Despite notable improvements, many species of Danube sturgeon remain on the verge of extinction.

It is also necessary to approach some measures to reduce the emissions of hazardous substances that must be further implemented in various fields. Adequate treatment of urban wastewater and application of Best Available Techniques (BAT) in industrial plants and large agricultural farms are elementary measures and can significantly contribute to mitigating hazardous contamination.

For some of the measures, a number of EU-supported funding programs are available. This is fundamental for some EU member states, as they have financial support from the EU for wastewater treatment measures, agriculture or hydromorphological changes. Funds were also available for programs such as PAC, LIFE, etc., and the member countries will be able to use them in the future to manage specific problems and to implement the necessary measures.

Among the achievements in the Danube River Basin in recent years are:

- The establishment of a number of projects dedicated to the revival and protection of Danube sturgeon species and their habitats
- Successful implementation of measures to simplify and improve groundwater management in Germany and Hungary.
- Projects to reduce nutrient pollution in the Danube.

Funding for measures is the responsibility of each national government (or private owners and operators of facilities affecting water quality). The EU Strategy for the Danube Region must provide support for obtaining financial resources for the realization of such projects and activities of strategic importance for the ICPDR.

Thus, a greater attention must be paid to the identification and implementation of priority measures. Also, the measures that require reduced funds have to be priority. The aspects related to the financing of the measures in some countries have to be used for informing and supporting the other Danube countries in addressing the financing mechanisms.

Key findings

River basin management plans provide a framework for integrated water resources management, with central objectives and required actions. As required by the Water Framework Directive, these plans must include a description of the characteristics of the river basin district, summaries of pressures and impacts of human activity on surface and groundwater, monitoring programmes and economic analyses of water use and measures.

The assessment of the status of surface water bodies in the Danube River basin shows a slight decrease in the percentage of the length of rivers with good ecological status and ecological potential from 25% in 2015 to 24.1% in 2021. Assessment methods are improved for small and medium rivers, but more difficult for large rivers due to multiple pressures, invasive species and climate change. Collecting information on invasive species and their influence on biodiversity remains an important area for development. In terms of chemical status, the percentage of good status decreased from 71% to 67.7%, due to more comprehensive analyses and changes in chemical status attributes rather than new pressures. Some priority substances are still not analyzed in all countries, which requires improvements in monitoring practices to develop appropriate and sensitive methods.

Pollution of surface water bodies in the Danube River basin is largely influenced by emissions from urban and industrial wastewater. In recent decades, significant progress has been made in reducing emissions of organics and nutrients due to massive investments in wastewater treatment infrastructure. However, efforts need to continue as improvements are still needed for wastewater treatment infrastructure in some areas and for the management of nutrients from agricultural sources. The problem of pollution by hazardous substances also needs to be addressed, and monitoring and implementation of measures must continue in order to manage this problem effectively. Financial support and capacity building is recommended to ensure improved management of wastewater and hazardous substances pollution throughout the Danube basin.

Hydromorphological changes in surface water bodies and related measures describes hydromorphological changes in water bodies in the Danube Region and measures taken to address them. Modifications such as dams, water abstraction and breaks in continuity have a significant impact on the aquatic environment. A total of 269 water bodies affected by dams, 62 water bodies affected by water abstraction and 357 water bodies with significant breaks in continuity were identified. To address these problems, numerous hydromorphological measures have been implemented, including fish migration aids, river restoration projects and wetland reconnection. For the period 2021-2027, even more measures are planned to improve the condition of water bodies. It is important to continue monitoring and promote best practices for water management in the region.

Groundwater quality in the Danube Region is variable, with 19 of the 25 national parts having good chemical status and six national parts having poor chemical status. Contamination with nitrates, ammonium, phosphates, sulphates, chlorides, trichloroethene and glyphosate are the main causes of poor chemical status. To achieve good status by 2027, it is crucial to reduce the amount of ammonium and nitrates entering groundwater bodies in the Danube River Basin. Implementation of the Nitrates Directive and other relevant regulations is essential to prevent groundwater pollution. Measures to combat surface water pollution also have a positive effect on groundwater quality. Where groundwater is already polluted, quality must be restored through strict application of the relevant EU legislation.

The assessment of groundwater quantity in the Danube Region shows that most of the transfers are in good quantitative status. Depletion of groundwater resources, damage to groundwater-dependent terrestrial ecosystems and impairment



of legitimate groundwater uses are the main causes of poor quantitative status. Direct and indirect over-extraction is the main pressure affecting groundwater quantity status.

In order to prevent deterioration of groundwater quantity and dependent terrestrial ecosystems, it is essential to establish adequate controls on the capture and retention of fresh surface and groundwater. Remediation solutions such as natural water retention and restoration of wetlands in direct contact with aquifers are also being explored. In addition, measures to protect groundwater resources are planned under the new Danube Cooperation Action Plan. Effective management of groundwater and surface water is essential to avoid overexploitation of groundwater basins and to ensure that adequate amounts of available groundwater are preserved.

The effects of climate change in the Danube River Basin have been recognized as a significant water management issue. The objective is to ensure that measures taken are resilient to climate change and that operational management objectives addressing mitigation and resilience to extreme hydrological events such as droughts and floods.

Protected areas in the Danube basin focus on habitat and species protection, including the conservation of sturgeons, the region's emblematic species. Integration is a key aspect of addressing the issues, and synergies and conflicts with other sectoral policies such as inland navigation, sustainable hydropower and sustainable agriculture are taken into account.

Socio-economic developments in the basin show significant variations between countries, and the impact of the COVID-19 pandemic adds uncertainty to GDP and investment needed for infrastructure development.

Climate change management and protection of natural resources are key issues for ensuring sustainability and sustainable development in the Danube basin.

In this context, DALIA will contribute to improving water quality, biodiversity and ecological status of Danube River Basin ecosystems by reducing waste, improving connectivity, biodiversity, and ecosystem services provided to local communities. Also, DALIA will contribute to strengthen the European research area on freshwater ecosystems restoration by approaching specific problems in different DPSs. By investing in river restoration, floodplain reconnection and improvement of its retention capacity either through sustainable engineering solutions or nature-based solutions, there is an opportunity to support the medium and long term economic development in DPSs area and associated regions.

1.1. National water management plan in Romania

General framework and objectives

The essential background document for establishing water management plan at different scales is represented by Water Framework Directive (2000/60/EC) complemented by the Directive on the Assessment and Management of Flood Risk (2007/60/EC). WFD establishes the general framework for protecting waters by preventing their deterioration, conserving and improving the state of aquatic ecosystems, promoting the long-term sustainable use of water resources and ensuring the gradual reduction of groundwater pollution and preventing its pollution. Water Law no. 107/1996 with subsequent additions and amendments, transposes into the national legislation the WFD and the Floods Directive (Directive 2007/60/EC), on the basis of which the River Basin Management Plan (RBMP) and the Flood Risk Management Plan (FRMP) have been elaborated.

D.1.1 – Detailed Analysis of Demonstrators Ecosystems

For the part of the international hydrographic district of the Danube River, included in the territory of Romania, including the coastal waters of the Black Sea, Romania contributes to the elaboration of the Management Plan of the Danube River Hydrographic District - updated 2021, a plan that constitutes a synthesis of the Management Plans at the level of 11 basins/watersheds established at national level.

The cadastral hydrographic network in Romania has a length of 78,905 km and is evenly distributed, having a radial configuration, 98% of the rivers originating in the Carpathian Mountains. On the Romanian territory there are the upper and middle courses of an important number of rivers. The water resources of the inland rivers are 40 billion m³, which represents 50% of the water resources of the Danube River. Romania has a specific resource from inland rivers of 1,870 m³/inhabitant/year and, from this point of view, ranks 13th in Europe (MMAP, 2021e).

According to the updated National Management Plan (2021), a total number of 3,025 surface water bodies were identified, of which: 2,741 water bodies are rivers, of which 1,772 are permanent water bodies, and the remaining 969 water bodies are represented by non-permanent bodies of water; 278 lake-type water bodies (natural lakes, heavily modified natural lakes, storage lakes, artificial lakes); 2 transitory bodies of water (lacustrine and marine); 4 coastal water bodies (MMAP, 2021f).

The environmental objectives for surface and underground water bodies and for protected areas aim at long-term protection, use and sustainable management of water. For surface waters, the environmental objectives are "good ecological status" for natural water bodies and "good ecological potential" for heavily modified and artificial water bodies. The environmental objectives regarding the "good chemical status" of surface water bodies and territorial waters are established in accordance with the Directive 2008/105/EC (amended by Directive 2013/39/EU). For groundwater, the environmental objectives are good chemical status and good quantitative status of groundwater bodies. The main reasons for not achieving environmental goals are related to technical feasibility, followed by disproportionate costs.

State of the aquatic ecosystems

Characterization of the state of surface water bodies is achieved by evaluating the ecological state/ecological potential and chemical state. For the classification of the ecological state of natural water bodies, the classification system includes five state classes, respectively: very good, good, moderate, poor and bad.

At the national level, the identified water-related protected natural areas have been also taken into consideration and grouped into 408 zones for the protection of water-dependent habitats and species. Their surface is approximately 65,095 km² (including the marine area). Regarding groundwater bodies, of the 115 phreatic groundwater bodies, a number of 54 were identified with probable dependence on terrestrial ecosystems, out of 141 sites of community importance. The analysis on the identification of protected areas for habitats and species where water is an important factor has been revised and updated taking into account the new information available on Natura 2000 sites and their related species and natural habitats. Thus, during the second planning cycle of the management plan, the legislation in the field of protected natural areas approved 54 new sites of community importance and extended areas for 29 existing sites (MMAP, 2021f).

In terms of economic activities, the national policy in the field of water comprises two distinct sectors, namely: the management of water resources and the management of water services, respectively water supply, sewerage and



wastewater treatment services. The share of water resources management activities, as an economic value, within the main economic sectors, respectively agriculture, industry or energy production is extremely low. Regarding agriculture, the share of management activities that only include the value of contributions for the use of water resources, for aquaculture and irrigation was 0.0073% in 2018. Regarding the industry (except electricity production), due to the reduction of industrial activities that use significant amount of water (e.g. steel, metallurgy, chemical industry), as well as the application of the "best technologies" in technological processes in relation to water saving, the share of water resources management activities in terms of the economic value was 0.1050% in 2018. Regarding the production of energy through hydroelectric power plants, the weight of water management activities, respectively the value of the contributions for the use of water resources for the hydroenergy production has an average value of 5.02% at the national level, related to the period 2016-2018 (MMAF, 2021e).

Related to the management of water services there are 45 regional companies that operate in the field of water supply and sewerage.

Environmental costs consist of the costs of damage to the environment as a result of the degradation or loss of aquatic ecosystems due to the pressures of certain water users. Thus, environmental costs were approximated by evaluating the costs of measures whose main purpose is to protect the aquatic environment based on existing legal (environmental) standards.

Ecological restoration measures

Among the potential factors generating hydromorphological alterations can be mentioned: electricity production, water supply (population, industry, irrigation, fish farming), flood risk management, agriculture (drainage systems), water transport. The measures taken to limit their negative impact on the aquatic ecosystems are as following:

- measures to mitigate the interruption of longitudinal connectivity for the fish fauna,
- measures to mitigate the alteration of the habitat conditions upstream of the dam work (minor bed, bank, major bed),
- measures to mitigate the alteration of the regime hydrological downstream of the dam work,
- measures to mitigate the alteration of the sediment regime downstream of the dam work,
- mitigation measures to improve the lateral connectivity and water retention capacity in the flood zone,
- measures to mitigate the alteration of the bank structure,
- measures to mitigate the alteration of the morphological conditions of the riverbed (increasing the morphological diversity/complexity of the riverbed) (MMAF, 2021e).

Ecological restoration measures refer to all water bodies categories, respectively rivers, lakes and coastal/transitional waters.

Considering both the positioning of Romania in the hydrographic basin of the Danube River and the Black Sea basin, as well as the need for environmental protection in these areas, Romania has declared its entire territory as a nutrient sensitive area. In the process of implementing the Nitrates Directive, Codes of Good Agricultural Practices and action

programs were developed and applied. Moreover, according to Annex I of Directive 2006/118/EC, quality standards were established for nitrates (50 mg/l) and pesticides (0.1 µg/l individually and 0.5 µg/l total) and, also, threshold values for the other parameters mentioned in the Annex II of Directive 2006/118/EC modified by Directive 2014/80/EU.

The restoration measures have been included in different funding programmes. Thus, within the Operational Programme Big Infrastructure 2014-2020, one of the specific objectives was related to “Increasing the degree of protection and conservation of biodiversity and restoring degraded ecosystems” (OS 4.1). A total amount of 138,295 thousand RON has been invested for technical assistance contracts.

Considering the National Recovery and Resilience Plan, within the Component 2- Protection of Forests and Biodiversity, Reform 2 - Reform of the management system of protected natural areas for the coherent and effective implementation of the European Biodiversity Strategy, Investment I4a - Elimination of obstacles from water courses in with the aim of facilitating the restoration of the connectivity of water-dependent habitats and species, several projects have been proposed. Thus, considering the investment target of 1,700 ha and an allocated value of 150 million euros, the project proposals add up to an area proposed for reconnection of 1,904 ha and a cumulative investment value of 100.12 million euros (MMAP, 2021f).

Additional planned measures have been identified with an investment value and other costs of approx. 5,218.8 million Euros, which will be implemented in the period 2022-2027, such as: measures to build/modernize tertiary treatment plants in settlements with 2,000-10,000 inhabitants; measures to build sewerage networks in settlements smaller than 2,000 inhabitants; measures for the construction of treatment plants (mechano-biological and tertiary) in settlements smaller than 2,000 inhabitants; other types of measures leading to the reduction of concentrations and quantities of relevant pollutants discharged/emitted into water bodies.

Additional measures for settlements are planned for implementation in the period 2022-2027 in order to achieve the objectives related to water bodies after 2027, with a value of investments and other costs of 356.3 million Euros, such as: construction measures /modernization of tertiary treatment plants in settlements with 2,000-10,000 inhabitants; - measures for the construction of sewerage networks in settlements smaller than 2,000 inhabitants.

In the process of identifying important water management problems, both at the level of the Danube International Hydrographic District and at the national level, four major categories of water management problems were identified (pollution with organic substances, pollution with nutrients, pollution with priority dangerous substances and hydromorphological alterations) for which programs of specific measures have been established in order to achieve the environmental objectives. It is also important to state that the specific measures established at the international level have been taken over and integrated at the national level.

By the end of 2021, at the national level, basic and additional measures have been carried out within the program of measures of the second planning cycle, with investments and other costs of about 7,884 million Euros, which represents approx. 55.5% of the total planned for the period 2016-2021.

Following the assessment of the situation made by the water users and the authorities that implement the program of measures in the period 2016-2021, it was found that, in some cases, there are problems regarding the implementation of the measures by the established deadlines.



For all the measures and sub-measures, in the period 2014-2021 approx. 6.1 billion euro have been planned, of which approx. 3.5 billion Euros (57.4 %) was spent until the end of 2021. The total payments made were monitored by the Agency for the Financing of Rural Investments. The mentioned basic and additional measures led to the improvement of the ecological status/ecological potential and chemical status of surface and groundwater bodies and is continuing in the period 2022-2027 (MMAF, 2021f).

All the above measures have been included in the National River Basin Management Plan and shows the extent and importance of the ecological restoration at national level. DALIA will have a significant contribution both at local scale by applying innovative solutions in the DPSs and at larger scale (regional or Danube River Basin scale) by amplifying the benefits of distributed nature-based or human-driven solutions.

Key findings

- There has been progress in WFD implementation, contributing to a much more precise and real compliance with European standards;
- The evaluation of the chemical state of the surface water bodies, at the national level, recorded improvements and developments compared to the one carried out in the 2016 National Water Management Plan;
- By carrying out the programs of measures, the improvement of the living standards of the population and the environmental standards is ensured, mainly aiming at the respect of the community environmental acquis in the field of water quality protection;
- The normative acts also address quantitative aspects and elements regarding climate change, in order to coordinate between basin management plans and flood risk management;
- It was found that the biological pressures generated by the invasion or introduction of some plant and animal species can cause the radical alteration of the structure of biocenoses in aquatic ecosystems;
- In the updated National Management Plan (2021) a total of 20,202 potentially significant pressures and 4,563 of significant pressures were identified. The largest share of pressures is represented by diffuse pressures originating, as in the case of potentially significant pressures, from settlements without collection systems and from agriculture (MMAF, 2021e).
- Regarding the risk of not reaching the environmental objectives for the year 2027, a total number of 371 surface water bodies that will not reach good ecological status/good ecological potential remain at risk;
- In Romania, the degree of connection of the population to the water supply systems has permanently increased, but the supply level remains significantly below the European average, a situation that requires continued investments in this field.
- In conclusion, at the national level, measures and instruments are needed for settlements, industrial and agricultural activities and other activities, in order to achieve the objectives of water bodies (periods 2022-2027 and after 2027), presented in the updated National Water Management Plans (MMAF, 2021e).

1.2. Local River Basin Management Plans

1.2.1. DPS6 Romania - Sturgeon migration by-pass Iron Gates I and II

THE BANAT RIVER BASIN MANAGEMENT PLAN

General context and objectives

The Banat River Basin is situated in the southwestern region of the country, sharing borders with the Mureş River Basin to the north, Serbia to the west, the Mureş River Basin and the Jiu River Basin to the east, and the Danube to the south.

The Banat River Basin includes areas from five counties: Timiş and Caraş-Severin counties in their entirety, as well as parts of Arad, Gorj, and Mehedinţi counties.

In 2018, the total population identified was approximately 1.109.183 people, with a population density of 61 per km². The major urban areas include Timişoara, Reşiţa, Lugoj, Caransebeş, and Orşova.

The Banat River Basin covers a total surface area of 18.312,20 km², which is equivalent to 7,68% of the country's surface area. The river network encompasses 389 registered watercourses, with 19 of them being smaller than 10 km². The total length of the watercourses is 6704,87 km, with an average density of 0,36 km/km². The Banat River Basin Area includes several sub-basins within Romania, namely Aranca with 9 tributaries, Timiş with 149 tributaries, Bega with 79 tributaries, Caraş with 30 tributaries, Nera with 35 tributaries, Cerna with 41 tributaries, and 40 tributaries of the Danube (MMAP, 2021g).





Figure 1: Banat Hydrographic area

The main objectives of the Banat District Management Plan are as follows:

- Ensuring the natural state of a catchment's geomorphology by avoiding any human-induced changes or alteration;
- Ensuring the prevention of watercourse and groundwater pollution caused by floods and minimizing their impact on the ecological quality of watercourses;
- Ensuring the safety and preservation of historical landmarks, monuments, protected areas, and ecosystems;
- Reduce or prevent the effects of climate change on flooding;
- Prevent and minimize flood risk to human communities and the population;
- Prevent and minimize economic losses by reducing flood risk to populated areas (MMAP, 2021g).

The Banat Hydrographic Basin contains various types of surface waters, which are categorized as follows:

Table 1:

Water bodies delimited in the Banat Hydrographic Basin (MMAP, 2021h)

| Surface water categories | No. of water bodies delimited in the Banat River Basin Management Plan |
|--|--|
| Natural water bodies, of which: | 236 |
| Rivers | 236 |

| | |
|---|------------|
| Heavily modified water bodies, of which: | 74 |
| Rivers | 65 |
| Reservoirs | 9 |
| Artificial bodies of water | 1 |
| <i>Total number of surface water bodies at the level of the Banat Hydrographic Basin</i> | 311 |

The total length of the rivers is about 6.704,87 km.

According to the National Forests Administration "Romsilva", the streams in the salmon farming area located on mountain streams are considered to have fish species with economic potential. These species include brown trout (*Salmo trutta fario*), graylings (*Thymallus thymallus*), and huchen (*Hucho hucho*). These streams have a total length of 1.176 km.

From the identified water bodies, 158 water bodies have a good ecological status and 37 water bodies have a good ecological potential. Also, 232 natural water bodies have a good chemical status, and 73 heavily modified/artificial water bodies have good chemical status (MMAF, 2021h).

Significant pressures

Aquatic ecosystems are at risk due to various activities and pressures that can impact the quality of water bodies. These include accidental pollution, fishing and aquaculture practices, extraction of gravel and sand from rivers, logging, and other unidentified pressures.

Potential sources of accidental pollution

In the Banat Hydrographic Basin, 198 water users have been identified as discharging treated or untreated wastewater. These users have developed plans to prevent and combat accidental pollution. In 2019, there were registered two events of accidental pollution of surface water bodies with wastewater. This pollution had a local or basin-wide impact, but due to the short duration of the pollution event and the resilience of the aquatic biocenosis structure, it only caused limited changes to the values of physicochemical indicators and did not significantly impact aquatic biodiversity on the long term (MMAF, 2021g).

Fishing and aquaculture activities

Aquaculture could have negative effects on aquatic ecosystems. The impact can vary from significant pressures caused by intensive aquaculture to minor pressures from semi-intensive or extensive fish farming.



In 2019, a study identified 22 potential sources of pressure on fish farming in the Banat Basin. These pressures come from both point and diffuse sources, as well as hydrological alterations, and affect 13 different water bodies. Additionally, fish farming was found to have a significant impact on three water bodies - two rivers and one lake - due to both point and diffuse sources (MMAF, 2021g).

Removal of gravel and sand from minor riverbeds

Gravel extraction pond is a common hydromorphological pressure that can affect rivers. They can cause changes to the shape of the river's longitudinal profile, alter the variability of deposits in the riverbed, and lead to degradation processes, including erosion.

Logging

Another important pressure for the forested area is logging. If the trees are exploited without respecting legal provisions and the local forest management plans, it can have negative effects on the stability of the land. These effects can include erosion, formation of torrents, landslides of banks, amplification of floods, and a decrease in the rate of replenishment of aquifers.

Ecological restoration in the Banat Hydrographic Basin

The ecological restoration issue has been included in different funding programmes and specific projects have been implemented. A few examples of such projects are as follows:

- Within Life+ Program having the main focus on conserving habitats and protecting species, a project related to the conservation of habitat 8310 located in the Natura 2000 site of Cheile Nerei – Beusnița has been implemented. The total value of the project was 849.430 Euro.
- Within the Large Infrastructure Operational Programme 2014-2020 two projects have been implemented:
- Development of the management plan for ROSPA0078 Satchinez Marsh, ROSCI0115 Satchinez Marsh, and 2.740 Marsh Reserve Satchinez Marshes. The total value of the project was 590.000 Euro.
- Development of Management Plans for ROSCI0287 Comloșu Mare, ROSCI0338 Forest Paniova and ROSCI0345 Cenad Meadow. The total value of the project was 420.000 Euro.

Also, the measures implemented in the period 2016-2020, connected with the implementation of the Nitrate Directive included:

- "Implementation of the Action Programmes and the Code of Good Farming Practice to comply with Nitrates Directive" (178 municipalities);
- Monitoring groundwater quality in the area of storage ponds;
- Application of the animal manure management, based on pedological and agrochemical studies and construction of individual manure storage platforms;

- Rational and efficient use of livestock manure (pigs) on agricultural land;
- Fertilization Plan / Organic Waste Management Plan;
- Staff training.

The updated Management Plan for the Banat River Basin Area (2021) stresses the importance of implementing Action Programmes to protect against nitrate pollution from agriculture and adopting the voluntary Code of Good Agricultural Practices throughout the river basin. Key measures include storing manure in individual or communal facilities, creating buffer strips to safeguard watercourses near farms, providing information and training to farmers and stakeholders, and continuing the "Integrated Nutrient Pollution Control (2016-2021)" project (MMAP, 2021g).

- During the period of 2022-2027, the primary measures that are being considered include:
- Funding the modernization of water supply and distribution systems, along with wastewater treatment, is crucial for ensuring that these systems meet the necessary standards for water quality and service coverage. In addition, such efforts can help reduce greenhouse gas emissions in cities and towns.
- Implementation of efficient sludge management from the wastewater treatment process;
- Research to support regional and local scale projections of global climate models to provide more accurate assessments of climate impacts in different catchments, enabling long-term water supply security.

Key findings

- The process of updating the Management Plan for the Banat River Basin Area (2021) began in 2018 and the document provides information on measures and consultation procedures for stakeholders and the general public during the planning cycle.
- To meet environmental goals for 72 water bodies, the projected costs for implementing planned measures from 2022 to 2027 and beyond is estimated to be 115.840.595 Euro.
- A total of 183 additional measures, with a combined investment cost of 159.612.271 Euro, and five instruments worth 352.788 Euro have been identified to reach the goals for water bodies in the Banat River Basin Area (MMAP, 2021h)
- The comparative analysis of data sets from 1971-2000 to projected trends from 2021-2050, revealed that certain river basins will experience significant deficits in their multiannual mean flows due to variations in meteorological parameters. Based on the analysis and simulations of flow evolution, the basins with the largest deficits will be Vedea, Jiu, Siret, Olt, and Argeş, located mainly in the southern and eastern parts of Romania.



1.2.2. DPS7: Romania - Danube Delta

MANAGEMENT PLAN FOR THE DANUBE, THE DANUBE DELTA, DOBROGEA HYDROGRAPHIC AREA AND COASTAL WATERS

General context and objectives

The general representation of the Dobrogea Hydrographic Area, Danube Delta and Coastal Waters, located in the south-eastern part of Romania, is delimited as follows:

- Dobrogea Hydrographic Area: North and northeast of the Danube Delta, east of the coastal waters of the Black Sea, south of the border with Bulgaria and west of the Danube;
- Danube Delta: north of the border with Ukraine, east of the Black Sea, and west of the Dobrogea Hydrographic Area;
- Coastal waters: north of the border with Ukraine, east of the Black Sea, south of the border with Bulgaria and west of the Dobrogea Hydrographic Area and Danube Delta.

Administratively, the Dobrogea Hydrographic Area and Danube Delta comprises the territory of two counties: Constanța and Tulcea. In 2019, the total population identified was approximately 1,008,030 inhabitants and the population density is 65 inhabitants/km². The main urban areas are Constanța, Tulcea, Medgidia and Mangalia.

The Dobrogea-Litoral river basin has a total area of 15,469.65 km², representing 6.49% of Romania's surface area and includes the Dobrogea Hydrographic Area, which covers 10,712.65 km², plus the Danube Delta with an area of 4,757 km². The river network has 16 registered watercourses with a total length of 542 kilometers and an average density of 0.035 km/km² (MMAP, 2021a).

The Danube belongs to the Dobrogea - Litoral river basin and is 275.5 kilometres long. The Danube Delta covers an area of 4,757 km² and accounts for 2% of Romania's territory. The Danube Delta's existing water network is represented by the three tributaries of the Danube, with a total length of 290 km and an average density of 0.06 km/km². In addition to the three tributaries of the Danube, there are also unlined water networks linking the deltaic lakes and the river arms (MMAP, 2021b).



Figure 2: Dobrogea Hydrographic Area, Danube Delta and Coastal Waters

The main objectives of the Management Plan for the Danube, the Danube Delta, Dobrogea Hydrographic Area and Coastal Waters are as follows:

- To guideline for land-use planning and development of the various economic activities and infrastructure, as laid down in the land-use and urban development plans;
- To integrate the environmental sustainability potential of the coastal zone within the strategic objectives and priorities;
- To elaborate a strategy for protection against degradation by marine erosion and for environmental rehabilitation of the coastal zone;
- To define and manage areas required for coastal zone security (MMA, 2021a).

The Dobrogea Hydrographic Area, Danube Delta and Coastal Waters District contains various types of surface waters, which are categorized as follows:



Table 2:

Water bodies delimited at the level of the Danube, Danube Delta, Dobrogea Hydrographic Area and Coastal Waters (MMAP, 2021b)

| Surface water categories | No. of water bodies within the Water Management Plan Danube, Danube Delta, Dobrogea Hydrographic Area and Coastal Waters (RO) |
|---|---|
| Natural water bodies, of which: | 92 |
| Rivers | 20 |
| Natural lakes | 68 |
| Transients | 2 |
| Coastal | 2 |
| Heavily modified water bodies, of which: | 15 |
| Rivers | 3 |
| Lakes | 6 |
| Reservoirs | 4 |
| Coastal | 2 |
| Artificial bodies of water | 5 |
| Rivers (canal) | 5 |
| Total number of surface water bodies at the level of the Danube, Danube Delta, Dobrogea Hydrographic Area and Coastal Waters | 112 |

In the Dobrogea Hydrographic Area, Danube Delta and Coastal Waters District there are different categories of surface waters, such as:

- rivers (natural, heavily modified and artificial) - 1,649.5 km (registered rivers);
- natural lakes - 74 with area greater than 0.5 km²;
- reservoirs - 4 with area greater than 0.5 km²;
- transitional waters - 781.37 km² (619.37 km² marine transitional waters and 162 km² Sinoe Lake);

- coastal waters - 571.8 km² (MMAP, 2021b).

Significant pressures

Aquatic ecosystems are at risk from a variety of activities and pressures that can impact the quality of water bodies. In the Dobrogea Hydrographic Area, Danube Delta and Coastal Waters, District the following types of activities/pressures have been identified that may affect the status of water bodies: accidental pollution, fishing and aquaculture activities, gravel and sand extraction from riverbeds, logging, unidentified pressures, etc.

Sources of potential accidental pollution

These affect the quality of water resources to some extent and can suddenly change their physical, chemical and biological properties. Thus, depending on the scale and impact of the pollution of surface and groundwater resources (local, basin-wide, transboundary), they can have consequences on the health status of the population in the affected areas. In the Dobrogea Hydrographic Area, Danube Delta and Coastal Waters District, 74 water users have been identified that may cause accidental pollution. Plans for preventing and combating accidental pollution have been drawn up. In 2020, 9 accidental pollutions of surface water courses with phosphate rock, bauxite, petroleum hydrocarbons, crude oil were registered. This pollution had a local or basin impact and due to the short duration of the nature of the pollutant, the length of the affected area and the resilience of the aquatic biocenosis structure, it caused only limited changes in the values of physico-chemical indicators and did not have a significant impact on aquatic biodiversity in the long term (MMAP, 2021a).

Fishing and aquaculture activities

Aquaculture can have negative impacts on aquatic ecosystems. Impacts can range from significant pressures caused by intensive aquaculture to minor pressures caused by semi-intensive or extensive fish farming.

In 2019, a study identified 37 potential sources of pressure on fish farming in the Dobrogea Hydrographic Area, Danube Delta and Coastal Waters. These pressures come from both point and diffuse sources and hydrological changes and affect 22 different water bodies. However, no significant impact has been recorded in relation to fish farming (MMAP, 2021a).

Gravel and sand extraction from minor riverbeds

This is a type of hydromorphological pressure that can affect rivers through the construction of the gravel extraction ponds. They can cause changes in the shape of the longitudinal profile of the river, alter the variability of deposits in the river bed and lead to degradation processes, including erosion.

Logging

Logging that is carried out hazardingly, without respecting legal requirements, can have negative effects on land stability. These effects can include erosion, the formation of torrents, landslides, increased flooding and a decrease in the replenishment rate of aquifers.



Invasive species

The introduction or invasion of plant and animal species can radically alter the biocenosis structure of aquatic ecosystems. At the level of the Dobrogea Hydrographic Area, Danube Delta and Coastal Waters, the natural protected areas for identified water have been grouped into 18 areas (46 natural protected areas) for the protection of water-dependent habitats and species. Their surface area is approximately 12,094.3 km².

Ecological restoration measures

For the protection of habitats and species an appropriate water quality is required. Collaboration between the authorities responsible for managing water resources and natural areas in order to set and achieve specific objectives for the protection of habitats and species is essential. Natura 2000 National Network provides detailed data and a management plan with a set of measures for habitats and species of community interest in the specific area.

Other specific measures to reduce diffuse nutrient pollution, such as the construction of communal manure storage platforms for application bans and the provision of equipment and machinery for the development of manure storage facilities, the prevention and control of pollution from agricultural activities in areas facing natural constraints, significant natural constraints or other specific constraints.

- The main ecological restoration measures are as follows:
- Measures to reduce the effects of pressures caused by effluent from agricultural activities
- Measures to reduce pollution by hazardous substances
- Measures to prevent and reduce the impact of accidental pollution
- Measures to reduce the effect of hydromorphological pressures that include: a) measures to ensure longitudinal connectivity; b) measures to ensure lateral connectivity, improving the morphology of banks and riparian zone; c) measures to establish the hydrological regime to ensure that the requirements of water uses are met and are compatible with ecological requirements (baseline measure); d) other specific additional measures to reduce hydromorphological pressures.
- Measures to ensure lateral connectivity, improve bank morphology and riparian zone
- Measures to improve lateral connectivity in the Danube
- Measures to restore lateral connectivity, improve morphology of banks and riparian zone
- Further measures to reduce pollution by organic substances, nutrients and priority substances to achieve good water status
- Additional measures to reduce the impact of human settlements
- Additional measures to reduce the effects of industrial activities

- Additional measures to reduce pollution from agricultural activities
- Measures for livestock farms - point source pollution, measures to reduce diffuse pollution from livestock farms, plant and agricultural land (MMAP, 2021a).

Key findings

- The implementation of the Dobrogea Hydrographic Area, Danube Delta and Coastal Waters Management Plan 2022-2027 has a planned budget for investment costs of about 171.67 million euro. To the investment costs are added annual operation and maintenance costs of about 4.93 million euro over the period (MMAP, 2021b).
- Regarding to the additional measures for agricultural activities planned for the period 2022- 2027, it generally refers to: reduction of soil erosion, application of cultivation practices to reduce the use/pollution with plant protection products, protection of water bodies against pesticide pollution, application of the code of good agricultural practices.

To achieve the environmental objectives for 14 water bodies, the total estimated investments and other costs for additional measures planned to be implemented in the period 2022-2027 and beyond 2027 are of 124,037,843 euro (MMAP, 2021a).

1.2.3. DPS9: Romania - Crisuri Water Basin Administration

CRISURI RIVER BASIN MANAGEMENT PLAN



Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily express those of the European Union or the CINEA. Neither the European Union nor the granting authority can be held responsible for them.

General context and objectives

The hydrographic basin Crişuri includes parts of the territory of 6 counties, namely: Bihor county, as well as parts of the territories of Arad, Hunedoara, Cluj, Sălaj, and Satu Mare counties.

The total surface area of the Crişuri hydrographic basin is 25,537 km², out of which 14,939 km² are within Romania, representing 6.27% of the country's total area. The hydrographic network comprises 365 registered watercourses, with a total length of 5,785 km and an average density of 0.39 km/km². In Romania, the Crişuri hydrographic area includes the sub-basins of Crişul Alb (4,263 km²), Crişul Negru (4,260 km²), Crişul Repede (3,001 km²), Barcău (2,015 km²), and Ier (1,400 km²) (MMAP, 2021d).

The relief of the Crişuri hydrographic area is characterized by three geomorphological forms: mountains (accounting for 22.4%), hills (29.3%), and plains (48.3%), distributed from east to west, with altitudes ranging from 1,849 m (Mount Bihor in the Bihor Mountains) to 85 m (in the low plain of Crişul Alb).

The total surface water resources in the Crişuri hydrographic area amount to approximately 2,937.4 million m³/year, of which the usable resources are about 394.734 million m³/year. It represents approximately 13% of the total theoretical surface water resources and are mainly formed by the rivers Crişul Alb, Crişul Negru, Crişul Repede, Barcău, Ier, and their tributaries. In the Crişuri hydrographic area, there are 9 important reservoirs (with a surface area greater than 0.5 km²), which have a complex use and sum up to a useful volume of 170.35 million m³ (MMAP, 2021c).

The main economic activities in the Crişuri hydrographic basin are represented by industry and agriculture (e.g., Extractive industry and oil processing; Leather and footwear industry; Furniture industry; Chemical industry; Garment industry; Construction materials industry; Construction industry; Food industry, etc.). Regarding agriculture, the dominant profile is mixed production, both crops and livestock. The main agricultural products in the Crişuri hydrographic basin are corn, wheat, rye, oats, barley, potatoes, sugar beets, sunflowers, vegetables, etc. Favourable conditions for cultivating grapevines for wine production can be found. The most suitable area for growing fruit trees (plums, apples, pears, cherries, and sour cherries) is Nuşfalău.

The environmental objectives of the water management plan essentially include the following elements:

- For surface water bodies: achieving good ecological status and good chemical status for natural water bodies and achieving good ecological potential and good chemical status for heavily modified and artificial water bodies.
- For groundwater bodies: achieving good chemical status and good quantitative status.
- Progressive reduction of pollution from priority substances and gradual cessation or elimination of emissions, discharges, and losses of hazardous priority substances into surface waters through the implementation of necessary measures.
- "Prevention or limitation" of pollutant discharges into groundwater through the implementation of measures.
- Reversing the significant and sustainable increasing trends of pollutant concentrations in groundwater.
- Non-deterioration of the status of surface and groundwater (Art. 4.1.(a)(i), Art. 4.1.(b)(i) of the Water Framework Directive).

- For protected areas: achieving the objectives provided by specific legislation (MMAP, 2021c).

The Crisuri Hydrographic Basin contains various types of surface waters, which are categorized as follows:

Table 3:

Water bodies delimited in the Crisuri Hydrographic Basin (MMAP, 2021d)

| Surface water categories | No. of water bodies delimited in the Crisuri Basin Management Plan |
|--|--|
| Natural water bodies, of which: | 205 |
| Rivers | 205 |
| Heavily modified water bodies, of which: | 29 |
| Rivers | 21 |
| Reservoirs | 8 |
| Artificial bodies of water | 7 |
| River (channels) | 6 |
| Lakes | 1 |
| Total number of surface water bodies at the level of the Crisuri Hydrographic Basin | 241 |

From the total number of surface water bodies, 64.73% have a good ecological state/ ecological potential (156 water bodies), 31.54% have a moderate ecological state/ ecological potential (76 water bodies) and 3.73% have a poor ecological state/ ecological potential (9 water bodies).

Aquatic ecosystems serve as habitats for numerous species that either feed or nest in these areas. A series of habitats of conservation interest have been identified in the Crisuri Basin like,

- Riparian woodlands with willow (*Salix alba*) and white poplar (*Populus alba*) are highly fragmented within the site.
- Rivers with muddy banks and vegetation of *Chenopodium rubri* and *Bidention*.
- Eutrophic natural lakes with vegetation typical of Magnopotamion or Hydrocharition.



- Rivers with muddy banks and vegetation of *Chenopodium rubri* and *Bidention*. This habitat appears on relatively large but fragmented areas, on fresh alluvium, along the banks of Crișul Repede.
- Eutrophic natural lakes with vegetation of *Magnopotamion* or *Hydrocharition*. This habitat is poorly represented along the course of Crișul Repede in places with slower flow of the river, but it is exceptionally diverse and well-preserved in the Girișul de Criș lake within the site's perimeter, where a rich birdlife is also present.

Also, an invertebrate species of interest has been identified, *Coenagrion ornatum* - Large Red Damsel (damselfly), a resident species of damselfly, with rare presence in the site and relatively difficult to identify. It prefers to rest in low and concealed areas of hygrophilous vegetation. The species has been identified only in the western sector of the site, in areas with slow flow.

Eight fish species of conservation interest are also identified in the Crisuri Basin, like: *Cobitis taenia* (Spined Loach), *Gobio kessleri* (Kessler's Gudgeon), *Gobio albipinnatus* (Whitefin Gudgeon), *Gymnocephalus schraetzer* (Ruffe), *Rhodeus sericeus amarus* (European bitterling), *Sabanejewia aurata* (Weather), *Zingel streber* (Danube Roach), *Zingel zingel* (Italian Stream Loach) (MMAP, 2021c).

Ecological restoration measures

To fulfil the environmental objectives at the hydrographic basin scale, a series of measures have been implemented. These measures, based on the WFD recommendations, are basic or supplementary measures that could be complemented by instruments, respectively long term administrative or economic measures. The basic measures are related to all water bodies, since the supplementary measures are related only to the water bodies at risk to not fulfil the environmental objectives. All measures are applicable in relation to the anthropogenic pressures, mainly related to human settlements, industrial activities, agriculture activities, hydromorphological pressures or other activities that could generate significant pressures. Until the end of 2021 year, the total investments for different measures were of 378,646 million euro, representing 55.14% of the planned investments. Most of the investments have been related to human settlements (water use and wastewater, water treatment), followed by costs for industrial activities and waste management and costs for the control and monitoring of the pollution sources (MMAP, 2021c).

A series of supplementary measures have been implemented until the end of 2021, respectively construction of wastewater collection and treatment technical facilities for settlements with less than 2000 inhabitants, application of the Code of Good Practices in Farms aiming to reduce nutrient emissions, research for improving the water management plan (integration of the protected areas, ecological state, ecological flow).

Key findings

- There is a strong interconnection and complementarity in implementation of European directives at national and local level and other strategies and programmes related to some specific aspects of the aquatic ecosystems and their hydrographic basins.
- The European Green Deal priorities are integrated into the action's programmes both at national and hydrographic basin levels.
- An important funding source is the National Recovery and Resilience Plan that includes investments and planned costs for reforming the national management system for protected areas to have a coherent and efficient implementation of the EU Biodiversity Strategy 2030. An important component is related to:

Integrated investments of ecological restoration of habitats and conservation of species from meadows, aquatic and dependent ecosystems.

- The measures for developing wastewater collection and treatment systems funded within the Large Infrastructure Operational Program 2014-2020 will be complemented by actions that are in line with the prioritization of the County Master Plans, respectively to comply with the provisions of the directive regarding the collection and treatment of urban wastewater for agglomerations with over 2,000 inhabitants. Efforts will also continue through the Sustainable Development Operational Program 2021-2027 and the National Recovery and Resilience Plan to improve the wastewater collection and treatment systems (MMAP, 2021c).

2. OVERVIEW OF DPS

Table 4:
Overview of all DPS

| DPS | Location and site description |
|------|---|
| DPS1 | The revitalization of the ecological system in the Szigetköz region of Hungary in DPS1 represents best practice in support of comprehensive water, environmental and agricultural policy planning. River engineering and hydropower exploitation has changed the river system and thus the water, environmental and ecological conditions. These changes and climatic factors in the Szigetköz natural area are reflected in continuous ecological succession processes of natural habitats in the land and riparian areas, as well as in the increase of extreme flood events. |



| | |
|------|--|
| DPS2 | The reconnected floodplain of the Upper Danube in Germany in DPS2 represents the best practices support to increase the biological consistency of the Danube and to recreate near-natural dynamics of water in the floodplain to conserve habitat and floodplain species. Hydropower barriers and the separation of river and floodplain by dams have greatly reduced the area of active floodplain and threaten it due to groundwater rise and lack of flooding/connection to the Danube. |
| DPS3 | The dyje sub-catchment of the Danube River catchment in the Czech Republic in DPS3 represents best practice to support comprehensive water and environmental management in the transboundary area bordering Austria. The issue most addressed is that the Dyje River in the Czech Republic is artificially dammed in several places, which has lead to water scarcity and fragmentation of original vegetation (e.g. floodplain forest). |
| DPS4 | The “Springs Reborn” in DPS4 in the upper catchment of Vah river Rehydration in Slovakia represents best practices that support effective water management (especially flash flood management and sustainable hydration) of the topmost sub-catchments. This is to better deal with frequent flash floods, land erosion, loss of soil droughts, biodiversity loss and groundwater declination. |
| DPS5 | The DPS5 in Serbia supports the use of sustainable ecosystem monitoring and restoration solutions. The goal here is to improve the water quality, hydrological regime and ecosystem of the Begečka jama wetland, which is severely affected by pollution and sediment input from the surrounding drainage area and farmland. |
| DPS6 | The sturgeon migration by-pass at DPS6 located in Romania at Iron Gates I and II supports the sustainable biodiversity and connectivity of the migration routes of the sturgeon specimens in the Danube River basin. |
| DPS7 | DPS7, located in the Danube delta of Romania, represents the improvement of monitoring system and knowledge of sediment flows in the Black Sea and the associated increase in sediment transport. |
| DPS8 | Based in Hungary, DPS8 supports the use of sustainable solutions for monitoring and removing plastic pollution from the Bodrog river in the Danube River basin, as in some cases the floodplain is constantly covered by litter brought there by floods. |
| DPS9 | DPS9 represents best practices to achieve good ecological status of water bodies in Crisuri basin and to revitalize the wildlife. An integrated management will be organized to allow development of socio-economic and leisure activities, and as well, will maintain a good ecological potential of the area. |

2.1. DPS 1

Author: Mate Chappon & Katalin Bene

Location: Szigetköz, West-transdanubia, Hungary

Short form of the organization: SZE - Széchenyi István University is located halfway between the capital cities of Hungary, Austria and Slovakia, on the banks of the Mosoni Danube. The University offers unique education and research in the region, which serves engineering oriented production activities and contributes to the development of the North Transdanubian economy and its social and institutional infrastructure. A Water Resources Research Group has been established at the University. The main focus of the research is to respond to short and medium- term water resource issues and to prepare effective water management decisions.

2.1.1. General Overview

The Danube exits the swift channels of the Alps and the Carpathians near Bratislava, Slovakia. Beyond this point, its gradient and velocity decrease significantly. The river deposits sediment, creating countless islands in a tangled system of river branches, commonly called an inland delta (Dr Göcsei Imre, 1979). The Mosoni-Danube forms the southernmost branch of the Danube. The area between these two branches is called Szigetköz (Maly Žitný Ostrov). Szigetköz is Hungary's largest island with a land area of about 375 km². There is also a large island on the Slovakian side called Csallóköz (Žitný Ostrov).

In the 19th century, Hungarian river regulators created the main riverbed (Old Danube) in the middle of a tangled system of branches by means of large-scale river regulation to improve navigation conditions. Following the river regulation, continuous flood protection dikes were built on both banks of the Danube in the early 1900s, dividing the historic floodplain into active and historic (inactive) floodplain areas.

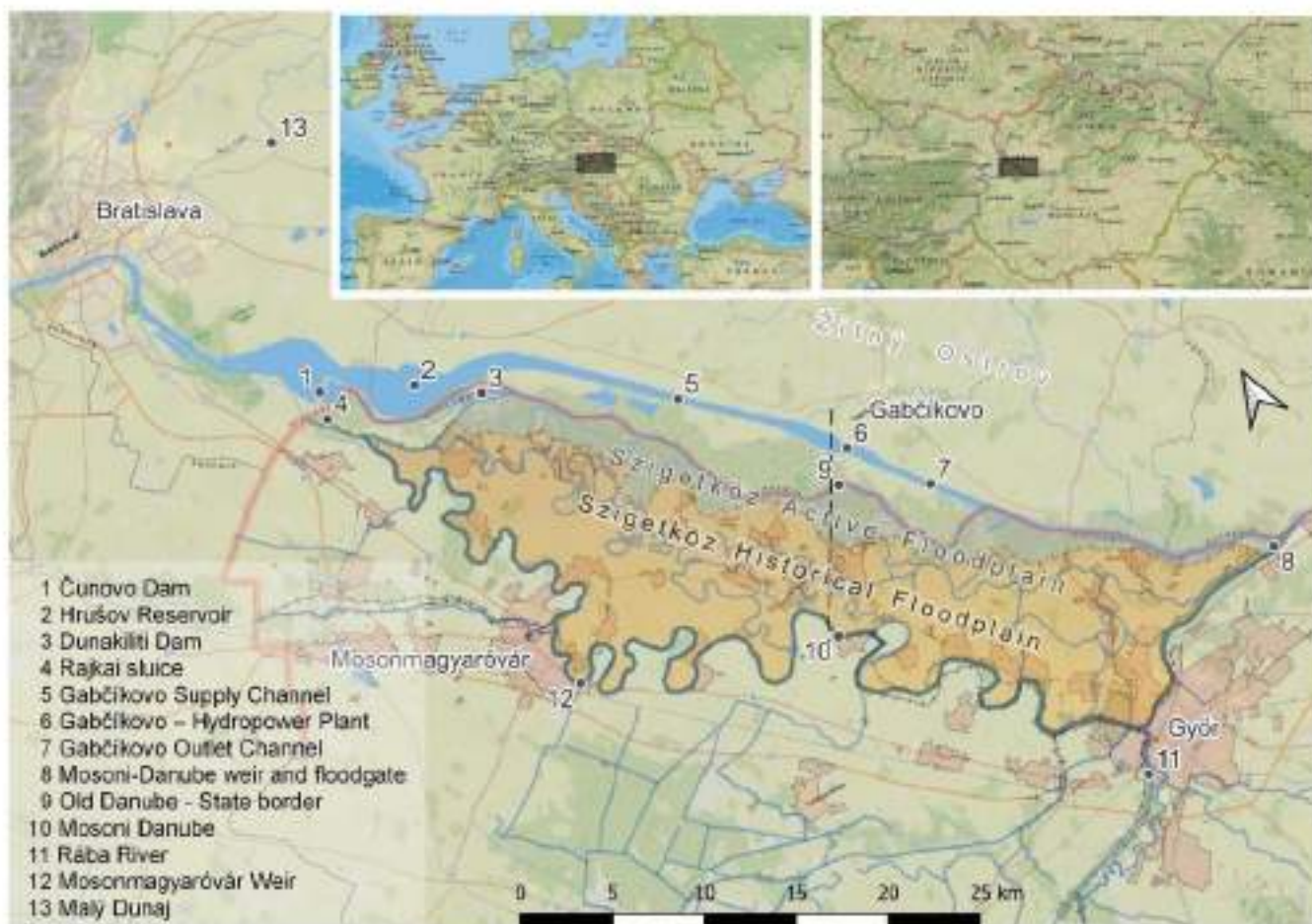


Figure 3: An overview map of the Szigetköz region



Several river branches fragment the active floodplain. The islands between the branches are mainly covered with floodplain forests (17% of the total area of Szigetköz) (Szabó, 2006).

The historic floodplain of Szigetköz is a mosaic landscape, the most important part of which is agricultural land, typically arable land (55%). There are smaller amounts of meadows and pastures (10%). Thin strips of forest, canals, oxbow lakes, swamps, reeds and other water bodies and wetlands (10%) form the edges of the landscape. More than 20 settlements (8%) are located within the historic floodplain.

There is a slight difference between the climatic parameters of the north-western (Upper Szigetköz) and the southern (Lower Szigetköz) parts of the region; where the NW is moderately cool and the SE is moderately warm, with a dry climate. The average annual temperature is 9.7-10.0 °C. The annual rainfall is 550-600 mm. The average number of snow days in winter is about 30. The prevailing wind direction is north-westerly, with an average wind speed of 3 m/s.

The soils of the Szigetköz developed from alluvial material under the influence of climate, vegetation and groundwater conditions (Várallyay, 1992). The soil-forming rocks of the area are young, typically sandy-silty alluvial deposits of the Danube. They are characterised by a light mechanical composition and carbonate nature, with varying degrees of underlying gravel at different depths (several hundred metres). Meadow processes dominate in areas that are not flooded but where the water table is close. Chernozem soil formation processes predominate in areas where the water table is deep.

Most areas of the active floodplain and some parts of the historical floodplain have been protected as the Szigetköz **National Landscape Protection Area** since 1987 and are part of the **NATURA2000 network**.

2.1.2. History of transformation

The natural character of the Danube at Szigetköz has been significantly altered by water management projects (see Figure 4).

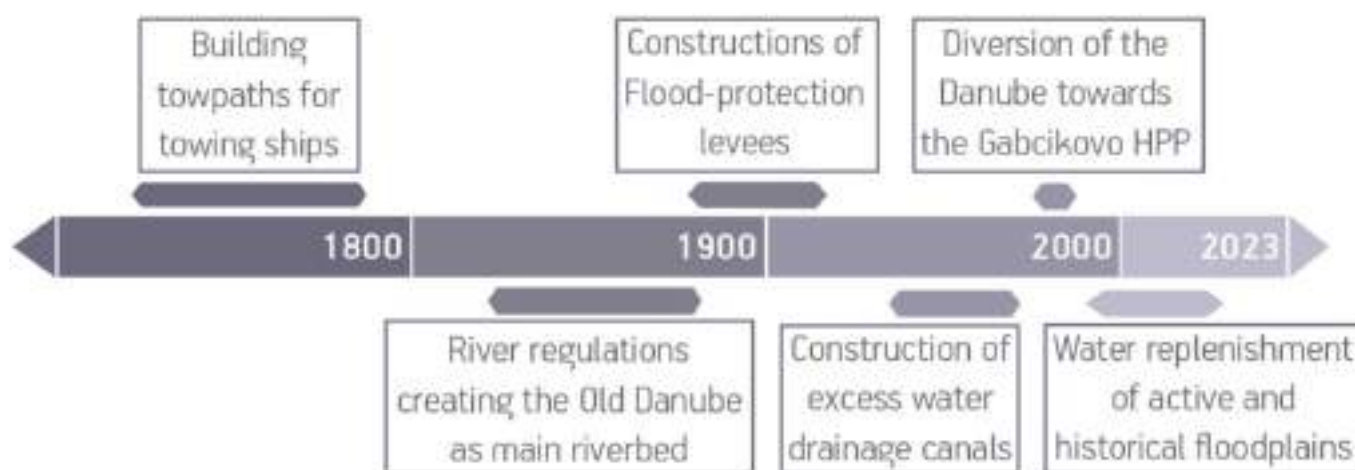


Figure 4: Timeline of the most significant anthropogenic changes in the Szigetköz floodplain between 1700-2023.

The most important water management measures were designed to make navigation possible. Szigetköz had many wide and narrow free-flowing branches, which changed with every major flood event. Therefore new navigation routes had to be continuously found in order to adapt to the ever changing conditions. The first intervention was the

construction of **towpaths** for inland navigation in the 17th and 18th centuries. Then, in the 19th century, the river was more profoundly changed by the **river regulations** (Szabó, 2005). At that time, the river regulations aimed to develop a main riverbed (today called "Old Danube") and to protect it from lateral morphological changes. **Flood protection dikes** were built on both sides at the beginning of the 1900s. Finally, the old Rajkai (Trianoni) **floodgate** and lock (a structure for regulating the water flow of the Mosoni-Danube) were built. With this floodgate, there was no longer a need to build flood protection dikes on the upper parts of the Mosoni-Danube. The floodgate and the Old Danube dikes separated the once connected system. They created a division of the main channel with the active floodplain and the historical floodplain on both banks of the Danube, fundamentally changing its hydromorphological character.

The historic floodplain was protected from flooding by river regulation and the construction of flood control levees. However, as a result, flood levels increased because suspended sediments were deposited in a much smaller floodplain; 2/3 of the floodplain had become inactive. As a result, the dikes had to be raised and strengthened over the years. During flooding, the higher water levels of the Danube caused more seepage, which led to a **surplus of water inland**. In the 1900s, **drainage canals** and **pumping stations** were built on the historic floodplain to protect against excess water. Drainage canals were often created by connecting old oxbows and inactive branches of the Danube. These canals followed the natural slope of the land (northwest to southeast) to join the Mosoni-Danube at the southern end of Szigetköz Island. The canals always had water, even after the construction of the flood protection dams, because the gravel soil of Szigetköz allowed for the seepage of the old Danube. However, the canals and the pumping stations had to be operated carefully. The soil above the gravel layer is very shallow, especially in the upper part of Szigetköz, and the groundwater level had to remain close to the surface in order to ensure agricultural production. A low water table in this area has a negative effect on the soil moisture content, as the thin soil cover dries out quickly.

In the 1950s, the river still had a dynamic connection with the active floodplain, as the river discharge was distributed between the Old Danube and the active floodplain branches. However, during low- and medium-flow periods, large debris from the upper Danube continued to enter the area, causing increasing problems for navigation on the Old Danube. This made the maintenance of the navigation route difficult, as the gradient of the river at Szigetköz was significantly reduced and the sedimentation of the riverbed in the Old Danube and its tributaries continued. Therefore, the regulation of the river continued in the 1960s, changing the hydromorphology even more. The riverbed was dredged, groynes were built, and finally the **side arms were closed with parallel weirs** to raise the water level in the Old Danube during low and medium flow periods. This meant that when the flow in the Danube was less than 2000 m³/s (later 2500 m³/s due to the incision in the riverbed), the active system of side arms did not receive flowing water. However, the side arms were still covered with water during these periods due to the high seepage rate from the Old Danube.

After the 1950s, many **barrages** were constructed in the upper Danube catchment in Germany and Austria. One of the major consequences of these dams was the reduction of bedload sediment transport in the Danube. As a result, after the 1970s, the low and middle water levels began to decrease due to the incision of the riverbed of the Old Danube. The active floodplain continued to be filled with suspended sediments during regular floods. During these years, the ongoing **industrial dredging** of the river exacerbated these effects. The dredged gravel was used for concrete construction for infrastructure and housing. These effects gradually lowered the level of the Old Danube riverbed below the riverbed of active floodplain branches, making seepage water supply for side branches less reliable. At the same time, flood levels increased due to climatic changes.



Based on these natural and man-made changes, **all water bodies of Szigetköz** (Old Danube, active floodplain branches, historical floodplain branches and the Mosoni Danube) **were heavily modified** by the end of the 1960s using the terms of the Water Framework Directive.

In 1992, the situation was aggravated by the Gabčíkovo - Nagymaros Barrage Project (GNP). The original purpose of the project was to generate hydroelectric power, improve shipping routes, increase flood safety, and ensure the water replenishment of oxbows and tributaries. In 1989, Hungary unilaterally withdrew from the project, Slovakia however, continued without consensus and diverted the Danube in 1992, causing widespread negative impacts. The average annual flow of the Old Danube at Rajka decreased by 80-90% from 2000 m³/s to 200-400 m³/s. The water level of the Old Danube decreased by an average of 3 meters. The groundwater flow direction changed due to the low water level of the Old Danube and the river started to drain the groundwater of the region. The average groundwater level dropped up to 1.5 meters (Bárdossy & Molnár, 2004). The active and historical floodplain branches in the Upper Szigetköz dried up completely as the Old Danube started to drain the surface and groundwater of the area. The branches of the Lower Szigetköz were initially less affected, but their situation worsened in the following years due to the increased incision of the riverbed downstream of the Gabčíkovo hydroelectric power plant. Aquatic habitats disappeared in the branches of the upper Szigetköz area because the water replenishment systems were not fully constructed when the Danube was diverted. Terrestrial habitats, agricultural production and forestry suffered greatly (Kerekes et al., 1998). The only positive change was the continuous water supply of the Mosoni-Danube, which had previously experienced supply difficulties through the Rajkai floodgate during low-flow periods. The southernmost branch of the Szigetköz received a discharge of 20 m³/s at Cunovo after 1992, as agreed in the Gabčíkovo-Nagymaros barrage project. A cross section of the presently separated water bodies is shown in Figure 5.

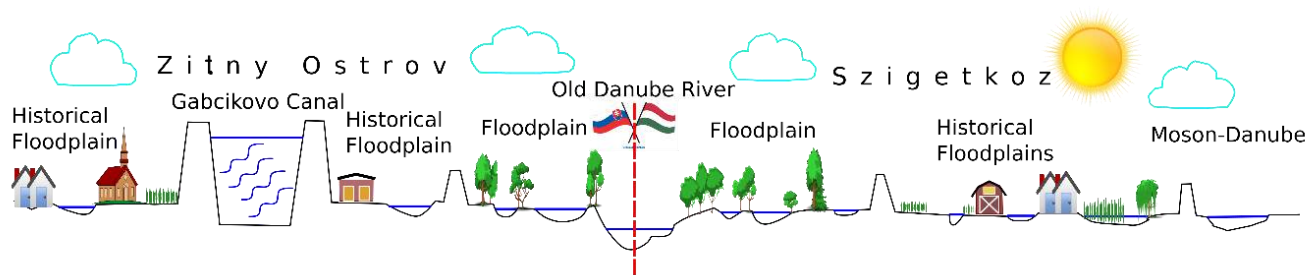


Figure 5: Spatially separated water bodies in the area of Szigetköz-Csallóköz. 1. Maly Dunaj (on the Slovakian side, not shown in the Figure), 2. Zitny Ostrov historical floodplain channels, 3. Gabčíkovo supply canal, 4. Slovakian side historical floodplain water system, 5. Slovak side active floodplain water replenishment system, 6. Old Danube, 7. Hungarian side active floodplain water replenishment system; 8. Hungarian side historical floodplain water replenishment system, 9. Mosoni-Danube

Another environmental problem was that the Szigetköz was originally covered with grassland, which gave way to agricultural land in the 19th and early 20th centuries. In the second half of the 20th century, agricultural land and grassland gave way to an increasing number of forests, mostly poplar plantations. Today, most of the active floodplain is covered with poplar plantations. In the last 30 years, the width of the river has shrunk by 1/3 due to the low water levels of the Old Danube (Rákóczi & Sass, 2006). As a result, the river banks have been overgrown with trees and dense shrubs, changing the former habitat and reducing the flood conveyance capacity.

The most notable change in terrestrial habitats in the active floodplain and main riverbed area has been the loss of natural grasslands. Long before the diversion of the Danube due to river regulations, the loss of the ecological connection between the river and the floodplain in the early 1900s prevented the passage of fish and other aquatic fauna during most parts of the year. Before the 1992 diversion, the Old Danube and the floodplain branches were connected for 30-35 days a year when the flow of the Danube exceeded 2,500 m³/s. After the diversion, this period

decreased to 2-4 days per year. Flood discharges into the Old Danube at Cunovo were made only when the discharge at the Gabčíkovo hydroelectric power station exceeded 4500 m³/s.

2.1.3. Implemented measures

The measures implemented, summarised below, resulted in the restoration of water levels and dynamic flow fluctuations in the active and historic floodplain tributary systems, with special emphasis on ecological connectivity and stakeholder involvement. The design, construction and operation of the system are detailed in the following sections.

Define the main objectives

After 1992, the main goal of local water management interventions was to redesign and complete the water replenishment system planned as part of the Gabčíkovo-Nagymaros Project. In addition to mitigating the harmful effects of the diversion of the Danube, the task was to define and achieve an ecological target condition. The target condition could have been either "good ecological status" or "good ecological potential". Local stakeholders were involved and participated throughout the planning and decision-making process.

The first and most important task of the stakeholders was to negotiate the restoration goals. Since the stakeholders sometimes expressed conflicting demands, it was necessary to reconcile the interests of the stakeholders. One of the first possibilities raised by the environmentalists was the restoration of Szigetköz to its natural state (dismantling all the water infrastructure, including the flood protection dams).

A common priority expressed by most stakeholders was to maintain flood protection, therefore the highly modified state of river bodies (where $\frac{2}{3}$ of the floodplain was separated by dikes) was accepted and the dikes would remain. Subsequently, the first main objective of the design of the water replenishment systems was to **improve the ecological condition** of the river branch system so that the **aquatic habitat types, which were characteristic of this section of the Danube, could be restored**.

A common basis for the planning of the water levels in the floodplain water replenishment systems was to **follow the natural fluctuations of the Danube discharges**. Thus, the interests of one stakeholder group should not be placed above the others during the restoration.

The next step was to determine the **reference period for good ecological potential**. For this purpose, the available hydrological and water quality data were analyzed. Continuous hydrological data were available since 1901, but for earlier conditions only maps and single measurements were available. The most important aspect of the selection process was to find a time period when the flow regime of the floodplain branches was determined by the natural flow regime of the Danube.



To find this period, the stakeholders looked back to the most significant interventions that changed the water supply of the active floodplain branches. These were carried out in the 1960s, when the active floodplain tributaries lost their natural connection to the main river as a result of river regulation activities carried out to maintain the shipping route of the Old Danube. Based on this, the **stakeholders selected the period of the 1950s as the basis for good potential**. The water levels and flows that characterized this period were not only suitable for the active floodplain tributaries, the Mosoni-Danube water supply was also continuous at that time through the Rajkai floodgate, following the natural flow dynamics.

Planning the water replenishment systems

Hydrological conditions similar to the chosen reference period had to be created in the branch system to achieve good ecological potential. The most important element was to ensure dynamic, daily or short-term changes in water levels, as seasonal averages mask natural dynamics (see Figure 6 and Figure 7).

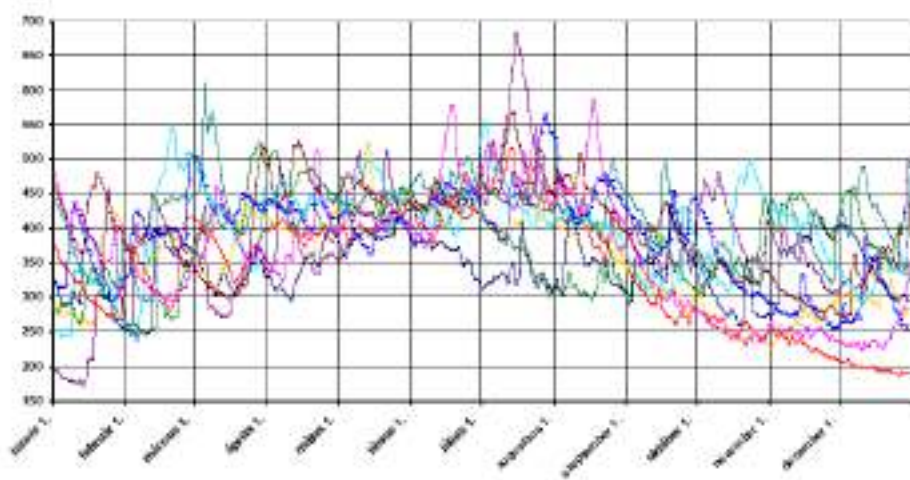


Figure 6: Daily water level time series of the Danube at Dunaremete (1826 rkm) between 1950-1959.



Figure 7: Monthly average water level time series of the Danube at Dunaremete (1826 rkm) between 1950-1959.

Therefore, the active floodplain replenishment system was designed to dynamically follow the natural fluctuations of the Danube discharge.

The establishment of good water quality conditions is as necessary from an ecological point of view as the reproduction of water level dynamics. Based on the analysis of previous hydrobiological data, eutrophication processes take place in the branch system when the residence time is longer than four days. The minimum cross-sectional average velocity was also important to minimize the risk of clogging the river bed. Based on calculations, this velocity was defined as 0.3 m/sec. The goal was to determine the minimum discharge to replenish the active floodplain. Hydrodynamic modeling was used to calculate the flow dynamics in the branch system. First, a geodetic survey of the tributary system was conducted, taking a cross section every 200 m. The model then determined a minimum discharge of 50 m³/sec, which met the required residence times and flow velocities.

The following basic criteria have been established for operation:

- a daily, dynamically controlled system;
- an average velocity greater than 0.3 m/sec;
- to maintain a residence time in the branches that is less than 4 days; and
- to discharge at least 50 m³/s into the active floodplain branches.

The aim of the design was to return water levels to the characteristic water levels observed in the reference period of the 1950s, including surface and underground waters. The engineering design of the hydraulic structures in the Old Danube and the floodplain branches is described in detail in the next section.

Construction and design of the water replenishment systems

After the diversion of the Danube, the water level of the Old Danube decreased drastically. As a result, the surface and groundwater levels in the active floodplain were dramatically lowered. In order to ensure the retention of water in the floodplain, hydraulic controls had to be built to separate the main riverbed from the active floodplain branch system on both the Hungarian and Slovak sides of the Old Danube, while restoring the reference period water levels in the active floodplain branches (see Figure 8).



Figure 8: Danube at Szigetköz, between Cunovo and Vámoszabadi. From top to bottom, the separated water bodies of the region can be seen: the supply channel of the Gabčíkovo power plant, the Slovakian active floodplain system, the Old Danube (the river banks that have dried up due to low discharge are marked in red), the Hungarian active floodplain system, the Hungarian historical floodplain water replenishment system (Map of the Szigetköz Floodplain).



The plan for the comprehensive rehabilitation of the Szigetköz was finalized with the participation of the stakeholders and received an official building permit from the Hungarian authorities. An agreement was also negotiated with the Slovakian side (Agreement, 1995), which was necessary to carry out important cross-border parts of the work.

After the planning process, the Upper Szigetköz (between Rajka and Ásványráró) floodplain replenishment systems were constructed in 1995. The active and historical floodplain replenishment is a gravitational system without pumping, relying on the backwater effect created by the Dunakiliti barrage and the Old-Danube submerged weir. The extension of the historic and active floodplain water replenishment system to the Lower Szigetköz area (between Ásványráró and the Mosoni-Danube outflow) and the ecological restoration of the Mosoni-Danube were carried out in 2014-2015 in order to reduce the detrimental effects of past river regulation, such as river bed incision and water body separation with dikes and locks. As part of the replenishment systems, fish passes (see in ANNEX NO 2.) were constructed to ensure fish migration along the river and between the floodplain and the river. The construction of the Mosoni-Danube outlet structure was completed between 2019 and 2022, and aimed to counteract the negative effects of past river regulation and riverbed incision. According to the joint Slovak-Hungarian plan of 1989, the Nagymaros barrage would have compensated for the small and medium water level drops caused by continuous regulation and dredging for the sake of navigation. Since the barrage was not built, the Mosoni-Danube outlet structure became necessary. The restoration of the water level in the Old Danube has not yet been realized, but plans have been made in cooperation with Slovakian experts to achieve this in the future.

The following maps (Figure 9 and Figure 10) show the main hydraulic structures in Slovakia and Hungary in the Szigetköz region. The individual water bodies of the Szigetköz area are also shown on the maps. The water outtake points between the water bodies are marked with red triangles, while the fish passes connecting the water systems are marked with green diamonds.



Figure 9: Overview map of the Szigetköz water replenishment systems.

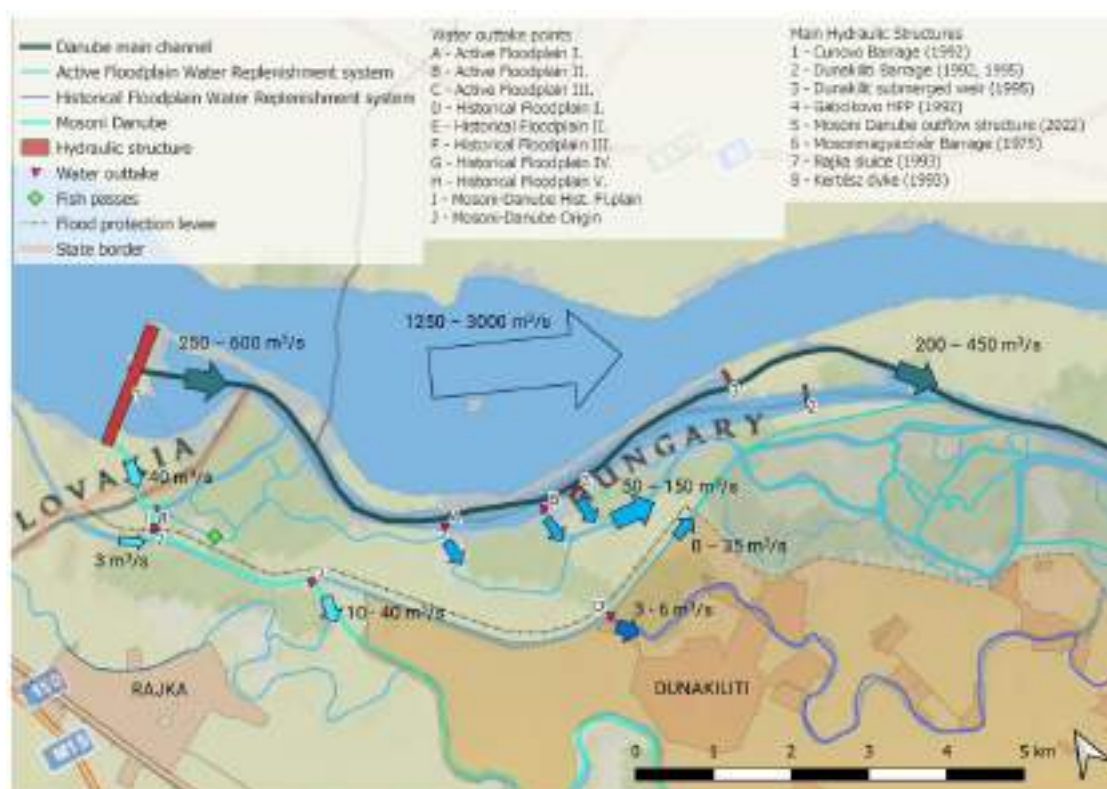


Figure 10: Main hydraulic structures and water outtake points of the Rajka - Dunakiliti region of Upper Szigetköz

Upstream control and structures play a critical role in managing the complex dynamics of water flow within the Danube River system. The discharge at Rajka is a key component in this complex process. This discharge, which ranges from 250-600 m³/s, originates from the reservoir and is released into the main riverbed at Cunovo in accordance with a bilateral agreement signed in 1995. This discharge into the Old Danube is based on the natural discharge of the Danube registered in Bratislava. This amount is then divided between the downstream part of the Old Danube (200-450 m³/s) and the active floodplain water replenishment system (50-150 m³/s). The flow is controlled by the Dunakiliti barrage (2) and the submerged weir (3), also based on the natural fluctuations of the Danube at Bratislava. The system is replenished at three points (A, B and C in Figure 8). The submerged weir was built in 1995. The Dunakiliti barrage, whose original function was to control the reservoir, the Gabčíkovo power plant, and the water replenishment systems, was also commissioned in 1995. Today, the barrage is used to control the water replenishment for the active floodplain branches and to control the water level and ice flow in the Old Danube.

The Mosoni-Danube receives 40 m³/s from Cunovo throughout the year. The flow is then divided between the Mosoni-Danube and the Historical Floodplain Water Replenishment System, with an overflow to the active floodplain, as shown in Figure 10.

The water introduced into the active floodplain in the Dunakiliti area is then conveyed through the many branches of the floodplain system down to the Lower Szigetköz. There are dozens of fixed crest weirs and other control structures in the active floodplain to control water levels and discharges within the many branches of the floodplain replenishment



system. There is a significant seepage loss to the Old Danube, and some water is also discharged to the Old Danube for hydraulic reasons and to operate near-natural fish passes.

At four locations (E, F, G, H in Figure 9) there is additional water recharge from the active floodplain to the historic floodplain. At these four locations, a discharge of 0.5-1.5 m³/s can be introduced into the historic floodplain. At Dunaremete (E) there is a controlled gate in the flood protection dike. At the same time, the remaining three locations (F, G, H) are siphons that use the water level difference between the active and historical floodplain water systems. In the historic floodplain water replenishment system, more than a dozen canals with a total length of about 250 km are filled with flowing water. Approximately 100 sluice gates control the water levels. Water allocation is based on stakeholder consensus, taking into account the physical limitations of the system (channel capacity, bottlenecks, and seasonal increases in channel roughness due to vegetation). Fish passes (see in **ANNEX NO 2.**) are located at 6 sites where historic floodplain channels join the Mosoni Danube, crossing the flood protection embankments. These structures are floodgates with two openings. In one of the openings, there is a double board lock gate with over- and underpass options to control upstream water levels. The other opening has fixed boards with gaps, creating a fish ladder type of passage for fish through the levee structure.

The water replenishment systems are **operated dynamically to mimic natural conditions**. The flows introduced into the active floodplain system are based on the undisturbed Danube flow regime of the previous two days, measured upstream at Bratislava. The water supply of the Mosoni-Danube follows a seasonal pattern. The target water levels of the historical floodplain system also follow the seasonal pattern.

The system operates with minimal maintenance. Morphological changes are monitored but not counteracted, and fallen trees and branches are not removed from the active floodplain unless they block water transport.

Establishment of the Szigetköz Operating Committee

Since the beginning of 1993, the stakeholders in the area have been involved in the planning process for mitigation of the damage from historical works. After the construction of the first phase of the water replenishment system in 1995, the Water Directorate, which is responsible for water management, wanted to maintain the trust that had been established during the planning process. Therefore, in 1999, after years of experience with the trial operation of the systems, the stakeholders were brought together in order to reach an agreement on the long-term operation of the system.

To determine the desired condition or state, the stakeholders agreed to prioritize the various needs and demands for restoration using a value analysis methodology. The value analysis was applied to all relevant stakeholders.

As a result, the following priorities were identified: flood control, maintaining adequate drinking water supply, nature conservation, fishing, forestry, and tourism. Note, the international shipping route was moved to the Gabčíkovo power plant supply channel and was therefore not included in the requirements.

Flood protection was identified as the most important priority, since the safety of settlements and the region is the basis of daily life. Since flood protection was the most important priority, the existing flood protection system was again justified.

After achieving the first priority and accepting the existing flood protection system, the goal was to achieve the remaining four priorities. Achieving these priorities requires good ecological potential while maintaining the heavily modified morphological character of the water bodies. (According to the WFD, good ecological potential can be targeted where the reason for the heavy modification is a justified morphological or hydrological change).

The Operating Committee was formally established in 2001 with the participation of all major stakeholders. The members of the committee are representatives of various sectors such as water management, disaster prevention, nature conservation, forestry, agriculture, local government, fishing and tourism organizations. The committee meets at least once a year. **They evaluate the operation of the water replenishment system and recommend necessary actions for the following year**, such as raising or lowering target flows or water levels at specific locations. The Operations Committee also serves as a forum for resolving conflicts among water users.

One of the achievements of the Operating Committee after the construction of the water replenishment systems, was the implementation of **artificial flooding** in the Szigetköz. The stakeholders of the committee suggested that annual artificial flooding is necessary to imitate the natural processes at the beginning of the vegetation period in the spring. This action will be carried out only if a natural flood comes from the upper reaches of the Danube. The required parameters for artificial flooding were determined on the basis of the 100% probability of a flood event (statistically occurring every year) under natural conditions. The basic requirement was a discharge of 3000 m³/s at the Bratislava section of the Danube. If the forecast shows that a flood of more than 3000 m³/s will occur, the artificial flooding can be started on the rising part of the flood hydrograph when the discharge reaches 2500 m³/s. This condition allows for a flood duration of about two weeks, which allows natural processes (groundwater recharge, fish spawning) to occur. During an artificial flood, an increased flow of 800 m³/s is introduced into the Old Danube at Cunovo. About 200-250 m³/s are diverted to the active floodplain. The artificial flooding has to start between April 1st and May 31st and the water temperature has to be above 10°C to meet the natural requirements. If there is a larger natural flood (> 5000 m³/s) during this period, there is no need for artificial flooding.

2.1.4. Impact of the measures on the environment

As a result of the water replenishment systems, **surface and groundwater levels** are higher than they were, before the Danube was diverted. Surface water levels in the active floodplain meet the levels from 1950s. A chain of diverse aquatic habitats has been restored in the area affected by water replenishment. Groundwater levels are slightly lower due to the draining effect of low water levels in the Old Danube. The following graph shows the surface and groundwater levels in the Dunakiliti region (cross section from north to south, from the Old Danube to the Mosoni Danube).



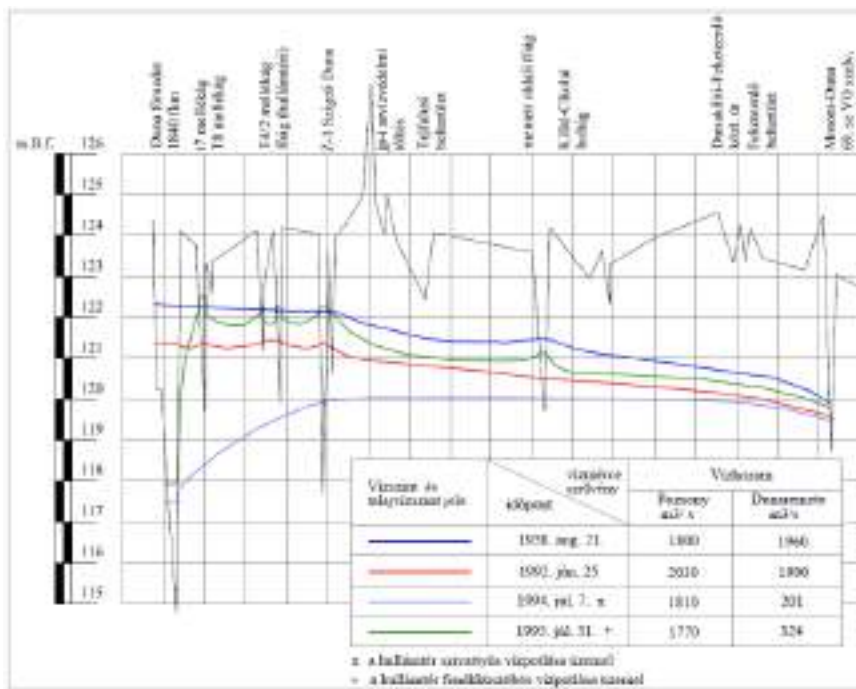


Figure 11: Cross-section between Dunakiliti - Feketeerdő. Surface and groundwater levels in the Szigetköz, from the Old Danube (left) through the active floodplain and the historic floodplain to the Mosoni-Danube (right). The lines represent different historical periodes, with similar discharges at Bratislava (Pozsony). Dark blue line: reference period (August 1958). Red line: before the diversion of the Danube (June 1992), Light blue: after the diversion, with pumped water replenishment in the active floodplain (July 1994), Green: after the diversion, with gravitational water replenishment using the Dunakiliti barrage and the submerged weir. (Németh, 2017)

Water quality has gradually changed since the start of water replenishment. Prior to diversion (due to the low and mid-flow navigation measures of the 1960s described above), most of the active and historic floodplain branches received the majority of their water from subsurface seepage. They had no flowing water supply and therefore TSS and nutrient levels were very low. On the other hand, residence time was high. After the diversion, water replenishment was solved with flowing water introduced from the headwaters of the Dunakiliti Barrage.

The flowing water resulted in a water quality closer to the natural conditions of Szigetköz when all branches were connected. These changes can be seen in the following pictures:



Figure 12: Active floodplain branch in the Upper Szigetköz region, from left to right: July 1988; May 1993; July 1995. (Németh, 2017) Picture 1-2-3: Active floodplain branch in the Upper Szigetköz region, from left to right: July 1988; May 1993; July 1995. (Németh, 2017)

A joint Hungarian-Slovak monitoring system was set up after the water replenishment system was commissioned in 1995. The results are summarised in a joint annual report. After the Water Framework Directive (WFD) was adopted, the parties started to apply the WFD methodology. Currently, the main challenge for experts is to determine the difference in ecological parameters between good ecological status and good ecological potential. It is important to

make a distinction because a change or pressure is significant if there is an ecological response to it. The study of fish migration has played an important role in both the previous monitoring and the WFD monitoring. A partial presentation of the monitoring results is given in **ANNEX NO 1.**

The number of **fish species** has changed significantly since the diversion of the Danube due to the continuous restoration activities from 1993 to 2015. For example, the number of fish species in the active floodplain Csákányi-ág öböl (middle floodplain) decreased from 17 species in 1992 to 9 species in 2011 and increased to 23 species in 2018 (Szigetköz monitoring reports 1995-2018 (Hermann Ottó Intézet, 2019)).

Since 1986, **forest growth** measurements have been carried out at about two dozen sites in the active floodplain of Szigetköz. The results of the measurements are shown in Figure 13.

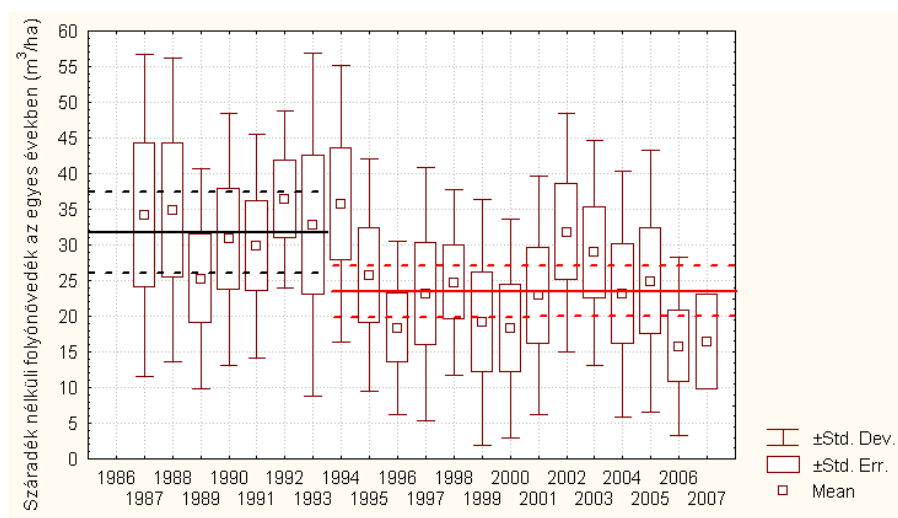


Figure 13: Forest growth [m^3/ha] in the Szigetköz region from 1986 - 2007 (Hermann Ottó Intézet, 2019).

The diversion of the Danube at the end of 1992 had a lasting effect on the forest growth of the Szigetköz floodplain. It is interesting to note that 2002 was characterised by two major flood events, one in March and the other in August. These events had a positive effect on forest growth in that year and the following year. Forest growth increased when artificial floods were carried out in 2004 and 2005. Forest growth decreased when there was no artificial flooding in 2006 and 2007.

Agricultural production suffered the most in the central parts of the Szigetköz (between the Upper and Lower Szigetköz, in the region of Darnózseli - Hédervár), where the effects of the Danube diversion caused the groundwater level to fall permanently below the lower surface of the topsoil. As a result, soil moisture in the root zone of agricultural crops decreased significantly. As a result, yields of major agricultural crops in the region declined by more than 10% on average (Kerekes et al., 1998) - although some of the decline was due to reduced fertiliser use in the early 1990s. Water replenishment has helped agriculture yields increase close to previous yields.



An additional benefit of the restoration of the active and historic floodplain branches has been the emergence of **ecotourism in the region**. In the late 1990s and early 2000s the number of camping sites and canoe rentals increased. It developed further after the spatial extension of the replenishment systems reached the Lower Szigetköz areas in 2014-2015.

2.1.5. Summary and recommendations

Meeting human water needs and demands has required, and in most places on earth still requires, significant intervention in natural water systems. Changes in water demand may, over time, lead to changes in these man-made systems and, in some cases, previous interventions may become unnecessary or even harmful to the environment and society. In such cases, there may be a need for restoration or an obligation to improve the ecological status of the water body. The "inland delta" of Szigetköz is an exceptional floodplain ecosystem where 75% of the Hungarian fish fauna, 57% of the Hungarian bird fauna and 48% of the Hungarian mollusc fauna can be found (OKTH, 1990).

A series of changes began in the 19th century, with river regulation for navigation and flood protection for agricultural land being the main drivers. Hydropower stations built in the Upper Danube catchment in the second half of the 20th century significantly altered bedload conditions and caused riverbed incision. The last step of severe modifications was the diversion of the Danube to the Gabčíkovo powerplant in 1992. After that, the restoration of the Szigetköz floodplain system became necessary.

The planning, construction and operation of the Szigetköz Water Replenishment Systems (described in the chapter "Implemented measures") provide a special opportunity to understand the principles and practice of restoring heavily modified water bodies in a river floodplain.

The Szigetköz water replenishment system has been established. It is operated in cooperation with stakeholders to dynamically control discharges and restore natural water levels on a 40 km stretch of active and historic floodplain river branch system along the Danube, creating diverse habitats while promoting ecological connectivity through fish passages.

The principles and detailed rules for dynamic control of the system to mimic natural fluctuations in floodplain water replenishment systems are presented in **ANNEX NO 1**.

The technical solutions used in the construction of fish passes to provide ecological connectivity between otherwise separated water bodies are presented in **ANNEX NO 2**.

Ecosystem restoration through the Szigetköz water replenishment system has resulted in: the restoration of water levels in surface water throughout the floodplain branches and in groundwater; establishing several eco-corridors by connecting separate water bodies for fish passages; the maintenance and improvement of flood protection including increased inland flood protection capacity; and in the creation of new water use opportunities (including irrigation on historic floodplain, ecotourism and fishing on both active and historic floodplain). All of these improvements were made taking into account the requirements of all stakeholders in the Operation Committee.

Table 5:

Design, construction and operation principles applied in practice during the rehabilitation of Szigetköz river-branch systems

| Principles | Practice |
|--|---|
| Careful consideration of hydrology, ecology, landscape and climate | Reference period selected with stakeholders based on existing hydrological and water quality data. Operation based on restoration of historical water levels with dynamic fluctuations based on natural flows. Landscape protection area established in 1987. |
| Multiple goals | Restoration of water levels for all floodplain branches and groundwater; connection of separate water bodies with fish passes in multiple locations; maintaining/improving flood protection and inland excess water protection capacities; creating new water use opportunities (irrigation on historic floodplain, ecotourism and fishing on both active and historic floodplain); achieving goals by taking into account the requirements of all stakeholders in the Operation Committee. |
| Designing the system as an ecotone | 1) river branches-river banks- softwood, hardwood forests - grasslands. 2) river branches and other wetlands of different potamon types (Amoros et al 1987) were restored on the active and historic floodplain |
| Minimum necessary engineering solutions | Most of the structures on the active floodplain are submerged, fixed crested weirs -allowing river continuity. Siphons are used to cross the flood protection levees. Historic floodplain sluices with double boards are used to control water levels under and over the sluice and to provide connectivity. Operation of existing navigation locks to enable fish migration. |
| Making use of natural energy sources | The entire system is gravity fed, with no pumping required. Headwaters are controlled by the Dunakiliti Barrage. The Mosoni-Danube outflow structure controls the surface and groundwater levels in the Lower Szigetköz. |
| Minimum maintenance | Mostly natural materials (riprap, gravel, wood); steel and concrete were used only if necessary. Active floodplain branches are only maintained to ensure the functioning of the system. Historic floodplain branches require regular dredging and weed removal. |
| Give time for the system to develop fully | 1995 – first phase (Upper Szigetköz) 2014 - second phase (Lower Szigetköz, Mosoni-Danube upper reaches) 2022 - third phase (Mosoni-Danube lower reach, and outflow structure) 2022 - planning phase: Old Danube riverbed |

From the very beginning of the planning of the Szigetköz water replenishment systems, stakeholders were involved in defining the main objectives of the systems. Stakeholder involvement is unavoidable in the case of heavily modified water bodies, as the measures are designed to achieve good ecological potential. Finding a consensus with the stakeholders and establishing priorities can help to attain parameters for good ecological potential. Stakeholders will also need to be involved in the establishment of a reference period for good ecological status.

Monitoring the effects of restoration is also key for evaluating and iteratively developing the system. More detailed information on the monitoring system at Szigetköz and the results of monitoring can be found in **ANNEX NO 4**.

Stakeholder involvement led to the formation of the Operating Committee which is a legal body that is regulated in the operational water right permit of the replenishment systems. The committee has a decision-making and supervising



role for the operation of the systems and can also initiate amendments to the operating permit if members of the committee agree. Finally, the committee is the main instrument for maintaining trust between stakeholders.

2.2. DPS 2

Authors: Veronika Ullmann, Tim Borgs & Bernd Cyffka

Location: Alluvial forest between Neuburg and Ingolstadt, District of Neuburg-Schrobenhausen, Bavaria, Germany

Short form of the organization: The Catholic University of Eichstätt-Ingolstadt (KUEI) is an independent, non-governmental, fully state-recognized university, founded in 1980 and supported by an ecclesiastical foundation under public law. The Aueninstitut Neuburg (AI) of the KUEI is a research center closely associated with the Chair of Applied Physical Geography at the Faculty of Mathematics and Geography. It focuses on applied research in floodplain ecology and restoration, on the development and improvement of near-natural floodplain solutions, on ecological monitoring, assessment and valorization of floodplain dynamics and related ecosystem services.

2.2.1. General Overview

The pilot site DPS2 is situated between the barrage Bergheim and Ingolstadt on the left side of the Danube. The floodplain forest in DPS2 is a small, about 8 km long part of a 2,100 ha floodplain forest area along the Danube in Bavaria, which is one of the largest contiguous floodplain forest complexes in Germany (MARGRAF 2004).

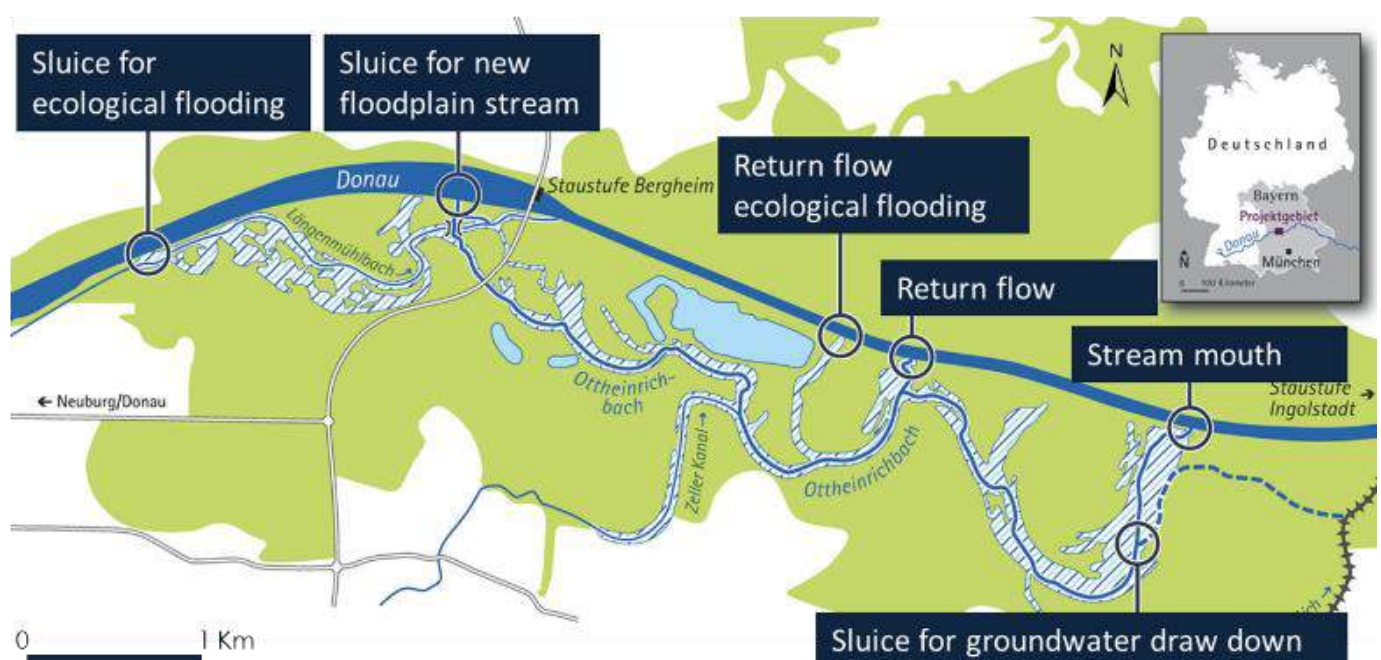


Figure 14: Study area of the DPS2 between the Bergheim barrage and Ingolstadt with labeling of selected important structures

The **Danube**, a 1st order water body (BAYWG Art. 2 2010), forms the border between the natural landscapes of the Alpine foothills and the German low mountain ranges and is not open to navigation. The discharge of the Danube is strongly influenced by the alpine tributaries Iller and Lech. In early summer, floods occur more frequently due to

snowmelt in the Alps, and periods of low water can be expected in late fall and early winter. When the Danube carries a lot of water due to snowmelt, ecological flooding can occur in the project area (DPS2). The **Danube valley** is demarcated as a separate fluvio-glacial natural area (BAYSTMLU 1999), which also includes the Danube moss in the Ingolstadt basin bordering the study area to the south. The Danube floodplains can be assigned to the floodplain type "river floodplains of the foothills of the Alps, rich in precipitation, with summer floods, gravel/gravel-dominated" (KOENZEN 2005).

In addition to the Danube, there are **other important surface waters** in the study area. Among them are two smaller but still significant flowing waters: One is the **Längenmühlbach**, which rises at the northwestern edge of the Donaumoos and flows into the Danube below the Bergheim barrage. (It was used as a drainage ditch after the construction of the Bergheim barrage.) The other is the **Zeller Canal**, which has its origin in the Danube moss, after which it flows into the Danube before dynamization. Since the opening of the bypass watercourse, it flows into the Ottheinrichbach. The water flow is periodic and strongly dependent on precipitation (drying up in summer). The largest oxbow (former river loop) in the project area is the "**Old Danube**". It is located north of Weichering and was largely disconnected from the Danube by a check valve before the dynamization project. Water could only flow into the Danube on one side in the direction of the flow of the Zellerkanal. Furthermore, there are numerous permanent or temporary **water-bearing ponds** and flood channel systems in the project area, which are flooded by surface water and/or filled by rising groundwater, especially during flood events (MARGRAF 2004). In addition, there are **several large lakes** in the study area (Albenschüttweiher, Großer and Kleiner Schlossweiher), which were formed anthropogenically by gravel mining. All three lakes are groundwater-fed.

It is also necessary to consider the **hydromorphological situation in the pilot area**, as it is important to deal with the soil properties so that the renaturation measures (e.g. stream course through the alluvial forest or ecological flooding) will work properly in the floodplain area. It is also important to consider backwater layers (aquiclude). It is especially helpful if there are thick gravel layers in the subsoil through which water can spread far into the floodplain forest. Soil properties and groundwater fluctuations were studied in more detail at the pilot site: The evaluation of the soil survey of the project area by FREYTAG-LORINGHOVEN (2000) shows: 87.9% are alluvial loams plus 0.1% alluvial loams with humic parts, 10.8% of the areas are occupied by gravels and 1.2% by sands. The water supply of the soils depends on the soil type, the distance between the groundwater courses as well as on the soil thickness. The gravel-dominated soils of the burns are the driest, while capillary rise is better in alluvial loam soils. According to FREYTAG-LORINGHOVEN (2000), well-watered soils (reservoir-fresh, ground-fresh, and ground-moist), measured by their water content, occupy the largest proportion of soils in the project area at 55.2%. 22.5% of soils have medium water supply, 19.1% are relatively dry (from very dry to moderately fresh), and only 3.3% are particularly moist and wet soils.



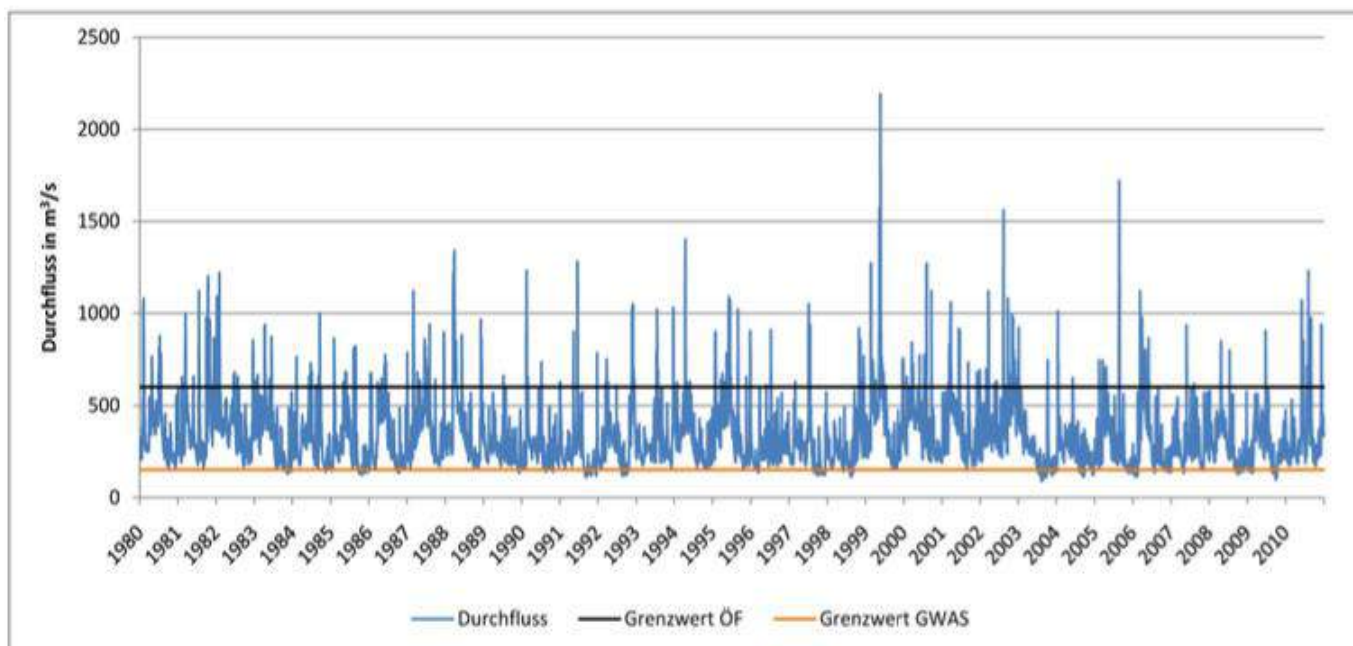


Figure 15: Flow rate Q in m^3/s at the Ingolstadt barrage from 1980 to 2010 (daily mean values, data WWA-Ingolstadt). The two lines mark the limit values for the dynamization measures Ecological Flooding (ÖF) and Groundwater Lowering (GWAS). Cyffka, B. et al. (2016): *Neue dynamische Prozesse im Auenwald.*: page 29, figure 2-4

The project area also has an important **international status**. It is designated as a landscape conservation area and is also registered with the EU as an FFH and SPA area as part of the European biotope network NATURA 2000 (HERRMANN 2004). The water protection areas Weichering (district of Neuburg-Schrobenhausen) and Buschletten (city Ingolstadt) are located in the study area. The near-natural floodplain areas (approx. 90% of the project area) with forests, water bodies, reed beds, burns, etc. are classified as "Official Biotopes" (§ 30 BNATSCHG and Art 23 BAYNATSCHG).

2.2.2. History of transformations

In the **19th century** it was the task of the state to maintain the river in a **navigable and raftable condition**. "As a means to this end, the correction of a river to medium water with the **straightening of its course** as much as possible was applied at that time (BAUER 1965, p. 146)." With this intention, two culverts were built above Ingolstadt around 1825. Since 1790, attempts had already been made to shorten five meander loops between Neuburg and Ingolstadt (MARGRAF 2004). Further major river straightening was carried out in 1826 and 1830. In the project area, a total of about **30 kilometers** were thus **straightened and regulated**. Somewhat later (1919-1926) flood **protection dikes** were built. Overall, the implementation of river straightening measures between 1825 and 1870 had a significant impact on the Danube, leading to a shorter, narrower, and deeper river channel. Several sources, including BSLU 1985, FINSTERER 1996, WAF 1998 in MARGRAF 2004, and SCHLEGEL 2000A, provide insights into these changes: The most notable impact was the **shortening** of the river's course, amounting to approximately 17% of its original length. Additionally, the **width of the river** decreased significantly, going from approximately 5 kilometers to just 150 meters. The process of river straightening also involved deepening the Danube. By the year 1969, the river's depth had increased by 1.73 meters. At the Neuburg level, specific measurements indicate further changes in depth. Between 1875 and 1909, the river's depth decreased by around 0.6 meters. From 1920 onwards, there was an additional decrease of approximately 0.3 meters, and between 1940 and 1960, a further decrease of 0.1 meters was observed. As a result the mean groundwater levels, before the construction of the barrage, were **significantly below ground level**.

In the 19th century, the course of the Danube was fixed with the stone bank protections and the bank-accompanying dike and dam constructions, and the **interconnectedness of river and floodplain was largely lost**. Triggered by the course shortenings, the flow velocity and the depth erosion of the river increased. This deep erosion was stopped at the end of the 1960s with the **construction of the four barrages** from the mouth of the Lech to Ingolstadt (barrages Bertoldsheim, Bittenbrunn and in the project area Bergheim and Ingolstadt) (RMD 1967). In 1927, the first barrage (Kachlet) was built on the Danube. This was followed by the further construction of transverse structures - also on tributaries - as well as the Ingolstadt (1971) and Bergheim (1970) barrages. However, these interventions are also resulted in a number of associated ecologically incompatible side effects. The natural alteration of the river and the adjacent floodplain was eventually **reduced to a minimum**. Before damming, the bedload regime of the Danube was strongly influenced by the alpine tributaries Iller and Lech (BSLU 1985), the Lech especially was very rich in bedload in the undammed state. However, the construction of the aforementioned barrages in the Lech valley **prevented bedload discharge from the Lech into the Danube** (DISTER et al. 1997). Some bedload transport can be expected during larger floods; additionally, a significantly increased suspended sediment load across the barrages is still expected in the project area (RMD 1967).

Various sources, including BSLU 1985, FINSTERER 1996, WAF 1998 in MARGRAF 2004, and SCHLEGEL 2000A, provide information on the changes: **Groundwater levels** in the floodplain areas were affected, with a rise of up to 0.75 meters in the upper water reservoir and a sinking of up to 0.25 meters in the underwater dam. These changes affected the overall **groundwater fluctuation**, which dropped from several meters to about 0.5 meters. Flooding of the floodplain via an **overflow weir** was possible when the Danube outflow exceeded 1,250 m³/s. Additionally **the bedload transport** of the river changed from alpine gravel to predominantly fine sediment. For the most part, barrage construction resulted in a drier Danube floodplain, but low-lying sites in the backwater area of the barrages became permanently wet in some places.

After the development of the Danube, the total bedload supply decreased from 540,000 m³/a to 120,000 m³/a within 20 years (BAUER 1965). In the natural state, the average annual bedload load on the Danube was at least 60,000 m³/a (BAUER 1965). In the developed state, the transport capacity increased to 150,000 m³/a due to an increase in erosion competence (BAUER 1965).

Subsequently, the Danube deepened, dredging for commercial purposes or for the construction of flood control dams increasingly intensified the process. Gravel extraction caused a deepening of about 130 cm around Ingolstadt between 1913 and 1940, which also continued upstream (about 30 cm at the Neuburg barrage between 1920 and 1940). The Danube dug in another 10-50 cm in the following years 1940-1960. It was not until 1960 that the withdrawals were completely stopped.

Before the construction of the barrage, the groundwater flow direction was almost perpendicular to the Danube, since then, however, it flows rather parallel (HERRMANN 2004). In most of the project area, a free groundwater surface is formed in the valley gravels. This is largely identical with the water level positions in the surface waters.





Figure 16: Transverse structure: Barrage in Bergheim (Photo: Veronika Ullmann)

Subsequently, in the spirit of the times in the 1960s/70s, the construction of **hydropower plants** was seen as a forward-looking form of energy generation. Unfortunately, the accompanying impairments and damage to nature were not recognized until later. Therefore, the **discharge dynamics** and **stream structure** were **significantly altered** by the operation of the Bergheim hydropower plant. Dynamics are essential in a near-natural floodplain, as they create a certain amount of "clutter" in the landscape.

The previously mentioned man-made alterations to the Danube have **disrupted the longitudinal and lateral connectivity of the river and its floodplains**. Resulting negative impacts include the **restriction of passages for aquatic life** and the **change of vegetation**. Since the **available water supply changed** due to the man-made disruptions, the vegetation also changed depending on the location and the availability of water. Vegetation changed from a rural forest, towards either **permanently moist alder swamp forests** or towards a **dry form of the hardwood floodplain** (Quercu-Ulmetum) (MARGRAF 2004, LANG et al. 2011). In particular, the rarer floodplain-typical habitats, such as softwood floodplains, showed rapid aging or a lack of regeneration. **Alternating water zones and reed beds disappeared almost completely** (MARGRAF 2004, CYFFKA et al. 2008). The development of **forest tree species is equally negative** due to the change in groundwater dynamics. Thickness growth and increment of pedunculate oak, sycamore maple and ash declined significantly in the 10 years following the construction of the barrage. Thus, succession communities of mountain maple-rich floodplain and ash-rich hardwood floodplains of different water balance dominated. A development towards flood-intolerant forest communities had thus taken place. The area of the old watercourse "Old Danube" is strongly influenced by the hydropeaking of the Ingolstadt barrage. Here, higher plants were not found in the area of the riverbed, neither in the seed bank nor in the current vegetation, which is probably due to the constantly changing flow directions. At higher water levels and thus reduced flow velocity through the barrage, deposition of fine sediments apparently occurs here, which are presumably resuspended by higher flow velocities when the water is released or dammed. This makes it **impossible to build a persistent seed bank and establish vascular plants**.

Nevertheless, before the start of the dynamization measures, the vegetation had numerous different habitat types ranging from aquatic vegetation to reeds and hardwood floodplains. MARGRAF (2004) recorded a total of 536 plant species, including 80 Red List species, in the floodplain forest between Neuburg and Ingolstadt. The largest area was occupied by the hardwood floodplain with various forms of an oak-elm-ash floodplain forest (MARGRAF 2004). Even though the floodplain forest on the Danube between Neuburg and Ingolstadt is one of the largest preserved in Germany in terms of area, it is still far from an intact floodplain in terms of habitat diversity and quality (DISTER et al. 1997, MARGRAF 2004).

2.2.3. Implemented measures

Due to the considerable changes in the Danube and the associated negative effects, the Free State of Bavaria decided on the project "Dynamization of the Danube floodplains between Neuburg and Ingolstadt", which was implemented step by step by the Ingolstadt Water Management Office beginning in 2005. To restore the Danube floodplains to their condition before regulation in the 19th century was considered unrealistic by the project group (HERRMANN 2001). About six years after completion of the planning phase and 14 years after the feasibility study (DISTER 1997), all implementation and construction measures for dynamization were completed in 2011. These are composed of three measures: **A new river (Ottheinrichbach)** flows with variable discharge through the floodplain area, at the same time it is a bypass watercourse of the Bergheim barrage (for fish); **ecological floodings** during mean high water of the Danube and **groundwater lowering** during low water periods of the Danube. The combination of the three measures aims to create floodplain-typical conditions in a backwater-regulated section of the Danube. Dynamic water conditions, which characterized the floodplain forest before the construction of the dam, are to be reactivated, the continuity for aquatic life is to be ensured and the cross-linking of the Danube with its floodplain is to be restored.

The first measure is the construction of an approximately eight-kilometer-long **watercourse/detour structure (Ottheinrichbach)**, shown as the big blue line in Figure 14, in the headwaters of the Bergheim barrage. The aim was to restore the continuity, groundwater dynamics and cross-linking of the Danube with its floodplain area by connecting the headwaters and tailwaters of the Bergheim barrage and making this transverse structure passable for aquatic life. Before anthropogenic interventions in the discharge dynamics, the Danube, influenced by the prevailing discharge conditions, repeatedly shifted its course or split into several arms. The new bypass watercourse is directed through one of these former side arms. Furthermore, the Ottheinrichbach flows through the originally temporary still waters south of the Albenschüttweiher, parts of the Zeller Canal and the large oxbow lake of the Old Danube. Through two return pipes, the Ottheinrichbach finally flows into the Danube. Up to 5 m³/s of Danube water can be discharged through the Ottheinrichbach via a newly constructed outlet upstream of the Bergheim barrage. **Fish passes** were installed to allow fish habitat continuity and connectivity.

As the second measure, the overspill weir at the Bergheim barrage was reconstructed to enable **ecological floodings**. These are carried out as controlled small floods, since it is precisely these annual floods that the floodplain forest lacks due to the barrage. The so-called "flood pulses" (JUNK et al. 1989) brought about by ecological flooding are a natural part of floodplain dynamics and serve to increase diversity and productivity. In addition, they have a structuring effect with regard to morphology, vegetation, nutrients and sediments. From a Danube discharge of 600 m³/s, up to 25 m³/s of Danube water can be channeled into the Längenmühlbach with the help of the diversion structure. After a few hundred meters, when the water level is rising, the water enters the new bypass watercourse Ottheinrichbach via two flood depressions and can flood parts of the floodplain forest, as well as drain the floodplain forest through the permeable gravel. The groundwater reserve is filled up and a lot of areas in the forest are flooded (directly by the stream water or indirectly by groundwater). These floods are intended to create potential natural site conditions in the floodplain. In addition, flood events above 1300 m³/s naturally flood the floodplain forest, as was the case before the dynamization measures. On the left side in the map in Figure 14, the sluice for the ecological floodings is highlighted. Directly flooded areas can be seen in the light blue colour. So far, 30 ecological floodings of different intensity and duration could be carried out.





Figure 17: **Right: Sluice for ecological floodings. Left: Shore vegetation of the Ottheinrichbach during ecological floodings. Below: Forest vegetation during ecological floodings. Old dry river channels are now spilled with water (Photos: Veronika Ullmann).**

The third measure, **groundwater lowering** aims to increase groundwater fluctuations in the eastern project area and to lower the unnaturally high groundwater levels resulting from the construction of the barrage by means of **discharge blocker** and targeted **groundwater management**. For this reason, a 2.1 km long drainage ditch was constructed (Figure 18), which transports the discharged water into the Aich River when required. As soon as the Danube discharge falls below 150 m³/s (mostly in late summer/fall), groundwater management is carried out and terminated when the Danube discharge exceeds 180 m³/s. In this way, natural dry phases with lower groundwater levels are replicated (BENDER et al. 2007; BÖHM et. al. 2014: 77ff, DEINDL et al. 2014: 4ff; GELHAUS & FISCHER 2016: 29, 38ff). This can favor the development of alternating water zones, for example in the area of the "Old Danube". Fluctuating water levels are critical to the development of floodplain-typical vegetation because they are transmitted to the soil via groundwater. On impounded rivers, low flow periods are also particularly important to promote floodplain dynamics. On the right side of the map in Figure 14 the sluice for the **groundwater management** can be seen.



Figure 18: Structures for groundwater lowering. Left: Diversion structure from the "Old Danube" to the diversion channel. Right: Insertion of the dam beams by WWA Ingolstadt into the 2nd cut-off structure (Photos: Peter Fischer)

2.2.4. Impact of the measures on the environment

The measures have different impacts on aspects such as vegetation, hydromorphology, water quality, groundwater, and wildlife corridors for fishes and fauna. These are explained further below.

First of all, the change in species composition along the **vegetation** transects and on the permanent monitoring plots shows that most of the surveyed recording plots are directly influenced by the **water level of the Ottheinrichbach**. However, significantly lower effects of the measures were evident on the higher elevation plots, which were less inundated by the Ottheinrichbach. An example of the massive upheaval of vegetation on flooded plots is shown in Figure 19 using plot 46, which changed significantly between 2008 and 2012.



Figure 19: Left: Condition of plot 46 before the start of measures (2008); right: after regular flooding by the Ottheinrichbach (2012) (Photos: Petra Lang).

Intensive monitoring of **aquatic and riparian vegetation** in the first few years after the Ottheinrich Creek was discharged showed an overall **positive response** to the dynamization measures. The created bypass watercourse provides new habitat for floodplain-typical target species around the watercourse bed and on the banks. Above all,



target species of the **alternating water zone** and the **water bodies** appeared, including many species of plants on Bavaria's Red List. In particular, species that indicate changing water levels or disturbance, but also typical reed species, were able to establish themselves. The species increase was greatest in the formerly dry oxbow lakes. Target species were already present in both the current vegetation and the seed bank, in areas that were already alternately wet before mitigation measures reintroduced water. Therefore, target species could continue to easily spread in these locations. In the sections with large oxbow lakes, there was a decline in species in the first year after the water discharge, as typical representatives of the stillwater vegetation disappeared. By 2013, however, species numbers had increased again due to the spread of floodplain-typical target species.

The 10-year flood in June 2013 also contributed to positive development. During the investigation of the **forest vegetation**, only minor changes could be detected in large parts of the study area. Areas that have not yet been directly affected by the measures showed no response to the changed hydrological conditions. In particular, the effects of ecological flooding on forest vegetation can be classified as weak. However, modeling of the Ellenberg Moisture Index indicates that an area wide increase in moisture can be expected as a result of the groundwater rise in the project area. It can therefore be assumed that the forest vegetation in the entire floodplain will respond with a time delay to the measures taken. The **forest tree species development** showed that the regeneration situation from 2009 to 2014 was very good on all sites, but the English oak could not establish itself. However, the susceptible seedlings and saplings survived even the short overstorms caused by the floods in 2013. A negative development is the accelerated and favored settlement and spread of **neophytes** after the start of the dynamization measures. This was promoted in the area both by the construction measures (soil disturbance and introduction of diaspores by vehicles) and by the dynamization measures (increased spread by water) (cf. also HAAG et al. 2014).

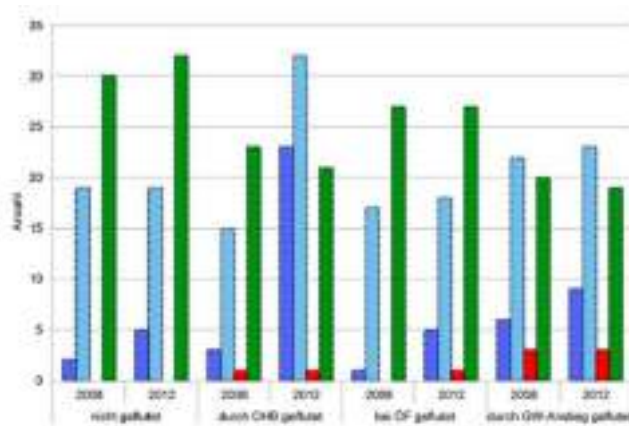


Figure 20: Change in target species range between years and groups; blue = alternate water zone species, light blue = reed bed species, red = softwood floodplain species, green = hardwood floodplain species. Quelle: Neue dynamische Prozesse im Auenwald: page 153 - (for more diagrams see 116, 126, 154)

Hydromorphological changes can be detected by sediment rearrangement, triggered by varying discharge conditions. This creates and changes habitats such as impact slopes, gravel bars, and riparian areas on the new floodplain stream as well. A development from a near-natural to a natural state of the Ottheinrichbach has been taking place since the first day of the diversion. In the meantime, the **self-dynamic development** and also the **natural drift of the artificially introduced deadwood elements, rootstocks and tree trunk pieces** have led to the formation and/or further development of the desired course structures (course widenings and narrowings, riffle-pool sequences). The initiated impact and sliding slopes have also developed further or formed new ones on their own in other places. This has promoted the formation of structurally rich banks and contributed to the development of natural sand and gravel bars. This development can be seen as the **first phase of a near-natural course development**. Especially clearly and right at the beginning of the measures, the processes have started in the area below the „Radbrücke“. Here, the large number of fallen trees and the structure of the banks (sand and gravel) influence the morphology. The gravels of the terraces,

which lie unprotected, can be eroded very easily, but can only be transported appreciably during increased runoff. The sand thus carried in facilitates the formation of scours and sweep and stillwater pools, deep channels and shallow water areas in their natural state (BROCKMANN-SCHERWAß et al. 2007). Even after the section of the stream downstream of the „Trogbrücke“, characterized by a large gradient and high flow velocities, there was the formation of a gravel island, which continues to increase in size downstream under water. Especially for the new section, water depth measurements and water structure mapping show a **mosaic of densely coexisting different habitats**. The river continues to develop dynamically, mainly due to natural dead wood input. This dynamic can also be traced by bedload measurements at the river bed, which leads to increased transport rates especially during ecological flooding. Eroded and washed-in bank material is deposited on the riverbed and, depending on the section of the watercourse, levels or increases the **substrate and structural diversity**. As a result, the riverbed is raised in sections of the Ottheinrichbach and **river widening occurs as a result of lateral erosion**. At the scan site "1st return line", a slope backward displacement, due to lateral erosion of more than 12 m in two and a half years, could be detected. At other sites, "relatively stable, less dynamic" stream reaches could also be identified by cross-section surveys. Thus, the most important prerequisite for a living watercourse with diverse functions has been created: There is possibility for a **self-dynamic flowing water development**.

Discharge and flow are important factors for the functionality of near-natural flowing waters such as the Ottheinrichbach (OHB). The extent of floodplains and **groundwater dynamics** in the adjacent floodplain are also critical. **Fluctuating water levels**, which are transmitted to the soil via groundwater, are particularly important for vegetation. The Ottheinrichbach and the ecological floodings cause groundwater levels in the vicinity of the creek to rise and fluctuate more than ever before. Due to the commissioning of the Ottheinrichbach, an **increase in groundwater level** can be observed, which in turn is also visible in the **rise of surface waters**. Thus, there is a **good hydraulic interconnection of the OHB** with the aquifers and especially sites in spatial proximity to the bypass watercourse. They show significantly more dynamic processes since the beginning of the measures. The **permeable gravel bodies** of the terraces allow **good hydraulic contact between surface and groundwater** in the area across diverse floodplain stages. This allows the floodplain stream to carry water underground into the area and promote **positive vegetation development**. Some sites in the floodplain forest are permanently flooded, while others are only flooded/dammed during higher discharge rates or Ecological Flooding. During Ecological Flooding, depressions fill with water; however, this water level rise does not result in a widespread floodplain.

Riverine floodplains with diverse freshwater habitats support a wide variety of **aquatic organisms**. The close interconnection between flowing water and floodplains is crucial for their ecological functionality (WARD et al. 1999, WARD & TOCKNER 2001, CLARKE et al. 2003). The Ottheinrichbach, with a height difference of approximately 5.0 m from its diversion to the mouth (SCHLEGEL 2004), incorporates a **fish pass** into its diversion structure. After about 170 m, a small part of the water flow (around 0.5 m³/s) is redirected through **another fish pass** to the Längenmühlbach, which leads to the tailwater of the Bergheim barrage after 600 m. In this way, the **passability** of the barrage **for aquatic life** is always guaranteed over a short distance. In order to enable the fish to ascend against the current, in addition to the two fish passes, **two fish ladders** were also built at the locations of the first and second return pipes.





Figure 21: **Left: Diversion structure with stilling basin and fishway. Right: Ottheinrichbach with short connection to the heavily turbid Längenmühlbach and trough bridge. In the background, the basin pass after the trough bridge (still without water) and the upper flood basin (area behind the detached group of trees), which is to lead the water into the floodplain forest during ecological flooding (photos: Peter Fischer).**

As a result of the initiation of dynamization, significant changes in the diversity of aquatic and terrestrial **fauna** could also be observed. After the commissioning of the Ottheinrichbach, the **habitat for fish** in the project area was greatly increased and considerably improved. Due to the permanent rise in water level, the water surface has greatly increased and the individual **water bodies have been more intensively interconnected**. The interconnection with the Danube and the other aquatic habitats has created a **diverse habitat complex for stagnophilic and indifferent as well as rheophilic fish**. The increase in flow velocity and the resulting successive increase in substrate quality have significantly improved the living conditions for most fish species, especially rheophilic fish. The **colonization** of the newly connected watercourse sections, consisting of old Danube watercourses and newly constructed watercourses, occurred **very quickly** for many species. A total of six fish species were detected in a survey of the newly constructed portion of the Ottheinrichbach. After ecological flooding in 2012, pike, guenster, and perch populations increased significantly in stream habitats. While **new fish species adapted to currents** were also found in the newly created areas of the Ottheinrichbach, the species composition in most of the old Danube waters hardly changed. The number of fish in the reconnected oxbow lakes increased, especially in the shallow, extensive oxbow lakes. Furthermore, small numbers of bitterling, perch and the alien species *Gasterosteus aculeatus* were detected as new species in the floodplain ponds. In contrast to natural flood events that had inundated adjacent pools for extended periods of time, some pools are only connected for short periods of time by ecological flooding. Therefore, mainly small fish and juvenile specimens of larger fish were found in the surveys of the ponds near the Ottheinrichbach stream (PANDER et al. 2014: 36f; PANDER et al. 2016: 212ff). After the first groundwater drawdown, the mapping of the watercourse revealed **draining**. Nevertheless, several pools formed that still contained water even after a prolonged dry period of more than ten days, thus acting as important **refuges for aquatic life**. Such refugia should always be considered in groundwater management, especially in light of climate change and the increasing need for protection for fish in the summer. If the water supply is insufficient, small standing waters can quickly overheat and show a lack of oxygen.

The **Terrestrial fauna**, as in Mollusks and Athropods occurred in different ways. The α -Diversity and biomass was significantly higher in moisture-dependent mollusks, there was a significant decrease in ground arthropod guilds and beetle species typical of floodplain forests, and no changes occurred in insect cenoses of higher vertical strata. Phytophagous species probably benefited from a **greater water supply** because it improved the quality of their food resources. In the avicenos, significant changes in α -diversity, space use, and abundance occurred during dynamization, primarily at the habitat level. **The increase in species and individual numbers may be seen as a**

response to improved food resources rather than directly to changes in hydrologic conditions. The Ottheinrichbach connects individual populations of mollusks, including those outside of the study sites, and enables the exchange of species. On the other hand, the increase in the number of individuals, especially in the forest species, can be attributed to an **areal reduction of the groundwater distance**. This effect is based on the **combination of water supply** by the Ottheinrichbach and **ecological flooding**.

The number of **bird** species and individuals increased significantly throughout the year in the dynamized condition. This effect was particularly pronounced during the breeding season. The **increased resource supply** increased bird abundance in the seasons with particularly high food demand during breeding and young rearing. This was especially true for resident birds during the breeding season and for short-distance migrants that migrate when food is scarce outside of the breeding season. Bark and twig feeders were particularly prevalent. Foragers such as insect and seed eaters also benefited from increased primary production. A large increase in herbivorous waterfowl and species that prefer or require high-energy foods (insectivores, seedivores, and fruitivores) was also noted during the breeding season. This indicates increased plant production in the floodplain lakes, which is promoted by the nutrient-rich Danube water that enters the floodplain via the Ottheinrichbach (UTSCHICK 2014).

Beavers are important **landscape designers** in floodplains and have positive effects on the biodiversity of woodpeckers and bats. With light and water, they control and change the living conditions of numerous species. **Higher woodpecker activity** and **twice the number of insects** were observed in beaver areas. Furthermore, studies using batcorders showed **significantly higher bat activity** at beaver structures. The increase in insects on beaver structures and the alteration of structures creates an attractive hunting ground for bats. With further development of the beaver population in the Danube floodplains and their dam building activity, this could have a significant positive impact on biodiversity.

The most noteworthy **successes of the pilot site** are the following: The restoration measures in the project area were implemented successfully and according to the plans. Despite the large area, **ecological floodings** proceed in a very controlled manner without unintentionally flooding roads or other areas. In this context, they are also an indispensable location factor for the Danube floodplains, as they are intended to replace the natural flooding of floodwaters. They are characteristic and vital for many floodplain-typical species and the continued existence of the floodplain itself. The vegetation in the riparian areas was especially influenced very positively by the restoration measures. Unfortunately, ecological flooding is bound by contract to a discharge of 600 m³/s on the Danube. Especially in times of global warming, such high discharges have not occurred often in recent years. In order to trigger more natural transformation processes in the forest vegetation far away from the Ottheinrichbach, the ecological floods should probably be more frequent and longer.

The **creation of a new floodplain watercourse** has also been a success. It is possible to divert the water from the Danube in a controlled manner first, with the help of some construction measures, through paved areas that cannot be eroded (at the beginning of the Ottheinrichbach) and then through old, already existing river loops and through a floodplain forest. In many areas, the flow is so strong that a baffle slope and sliding bank were created naturally, demonstrating that erosion and accumulation processes have been stimulated again. The connection of the Ottheinrichbach with the Danube and other aquatic habitats creates a **habitat complex** that supports a **variety of animal and plant species**. Moreover, **gravel banks** are created that change the dynamics of the watercourse and create new habitats for pioneer plants and animals. The structurally rich riparian zones form numerous niche habitats for plants and animals and large reed zones, which can now be preserved. Also **scours** were created that are morphologically valuable. Overall, the Ottheinrichbach **keeps the riparian zone alive and creates new floodplain-**



typical structures due to the permanent water flow. The gravel layers (former gravel areas of the Danube) distribute the groundwater over a wide area in the forest, providing them with more water and preventing the lakes from drying out. This is a great advantage, especially in view of the increasingly rapid depletion of groundwater levels due to climate change, thus helping to protect the forest in the long term. Furthermore, the **neophytes are also driven away** from the riverbank by the permanent moisture. The Dynamization in the project area may re-promote and/or re-initiate typical floodplain communities, however, only over a relatively narrow area along the new floodplain river. Above all, the **fish passes** used have also been very successful, as they ensure **unrestricted passage for aquatic life** and thus **enable connectivity between different habitats**. The fish accepted the three fish passes and the stream mouth and first return flow (for fish that rise against the current). They use it as spawning habitat or to pass up the stream. The populations increased very quickly within the first years in the Ottheinrichbach. **In conclusion, the combination of the three implemented measures together have made a great impact to the ecosystem of the area. The combination of the restoration activities has led to a higher dynamic and a stronger positive impact than each individual measure would have made alone.**

2.2.5. Summary and recommendations

For the floodplain ecosystems between Neuburg and Ingolstadt, a "**controlled floodplain dynamic**" has been achieved. This situation is quite positive, although not really sustainable, in the sense of self-regulating, and in terms of runoff. In addition, the secondary floodplain with Ottheinrichbach is **separated from the natural bedload supply** by the diversion structures. But overall, **the health and diversity of the ecosystem has greatly improved compared to its previous condition**. Through the dynamization project, the missing ecosystem functions of the dam-regulated Danube in the area of the Ottheinrichbach has been **partially compensated**. Overall, it can be said that the three measures work satisfactorily and **help mitigate the impacts on the ecosystem** caused by barrage construction. The speed of transformation of a semi-terrestrial floodplain forest ecosystem to a terrestrial forest ecosystem **can be reduced**. However, the resulting changes **cannot be revised** - in the sense of a real renaturation!

In conclusion, one should therefore emphasize certain **recommendations for action** in order to continue to positively promote this development. The results show that the negative trend of vegetation development after embankment and barrage construction could be stopped and reversed, at least in the direct area of influence of the bypass watercourse. However, for a medium to long-term and above all more extensive promotion of floodplain-typical plant species, the **dynamization measures must be further optimized**. In this context, it is necessary to **increase water level fluctuations**, especially in the extreme areas and **mechanical disturbances**. This would allow larger areas to remain dry longer, improve establishment opportunities for riparian plant species, and **prevent the excessive spread of dominant species and some neophytes**. **Larger amounts of water** would also be necessary, especially during ecological flooding (more frequently and/or over a longer period of time), in order to reach the entire width of the Danube floodplains between Neuburg and Ingolstadt. Only in this way can the **floodplain-typical dynamics be generated over a large area** and the corresponding habitats such as water exchange zones (e.g. FFH habitat type 3270 "Muddy river banks with pioneer vegetation") and softwood floodplain sites (FFH habitat type 91E0* "Alder-ash and softwood floodplain forests") could be established in the long term. If permitted and desired by conservationists, an important issue is the **targeted release of organisms** to support restoration, e.g., through planting or stocking. For floodplain vegetation, sufficient potential was found in the seed bank and in the area. For mollusks, the deficit of floodplain-typical species was attributed to the organisms' lack of dispersal ability. With regard to fish fauna, no new species were detected in the water body after two years, and the supply biotope of the Danube appears to be exhausted in the immediate vicinity. If the Ottheinrich Brook is to be colonized with additional and rare Danube-typical species in the foreseeable future, more advanced management strategies will need to be considered. This includes the **development of new supply biotopes** (continuity of the Ingolstadt barrage), and/or **initial stocking with the appropriate species**.

2.3. DPS 3

Author: Adam Vizina, Adam Beran & Petr Pavlík

Location: Dyje subcatchment of the Danube River catchment, Czech Republic

Short form of the organizations:

The T. G. Masaryk Water Research Institute (TGM WRI), a public research institution, was established as one of the first scientific institutes in the independent Czechoslovak Republic. In the field of hydrology, TGM WRI focuses on



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issues of quantification and protection of water resources (especially in response to a series of major floods and droughts), development and application of methods for measuring and monitoring parameters of water movement in watercourses and reservoirs, as well as issues of hydroecology and various aspects of water quality in general.

The Czech University of Life Sciences Prague is the third largest university in Prague. Backed by one hundred years of history, CZU combines cutting-edge technologies, advanced science and research in agriculture, forestry, environment, engineering, economics, management and business. CZU offers complete higher education, summer schools, lifelong learning courses and the University of the Third Age to more than 20,000 people. CZU cooperates with a number of private and public organizations and research institutions both locally and internationally. The university is a member of the EuroLeague for Life Sciences (ELLS), a prestigious network of universities. It is also one of the twenty-eight members of Agrinatura, a group of European universities and research institutions dedicated to sustainable agricultural development. In recent years, CZU has established the Center for Precision Agriculture, the Bioeconomy Platform of the Czech University and the Center for Water, Soil and Landscape.

2.3.1. General Overview

The Demonstration Pilot Site 3 (DPS3) covers the entire catchment area of the Thaya River.

The Thaya River Basin drains a total area of 13,419 km² and is located in the southern part of the Czech Republic (83%) and the northern part of Austria (17%). The Thaya River (in Czech language Thaya) is formed by the confluence of the Austrian (or also called German) and Moravian Thaya Rivers in Lower Austria and is the longest tributary of the Morava River (Danube basin). The sources of the two tributaries are both located in the highlands at altitudes of 676 m (AT) and 635 m (CZ). The main tributaries are located in the Moravian part of the basin and flow mainly in a NW-SE direction. The Jihlava flows through the city of the same name and the Svatka, together with the Svitava, drains Brno, the second largest city in the Czech Republic. The upper reaches of the river are formed on crystalline bedrock, while the lower parts consist of quaternary sediments. Soils follow a similar pattern, consisting mainly of cambisols in the highlands (58%) and fertile chernozems in the lower reaches (20%). The middle and lower course of the Thaya is characterised by anthropogenic modifications, including large reservoirs built for water supply or irrigation purposes.

The long-term annual (precipitation) of the higher parts of the Thaya catchment exceeds 650 mm and the annual (runoff) coefficient is between 0.2 and 0.3 with a mean annual runoff of 187 mm. However, the lowland region with lower annual precipitation combined with high evapotranspiration (ET_o) results in a significantly reduced runoff coefficient (0.1-0.15) due to a mean annual runoff of almost 60 mm. The relatively limited water resources barely meet the water needs of households, industry, energy and agriculture. The water shortage is partly solved by water retention in 21 surface water reservoirs on the Thaya or its tributaries.

The characteristics of the lowlands, together with the mild and warm climate, make the agricultural landscape of the Thaya basin fertile. **Arable land covers 66% of the basin, while forests cover 28% (16% coniferous, 6% mixed and 6% deciduous).** The coniferous forests faced an unprecedented bark beetle outbreak, forced by high T_a (temperature) and a severe drought period from 2015-2019. This outbreak caused a significant decline in coniferous forest stands, requiring a radical increase in sanitary logging, which by the end of 2020 represented about 30% of the total area of coniferous stands in the basin compared to 2012.

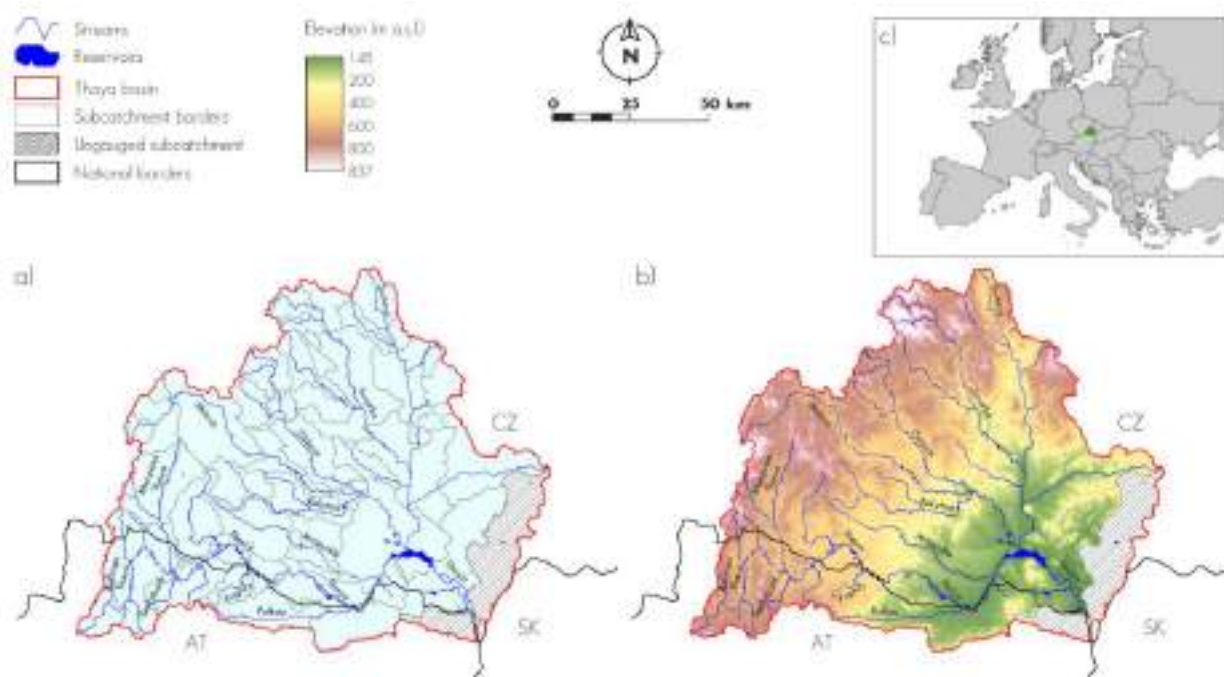


Figure 22: a) The Thaya river basin with 42 surveyed sub-basins and river/reservoir network; b) Digital elevation model of the basin; c) Position of the Thaya river basin within Europe

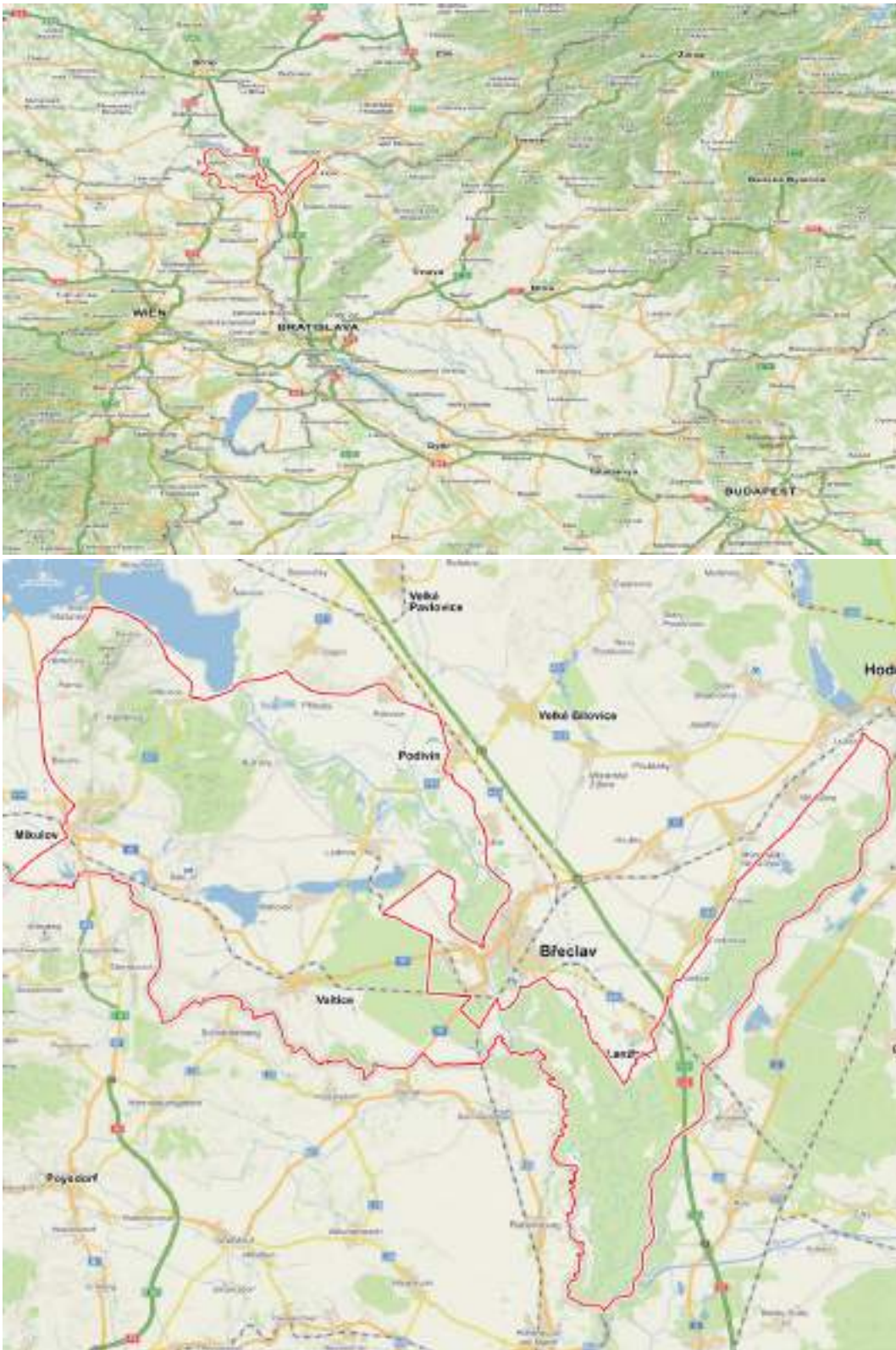


Figure 23: Location of the Morava-Dyje confluence floodplain forest

The Thaya River flows into the Morava River (which flows into the Danube) in the border triangle of the Czech Republic, Austria and Slovakia, in an area of extensive floodplain forests. The area is called the Lower Morava Biosphere Reserve (BR) (dolnimorava.org), which was proclaimed in 2003 as an extension of the former BR Pálava, originally proclaimed in 1986, covering an area of 349 km². It is located in South Moravia, about 35 km south of Brno,

on the borders with Austria and Slovakia. The dominant landscape of BR is Pavlovské kopce - Pálava. It is formed by limestone cliffs and its steep slopes are covered with steppes, forests and meadows, as well as vineyards and fields.

The northeastern part of the BR is located in the flat floodplain of the Thaya River, which is intensively used economically, especially for agriculture, so that there are only remnants of the original floodplain meadows and forests. Arable land predominates in the southern and eastern parts of BR. However, in the south-eastern corner of the territory, in the triangle defined by Břeclav, Týnec and the confluence of the Morava and Dyje rivers, there is the **largest complex of hard floodplain and floodplain** meadows in Central Europe (approximately 8,000 ha in total). The central part of the BR is located in a depression with ponds and a man-made landscape created in the 19th century, which is currently on the UNESCO World Heritage List. The pilot area is part of the RAMSAR Convention for the protection of wetlands. The Dolní Morava BR includes a large number of sites of national and international importance. These include, for example, the territory of the European Natura 2000 system, specially protected areas led by the Pálava Protected Landscape Area, the Lednice-Valtice area, wetlands registered under the Ramsar Convention, two nature parks (Niva Thaya and Mikulčický Luh) or the protected area of the natural water accumulation of the Morava River Quarter and others. The Nature and Landscape Protection Act No. 114/1992 defines several categories of specially protected areas. These are: national parks (NP), protected landscape areas (PLA), national nature reserves (NPR), nature reserves (PR), national natural monuments (NPP) and natural monuments. In the Dolní Morava BR you will find all of them except the National Park.

2.3.2. History of transformations

River engineering works were carried out along the Thaya to protect settlements and their immediate surroundings. As a result of deforestation in the upper part of the Thaya catchment area in the 17th and especially in the 18th century, the flow conditions worsened and many floods occurred. Before major channel adjustments were made, floods were prevented by the construction of dikes. The first major efforts to change the course of the Thaya were made between 1834 and 1855. During this period, the river channel was straightened and widened between km 120.0 and 85.5, and a series of dikes were built along its course. It is likely that these works disturbed natural fluvial processes and thus had an indirect impact on the study area. Similar works were carried out between 1888 and 1902 along a stretch between km 85.5 and 64.0. In 1911, local modifications of the canal were carried out in Břeclav. In 1934-1936 further works were carried out between km 67.0 and 64.0.

The Vranov dam and reservoir with a hydroelectric power station was completed in the 1930s. The Znojmo dam and reservoir were completed in the late 1960s. Since then, the flow regime and water characteristics of the Dyje River have been permanently changed. However, the most profound changes to the river channel and floodplain were the result of major river engineering works carried out between 1975 and 1988. During this period, a section from the village of Dolní Věstonice to the confluence of the Dyje and Morava Rivers was modified and a large water body called Nové Mlýny was created in the area between the village of Brod nad Dyjí, the confluence of the Jihlava, Svratka and Dyje Rivers and the village of Nové Mlýny. Before the dams, it was the largest grove landscape in Central Europe, after which, the landscape changed a lot due to the rectification of the rivers (Skokanova 2008).

Decreasing landscape retention capacity in catchment areas, river modifications, increasing demand for drinking water abstraction from surface and groundwater, and more frequent occurrence of torrential rains has led to the fluctuation of water regime in the riparian forests of South Moravia and to the subsequent change of ecological conditions and reduced water availability for forest vegetation. Due to the decreasing retention capacity of the landscape, there is a



long-term increase in runoff and associated disturbance of the water balance in the landscape. The result is a decrease in groundwater reserves and water sources in general.

The availability of water is becoming a global problem for the planet. The strategic role of water is particularly important in food production, where irrigation accounts for 50-80% of water use. It is likely that the Czech Republic will also face problems with water availability in the future, as groundwater reserves are dwindling. Up to half of Czechs could be affected by water shortages.

The whole problem of diminishing water reserves is caused by the combined effect of several major factors such as: global climate change; irregular distribution of rainfall throughout the year; undesirable anthropogenic interventions in the landscape by farmers and water managers that lead to reduced landscape retention capacity; surface and groundwater abstraction strategy; and more frequent torrential rains, which due to the rapid run-off from the area via straightened river beds, do not fill dams, leading to floods and landslides and associated damage and potential loss of life. Expert forecasts are not very optimistic and groundwater reserves are threatened, especially in spring. Recent significant droughts in the Czech Republic occurred in 1982-1984, 1990-1995, 2003-2004 and the most recent drought episode has been ongoing since 2014. The issue of drought is also very relevant for the region of South Moravia, especially in the water meadows of riparian forests (Hornová & Černá 2019).

The lower course of the Morava and Dyje rivers is an example of a bifurcated river system - an anastomosis, in which the river is divided several times into a number of parallel, long-distance branches that are connected to each other. Already in the 18th century, the main branches of the Morava and Dyje rivers and their side branches, which have been preserved only in plan view, could be distinguished within this branching river system. Today the Kyjovka River flows through one of these branches. The branches are an important element of the floodplains of modified rivers, and in many places they are the last remnants of natural, morphologically valuable riverbeds. The floodplain of the Morava and Dyje rivers is separated from the "mother" rivers in the area of Soutok by modifications and fences of both rivers. As a result, the basic interactions between the river and its floodplain are partially disrupted, in particular, the complete dynamic fluvial succession of floodplain biotopes is excluded. Natural floods no longer occur in the area, and only in the last two decades has the possibility of controlled flooding of the floodplain forests, made possible by the Pohansko relief dam, been used irregularly. As a result of the changes in the water regime, a significant part of the floodplain forests was endangered, as they were completely cut off from the effects of floods, which are necessary for this type of floodplain ecosystem. In particular, the short-term floods that occur every year have a very favourable effect on the water regime of the floodplain forests, bringing necessary nutrients to the area. The deepening of the rivers (Morava, Dyje) also led to a lowering of the groundwater level (on average by about 1 m) in the area of the floodplains. The alluvial forests began to change into a different, drier type of forest. In the 70s and 80s of the 20th century, the Morava River was regulated and dammed in the section from Hodonín to the confluence with the Dyjí River (it also carries centuries-old water), thus separating it from the floodplain forests and its meanders and blind branches, and unifying the shape and denaturalisation of the river. Channel-forming processes (bank erosion, gravel alluvium, alternation of fords and pools) are not allowed here, the natural development of the river has been interrupted by the modification and it is still suppressed. The regulation has significantly degraded and damaged the surrounding ecosystem, so remedial measures and appropriate protection of the surrounding ecosystem are desirable for rapid regeneration of ecosystems, not only floodplain forests. The Dyje River was also regulated, fenced and partially modified (straightening of the course of the confluence), often its course was led through a completely new bed (the old bed of the Dyje River is represented today by the Zámecká and Stará (Cerná) Dyje). Upstream of the Dyje, the largest water management structure in the area was also built - the Nové Mlýny waterworks with three reservoirs, where all the flood water is collected. In the past, naturally flooded alluvial forests were not only located in the vicinity of the confluence of the Morava and the Dyje, they were also present here. The flood regime and its possible changes have a fundamental influence on the ecological connectivity of river floodplains and their ecosystems. There is a decrease in the dynamics of the fluctuating spring maxima and thus an overall decrease in the water supply for these ecosystems and a negative impact on the flood-dependent floodplain ecosystem. In 1991-1999, as part of the revitalisation of the water system, a complex system of water channels, sluices, tumblers, culverts and gates were built in the floodplain

D.1.1 – Detailed Analysis of Demonstrators Ecosystems

complexes, with the possibility of influencing the groundwater level in the forest stands. As part of the revitalisation of the water regime, the system of river branches was also transformed into a system allowing flooding.

2.3.3. Implemented measures

Within the pilot area of the Thaya Basin, the results of the research carried out in the territory of the Lower Morava Biosphere Reserve will be used in particular. The most important revitalisation actions are described below. All these actions characterize the uniqueness of the Thaya River Basin pilot site and try to improve the condition of the local landscape individually. However, these actions cannot be considered replicable in terms of scale and financial cost, they only provide an idea for another pilot site. Replication actions will be smaller in scale to fit within the scope of the Dalia project.

Most of the concrete revitalisation measures in the pilot area of the Thaya catchment are briefly presented here:

First, the **restoration of wetlands in the Lower Morava Biosphere Reserve**. The forests, meadows and wetlands of the Morava and Dyje floodplains have always been one of the most important ecosystems of the Lower Morava Biosphere Reserve. In the past, the floodplains along the lower reaches of the Morava and Dyje rivers were characterized by extensive flooding. The floodplains of both rivers consisted of a large number of different wetlands. However, the original character of the landscape has been increasingly changed by human activities in recent centuries. The changes began with land reclamation, especially in small river basins. Land reclamation led to a shift from the original meadows and pastures to arable land. The result was the destruction of the natural character of small streams. Pressure for intensive agricultural use of the landscape increased. Over time, much of the floodplain was converted to meadows and fields, resulting in the loss of most wetlands.

The biggest changes in the floodplain landscape were caused by the water management and torrent control project carried out between 1968 and 1989, when the Nove Mlýny dam and reservoir were built. The aim of the project was to reduce the negative impact of floods on the local population, but it radically changed the natural hydrological conditions of the whole area. Almost all of the former floodplains, with the exception of a small area along the lower reaches of the Thaya River, became inaccessible to floods. The hydrological regime behind the dikes changed dramatically, with all the associated negative consequences to the environment. A considerable part of the alluvial meadows was converted into arable land and a number of wetlands were filled in.

Despite the strong influence of water management measures and the conversion of meadows to arable land in the past, there were still a number of sites with the occurrence of unique insects (*Lucanus cervus*, *Rosalia alpina*, *Aromia moschata*) (Háva 2018, AOPK 2023a), amphibians, reptiles, birds (*Aquila heliaca*, *Haliaeetus albicilla*, *Ciconia nigra*) and exceptional plant communities (*Parnassius mnemosyne*, *Ficaria verna*). These species require a landscape with permeability for migration, a natural water regime with spillways and natural and semi-natural watercourses, which are found in the confluence. In particular, insects are often associated with dead wood and form lowland floodplain forest communities of high biological value and species diversity, inhabiting summer oak woodlands with a significant presence of senescent trees and standing timber, mixed ash-alder floodplain forests, wet alder woodlands and Pannonian oak woodlands. These areas are worthy of protection and have been included in the international list of wetlands of the Ramsar Convention. The composition of plant and animal species is diverse. The natural conditions of the area have facilitated the occurrence of many plant species that cannot be found anywhere else in the Czech Republic. There are dry grasslands, psammophilous vegetation, thermophilous oak forests, loess oak forests with a



rich undergrowth of species or Pannonian oak-hornbeam forests. In the alluvial plains of the Thaya River, under the limestone cliffs of the Pálava Hills, there are alluvial broad-leaved forests of pedunculate oak and narrow-leaved ash, as well as remnants of floodplain meadows. In the southern part, remnants of halophytic vegetation are preserved on the banks of the Nesyt fishpond. In the Pálava Protected Landscape Area there are four national nature reserves, one national nature monument, five nature reserves and four nature monuments (dolnimorava.org).

The Convention on Wetlands of International Importance especially as Waterfowl Habitat, better known as the Ramsar Convention, was signed in Ramsar, Iran, in 1971. It was the first international convention focusing on the protection and sustainable use of natural resources. Its aim is the worldwide protection of all types of wetlands (www.ramsar.org).

Lower Morava Biosphere Reserve has two wetlands enlisted as Ramsar sites:

The **Lednice Fishponds** (area 650 ha, enlisted in 1990) is of international ornithological importance. It is the habitat of several protected bird species and an important migratory stopover. Together with extensive reed beds and reed mace, it is the site of important aquatic and halophytic plant species, as well as specific communities of periodically exposed banks.

The Floodplain of the Lower Dyje River (area 11 500 ha, enlisted in 1993) is characterised by the largest complex of floodplain forests and floodplain meadows in the Czech Republic. It has a number of permanent and periodic pools, oxbows and forest channels. It also includes the central and lower basins of the Nové Mlýny reservoirs, which are among the most important nesting areas for several species of waterfowl in the Czech Republic. They are also an important stopover and wintering area for migratory birds, especially geese.

Since the change of political regime in 1989, new initiatives have been taken to eliminate the negative effects of water management and torrent control on the landscape. The business sector, private landowners and public authorities are all carrying out these positive projects. Some of the projects that have been implemented in the area of the Lower Morava Biosphere Reserve are described below. These projects are examples of how to restore wetlands in areas lacking "creative" river dynamics and/or in areas with advanced natural forest succession.

An artificial cascade of seven forest ponds with an exotic name - Allahy - was built in the forest between the town of Valtice and the Lednice fishponds by the Liechtenstein family in the 19th century. Only five of them have survived to the present day. In the 1990s, the ponds were in danger of collapsing due to a long period of non-use and lack of maintenance. In 1999-2000, the state-owned company Forests of the Czech Republic - the legal manager of the whole area - started the reconstruction of four ponds (total area of 4.2 ha). The first step was to remove the overgrowth, excavate the silt deposits, reinforce the dams and restore the technical equipment. In 2002, the forest managers began restoring the surrounding forest stands, using the methods of their Liechtenstein predecessors. The area became important as a habitat for protected amphibian and plant species.

Another restoration project was carried out by the Forests of the Czech Republic, s.e. in the **Herdy forest district**. The aim was to improve the hydrological conditions in the area. The result included the restoration of selected forest channels with a total length of 3.14 km and the construction of several small weirs to provide water for small-scale flooding of the surrounding forest stands.

The project with the aim to divert water into dried-up canals and ponds was implemented by the Forests of the Czech Republic, s.e. in the **Kanci obora** area (wild boar reserve) between 1991 and 1996. This irrigation system can affect 633 ha of forest and 150 ha of agricultural land between the towns of Breclav and Lednice. The total length of the irrigation channels is 21.6 km and their area is 6.5 ha. Permanent pools cover an area of 9.6 ha and periodic pools cover an area of 4 ha. The project also included the reintroduction of previously extinct plant and animal species.

The Palava Protected Landscape Area completed work in 1994-1995 to ensure a sufficient water regime in the **Krize jezero** (Crooked Lake) **National Nature Reserve**. The aim of the project was to dredge and widen the canals and to construct a number of sluices and openings to control the flow of water from the main intake canal and to maintain the required water level. The measures implemented make it possible to simulate different flow rates, from normal flow to critical flood conditions. The operation of the sluice gates makes it possible to quickly and easily drain the soil profiles of the meadows for a short period of time, allowing for smooth mowing. The site is one of the most interesting in the Lower Morava Biosphere Reserve.

The project in **Obelisk** is an example of private activities in the field of wetland restoration. The floodplain around the Obelisk - one of the architectural monuments of the Lednice-Valtice Cultural Landscape - was also affected by water management measures in the 1970s. Part of this area, with a total area of 440 ha, is now privately owned and used as a game preserve. The owner's landscape management activities include wetland restoration. Prior to project implementation, the area consisted of 15.5 ha of wetlands, of which 5 ha were permanent water bodies; in 2006-2007 the owner increased the proportion of permanent water bodies by 5 ha. The plans are to restore a total of 25 ha of wetland, of which 15 ha will be permanent water pools. It is also worth noting that the owner facilitates regular scientific monitoring on the property.

The largest restoration project was carried out in **Soutok** (Confluence), named after the confluence of the Morava and Thaya rivers. Favourable conditions allowed controlled flooding of the floodplain biotopes, simulating a near-natural water regime that existed before the implementation of ill-considered water management measures. Four large sluice gates and six openings were built into the Hrazova road - the original elevated road across the Soutok polder (catchment area protected by dikes). The road serves as a bank for storing incoming water for flooding the adjacent forest. In the period 1990-1999, a total of 70 km of forest canals were renewed, 25 sluices and 84 openings were built. The combination of irrigation and flooding proved to be optimal for the area. The project was implemented by the Forests of the Czech Republic, s.e.

The restoration project in the floodplain forests near the village of **Tvrdonice** began in 1993 under the supervision of the Forests of the Czech Republic, s.e.. The first step was the construction of connecting canals between the Morava River and the network of forest canals. The project involved dredging several kilometres of the river and building sluices to fill in the adjacent meanders and pools. In the first stage of the project, the main intake channel and the Zabnik reservoir were dredged. The second stage was completed in 1998-1999 with the construction of 18 sluice gates in the restored forest channels.

In addition, there is another **planned project**: the construction of a dam on the River Thaya, which has already started in September 2023. The aim of the project is to raise the level of the river and irrigate the canal system of the country's most extensive floodplain forests suffering from drought. The nearly CZK 180 million project, which is expected to be completed in November 2025, also includes the revitalisation of the original sluices, sluice gates, canals, culverts, as well as the creation of new wetlands at fourteen sites in the upcoming protected landscape area, all as part of the Giving Water Back to the Forest programme.

Legal protection of the whole area is now under negotiation. Notice of the submission of the plan for the declaration of the Soutok PLA area (MŽP 2023).



2.3.4. Impact of the measures on the environment

Throughout the 19th and 20th centuries, the water management of rivers and their floodplains was mainly carried out by means of technical adjustments, and its main purposes were the drainage of waterlogged soil and protection from floods. River engineering works narrowed the channels of streams and rivers, replaced natural channels with artificial ones of simplified shape, and eliminated meanders, oxbow lakes, pools and swamps. Gradually there was a growing awareness that such actions were one-sided and counter-productive from both a landscape and water management perspective (Just et al 2005). This led to the implementation of revitalization or river restoration schemes. Such works affect both the channel itself and the surrounding floodplain. They should be based on an understanding of the processes by which biological communities are maintained, rather than simply aiming to improve channel conditions. They should aim to restore natural low flow regimes and flood patterns, and to create floodplain water bodies and side channels. Such restoration is expected to help meet wetland biodiversity obligations, contribute to pollution management, mitigate the effects of floods and droughts, and provide opportunities for people to enjoy and benefit from rivers and their environment (Peacock et al 2003). In revitalization works, it is necessary not only to consider individual problems caused by river regulation, i.e. to carry out single-purpose projects, but to take into account all aspects of a river or floodplain habitat. The artificial spring flooding of meadows and the reconnection of cut-off meanders in the Lower Morava are clear examples of conflicts between different interests. In the first case, the flooding of meadows was intended to facilitate fish spawning, but at the same time it endangered bird populations that nested in the meadows. In the second case, the reconnection of the cut-off meanders was intended to restore the diversity of hydrological and physical characteristics of the straightened channel, but at the same time threatened the survival of protected plant species that had developed in the meanders in the meantime (Lusk et al 2004). These two examples show that revitalisation projects should take an ecosystem approach rather than focusing exclusively on a particular species. Natural processes, such as flooding, invariably have both negative and positive effects on individual plant and animal communities, and so do revitalisation works that simulate particular natural processes and/or influences. As mentioned above, some of the measures were carried out outside the Soutok site, but still in the vicinity, and since Soutok is at the confluence, their effect counts towards the overall result. Both the implemented and planned measures have a common goal of renaturation and restoration of biologically significant parts of the catchment in order to increase the resilience and resistance of the area.

2.3.5. Summary and recommendations

The **original situation** includes extensive floodplain forests, the largest in Central Europe, rich in biodiversity and abundance despite centuries of human presence, but unprotected from extreme climatic events, especially floods.

Negative impacts of the dam include reduced water retention in the landscape and a significant reduction in floodplain forests due to the interruption of natural flooding. The dam has led to the disappearance of more than 1000 ha of floodplain forest (AOPK 2023a). Water management of the landscape in the second half of the last century and especially in recent years, including drought, has led to a prolonged loss of water in the area, natural flooding has ceased and the water table has dropped by about two and a half metres (LESY ČR 2023). However, water is a necessity for the floodplain forests and they have started to shrink visibly.

The **measures already implemented** include individual measures at various sites, such as meander restoration and controlled flooding in Soutok, wetland restoration in the Obelisk Game Reserve, channel connection in the meander and pool restoration in Tvrdonice, channel and weir restoration in Herdy, and dredging and widening of channels and construction of several sluices and openings in Krive Jezero. The **planned measures** are the new flap weir, which is under construction until 2025 (far above the budget limits of the HE and not realised by the TGM WRI).

Our assessment of **possible replication** is as follows: At the scale of the replication actions within the Dalia project (€100,000 per action), we could consider refining the hydrological balance in the catchments. In order to take sufficient account of flows, precise measurements need to be made. This includes not only streamflow, climate and groundwater observations, but ideally also irrigation and industrial water use. In recent years, TGM WRI has been working on precise monitoring of evaporation from the water surface, which is becoming increasingly important in the overall hydrological balance due to rising air temperatures caused by climate change. This flux in our climate could account for more than half of the precipitation loss, and in practice it is roughly estimated. TGM WRI measures evaporation using a unique technique of floating evaporimeters directly on water bodies. This method of monitoring is easy to replicate (fits well within the boundary) and can give a more accurate indication of water losses from the catchment due to evaporation.

2.4. DPS 4

Author: Michal Kravcik

Location: Slovakia Upper Catchment of Vah River, Kysuce Region

Short form of the organization: Founded in August 1993, the NGO People and Water supports municipalities and regions in the development of integrated water protection programs. The NGO's activities are devoted to education, implementation of pilot projects, awareness-raising and support of legislative changes related to the use and protection of water resources, flood protection, water scarcity, enhancement of biodiversity and negative consequences of climate change mitigation.

2.4.1. General Overview

The hydrology of the Danube River is significantly influenced by the management of rainwater in the landscape. The underestimation of the impact of human economic activity in the rural landscape on the water regime of the country has led to the decrease of water resources in headwater areas both in Slovakia and throughout the entire Danube basin. As a result, springs and small watercourses in Slovakia are drying up on a large scale, which has a significant impact on the reduction of river flows during long-term droughts. Our experience confirms that it is realistically possible to restore the supply of underground water sources and the yield of springs by simple and inexpensive measures applied in a knowledgeable and systematic way. Because of this, the Slovak pilot site of the DALIA research project is focused on measurement and demonstration, in order to prove that by strengthening the water retention capacity of damaged ecosystems we can improve the yield of surrounding water resources in spring areas. The results can be a significant contribution to the strategic planning and integrated management and use of watersheds, in Slovakia and elsewhere.

The Slovakian part of the Danube basin, with an area of 46,961 km² (5.9% of the total area of the Danube basin), is characterized by spring water resources, which influence the hydrology of the Danube through natural factors. The various types of land use including forestry, agriculture, and urbanization of the landscape also greatly impact the hydrology of the region. The Slovakian headwaters are crossed by more than 65,000 km of small watercourses, which flow into larger rivers and streams that directly feed the Danube or contribute to the hydrology of watercourses on the Hungarian side. These watercourses form the backbone of the Danube's tributaries.



Approximately 1/3 of the territory of Slovakia is the watershed of the Váh River with an area of 15,782 km². Together with the Hron River (5,465 km²), these two rivers are the only two rivers in Slovakia that flow directly into the Danube. Other rivers flow into Hungary and influence the hydrology of the Hungarian lowland rivers before they reach the Danube. This means that what happens in the river basins of Slovakia is sensitively reflected in the rivers of Hungary and also directly in the Danube, even if only in a small percentage.

Long-term observations show that 34.3 billion m³ of rain and snow fall on Slovakia every year. From this precipitation, about 12 billion m³ of water will flow through river networks to the Danube.

From a hydrogeological point of view, the petrographic-lithological environment of the flysch sediments represents **variable hydrogeological conditions**. The accumulation and circulation of water is concentrated in weathered zones in contact with overlying debris, on gentle slopes and in partial depressions, and deeper in positions of more permeable sandstones. In general, the Paleogene sediments, represented by the flysch formation with a predominance of clays, represent a poorly permeable to impermeable environment.

The lithological nature of the units does not create particularly favorable conditions for significant accumulation and circulation of groundwater. A significant part of the territory of the Paleogene flysch zone is a typical example of an area where the underground zone plays a decisive role as the main hydrogeological collector. On the slopes of more morphologically fragmented areas, the underground zone acts only as a transit zone, because after the interruption of the precipitation subsidy, this collector is gradually drained by the natural gravitational outflow of groundwater. Thus, the influence of the geological structure on the groundwater circulation is strongly suppressed by the **geomorphological conditions**. The share of the deeper stratified water circulation in the total circulation is relatively small due to the higher permeability of the near-surface zone and the significant decrease of the average permeability of the rock massif with depth. Due to the dominance of fracture permeability, the influence of tectonic disturbance is significant. The near-surface loosening zone has a significantly higher permeability than the deeper parts of the massif. It shows a more or less regular decrease of the average permeability with depth.

Groundwater collectors in the flysch zone are formed by sandstones, characterized by fracture permeability, clays are in the form of a hydrogeological insulator. Vsetin layers building the territory in question, i.e. formation in the sandstone development represents hydrogeological collector. Its drainage is associated with fractures, weathering zones and cracks of tectonic origin.

Geographical position and altitude have a significant influence on the **climatic conditions** of the area. The Kysúc region belongs to the moderately cold climatic zone (C1), humid sub-region, with cold winters. The natural conditions are manifested in a different annual and daily course of all climatic elements, which have distinct continental features. The winter is relatively long, the spring comes slowly and the summer temperatures are low. Rainfall is usually short and intense. Most of the precipitation falls during the summer months. Winter is relatively dry. The evaluated area is characterized by a basin climate with a large inversion of temperatures, slightly dry to humid, subtype moderately warm.

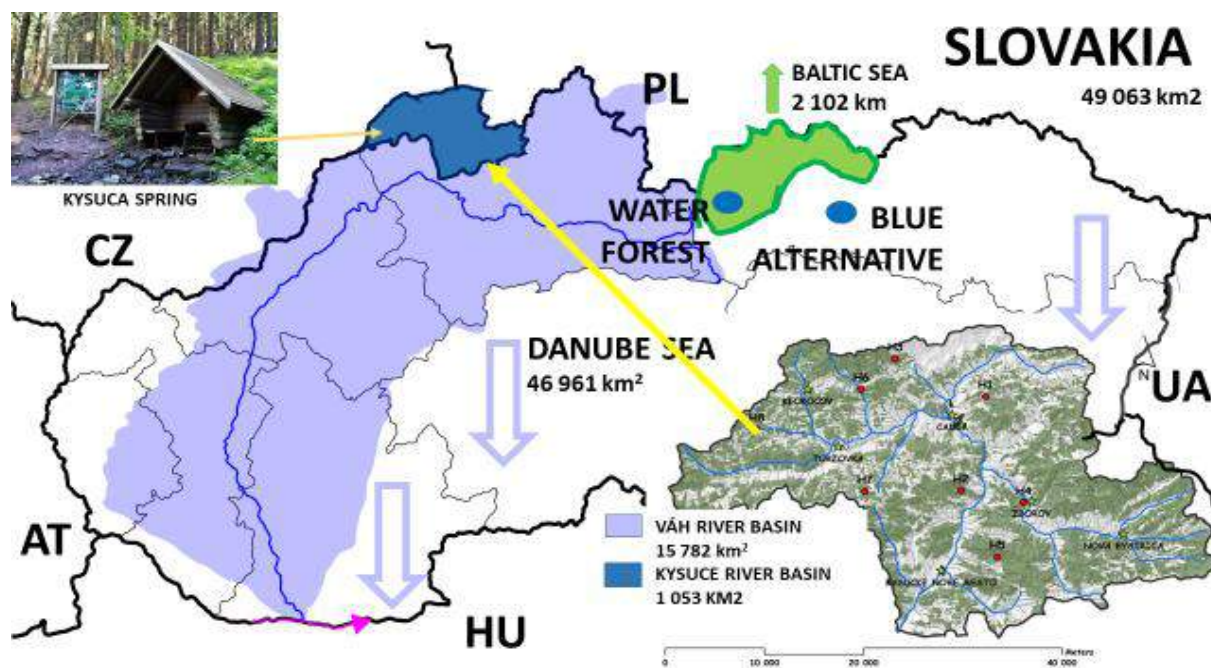


Figure 24: Map of Slovakia, Váh River basin with Kysuca river tributary, location of pilot projects in Slovakia (Blue Alternative and Water Forest)

In the Kysúce basin there is an economically used area with a forest cover of 51%. This area has been significantly damaged by flood disaster, which is reflected in the hydrological regime. The northwestern part of the Kysúce Basin consists of the Kysúce **Protected Landscape Area** with an area of 65,462 ha. There are 13 small protected areas with the status of "nature reserve" or SPA.

2.4.2. History of transformations

A significant part of the district, almost 59%, is covered by forests, mainly coniferous, as a result of the deforestation of valleys and slopes in the past. These stands have been damaged in many places by bark beetles and occasional droughts. The preserved remnants of the original plant communities include deciduous and mixed forests, mainly beech and hemlock.

In addition to the natural conditions of the territory, the hydrology of Slovakian rivers is also influenced by the landscape structure and land use. As a result of the industrialization of mainly agricultural land, the landscape changed from fragmented agricultural land to large mechanically cultivated rural fields.





Figure 25: Diversity of the original landscape structure in Slovakia (Kysuce highlands in the 60s). Meaningless canalization of watercourses - the Latorica River (a tributary of the Tisa River – a tributary of the Danube)

Terraces, drains and wetlands have been removed from more than 20,000 km² of agricultural land. More than 5,000 kilometers of improved drainage canals have been constructed on agricultural land. Rivers have been straightened and meanders have been eliminated. More than 3,800 km of watercourses have been regulated, mainly in an urbanized environment. The result of these changes in the landscape is a change in the hydrological regime of watercourses, streams and rivers. Thousands of springs have dried up in the agricultural land. Water flows in the small watercourses only during the rainy season.

These interventions in the structure of the landscape results in a faster surface runoff of rainwater from agricultural land and a reduction in the duration of rainwater infiltration into the soil and subsoil (Antal, Igaz, 2003). The most intensive process of surface runoff of rainwater in the other half of the century occurred in the urbanized landscape, where the decrease in groundwater levels was most pronounced (Bárek, Halaj, 2007). Increased surface runoff of rainwater results in both a decrease in soil and underground water reserves, and a change in energy flows within the atmosphere due to a decrease in evaporation through vegetation (Kravčík at all, 2007, Pokorný at all, 2021).





Figure 26: The principle of the old water paradigm in practice. We get rid of rainwater as something that makes our lives uncomfortable. We do not see the connection that all the water we have in Slovakia comes from rain (Photo: Kravčík., M.,)

Slovakia belongs to the most forested countries in Europe (41% of the territory). The condition of the forests and the transport infrastructure within them, harms the underground water reserves, weakening the yield of the springs, and threatening the communities below the forests (especially during the ever increasing extreme rainfall events). We need to strengthen the connection so that the forests protect and produce not only timber but also enough water for the communities below. Therefore, we consider it a major priority to gain knowledge on how to manage commercial forests, and how to restore them, so that the forests fulfill not only an economic, environmental, and climatic function but that they also provide water security for local communities. In order to address the wider problem of droughts and flooding in Slovakia, floodwater management needs to begin at the source of the problem, within the forests, where the process of rainwater runoff is accelerated especially during extreme heavy rainfall events.

To protect water resources, the spring areas of the Kysuce basin are formally subject to the EU Water Framework Directive. In fact, there are relatively large reserves in water protection in the basin of streams and rivers in Kysucie. The method of logging damages the earth's surface in forest ecosystems, and as a result, the spring areas suffer from drying out due to the rapid outflow of rainwater from the drainage areas. In addition, there is a deterioration of the water quality in the streams and in the Kysuce river due to intensive erosion.





Figure 27: After the licorice calamity, the forests are being heavily logged. Heavy equipment is also used in the logging process, creating huge forest roads. These roads are subject to erosion and contribute significantly to the formation of floods during torrential rains (photos: Michal Kravčík)

2.4.3. Implemented measures

The Slovakian DPS prioritizes spring areas with the aim of demonstrating the impact of revitalizing the degraded landscapes through NBS and how this work will help with the restoration of springs and small watercourses. The work is also about protecting communities from flooding with a positive reduction in the relative fluctuation of flows. The aim of this project is also to find answers to the following questions:

- How to create a benefit for the extraction of water resources from the rainwater running off the damaged land without increasing the risk of local flooding.
- Testing methods for calculating the volume of rainwater runoff to realize the potential possibilities of creating water resources in spring areas and confronting these methods with the results obtained in the field.
- Obtaining knowledge of the effect of implemented NBS on the yields of springs and the hydrology of small watercourses.
- Describe NBS technologies used for improving the hydrology of small watercourses
- To use the research results to develop methodological, technological and financial tools for obtaining new water resources through ecosystem restoration of damaged landscape areas.

This knowledge will be verified, tested, generalized and, based on the cluster of landscape features, will be made available to partners for better planning of ecosystem services, helping to mitigate increasing problems that stem from climate change. As a model area, we chose the headwaters of the Kysuca River, a tributary of the Váh River, with an area of 1053 km².

Therefore, in addition to gaining knowledge about the effects of landscape revitalization on the restoration of dry springs and small water flows, as part of the Slovakian DPS, through an established monitoring network, information will be obtained to help develop a methodical procedure of how to restore water to the damaged landscape. In this way, it will be possible to initiate systemic restoration measures within river basins for restoring hydrological processes to alleviate flood conditions and to improve minimum flows, with the perspective of strengthening river hydrology. This will ensure water, food, environmental, climatic and social security for river basin communities. To realize such expectations, we need to be realistic about the impact of landscape structure on hydrology in its current state and deal with the loss of water from the extreme runoff occurring in our watersheds when rainwater runs off the surface of damaged land.

The first example of rainwater retention for the creation of water resources in Slovakia was applied in the Torysa river basin (Tisza basin) in the 1990s. The goal was to find an alternative that could produce as much water resources as the proposed water reservoir on the Torysa River. This initiative was coordinated by civic activists and volunteers who implemented the Blue Alternative pilot project.

These volunteer activities showed that it was realistic to create water resources in an ecosystem by retaining rainwater. The problem was that at that time the scientific community was not interested in studying these experiments. Unofficial observations showed that in the given geological, soil, relief and vegetation characteristics it was possible to obtain one liter of water per second by building about 5 thousand m³ of water retention measures. However, there is no official research on this experiment. This deficiency should be eliminated within the framework of this project.

The **methodology of the experiment** is necessary for the selection of the experimental areas. A hydro-meteorological station will be installed in the main catchment area of each of the ten selected micro-catchments in the mountains, which will continuously measure the parameters of precipitation runoff, especially the amount and intensity of precipitation, as well as the amount of water draining from the wetland. This data will be used to assess the response of the micro-catchment to the precipitation events. This information will then be used to evaluate the slowing of direct surface runoff, possibly runoff associated with erosion, and the behavior of springs during dry periods. Of the ten micro-watersheds to be monitored experimentally, six will be randomly selected for the application of semi-natural water retention measures. Experience from 30 years of PAW interventions will be used. The remaining four micro-watersheds will not be modified and will serve as a control group for the experiment.

Through the selection of the selected micro-catchments and the results obtained, it is possible to control and achieve proper management of freshwater. This will be accomplished by: the slowing down of water runoff; the reduction of soil erosion; by the rehydration of the environment; by increasing the water table; through the introduction of measures against flooding; and by the increased cooperation among the water management authorities. The above points of view with reference to the previously described facts, geological and hydrogeological conditions, and the resulting frequent flash floods, soil erosion, soil stratification, drought, loss of biodiversity, decline of groundwater in the KYSUCE region.





Figure 28: The impact of constructed NBS after the implementation of the Blue Alternative in the Torysa river basin (timeline 1996 -1996 – 1997 – 2003 – 2013 – 2018), (Photo: Kravčík, M.,)

On November 19, 2004, Slovakia was affected by a windstorm that hit the High Tatras National Park. During this event, a storm caused by the convergence of frontal systems led to the occurrence of downdrafts with speeds exceeding 230 km/h along the Tatra ridges. The storm uprooted 12,600 hectares of forest, mostly spruce.

After the Tatra storm, there were different opinions in society about how to help nature recover. On the one hand, environmentalists suggested to leave the fallen wood in the damaged forest and let nature recover by itself. On the other hand, foresters demanded to remove all wood material from the forest.

In response to the restoration of the Tatra nature, the project “WATER FOREST OF SLOVAK SAVIN BANK – ecosystem restoration of damage forest in High Tatra National Park after windstorm in 2004” was initiated. The Water Forest project introduced an innovative approach, focusing on removing wood mass and repurposing the remaining waste wood for water retention measures. These measures aimed to retain rainwater and create optimal humidity conditions for new vegetation to thrive. In 2005, over 4,000 water retention measures were implemented on a 42-hectare site, and 34,000 seedlings, including spruce, red spruce, pine, fir, whitebeam, mountain maple, and elm, were planted. During the summer, 120 to 140 volunteers from 26 different countries worked daily on the project. The initiative was a collaborative effort with the Scouts and received financial support from Slovenská sporiteľňa, which contributed €330,000. These funds were used to establish two additional sites covering a total area of 41 hectares. The project was coordinated by the NGO People and Water.





Figure 29: Timeline of the restoration of Tatra forest after a windstorm using the example of the Water Forest (2004 – 2005 – 2006 – 2017 – 2022) (Photo: Kravčík, M.,)

2.4.4. Impact of the measures on the environment

We assume that all of the rainwater that is retained in ecosystems by water retention practices infiltrates into the soil and saturates the soil profile. The water gravitates to the subsoil, collects there, and then flows to the surface in small trickles once the capillary pores are saturated. But there are other benefits in the form of ecosystem services. The water retained in the capillary pores supports chemical and biological processes in the soil, as well as vegetation growth. A sufficient water supply supports photosynthesis and fixes carbon in the soil. We know that 0.4 kilograms of carbon are fixed in each kilogram of biomass (dry matter). We need water to support vegetative growth. It takes about 500 liters of water to produce one kilogram of biomass.

In addition, more water in the landscape has other positive consequences. One of the most serious positive impacts, is the ability for water to temperate climate by pumping heat from evaporated water to colder layers of the atmosphere (Pokorný, 2011). By pumping out heat, the cooling and warming processes are slowed down. Another significant benefit is the increase in biodiversity wherever there is a high amount of water.

To be able to make strategic decisions at the community level, we need to understand the potential for using stormwater runoff to create new water sources. The concept of ecosystem-based water resource protection was explored for the City of New York. The World Bank and the WWF developed the Running Pure study. This study showed that it was an order of magnitude cheaper and more efficient to obtain water resources by protecting forest ecosystems than by building dams.

We know that during heavy rains, a lot of rainwater flows from damaged land directly into ravines, streams, and rivers. This water creates flood hazards in river valleys. With more extensive frontal systems, more extensive floods occur in watersheds. The largest historic floods in Slovakia occurred in three waves in 2010. They caused damages of more than 500 million €. At that time, more than 1 billion m³ of rainwater flowed out of Slovakia. This event prompted the government of the Slovak Republic to begin considering solutions to these problems. In October 2010, the government approved the Program of Landscape Revitalization and Integrated Landscape and Flood Management with mass participation of municipalities in the implementation of water retention measures. In 2011-12, the program was implemented in 488 municipalities (see the map of the locations of water retention measures in Figure 30). More than



100,000 water retention measures were implemented with a cyclic water retention capacity of more than 10 million m³.

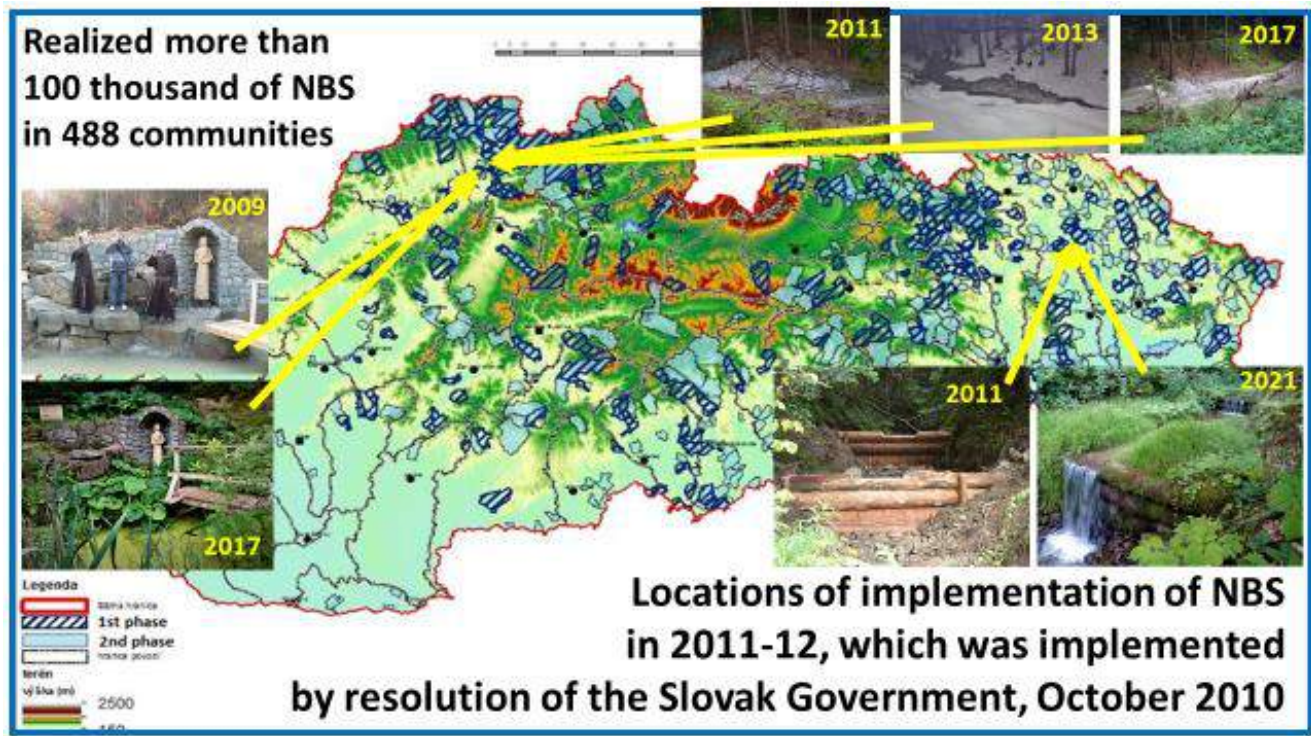


Figure 30: Location of NBS implementation in 2011-12

We present some NBS solutions implemented in the Kysuca River Basin in 2011-12. The basic indicator set by the Country Revitalization Program was the volume of water retention measures, so that the costs for the preparation, implementation and evaluation of the NBS reached a maximum of 4 € for the creation of one cubic meter of water retention volume in the first spring areas of the drainage basins, with the creation of at least 10 job opportunities for the unemployed. These 3 indicators motivated the implementation of water retention measures in places where they were really needed and with low budgetary costs. In this way, entire cascades of water retention measures were created in mountain forest areas.



Figure 31: The creation of NBS cascades strengthens the responsibility for managing one's own country (Kravčík, M)



Figure 32: **Water retention measures in the Kysuca river basin (Snežnica, Dunajov, Skalité, Stará Bystrica) and their functionality during intense rainfall. (Photo: Kravčík, M., Šuty, P., Petrákova, D.,)**

We believe that research results should be translated into recommendations for integrated watershed management in relation to water, soil, energy, biodiversity and climate for entire territories or watersheds, as offered by the case study "Landscape and Watershed Restoration Program for the Košice Region of Slovakia". It defines the principles of using rainwater retention ecosystems in the territories of all municipalities in the Košice Region, and also defines how rainwater retention ecosystems can be used to provide water resources and other ecosystem services.

2.4.5. Summary and recommendations

There is a great deal of anecdotal evidence that rainwater retention and runoff retardation are effective and cost-effective measures to restore groundwater resources, replenish springs, reduce soil erosion, reduce flash flood risk,



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and hydrate the environment. However, we are not aware of a single case where this has been proven experimentally. Therefore, our goal is to use DPS to try to prove its effectiveness.

Our hypothesis is that rain retention and runoff slowing will have an effect on microcatchment behavior (H1) and a positive effect on spring stability (H2), spring yield (H3), and surface runoff mitigation that reduces flash flood risk (H4). In addition to hypothesis testing, detailed tracking of material and labor costs will provide reliable guidance for future cost-benefit planning.

The idea of the impact of rainwater retention in ecosystems on the strengthening of ecosystem restoration processes in wind-damaged forests has been fully demonstrated. Not only did the planted trees thrive, but the grass vegetation is also very diverse and of high ecological value. According to the monitoring of the restoration processes, this part of the Tatra Mountains is recovering the most vigorously.

The innovative idea of the project lies in restoring the wind damaged forest, which is monocultural in terms of age and species, by retaining rainwater and planting a diversified forest.

We used this methodology for the analysis of rainwater runoff for extreme precipitation in each territory of the administrative unit (community) of the Kysuce basin, which generally defines the volume of runoff from precipitation in the given natural conditions of the territory from the drainage areas to the river network. These results can be very valuable as boundary conditions for modeling the passage of flood waves in the Kysuca River. We assume that their actual use will also be beneficial for other rivers in the Danube basin.

We analyzed the cadastres of 27 towns and villages with an area of 917 km², which is 87% of the basin area (1053 km²). Part of the Kysuce River Basin crosses the border into the territory of Poland and the Czech Republic, and part extends into other cadastral territories. Calculations were made for several collision angles in cadastral areas belonging to two Kysucké districts (Čadca and Kysucké Nové Mesto).

| KYSUCA RIVER BASIN | | Estimated volume of runoff from the landscape (m ³) to the Kysuca River network for various cases of extreme precipitation based on the calculation using the CN curve method (Hawkins and all, 2002). | | | | |
|-----------------------------|------------------------------|--|----------------|----------------|----------------|----------------|
| Kind of landscape | Area (km²) | 30 mm | 40 mm | 50 mm | 60 mm | 80 mm |
| Arable lands | 40,79 | 85107 | 154997 | 293679 | 456835 | 807618 |
| Gardens | 11,65 | 1569 | 28552 | 97893 | 167234 | 383415 |
| Meadows and pastures | 249,42 | 10604 | 32631 | 77499 | 216181 | 420125 |
| Forests | 551,01 | 12237 | 24473 | 57243 | 183550 | 371178 |
| Urban lands | 42,26 | 460187 | 666525 | 956087 | 1459370 | 2198439 |
| other surfaces | 22,31 | 245225 | 475628 | 747681 | 1046527 | 1699329 |
| Together | 917,43 | 814928 | 1382807 | 2230083 | 3488660 | 5839314 |

The aim is to assess the extent to which the calculations of the volume of stormwater runoff realistically reflect the potential within the research scope of the project. If we consider the volume of rainwater runoff from forests (59% of the catchment area), then the volume of rainwater runoff contributes about 6% to flood waves when 80 mm of precipitation occurs. Surprisingly, urbanized areas, which, according to calculations, represent only 4.6% of the

territory, contribute to about 38% of the occurrence of a flood wave with 80 mm rainfall. These results need to be further verified through the monitoring network established in the project.

Looking at the amount of rainwater that flows out of the country's watershed, approximately 5.8 million cubic meters are discharged into the river system when 80 mm of rain falls (occurring once every 20 years). Nearly 3.5 million m³ will flow out of the basin with 60 mm of rain (the probability of this occurring is about once a year). Since these calculated volumes are real, they will be monitored as part of the monitoring project. The aim is to find a correlation between the volume of water retention created in landscape structures where rainwater is collected, absorbed and evaporated, and an increase in water resource yield. It is assumed that the construction of each 5,000 m³ of NBS water retention measures will result in a sustained increase of 1 liter/second at the water source. The analysis of the monitoring of the revitalization of the landscape of the observed micro-watersheds for the change in the yield of springs and small watercourses will prove how realistic it is. It will also be necessary to answer how much rainwater is collected by the water retention measures during the year and how to quantify the relationship between water retention volume, retained water volume and spring yield.

2.5. DPS 5

Author: Bosko Blagojevic, Atila Bezdán & Jovana Bezdán

Location: Begečka Jama, Serbia

Short form of the organization: The Faculty of Agriculture is a part of the University of Novi Sad, an institution of higher education and scientific research whose mission is to stimulate quality educational processes, development of scientific disciplines and dissemination of knowledge gained in the economy and society. The Faculty of Agriculture carries out its mission in three interrelated groups of activities: higher education, scientific research, and application of knowledge in the field of economy. Moreover, as a part of the comprehensive educational and scientific system, it is a driving force for social development and the initial force for the development of agriculture in Serbia and the Western Balkans.

2.5.1. General Overview

The area of the pilot site *Begečka Jama* is located in the province of Vojvodina in Serbia, on the left bank of the Danube, about 20 km west of the city of Novi Sad. It comprises the protected area (*Begečka Jama Nature Park*) and the surrounding drainage basin (Begeč-Gložan drainage system) (Figure 33).





Figure 33: General overview of the area of the DPS 5 Begečka Jama (Map made by Atila Bezdán)

Excess inland water, together with organic and inorganic pollutants from agricultural production, sewage from settlements and pollution from other sources, flows through the Tatarnica watercourse (the main channel of the drainage system) via the pumping station into the Begečka Jama. These pollutants pose a significant threat to the ecosystem of the Begečka Jama Nature Park.

The catchment area of the drainage system is about 4750 ha. The total length of the canal network is about 59 km, and the length of the main canal, the Tatarnica river, is 12 km. Excess water is pumped out of the drainage area by the pumping station, with a capacity of 2 m³/s.

An overview of the land cover/land use in the area is given in Table 1:

Table 6:
Land use/land cover in the area (Corine Land Cover 2018)

| Code | Land cover/land use class | % |
|------|--------------------------------|------|
| 112 | Discontinuous urban fabric | 14.1 |
| 121 | Industrial or commercial units | 9.3 |

| | | |
|-----|--|------|
| 211 | Non-irrigated arable land | 8.5 |
| 242 | Complex cultivation patterns | 18.7 |
| 243 | Land principally occupied by agriculture, with significant areas of natural vegetation | 9.4 |
| 311 | Broad-leaved forest | 23.8 |
| 324 | Transitional woodland/shrub | 9.2 |
| 411 | Inland marshes | 4.4 |
| 511 | Water courses | 1.4 |
| 512 | Water bodies | 1.2 |

A short general overview of the **protected area** *Nature Park Begečka Jama*, is given in the next paragraph, based on the analysis and data presented in the following studies and reports: Institute for Nature Conservation of Vojvodina Province (2011) and Danube Floodplain Project Reports (<https://www.interreg-danube.eu/approved-projects/danube-floodplain>).

Begečka Jama Nature Park is an active floodplain located on the left bank between 1276.2 km and 1284 km of the Danube, 18 km west of the city of Novi Sad. The length of the area is approximately 7.8 km while the central point is 45° 13' 23"N, 19° 36' 23"E. It extends over an area of 379 hectares. The protected area contains a series of geomorphological forms of river erosion, including a fluvial lake and, consequently, a mosaic of wetlands in different stages of succession of floodplain vegetation. The survival of the wetland vegetation is due to the natural dynamics of flooding. A fluvial lake is connected to the Danube by a canal and has a constant presence of water. The length of the lake and the canal is about 1.8 km. The area is characterised by its **marshy-meadow vegetation and poplar plantations**. The special value of the vegetation of this area makes one white poplar and four black poplars very rare representatives of typical floodplain vegetation in Vojvodina, which are now protected as a nature reserve - the rare specimens of flora. In the area of the *Nature Park Begečka Jama*, about 150 **species of birds** can be observed, most of them migratory, transient and wintering. Apart from reveling in the countryside, it is also possible to go fishing. It is an extremely important **breeding ground for a large number of Danube fish species**, as well as a breeding centre for amphibians in the wider area. In accordance with the dynamics of flooding, micro, and meso-terrain configuration, **autochthonous forest communities, aquatic and wetland habitats** are present. Similar wetland- / floodplain areas are very common along the entire length of the Danube and its tributaries.

The following information on wildlife in this section is provided by the UNSFA Department of Animal Husbandry. They emphasise that the Nature Park Begečka Jama is under **state protection** and is a **significant natural asset** of the second and third category. It is an important habitat and breeding ground for **14 species of fish**, such as catfish, carp, pike, perch and others. It is a breeding ground for **11 species of amphibians** and **6 species of reptiles**. The area is



also home to around **150 species of birds**. Some of them are red-headed swans, a symbol of Begeč, great cormorants, grey herons, etc. As the Begečka jama is located in an area of intensive agriculture, the problem of heavy metal pollution from phosphate fertilizers and pesticides in watercourses is real and needs to be monitored. The management of the Begečka Jama reserve has been transferred from the local hunting association to the rangers, and the ban on hunting all animal species has come into force. This is another reason for the need to monitor the growth of wildlife populations in the area. The increase in the population of wild species in the area of Begečka jama can also cause a kind of human-wildlife conflict. The presence of heavy metals in protected wildlife areas can also have a significant impact on both wildlife and the environment.

According to the Public Enterprise “Urbanizam” (2021b), the following **protected areas and ecological corridors** are located in the pilot area *Nature Park “Begečka Jama”* - protected area of regional importance; habitats of protected and strictly protected species of national importance “NSA 01, Ada Koruška“; River Danube - international and ecological corridor; River Tatrarnica - local ecological corridor.

2.5.2. History of transformations

A brief description of the history of problems, critical points, and restorations is given in the next paragraph based on the analysis and data presented in the following studies and reports listed in the reference list (The Public Enterprise “Urbanizam” (2021b); The Public Enterprise “Urbanizam” (2021a) and Institute for Nature Conservation of Vojvodina Province (2011)).

In the first half of the 19th century, before the **construction of embankments** along the Danube and the **building of canals and drainage systems**, a large part of the territory of Vojvodina was covered with wetlands and swamps. Many wetlands and marshes disappeared as a result of the construction of **defensive embankments** in the struggle to conquer new areas for agriculture and to protect settlements. Today, the wetlands are mostly reduced to narrow strips between the river and the embankments.

The area of *Begečka Jama* is characterized by a wetland ecosystem which, despite strong anthropogenic pressure and negative influence, still contains elements of authenticity, preservation, representativeness, and landscape value.

The water regime, as well as the natural change of water due to constant flooding, is the basic ecological factor for the survival of the flora and fauna in the protected area. Therefore, the **main threat** is the altered flood and groundwater regime. Human influence is also manifested in water management and interventions that lead to changes in the regime and level of surface and underground waters. These works include dewatering and drainage, as well as the input of wastewater. Both natural and anthropogenic changes have had a significant impact on the deterioration of the hydrological regime.

The *Begej Canal*, which supplies the lake with water from the Danube, has been partially filled in. Same for the marshes and oxbows that once provided a connection to the Danube. Human activities (forestry, Danube regulations) have contributed significantly to this, resulting in a changed coastal zone, where the former marshes and oxbows have lost contact with the main river at low water levels.

Water pollution in the Begečka Jama is a perennial problem that needs to be solved systematically. The Tatrarnica River, which collects inland water from the fields around Čelarevo, Gložan and Begeč, flows through the pumping station into the Begečka Jama (Figure 34). In addition to pollutants from agricultural production, significant amounts enter the protected area through the actions of citizens who dispose of municipal waste along the banks of the canals,

emptying the contents of septic tanks into the drainage canal, and through the input of untreated wastewater from urban areas located in the canal's catchment area.



Figure 34: Areal photo of the Begečka Jama and the pumping station of the drainage system (left). Areal photo of the Tatrarnica watercourse (main canal of the drainage system) and the illegal dump site (right). Photos by Atila Bezdán, Jovana Bezdán-UNSF

The surrounding settlements (*Begeč, Gložan, Čelarevo*) have an indirect impact on the protected area. The impact is mainly manifested in the input of untreated (or insufficiently treated) municipal, industrial and atmospheric wastewater and the disposal of solid waste on the banks of the *Tatrarnica River*.

One of the most significant threats to the protected area is along the left bank of the *Tatrarnica River*. In this area, solid waste has been dumped illegally for many years, and there are no soil or groundwater protection measures in place (impermeable layer, system for collecting and cleaning leachate, covering of waste with inert material, etc.). In illegal landfills, the problem of contamination in the surrounding soil, surface water and groundwater by leachate, in addition to windblown waste is very pronounced. Viral and bacterial infectious diseases can be expected in the filtrate.



Figure 35: **Illegal dumpsites that stretch along the Tatarnica watercourse**
(photo by Atila Bezdán, Jovana Bezdán-UNSF)

2.5.3. Implemented measures

Since the Nature Park *Begečka Jama* is a dynamic system that is very sensitive to natural changes and at the same time is under strong anthropogenic influence, it is necessary to define and implement protection measures that would preserve and improve the existing natural values and control and reduce the anthropogenic influence as much as possible.

For this reason, the Decision on the protection of the nature park *Begečka Jama* was adopted in 1999. Many of the threatening factors still exist, only the problems of municipal wastewater treatment have been partially solved by the design and implementation of the **constructed wetland system (CWS) for wastewater treatment** of the *Gložan* settlement. Figure 36 shows the CWS in *Gložan*. Only the field of common reed can be seen. Below the reed there are three cells through which the wastewater flows.



Figure 36: Constructed wetland, NBS wastewater treatment facility (photo by Atila Bezdán, Jovana Bezdán-UNSFA)

Constructed wetlands are engineered systems that use the natural functions of vegetation, soil and organisms to provide secondary treatment of wastewater (Arden & Ma, 2018; Vymazal et al., 2021). The design of the constructed wetland must be tailored to the type of wastewater to be treated. Similar to natural wetlands, constructed wetlands can also act as a biofilter and/or remove a range of pollutants like suspended solids, organic matter, nutrients (nitrogen and phosphorus) and all types of pathogens (i.e. bacteria, viruses, protozoa and helminths) (Maiga et al. 2017).

In the following text, the detailed description of the CWS in *Gložan* is given from the research of Josimov-Dunderski et al. (2011, 2012). The construction of CWS *Gložan* started in 2002, was completed in 2003 and started operating in 2004. The design, construction and maintenance costs are significantly lower than for conventional wastewater treatment systems (Pillai & Brijesh Nair, 2015). The CWS is located in the inundation zone of the Danube alluvial plain, south of the *Gložan* settlement, between two land drainage canals. The terrain is almost horizontal and its altitude is 76.50 m.a.s.l. The site itself has characteristics of a marshy landscape. The CWS consists of three cells with a total area of 9400 m². The constructed CWS is a horizontal sub-surface flow. The substrate consists of gravel beds 0.6 m wide and 0.6 m thick alternating with 1.0 m wide bands of natural soil. The surface layer consists of gravel mixed with soil and reed vegetation. Common reed (*Phragmites australis* (Cav.) Trin. ex Steud.), which grows naturally at the CWS site, is used as the biofilter vegetation. The liner consists of an impermeable layer of clay that was present on the wetland site. The wastewater is treated by passing through three cells with retention times of 24, 48 and 33 hours in cells I, II and III respectively. The technological process includes the collection and conveyance of used water, its treatment in the CWS and its discharge into the recipient, a canal connected to the Danube. The system has a section for the treatment of raw sewage before it enters the wetlands. Water from a lagoon is passed through a coarse screen to remove large suspended solids and floating material. The sedimented waste water is then directed to cell I.



Today, constructed wetlands as nature-based wastewater treatment solutions can be found in many developed countries. These systems have become increasingly popular because they use natural processes and mimic the functions of natural wetlands to capture rainwater, reduce nutrient loads and create favourable habitats for wildlife (Agaton & Guila, 2023).

2.5.4. Impact of the measures on the environment

Constructed wetlands can provide numerous benefits to various stakeholders and improve local environmental conditions. Some of the positive effects of these systems are improvement of water quality, promotion of wastewater reuse and recycling, flood storage, desynchronisation of storms and they have the ability to tolerate fluctuations in flow. They have a positive effect on fish and wildlife habitats and habitats for wetland organisms, and these systems can be built in harmony with the surrounding environment, with benefits to human health. Constructed wetlands can also be integrated into a landscape design and have a positive effect on recreational activities such as hunting, photography, etc. The positive impact is reflected in the efficient removal of a wide range of pollutants. They are less expensive than conventional solutions and have lower operating and maintenance costs, but they require large areas. In some cases, unpleasant odours can occur, for example during periods of low vegetation cover or in the event of sewage overflows. In addition, constructed wetlands may have some limitations in treating some types of complex pollutants.

The *Glozan* constructed wetlands are located in the inundation zone of the Danube alluvial plain between two land drainage canals and were designed to receive local municipal and domestic wastewater (Josimov-Dundžerski et al., 2012). This biological treatment system, whose final recipient is the Danube River, was constructed on the site of a natural swamp on an area of 1 ha (Nikolić et al., 2009). Since its construction, numerous researchers have been monitoring and analysing the impact of these systems on water quality, and various projects and studies are being conducted at the Department of Water Management - UNSFA (2008, 2008b, 2011-2012). Numerous scientific and professional publications have been published from these investigations (e.g. Josimov-Dundžerski et al., 2012; Josimov-Dundžerski & Belić, 2011; Belic & Belic, 2012; Josimov-Dundžerski & Belić, 2010; Josimov-Dundžerski et al., 2015; Josimov-Dundžerski et al., 2011; Nikolić et al., 2009). Josimov-Dundžerski et al. (2015) analysed the efficiency of wetland systems in the period from 2005 to 2012, and the authors concluded that they are durable, reliable and usable in our climatic conditions, and that they could contribute to sustainable development and environmental protection in Vojvodina.

Josimov-Dundžerski et al. (2011, 2012) concluded the following:

- The system appeared to be able to remove 94% of suspended solids, while the reduction of organic matter, expressed in terms of biological oxygen demand (BOD₅), was 80.9% during the study period.
- The removal efficiency of nitrogen compounds ranged from 47.3% for nitrates, 47.5% for ammonium to 78.3% for nitrites, while the total phosphorus removal efficiency was 29.1%.
- The results of the microbiological analyses confirmed the sanitary safety of the effluent.
- The results of the chemical composition of the reed confirmed the bioaccumulation of nutrients in the plant organs. The best results were obtained at the end of the growing season (autumn).

2.5.5. Summary and recommendations

CWS are convenient, nature-based wastewater treatment solutions suitable for small settlements. CWS have no negative impact on air, water, soil, population, climate and ecosystem. They help to maintain and improve the quality of the environment. It is a clean technology that uses solar energy to produce clean water and usable biomass as end products. They are cheaper than conventional solutions and have lower operating and maintenance costs. Therefore, they could be useful to transfer to other locations and areas where it is suitable.

The expected lifetime of the CWS is about 15-20 years. Efficiency monitoring should be carried out and possible revitalization measures could be designed. As it was designed 20 years ago, there are possible new solutions or new materials that could be incorporated into the existing system or recommended for inclusion in new designs.

There are also some **measures planned for the future** that have not yet been implemented. Firstly, it is planned to **clean and widen the existing connecting canal (Begej)** between the Danube and the area of Begečka Jama in order to increase the surface area and depth of the lake, oxbows and existing canals. It is also planned to **reconstruct the existing weir** at the Begej canal to prevent water loss from the area during the spawning season. There are also plans to **install a pumping station** to pump water from the Danube into the lake when the water level in the lake is low.

All these measures will create more favourable hydrological conditions (more stable water levels) and, as a result of the habitat restoration, improve water quality and the status of the spawning areas and lead to an improvement in overall biodiversity. This would also improve the attractiveness of the Begečka Jama Nature Park area for both the local population and visitors.

2.6. DPS 6

Author: György DEÁK, Georgeta Tudor, Isabela Sadica, Monica Matei, Mădălina Boboc & Elena Holban



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Location: Sturgeon migration by-pass Iron Gates I and II, Bucharest

Short form of the organization: With more than 60 years of accumulated experience, the National Institute for Research and Development in Environmental Protection Bucharest (INCDPM) is a leading Romanian institution in the field of environmental protection and in the development of solutions for the sustainable use of resources and the services they provide. Its mission is to meet the needs of society in the fields of sustainable development, environmental protection, biodiversity conservation and climate change, at national and international levels.

2.6.1. General Overview

DPS 6 activities cover a Danube sector starting in the Danube Delta, where the river flows into the Black Sea, followed by all the Romanian and Serbian parts of the Danube, and ending on Hungarian territory at Danube km 1780. The boundaries for the river course, together with the territorial data and the type of activities that INCDPM will carry out in the DALIA project are presented in Table 2 and in Figure 37.

The proposed activities will be carried out in phases corresponding to the sections of the Danube to be assessed:

- Scientific fishing will be carried out on the territory of Romania from the Black Sea to the Iron Gates II (up to km 863 of the Danube). In the region of the Iron Gates I, the innovative bypass measure will be implemented with the aim of resolving the disruption of the historical migration routes of anadromous sturgeon populations in the Danube caused by the hydrotechnical construction.
- In order to validate the effectiveness of the proposed measure, monitoring and recovery activities of sturgeon ultrasonically tagged in scientific fishing campaigns will be carried out on the territory of Serbia from river km 1073 to km 1433 and on the territory of Hungary from km 1433 to km 1780.



Figure 37: Location of the Danube sectors targeted by INCDPM in DPS6

The Iron Gates Natural Park (www.pnportiledefier.ro) corresponds to the IUCN category V - **Protected Landscapes** and represents a protected area established by Romanian legislation in Law No. 5/2000 on the Approval of the National Land Use Plan - Section III a - Protected Areas (PR, 2000), as an area where the outstanding beauty of the landscapes and the biological diversity can be exploited under the conditions of unaltered preservation of traditions, and where the quality of life of the communities is the result of the economic activities of the inhabitants in permanent harmony with nature.

In accordance with the provisions of *Law no. 5/2000*, *Order no. 552/2003* (MAPAM, 2003), *G.D. no. 2151/2004* (GR, 2004) and *EOG no. 57/2007* (GR, 2007), the Iron Gates Natural Park includes 18 **protected areas/reserves**, of which those directly affected by the Iron Gates hydropower system are listed in the

As part of the European ecological network NATURA 2000 in Romania, two Special Protection Areas have been proclaimed on the territory of the Iron Gates Natural Park in accordance with G.D. No. 1284/2007 (GR, 2007): **ROSPA0026 Danube – Baziaș - Iron Gates**, with an area of 10,124.4 ha and **ROSPA0080 Almăjului - Locvei Mountains**, with an area of 118,141.6 ha.

In addition, pursuant to Regulation no. 1964/2007 (MMDD, 2007), **ROSCI0206 Iron Gates**, an integral part of the European ecological network NATURA 2000, has been declared a site of Community importance with a total area of 1,242,930 ha.

2.6.2. History of transformations

The history of the Iron Gates Hydropower and Navigation System (HE, 2019), a venture of the Romanian and Yugoslav (now Serbian) governments, began in 1964 (Figure 38) with the construction of the Iron Gates I dam, which was commissioned in 1972.



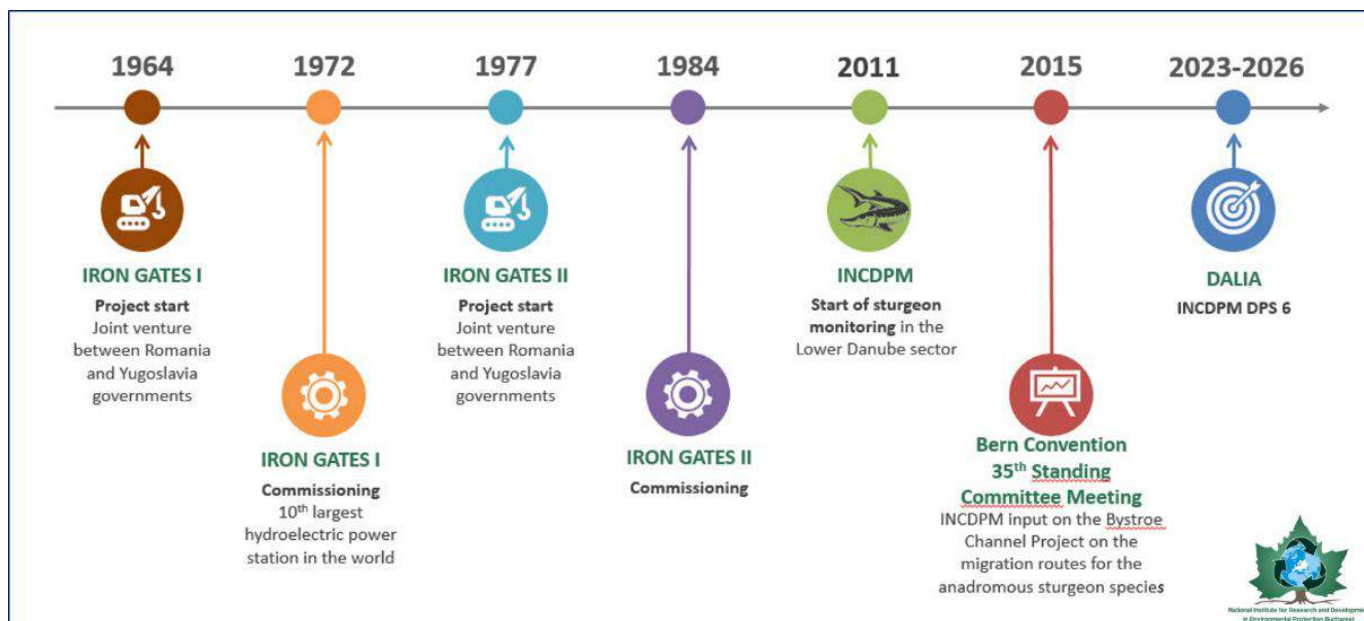


Figure 38: Timeline of connection between IRON GATES I and II Hydropower Stations, sturgeon species migration and INCDFM

The Iron Gates II dam was commissioned in 1984. It was one of the largest projects in Europe at the time and remains the most important and largest hydroelectric initiative in the region. With its functions of generating electricity, supplying water for irrigation systems, improving navigation conditions and thus increasing the capacity to import and export goods, it has been an important adjunct in the management of water flows. Romania and Yugoslavia had become the largest energy producers in Europe at the time (Crețan & Vesalon, 2017).

In this context, comprehensive studies of the potential impact of these works on natural habitats and specific biodiversity were not considered, resulting in a gradual ecological transformation of the area until the ecosystem was completely altered.

Numerous Ponto-Caspic relict species had been identified in the river **prior to the construction** of the Iron Gate I: *Manayunkia caspica*, *Hypania invalida*, *Hypania kowalevski*, *Limnomizis benedeni*, *Diamisis pengoi*, *Aselus acvaticus*, *Dikerogammarus*, *Chaetogammarus*, and *Pontogammarus*. Species such as *Acipenser ruthenus*, *Huso huso*, *Acipenser stellatus*, *Acipenser guldenstaedti*, and *Alosa pontica* migrated upstream to reproduce (Brezeanu & Cioboiu, 2006).

According to the most recent global assessment conducted by the IUCN-SSG (International Union for the Conservation of Nature - Sturgeon Specialist Group) in 2010, all 27 species belonging to the order *Acipenseriformes* and are classified as Vulnerable (VU) or Critically Endangered (CR).

The updated version of the same report was published on July 21, 2022 (IUCN-SSG, 2022), highlighting the continuing decline of this taxonomic group on a global level. The sturgeon species currently extant in the Lower Danube (*Acipenser stellatus* - the stellate sturgeon, *Huso huso* - the beluga sturgeon, and *Acipenser gueldenstaedtii* - the russian sturgeon) maintain their previous classification, as **Critically Endangered, with a consistent population decline trend**.

The team of experts from the **National Institute for Research and Development for Environmental Protection, Bucharest** have already demonstrated the extinction of two sturgeon species with historical distribution in the lower

D.1.1 – Detailed Analysis of Demonstrators Ecosystems

Danube basin, namely *Acipenser nudiiventris* and *Acipenser ruthenus*, through monitoring studies of wild sturgeon populations and stocks.

The assessment of the volume of information on catches from 1955 to 1993 indicates an alarming situation in the Lower Danube (Bacalbaşa-Dobrovici, 1989, 1991), as illustrated in Figure 39, which shows the severe decline trend of the sturgeon species.

This decline was exacerbated, among other factors, by the disruption of migration routes due to the hydrotechnical structures Iron Gates I (commissioned in 1972) and Iron Gates II (commissioned in 1984) (DEÁK et al., 2017). Figure 39 also includes data on sturgeon catches between 2002-2005, provided by the IUCN Red List of Threatened Species assessment (IUCN, 2022), and marks the beginning of the implementation of prohibition measures in 2006.

As this severe decline **could only lead to the extinction of these species**, Romania has, since 2006, enabled a series of measures to ensure the sustainability of sturgeon populations by banning commercial fishing, the use of specific equipment to catch sturgeon, the marketing of sturgeon products, and by supporting aquaculture to implement restocking programmes to support wild populations.

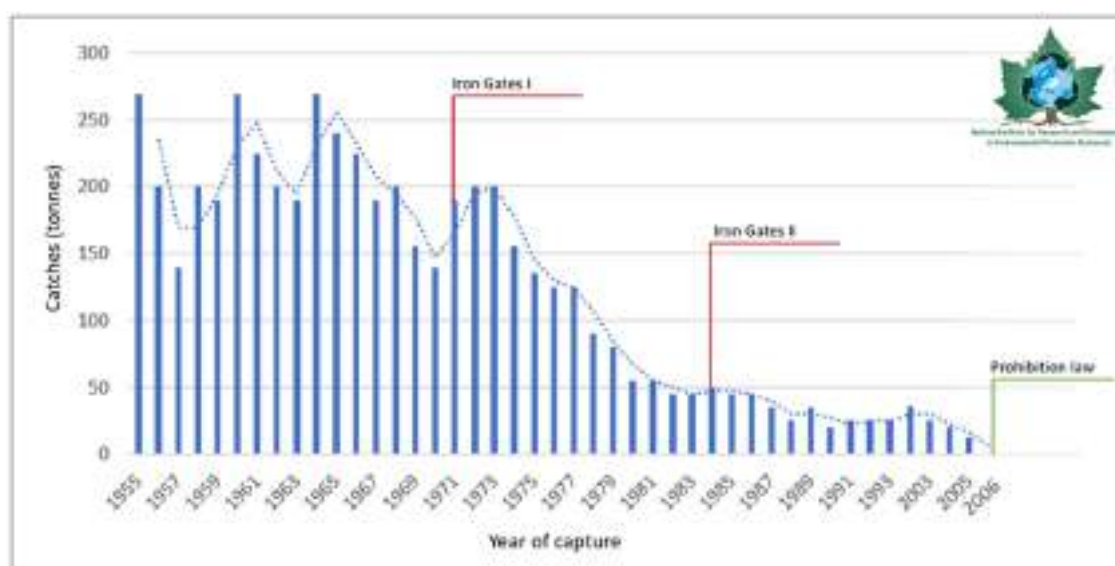


Figure 39: **Severe decline in commercial catches of sturgeon species (combined) between 1955 and 2005 (Source: DEÁK & Sadíca)**

An analysis of the impact of the Iron Gates hydroelectric plant on the ichthyofauna (Ionita, 1997) states that the creation of the reservoir, by damming the Danube has led to an imbalance in the piscivorous fauna. The analysis of the industrial fishing in the Baziaş-Salcia basin (1995) confirms the cyprinicolous structure of the region, with the predominant species being *Carassius gibelio* (prussian carp), *Abramis brama* (common bream) and *Alburnus alburnus* (common bleak).

In addition to the changes in the ichthyofaunal composition of the area, it is worth mentioning the creation of the reservoir, which suddenly and irreversibly changed the hydromorphodynamic character of more than 100 km of the river, as seen in Figure 40. Large areas have been flooded as a result of the increase of the water level near the dam to



approximately 30 metres above the previous level; the total flooded area exceeds 10,000 hectares on the Romanian territory alone. The new ecosystem contains a variety of habitats, including the gulfs of the tributaries' mouths, the flat areas on the terraces located near the river before the flooding, and the former course of the Danube. The water velocity decreased from 3 - 5 m/s, along the sectors with a steeper slope, to 1 m/s and in certain areas (gulfs and flat areas) to almost 0 m/s. Due to the decrease in water velocity, organic-mineral deposits are extremely abundant and represent one of the most important economic phenomena of the reservoir. Over a period of 10 years, the deposits at the bottom of the reservoir reached a thickness of 10-11 metres, particularly in areas of low water velocity. As the water level rose and the surrounding areas were flooded, the biocoenosis underwent a radical transformation (Brezeanu et al., 1974). Under these new environmental conditions, some species disappeared (those unique to springs and floodable ground areas), while others, mainly fish (originally restricted by their limited habitat size), rapidly increased in number and became dominant (e.g. *Dreissena polymorpha*). The new anthropic ecosystem includes lotic and lentic conditions, and the biota reflects this diversity: rheophilic organisms continue to play a significant role in the biocoenosis, but other organisms have also found refuge here (Brezeanu & Gruia, 2000).

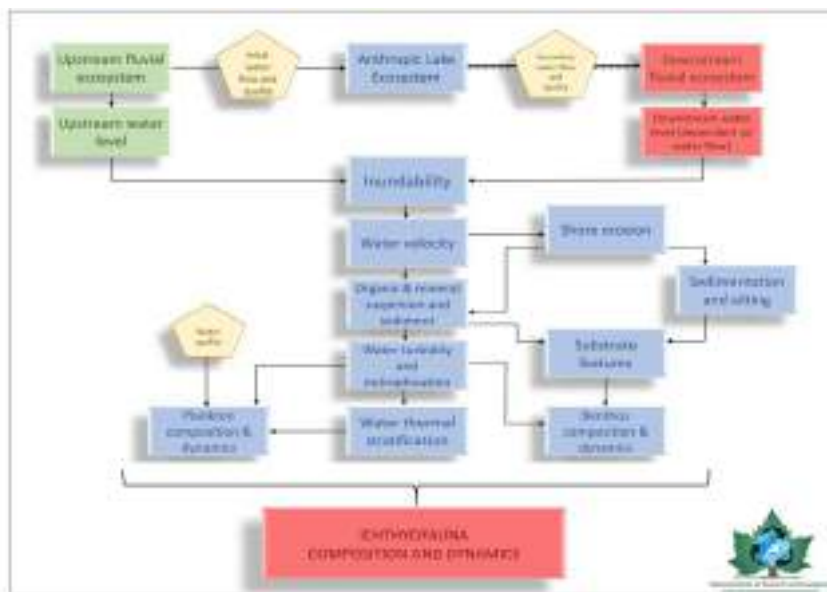


Figure 40: Structural and functional relationships for processes in the anthropogenic Iron Gates water reservoir (Source: DEÁK & Sadica, 2023)

Furthermore, the results of the study presented in (Humborg et al., 1997) indicate that the storage of water and detritus in reservoirs behind the Iron Gates has altered the biogeochemistry not only of the river but also of the adjacent Black Sea coastal waters. Seawater parameters such as alkalinity and pH are significantly controlled by a decrease in silicates and a species shift towards carbonate-producing coccolithophores (algae species) can occur. In addition, the amount of toxic flagellate colonies may also increase.

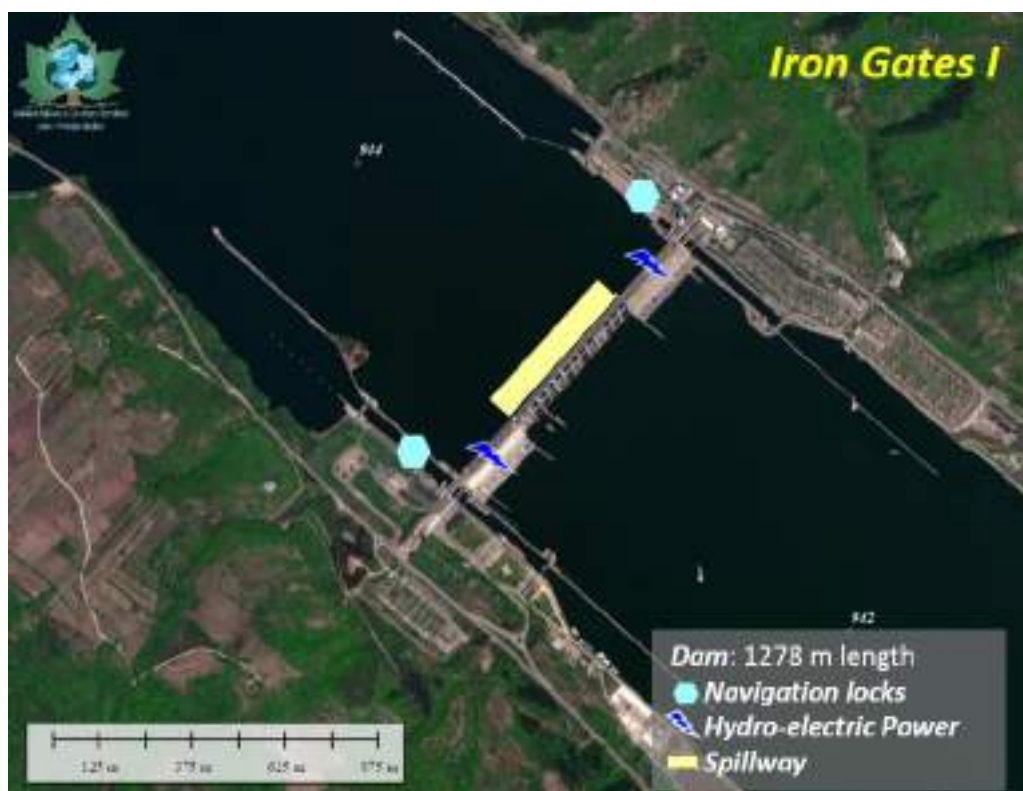


Figure 41: Iron Gates I Hydropower station – satellite imagery and technical details



Figure 42: Iron Gates I – Photo credits: Agerpres



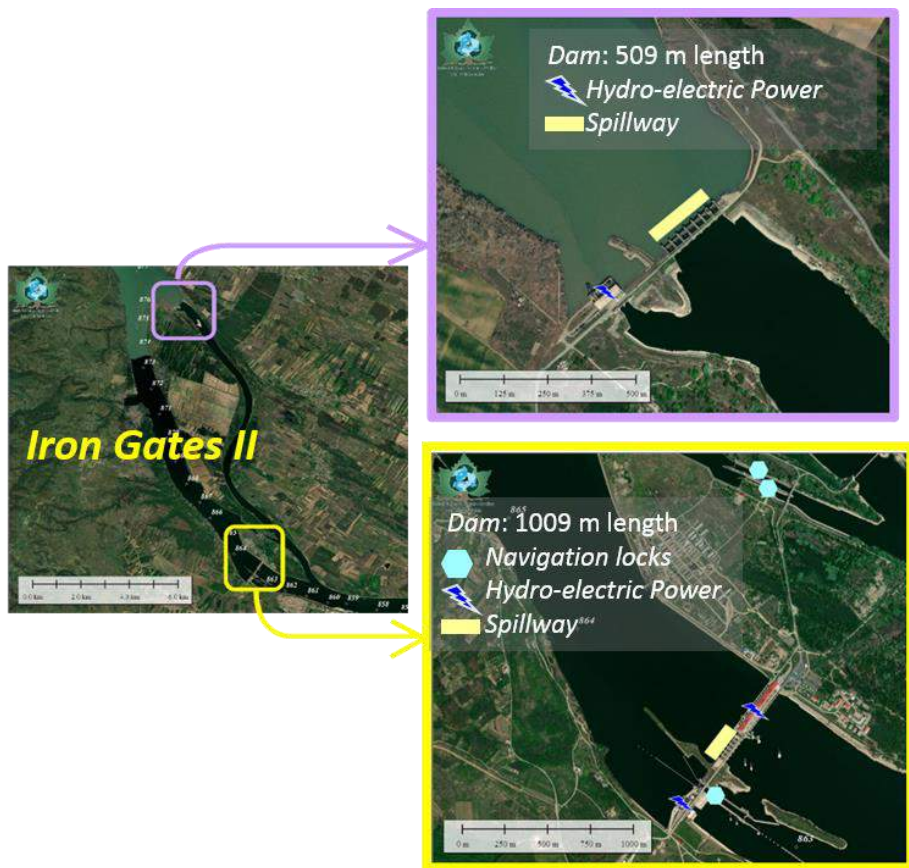


Figure 43: Iron Gates I Hydropower station – satellite imagery and technical details



Figure 44: Iron Gates II – Photo credits: Agerpres, 2022

2.6.3. Implemented measures

Table 7:
DPS 6 Danube sectors

| Country | Danube sector | | DALIA INCDPM activities |
|---------|--|---|---|
| | from | to | |
| Romania | Danube river mouths to the Black Sea <i>Tulcea County</i> | km 863 Iron Gates II <i>Mehedinti County</i> | Scientific fishing |
| | km 863 Iron Gates II <i>Mehedinti County</i> | km 943 Iron Gates I <i>Mehedinti County</i> | Innovative by-pass strategy and solutions implementation |
| | km 943 Iron Gates I <i>Mehedinti County</i> | km 1073 <i>Caras-Severin County</i> | Innovative by-pass strategy and solutions implementation |
| Serbia | km 1073 Ram <i>Braničevo District</i> | km 1433 Bezdan <i>West Bačka District</i> | Monitoring and recovery of ultrasonically tagged sturgeon species; demonstration of the innovative solution effectiveness |
| Hungary | km 1433 Mohács <i>Baranya County</i> | km 1780 Komárom <i>Komárom-Esztergom County</i> | Monitoring and recovery of ultrasonically tagged sturgeon species; demonstration of the innovative solution effectiveness |

Scientific fishing

Sturgeon specimens will be caught in accordance with current legislation using nets specifically designed for sturgeon fishing. No equipment prohibited by law will be used.

The procedure for catching sturgeon species is to launch a gillnet from a boat, which is moved by the current and drifts between 500 and 1,000 metres, depending on the fishing area, as shown in Figure 45. Once the net has filtered the water for the agreed distance, the fisherman lifts it into the boat to examine the catch. The captured fish are untangled from the net without compromising their integrity.

The experts who will carry out the scientific fishing of sturgeon are registered with scientific fishing permits issued by the Romanian National Agency for Fisheries and Aquaculture, the Ministry of Environment and Forests, following the positive opinion of the Romanian Academy, and the Romanian National Agency for Protected Areas.

Scientific fishing with filter nets will be carried out throughout the year for sturgeon species, but mainly during the main migration periods (spring and autumn). During the summer period, the use of this method is particularly recommended for the capture of juvenile sturgeon resulting from the natural summer spawning.

Individuals caught in nets are released unharmed after metric and mass data have been collected.





Figure 45: Scientific using specialized filtration nets, in accordance with the national law.

Monitoring and recovery of ultrasonically tagged sturgeon species

Specimens of sturgeon are tagged with ultrasonic transmitters according to a protocol developed by the INCDPM and approved by the international and national community of experts (<https://www.incdpm.org/post/open-positions-for-research-assistants>), as shown in Figure 46. The devices are surgically implanted in the fish's abdomen by experts assisted by a veterinarian, who simultaneously checks the fish's vital signs to ensure they are within optimal parameters. A local anaesthetic is used before the incision, and the area is disinfected after suturing to ensure that the sturgeon's integrity is not compromised. DNA samples are also taken.

A special anti-poaching tag with the sample code and the institute's contact information is also attached. After this procedure, the sturgeons are returned to their natural habitat.



Figure 46: The capture-tag-release protocol developed by INCDPM and approved by the International Community of Experts.



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Monitoring is carried out by both fixed and mobile/floating stations that provide data on water temperature, depth at which the specimen is located, and information on migration routes.

By positioning the monitoring stations (Figure 47), patented by the INCDPM expert team (DKMR and DKTB), at strategic points and distances to ensure connectivity of potential migration routes, a better understanding of sturgeon behaviour and the accuracy of the data collected is ensured.



Figure 47: DKR-01T monitoring stations developed by INCDPM

Innovative by-pass solution

The innovative Iron Gates system by-pass solution that will be implemented, tested and validated by the INCDPM team of experts as part of DALIA project activities differs from the known, established approaches like fish passes/fishways/fish lifts because it does not involve setting up a new construction adjacent to the hydropower dams. The by-pass strategy represents a combination of scientific fishing of ultrasonic tagged sturgeon specimens that will be assisted to pass upstream by special transport device to be patented by INCDPM, followed by monitoring of their behavior both by using fixed detection gates and by mobile receivers on boats in their upstream and downstream migration on Romanian territory. In order to extend the ultrasonic tagged sturgeons monitoring processes further 700 km upstream Danube, the assistance of our Serbian and Hungarian partners will be required due to INCDPM budget scarcity.

In the strategy and solution development, different possible sturgeons' behavior scenarios have been considered in order to ensure their safety in their upstream and downstream by pass of the Iron Gates dams. The risk of the specimens to suffer injuries/death from the hydropower turbines will be mitigated either by recapture at Bazias, the start point of the Romanian Danube sector, or by navigational locks opening when the DKMR alarm station signals their approach.

The project is currently in the theoretical phase and the technical scheme and patent application for the installation have already been developed. Once the solution has been implemented and evaluated, its impact on ensuring the continuity of sturgeon migration routes from the lower Danube to the upper river sector can be quantified.

2.6.4. Impact of the measures on the environment

The following section presents the status of the wild sturgeon population in the Lower Danube, based on the report of the IUCN Red List of Threatened Species, published on 1 August 2022. The data source is the experience of more than 10 years of INCDPM Bucharest in this field of research (DEÁK et al., 2023).

According to the experience of more than 10 years of INCDPM Bucharest, based on the activities of capture, ultrasonic tagging and release, it was found that the recovery trend of the sturgeon population is unsatisfactory (Raischi, 2019). Moreover, for the period 2017-2022, we are faced with a lack of information to verify the migration routes of sturgeon,

both for administrative reasons and due to the fact that the migration period from the Black Sea to the Danube is species-dependent and varies between 3-5 years.

However, INCDPM experts have analysed the status of sturgeon populations in the Lower Danube based on IUCN Red List of Threatened Species data published on 1 August 2022, when the last stock size assessments were made, using realistic scenarios (based on more than a decade of monitoring experience). In four years, the Stellate Sturgeon (*A. stellatus*) population has declined by 72.5%, the Beluga Sturgeon (*H. huso*) by 60% and the Russian Sturgeon (*A. gueldenstaedtii*) by 99%. These data were taken from the official catches reported by Romania in 2005, on the basis of which the first prohibition law was introduced in 2006.

The INCDPM used this public data as a reference point to determine the current population size of the species of interest, based on a total of 630 individuals: 401 Stellate sturgeon, 71 Russian sturgeon and 158 Beluga sturgeon.

Figure 48 shows the normal distribution of population size values for each species over different time intervals, including the entire catch, tag and release interval covered by the INCDPM field activities. Figure 49 shows the population values derived from the monitoring of ultrasonically tagged sturgeon, which also assesses the impact of illegal fishing on wild sturgeon stocks.

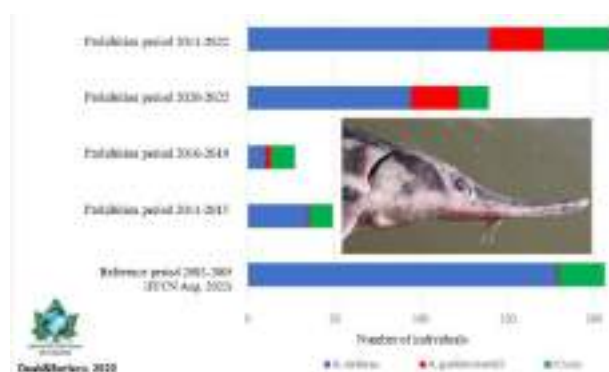


Figure 48: Evolution of wild sturgeon population size, compared to the reference period (IUCN) (Source: DEÁK et al. 2017, Raischi et al 2017,2019,2020)

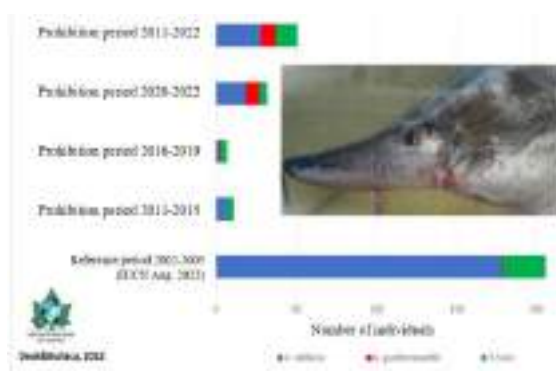


Figure 49: Evolution of sturgeon population size under the impact of poaching, compared to the reference period (Source: DEÁK et al. 2017, Raischi et al 2017, 2019,2020)

In this context, it should be noted that an example of good practice and sustained monitoring activity carried out by the INCDPM has provided favourable conditions for a real assessment of the trend of population decline for anadromous sturgeon species, as demonstrated by field data collection activities over a 10-year period. In the absence of illegal fishing activities, the rate of sturgeon population decline has been observed to be decreasing, comparable to the baseline period.

Notwithstanding the fact that the analysis presented in Figure 48 indicates that, as a result of the measures taken by the Ministry of Environment, there may be positive effects over time that could lead to the natural recovery of the wild sturgeon population in the Lower Danube and the Black Sea in the long term, the findings of the INCDPM experts indicate contradictory aspects due to anthropogenic pressures.



In view of the above, the actual situation reported by INCDPM Bucharest after more than 10 years of monitoring, shown in Figure 49, reveals that the impact of poaching has a critical influence on the natural evolution of wild sturgeon stocks, without excluding other pressures that may aggravate this situation (Raischi et al., 2017, 2020).

Uncertainty regarding the status of the Lower Danube sturgeon population was also assessed for the period 1992-2001 using the annual percentage of the species caught in commercial fisheries (Ciolac, 2004) and for the period 2011-2022 by INCDPM using data on the annual percentage of ultrasonically tagged sturgeon specimens caught and released in scientific fisheries. It should be noted that the time intervals for scientific fisheries could not cover full years.

Figure 50-A shows the annual percentage participation of sturgeon species caught in commercial fisheries (Ciolac, 2004), while Figure 50-B shows the annual percentage participation of ultrasonically tagged sturgeon specimens caught and released in scientific fisheries.

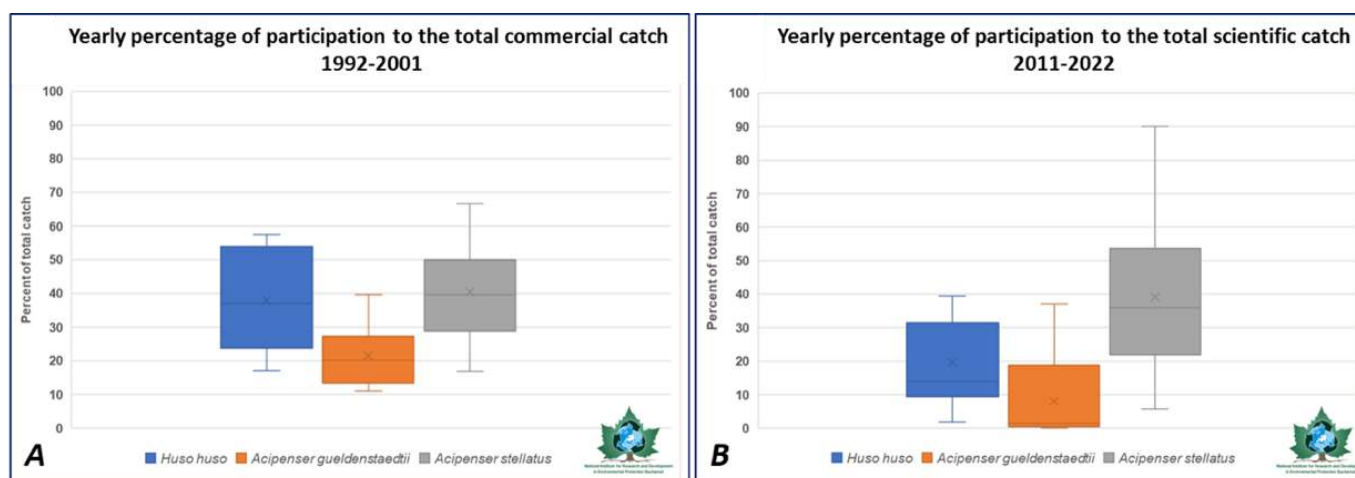


Figure 50: Annual percentage participation of sturgeon species in commercial catches 1992-2001 and in INCDPM scientific fisheries between 2011 and 2022 (source: DEÁK & Burlacu)

It should be noted that the situation of the species *Acipenser gueldenstaedtii* is still critical from the point of view of the share of its stock in the total number of sturgeon species monitored scientifically, as it is the species with the lowest share and can therefore be considered as the **rarest species of sturgeon in the Lower Danube**.

The anadromous sturgeon species, namely *Huso huso*, *Acipenser gueldenstaedtii* and *Acipenser stellatus* have been affected by a **significant reduction in historical migration routes and fragmentation of breeding habitats**. Over time, this has led to the current situation where none of the three species migrate upstream of the Iron Gates dams. This fact has also been confirmed by INCDPM through more than a decade of research on the migratory behaviour of ultrasonically tagged wild sturgeon monitored by telemetry techniques (DEÁK et al., 2014, 2017; Raischi et al., 2016, 2020; Holban et al., 2022).

2.6.5. Summary and recommendations

The study area is represented by the River Danube, from where it flows into the Black Sea and to its upper reaches. The main focus of DPS6 is the region of the Iron Gates hydropower plants, where we intend to implement an innovative bypass solution. Once the strategy of the proposed measure has been fully developed and implemented, and the results evaluated, we will be able to develop improvements for replication in other areas.

The wild sturgeon will be caught through scientific fishing activities authorised by the Romanian National Agency for Fisheries and Aquaculture, the Ministry of Environment and Forests, following the positive opinion of the Romanian Academy, and the Romanian National Agency for Protected Areas.

Once captured, individuals will be tagged with ultrasound, released back into the natural environment and monitored to measure the success of the proposed solution. The methodology of capturing sturgeon through scientific fishing and then tracking them with ultrasonic emitters, based on INCDPM's more than 10 years of experience in this specific field, has been approved by the international and national community of experts.

2.7. DPS 7

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Location: Danube Delta, Sulina Branch, Tulcea, Romania

Short form of the organizations:



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The UGAL - "Dunarea de Jos" University of Galati (UDJG) is a higher education institution in Romania. The university has a legacy with the Danube River and the Danube Delta (due to its location on the banks of the Danube) through its research activities. UDJG will be involved in this project through REXDAN research infrastructure. REXDAN has the latest generation of powerful research equipment including a river research vessel. UDJG is involved in research areas related to water, sediments, soil, air, biodiversity, bathymetry, hydromorphology, etc., thus taking part in multiple domains including: chemistry, biology, physics, environmental science, ecology, bathymetry, topography, atmospheric chemistry, sustainable development, etc. UGAL's management is supported throughout the organization, helping to guarantee efficient feedback, and to ensure that all the necessary requirements for the implementation of national and international projects are met. It also helps optimize operational management within the project consortia.

The National Institute of Hydrology and Water Management (NIHWM) is a public institution. It is the national authority in the field of hydrology, hydrogeology and water management. NIHWM develops research activities and provides operational services of national and international public interest for the protection and socio-economic well-being of people. The Institute's activities are very dynamic, constantly adapting to new needs and concerns.

2.7.1. General Overview

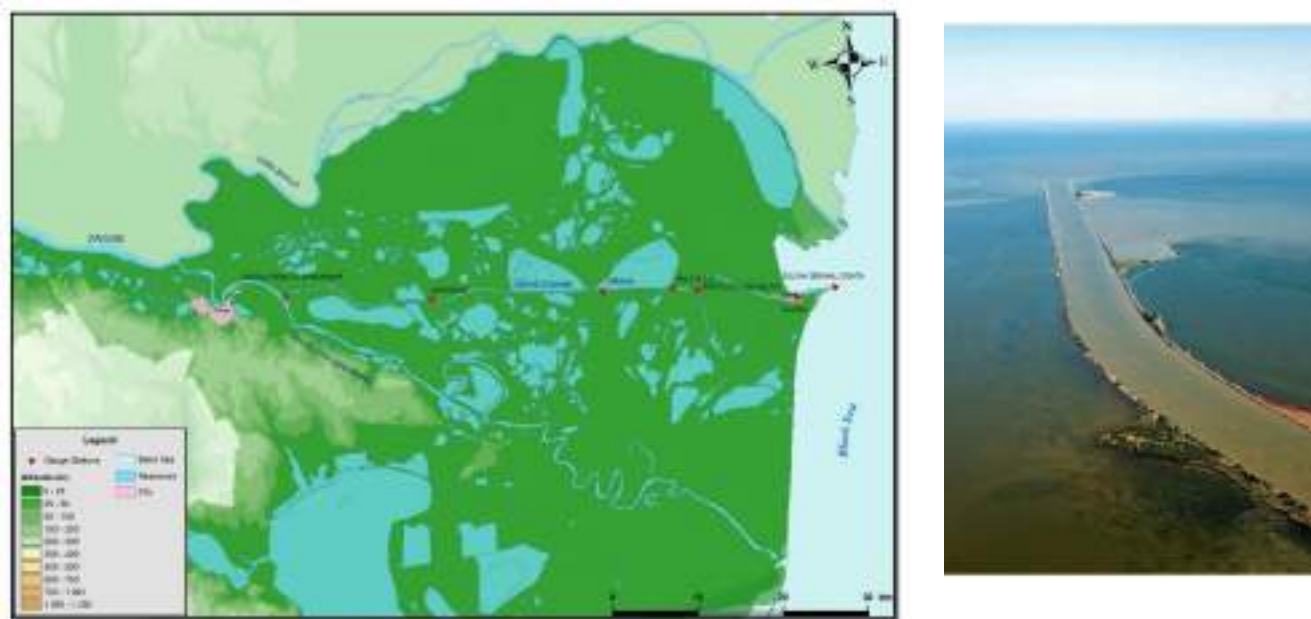


Figure 51: Location of the DPS 7: in the immediate vicinity of the mouth of the Danube into the Black Sea. (source: <https://www.facebook.com/Dobrogea.Dobrogeni.Romania/photos/>)

This map is intended to give an overview of the location of the DPS 7: the immediate vicinity of the mouth of the Danube into the Black Sea.

Located at the contact between the Danube River and the sea, it is considered as a "buffer zone" for the river-delta-sea system (Danube River - Danube Delta - Black Sea). At Ceatal Izmail, the Danube divides into two branches, the northern one, the Chilia branch, and the southern one, the Tulcea branch. The latter is divided, 17 km downstream, into two other branches, Sulina and Sfantu Gheorghe: the **Chilia branch**, the most important of this system, is 117 km long and forms the border with Ukraine. At its mouth it forms a secondary delta of about 24,000 hectares. The

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Sulina Branch (Figure 52), 71.7 km long and extending another 8 km into the sea, located in the central part of the Danube delta, is the navigable branch as a result of numerous rectifications (from 1868 to 1902) and dredging works. It has reinforced parallel embankments (made of large boulders) to prevent the erosion of the banks caused by the navigation of ships. As the only canalised branch of the river, it connects the Danube with the Black Sea. The main purpose of building this huge system of dikes is to prevent the entrance to the Danube - the Sulina branch - from becoming blocked. Through this system of dikes, the northern current of the Black Sea is diverted to the north-northeast and the Danube alluvium cannot be deposited at the entrance of the navigable canal, but is directed to the sea, where the water depth exceeds 15-20 m. The **Sfântu Gheorghe branch**, the last branch of the Danube delta, is morpho-dynamically active and forms a secondary delta at its outflow into the sea.



Figure 52: **Sulina branch extended into the sea with stone embankments**
 (source: a) NIHWM, 2021; b) <https://dunare.ro/sulina-oras-din-romania/bara-sulina/>)

a)

b)

The Sulina Branch is **extremely dynamic** from a morphological, hydrological and sedimentological point of view, due to its rectification, its dammed banks and especially to the presence of groins, which significantly influence the morphological evolution of the bed and the sediment transport from upstream to downstream. The Sulina branch is hydrologically monitored by 4 main hydrometric stations (h.s.), located at Ceatal Sfântu Gheorghe (sea mile 33.6), Crişan (sea mile 11.5), Sulina Port (sea mile 2.5) and Sulina Semnal Ceaţă (Hectometer Hm72+18m).

The analysis of the mean annual evolution of sediment volumes on the Sulina Branch aimed to highlight the temporal and spatial variability of the solid component between stations. It was found that from the entrance of the Sulina Branch to the exit, in the Black Sea, the solid input is constantly deposited annually, which is highlighted by the negative balance obtained on the areas between two consecutive stations located on the branch (h.s. Crişan - h.s. Ceatal Sf. Gheorghe; h.s. Sulina Port - h.s. Crişan; h.s. Sulina Semnal Ceaţă - h.s. Sulina Port). The largest alluvial deposits are recorded in the first 41 km (maximum 1.8×10^6 tonnes, Figure 53a) and the most alluvial deposits, almost every year, in the last 11 km (maximum 0.5×10^6 tonnes, Figure 53c).

The comparative analysis of the three sectors has shown that there is an alternation of the phenomena of deposition/erosion and allochthonous sediment sources between the analyzed sectors. Also, the solid input constantly deposited along the Sulina branch is evidenced by the negative balance between the outflow from the branch (h.s.



Sulina Semnal Ceață) and the inflow to the branch (h.s. Ceatal Sf. Gheorghe), which reaches an average alluvial volume of $1,1 \times 10^6$ tons (Figure 53d).

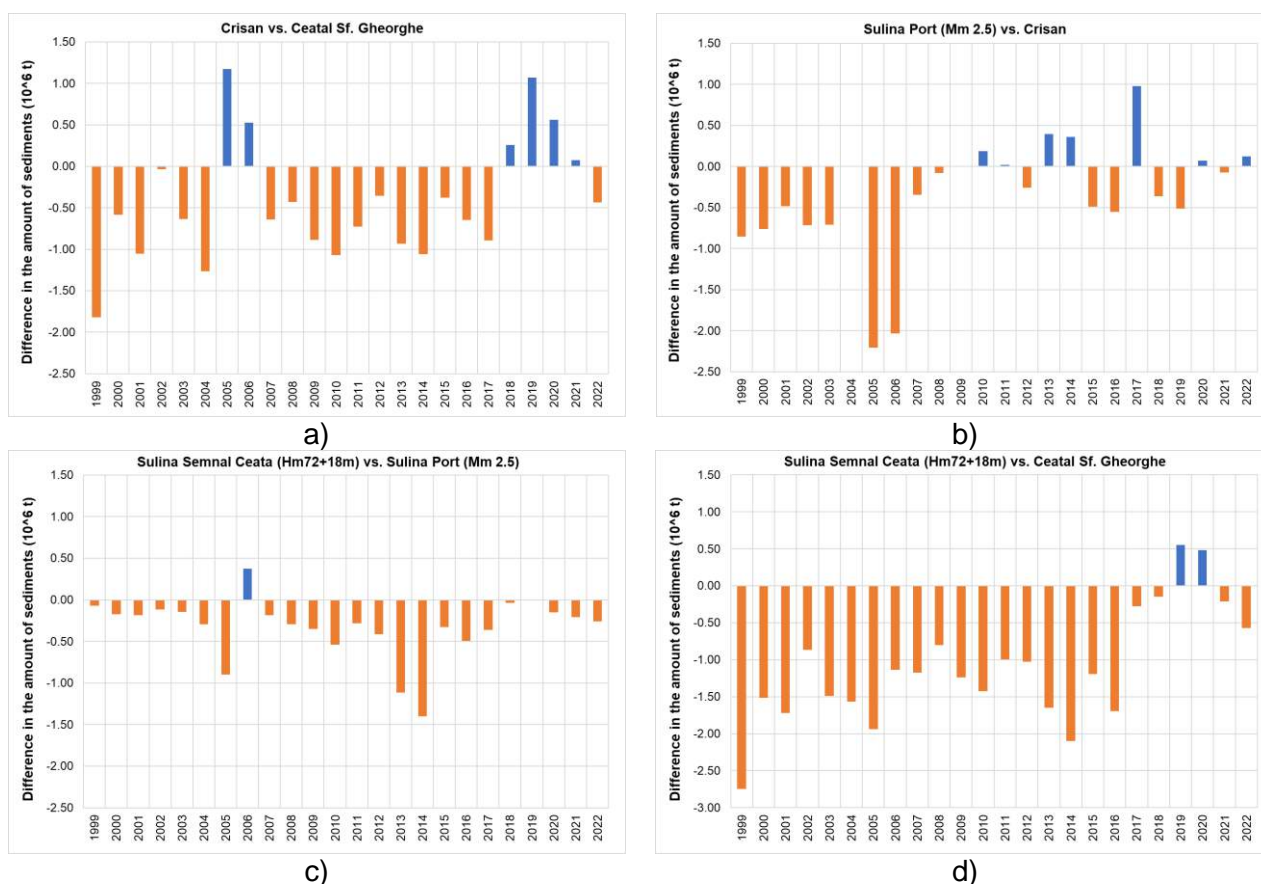


Figure 53: Annual amount of sediment between the hydrometric stations, on the Sulina branch (1999-2022); sediment deposition (orange color), sediment erosion (blue color)

The spatial analysis of the total volume of sediments along the Sulina branch, during the last 23 years (2000 - 2022), also shows a progressive decrease of the sediment volumes transported from the entrance to the Sulina branch to the exit to the Black Sea, i.e. a decrease of 36% (from 66.46×10^6 tons to 42.77×10^6 tons), while the total volume of water decreases only by 14%.

Table 8:

Values of water/sediment discharge and total volume for the period 2000-2022 at hydrometric stations on the Sulina branch

| Hydrometric station | 2000-2022 | | | |
|---------------------|--|---|--|--|
| | water | | sediment | |
| | $Q_{\text{mean multian}}$ (m^3/s) | V_{total} (km^3) | $R_{\text{mean multian.}}$ (kg/s) | V_{total} (10^6 t) |
| CEATAL SF. GHEORGHE | 1251 | 907.10 | 91.63 | 66.46 |
| CRİȘAN | 1139 | 826.22 | 80.09 | 58.09 |

| | | | | |
|---------------------|------|--------|-------|-------|
| SULINA PORT | 1228 | 890.69 | 69.79 | 50.62 |
| SULINA SEMNAL CEATĂ | 1077 | 780.97 | 58.97 | 42.77 |

The analysis of the evolution of water flows for the period 2000 - 2022, at the Sulina Semnal Ceata Hydrometric Station, shows a decreasing trend in all three regime phases (Figure 54). In the case of the sediment discharge, the trend in the evolution of the maximum and minimum sediment flows is increasing, in conditions of a not very marked variability, considering the small differences in the values of the maximum sediment flows, between 113 kg/s (in 2003, 2011 and 2022) and 976 kg/s (in 2005), and especially the values of the minimum sediment flows in the range of 0.27 kg/s (in 2001) - 8.88 kg/s (in 2021). At the mouth of the Sulina branch the maximum flow of suspended matter does not exceed 1000 kg/s.



Figure 54: Evolution and trend of mean, maximum and minimum annual water and sediment discharge series for the period 2000-2022 at the hydrometric station Sulina Semnal Ceata



The **general characteristic of the soils** in the Danube Delta is the reduced development of the soil profile. In the area of the hydrometric station the characteristic soils are protosols, alluvisols with different subtypes and psamosols. The soil texture varies from coarse to fine. It has a neutral to moderate reaction (pH = 7.5-8.4) and contains calcium carbonate from the surface. Granulometrically, the sand deposits become finer towards the surface, which proves that the alluvial power of the river has decreased over the years. The embankment of the city is subject to reflooding during high tides and easterly winds that block river discharge and sea level rise.

Considering the reduced supply of organic matter and macronutrients, the reduced capacity of the soil to store water and, therefore, the increased risk of drought, the **ecological value of alluvial soils** is moderate. Between the layers of sedimentary sand there are layers of sand containing peat. Historically, the alluvial banks, underwent great floods in the past, which carried alluvial suspensions, combined with rotten organic remains and horizons of dusty, saturated, loose mixtures, resulting in the geological combination of the ancient extended area of the Delta. **Histosols (organic soils) support of the vegetation in the wet areas, where the reed beds and the submerged aquatic vegetation develop.**

From the point of view of the shallow aquifer, in the area of Sulina, the **groundwater level** is at a depth of -1.50 m to -2.00 m, in the sand.

In the area of the Sulina canal, some **climatic records** for Romania have been established including: the lowest haze; the highest solar radiation; the most sunny days; 225 days without frost; and the lowest annual rainfall (330-350 mm).

In the Danube drainage area, the particularly favorable **biological conditions**, created by the permanent or almost permanent presence of water, make the **luxuriant development of the vegetation**. The vegetation in this area is specific to the delta, composed of deciduous trees, shrubs and grasses, and also vegetation composed of agricultural crops.

At its confluence with the sea, the Danube River has formed, on an area of 5,800 km², one of the most important deltas of Europe, the Danube Delta, which has been declared a UNESCO World Heritage Site, a Biosphere Reserve and a Wetland of International Importance (within the RAMSAR Convention). The study area, DPS7, is included in this large **protected area** (Danube Delta Reservation), which represents a protection zone for habitats and species, for water abstraction and aquatic species. Inside the Danube Delta there are small protected regions, regions that have been proposed for ecological reconstruction, fish farms, forestry regions, agricultural regions.

2.7.2. History of transformations

On the Danube, development works began as early as the seventeenth century with the aim of controlling floods, improving navigation conditions, building irrigation systems and producing energy. The works consisted of the construction of dams and reservoirs, dikes, embankments, canals, dredging and meander correction.

The evolution of the Danube Delta has been influenced by intensive human activities during the last centuries (Trifu et al., 2022). This factor has become decisive for water discharge and sediment transport from the upstream area. The most important regulation works started with the establishment of the European Commission of the Danube in the city of Galați, in 1856. At the beginning of the 20th century, the Romanian Fishing Authority started to regulate the channels in the Danube Delta in order to improve the navigation in the Delta. All these anthropogenic interventions had an impact on the flow regime of the Danube, on the sediment balance in the coastal area in front of the delta,

between the Sulina and St. George branches (Stanică and Panin, 2009, mentioned in Dutu, 2014), and also on the morphology of the shelf area in the northwestern part of the Black Sea.

The hydrotechnical works on the Sulina branch had the initial effect of increasing the water discharge from 7-9% to 16-17% of the total discharge of the Danube in 1921 (Almazov et al., 1963, mentioned in Dutu, 2014) to current levels at 18-20%. All modifications of the natural course of the Sulina branch have led to changes in the hydrological and sedimentary conditions, causing variations in the annual distribution of liquid and solid flows. In general, since the 1990s, the variability of sediments on the Sulina branch has decreased, with annual average values below 200 kg/s.

In the period 2002 - 2012, the average annual discharge values on the Sulina branch showed an increased variability, with extremes recorded every 1 to 2-3 years, with low values in 2003, 2007, 2008, 2011 and 2012, and high values in 2002, 2005, 2006 and 2010. After 2012, with the exception of the point where the Sulina Branch flows into the sea (Sulina Semnal Ceață hydrometric station), the degree of variability of the mean annual discharge gradually decreased.

Concerning the liquid flow, the contribution of the Sulina Branch to the Black Sea was analyzed at annual and seasonal level, based on the ratio between the flow values at the outlet (h.s. Sulina Semnal Ceață) and the inlet (h.s. Ceatal Sf. Gheorghe) of the branch (Figure 55). The analysis for the period 1991 - 2022 shows that the Black Sea receives on average 85% of the discharge at the beginning of the Sulina Branch, the remaining 15% can be allocated to the Danube Delta.

There are two periods, 1993 - 2002 and 2013 - 2019, when the liquid contribution of the Danube to the Black Sea through the Sulina branch had been continuously increasing, reaching 100% in 2002 and 2019, respectively. At the same time, in the last period 2020 - 2022, a decrease of the liquid input into the Black Sea was observed, which means a higher volume of water was kept in the Danube delta or lost by evaporation (Figure 55). The average annual water velocity is about 0.75 m/s (2018).

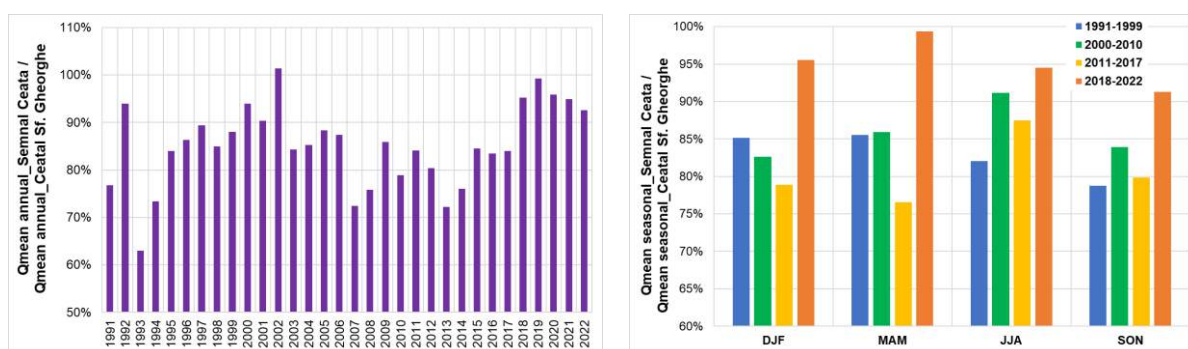


Figure 55: Contribution (%) of the Sulina branch to the the Black Sea discharge

The Sulina branch, the object of this study, represents the central distributor of the Danube within the Delta. It is the only canalized tributary, hence the name Sulina Canal; it is used for maritime and commercial navigation and provides the connection between the Danube and the Black Sea. Its course is the result of a complex evolution, carried out in different chronological stages and on different sedimentological bases.



Until 1857, the current Sulina Chanel was in a natural state. The old branch had a sinuous appearance, 83 km long, with a width that varied between 120 m and 250 m, and with the depth of the thalweg between 2.5 m and 9 m below the local low water level (etiage) (Bumblebee and Papadopol, 1972; Bumblebee and Panin, 2000 mentioned in Dutu, 2014). The hydrotechnical works determined, over time, the deepening of the canal from less than 2.5 m in 1857 to at least 9.5 m in 1959. The work of shortening and deepening the bed of the arm completely changed the flow regime of the Danube in the Danube Delta by increasing the water flow of the Sulina branch.

Between 1858 and 1902, several alterations were made to the meanders on the Sulina branch, among which the most extensive works were the of cutting of the two meanders known as "Big M" (Figure 56), which allowed the shortening of the Danube between the city of Tulcea and the Black Sea. These hydrotechnical works facilitated navigation on the channel by ensuring a constant width of 80-250 m and a depth of 7.32-18 m (Bumblebee and Panin, 2000; David, 2010, mentioned in Dutu, 2014). As a result of these works, the Sulina channel was shortened by about 25 km, from 83.8 km to 71 km (Bumblebee and Papadopol, 1972, mentioned in Dutu, 2014).



Figure 56: Rectification of the meanders on the Sulina branch - the red cycle emphasises the two meanders we refer to as the „Big M” (source: <https://www.researchgate.net/figure/Harta-Deltei-Dunarii>).

As the Sulina arm is an important shipping channel, the increased shipping traffic affects the water and sediment quality. The banks, generally protected by stones, gravel or groynes, alternate with natural areas that erode during high water or due to waves caused by ships. A continuous process of erosive sand deposition occurs due to changes in water currents. The effect on the southern part of the dike and the beach of Sulina (Figure 57) has been to increase its surface area and to move the beach towards the sea by about 400 m.

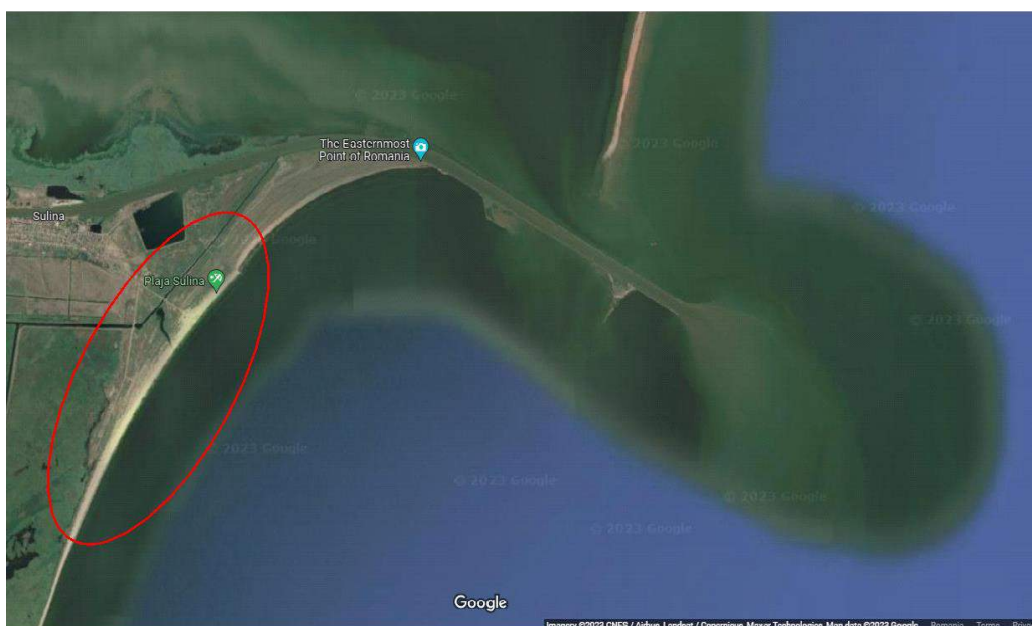


Figure 57: The Sulina beach has grown due to the deposition of erosive sand (source: Google Maps, 2023)

All the pollutants brought to the city of Sulina from the upstream area are due to the discharge of polluting substances, as well as to the use of ships and boats (the transit of naval vessels), which are the only means of transportation in the area. The pollution of the waters of the navigable branch, as well as of the canals, ponds and lakes directly or indirectly connected to the Danube, occurs more and more frequently with wastes of non-degradable materials.

The city of Sulina has a water supply system based on the intake of water from the Sulina branch, so any water pollution accident directly affects both the inhabitants of Sulina and the entire ecosystem of the Danube Delta. Air pollution is not a problem for the administrative territory of Sulina, instead, **water and soil pollution are problematic in the area.**

Port activities have negative impacts, especially in terms of pollution; in addition, they also actively contribute to the phenomenon of global warming. For this reason, it is important to study the evolution of sediments and their quality, as well as water quality, taking into account various anthropogenic causes. The aim is to create a usable tool, which helps key decision makers make the right choices in terms of development and restoration activities. For example, limiting various industrial and transportation activities, and applying NBS (nature-based solutions) or hydraulic engineering solutions.

2.7.3. Improvement of the monitoring system

Sediment quality monitoring requires both sampling and analytical determination, which are complex and costly procedures. This raises issues of economic sustainability and limits monitoring activities to a limited set of data, which may not be relevant for decision making, as sediment transport and pollutant dynamics may vary during the year (e.g. seasonal differences or differences due to unexpected disturbance events). Most of the stakeholders in the region do not have the necessary knowledge and technical background to perform complex analysis, nor do they have the



necessary budget. However, since, capacity building is one of the key project goals and virtual sensors do not require special skills (when compared to the chemical analytical procedures), the implementation of a holistic sediment - water quality monitoring system based on 4.0 Artificial Intelligence (AI) techniques will fit perfectly in the general framework of the project objectives, while also empowering science among the communities of practice.

As both the water and sediment quality matrices in DSP 7 are interrelated and can strongly influence each other, an integrated water-sediment approach needs to be considered. With limited financial and time resources, the objective is to define an appropriate analytical framework that can assist and support decision making and ensure continuous accurate data.

At present, the monitoring of the water quality of the Sulina River (chemical parameters) is carried out by 3 control stations, with a frequency of several times a year. There is no monitoring system for sediment quality in DSP 7. Concerning the sediment quantity, individual measurements of alluvium, limited to one point, located on the accessible bank, are carried out by the hydrometer operator twice a day, together with water level measurements, at the four gauging stations mentioned at the beginning of the document. The individual turbidity is determined as the arithmetic mean of the turbidities of the samples collected. During the expeditionary measurements (3-4 campaigns/year), "complete" alluvial measurements are taken over the entire bed section, and the average turbidity per section is determined based on the relationship between the complete suspended sediment measurements and the individual turbidity.

Therefore, PP11 and PP12 aim to improve the quantity and quality of sediment monitoring and link it to the water quality matrix by developing predictive models for the main parameters - dependent variable - based on other parameters that are less costly and easier to determine (predictors). However, in order to define the models, an ecosystem assessment will be carried out in order to create a database, since historical data on sediment quality do not exist and water quality databases in the region are incomplete or poorly defined. The assessment will also consider hydromorphological (batimetric) data, as well as granulometric data, in order to broaden the applicability of the prediction models and the lateral connectivity with other data, which will increase the accuracy and holistic character.

The resulting predictive models can therefore be used as virtual sensors that are both economically and environmentally sustainable and do not require special skills to use, thus facilitating knowledge transfer to stakeholders and other communities of practice. Virtual sensors must be based on models that result from training and validation of large data sets recorded during different operational scenarios. This provides a high degree of accuracy of the soft sensor solutions and good predictability in different operational scenarios. The machine learning (ML) workflow for virtual sensor development involves a series of steps, as shown below (Figure 58), which illustrate the need for model training, adaptation, and validation.

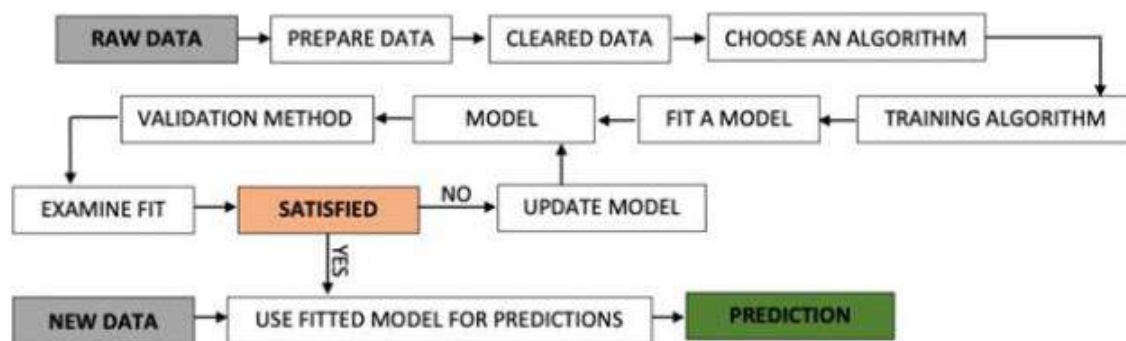


Figure 58: Machine learning (ML) -based workflow for virtual sensor development

In addition, the main sediment and water quality indices will be mapped and a simplified framework based on the most relevant predictors will be developed to provide an accurate and easy to use methodology for assessing ecosystem status. If time series data are available, predictive models could be run to improve operational management within the DSP7. Neural networks could be used, depending on the structure that will define the final database resulting from the ecosystem status assessment.

Furthermore, quantification of sediment dynamics in the study area will be pursued with the help and expertise of other consortium partners.

The transport of pollutants from the catchment area into the marine system is of particular importance when dealing with sediments. In this perspective, one of our objectives is related to the measurement of physico-chemical and biological parameters to determine the quality of the watercourse. We will perform seasonal monitoring and evaluation of water and sediment quality in the Sulina branch sector, focusing on physico-chemical parameters, i.e. pH, DO, BOD5, COD, N-NH₄⁺, N-NO₃⁻, N-NO₂⁻, total N, total P, SO₄²⁻, Cl⁻, total Fe, Zn²⁺, total Cr; Cd²⁺, Ni²⁺ etc. Based on these parameters, the Water Quality Index (WQI) and the Potential Ecological Risk Index (RI) will be calculated. We will evaluate the influence of anthropogenic activities on the level of heavy metal contamination in surface sediments using specific pollution indices, i.e. Geo-accumulation Index (I_{geo}), Contamination Factor (CF) or Pollution Load Index (PLI). The obtained data will be used for training to develop new innovative methods based on modeling (i.e. machine learning, deep learning, neural networks) to establish an analytical framework based on virtual sensors and predictive models suitable to support environmental management strategies within the Danube River.

Therefore, in order to achieve this goal, the following activities will be considered: the development of predictive models related to both water quality matrix and suspended sediment quality; the development of predictive models based on water quality and sediment quality time series data using models such as ie. ARIMA, as well as ANNs where necessary and where data structure allows it; the development of a deep learning (CNN - Convolutional Neural Network) based framework capable of identifying the water quality status as well as the sediment quality status within the Danube River study sector - new simplified methods for some environmental quality indices (i. New simplified methods for some environmental quality indices (i.e. WQI) will be proposed for application within DSP7, taking into account the specificities of the region; Development of an analytical framework that integrates data provided by our partners, related to sediment dynamics, with data related to water and sediment quality.

The monitoring system is based on a database of historical data, as well as on data obtained during the implementation phase of the project (the result of the analysis of water and sediment quality, with certain and fixed periodicity). Both water and sediment quality have been and will be measured by in-situ sampling and sensors. Thus, the data will be statistically analyzed and used to generate various predictive models that will serve as a basis for the development of virtual sensors - a more sustainable way of environmental monitoring in terms of water and sediment chemical composition. The time series data generated by the sensors will also provide the opportunity to generate various predictions.

Numerical data in the form of water and sediment quality - target physico-chemical parameters, i.e. pH, DO, BOD5, COD, N-NH₄⁺, N-NO₃⁻, N-NO₂⁻, total N, total P, SO₄²⁻, Cl⁻, total Fe, Zn²⁺, total Cr; Cd²⁺, Ni²⁺ etc. in different seasons will be included in the model. The data, arranged as constant time series, will be used to generate predictions. However, if other partners can contribute and help with some image databases related to the present site, computer vision techniques and some CNN techniques can be tried to develop a more complex monitoring system. Generalized



Additive Models (GAM) will also be used to better explain the dynamics of a variable depending on another variable. A specific framework will be created to alternate different modeling techniques, aiming for the best metric results in the end.

In addition, Imagistic data can also be used, but only if the creation of image databases is linked as an activity with other partners of the project. We have some experience with image processing through computer vision and deep learning, so we can contribute in a limited way (detection of different objects in the environment) to some tasks that could involve the use of these techniques. However, we need support in terms of collecting the image database, as well as assistance/teamwork during processing, from researchers who have more in-depth knowledge related to the use of computer vision and convolutional neural networks (CNN) for sediment and water quality assessment. The numerical data processing will be done as mentioned above. However, it would be interesting to work together to find a way to integrate both numerical and imagery data in the spirit of the digital twin.

We can use NNs' for generating predictive models and detecting future importance in order to detect which component (analyzed variable) is the most important in determining the environmental indicators mentioned in the above answers, namely Water Quality Index (WQI) and Potential Ecological Risk Index (RI), Geo-accumulation Index (Igeo), Contamination Factor (CF) or Pollution Load Index (PLI). Neural networks (NN) will also be used to identify predictive/feature significance among sediment chemical parameters, as well as in an integrated sediment-water database. If support is offered, CNN can be used on imagistic data - however, this depends on the conditions mentioned in the above answers, since our capacity to deal with such situations is limited (i.e. we have previously detected, classified and measured various objects).

The **main objectives** of the monitoring system and the new virtual sensors and prediction models to be created are as follows: An integrated spatio-temporal observation system to define the main problems on the Danube, compared with the monitoring activities in the main areas of the Danube Delta, in order to improve the knowledge of the quantity and quality of sediments discharged into the Black Sea. A continuous monitoring station with optical sensors for suspended sediments at the outlet of the Sulina branch and also AI/ML techniques for water and sediment quality parameters will be used. A combination of direct and indirect methods will be used to measure suspended sediment transport.

One of the recommendations of the "Danube Sediment" project concerning the improvement of the monitoring systems is the measurement of the suspended sediment concentration (SSC) at one point in the cross section with high temporal resolution (e.g. 15 min) using optical or acoustic backscatter sensors. In order to measure the temporal variability of suspended sediment transport to the Black Sea, an optical sensor will be installed in DPS7 to continuously record the turbidity at one point in the cross section (near the bank). The automated monitoring station will be equipped as follows: 1) radar water level sensor; 2) air temperature sensor with 5 m cable and solar protection; 3) Hach Solitax turbidity and suspended solids sensors (unit of measurement mg/l); 4) salinity and water temperature sensors; 5) photovoltaic panel (minimum 60 W); 6) Net DI 500 data logger with analog module, with built-in GPRS modem. The sensor is calibrated "in situ" with water samples. A similar Solitax ts-line turbidity sensor is located in Austria, at the Aschach power line monitoring site.

Sediment data are a prerequisite for proper planning and evaluation of any sediment management activity. Long-term, regularly measured data must be available to assess trends and long-term effects of sediment management measures and climate change. The results of DPS7 could be extended to a medium- and long-term integrated system, with the possibility of spatial extension, for the major river basins. The proposed solution applied in DPS7 could represent an integrated environmental monitoring system for all river basins and at the same time be a support system for decision makers.

2.7.4. Impact of the measures on the environment

The monitoring of the watercourse will be carried out periodically. First, all the parameters proposed in the grant application will be monitored using standard analytical methods (chromatographic, spectrophotometric, electrochemical, etc.). Then, after the creation of the neural network and machine learning algorithms, some of the parameters will be determined using the resulting virtual sensors, without the need to involve complex and costly laboratory analytical procedures. In this way, monitoring costs will be reduced and highly accurate predictions of the evolution of water and sediment quality will be possible. In addition, predictive models will provide data on what will happen in the future in terms of water and sediment quality, providing valuable time to create action plans. The developed analytical framework will serve as a decision support system for optimizing operational and decision management in the study area.

Through the use of historical data and the collection of seasonal and time series data, the resulting database will provide all that is necessary for the development of a highly accurate analytical framework. This analytical framework will ensure high economic sustainability of the monitoring campaigns and provide predictions and solutions for action in different scenarios. What we are proposing is a high economic sustainability solution that will increase the efficiency of the environmental decision-making process in the studied area.

The developed analytical framework will act as a decision support system for the optimization of operational and decision management in the studied area. Thus, the system will provide valuable information with limited resources (high economic sustainability) that can be used by decision makers and scientists to make the best recommendations in different development scenarios.

Also, the resulting databases created during the ecological status assessment of DSP7 and the databases used for the validation of the resulting models, as well as data related to hydromorphology and granulometry, will complete the knowledge related to both water and sediment quality within this site. These data, synergistically integrated with the information related to the sediment presence dynamics and transport, will provide the necessary knowledge for the creation of future action plans to empower the attempts to design, optimize and test different in-situ solutions, and will also facilitate the identification of possible barriers and ways to overcome them, during the replication activities.

As the DSP7 is an area where sediment-water linkages and dynamics have not been explored in the past, the impact of the ongoing activities is consistent. It is expected that highly accurate virtual sensors will be generated, thereby building the capacity of stakeholders and communities of practice, while also facilitating data flow. In addition, the predictions will provide a better understanding of the complex interconnected processes within the DSP and provide the basis for future decisions aimed at ecological restoration and protection. Prediction tools will improve the capacity to respond to various future threats and increase resilience to disruptive factors generated by climate change. It is also expected that the results obtained, including the knowledge of sediment dynamics, will provide the basis for proposing new protection policies that will facilitate the transition from blue to green economy and the reduction of chemical and morphological impacts on the DSP7.



2.7.5. Summary and recommendations

The **replication process** depends mostly on the historical data recorded at the replication site. Thus, models can be slightly adjusted based on this data, but the analytical framework structure remains the same. However, the replication site must have some similarity in terms of type, climatic background, and so on.

The monitoring systems should be improved, as the current system is based on analytical methods and provides limited coverage and limited amount of data, which is insufficient to provide a holistic picture and assessment of the status of the current situation. Also, the sediment quality monitoring system is not implemented in the DPS7 or even in the Danube Delta. In order to change attitudes and involve citizens and stakeholders, we need to build capacity among them - thus, the new proposed monitoring system offers this feature. Another aspect is related to the dynamics of changes within the DPS7, which are also amplified by the presence of several disruptive factors such as climate change. Thus, the new machine learning analytical framework solution adapts to these emerging challenges, adapting in time and facilitating a mode of frequent evaluation of the actual in-situ situation in order to make the necessary decision on time.

Experts have identified the main drivers of sediment regime change as flood control, hydropower, navigation, water supply and commercial dredging. Due to human intervention, sediment deficiency and coastal erosion can be observed. Improvement of the monitoring system is needed at the outflow of rivers into the sea. This can be done using continuous monitoring with high temporal resolution, to determine the sediment load that has arrived in the sea. Also, in terms of replicability, the proposed solution is a strong point, since it uses AI techniques that can be easily adapted to perform accurately in different scenarios. However, as with most solutions, this one also faces several obstacles, the most decisive being the one related to the limitation of the databases necessary to optimize the developed models in situ.

For successful replication, it is **recommended** that an initial ecosystem assessment be conducted at the intended replication site to optimize and then validate the proposed analytical framework.

2.8. DPS 8

Author: Attila D. Molnár & Miklós Gy. Korpos

Location: Bodrog River, Hungary

Short form of the organizations:

The Plastic Cup Society (THU by its former name), originally founded in 1996 under the name Naturefilm.hu Society, began as a passionate team of nature filmmakers. The society produced an environmental television documentary series focusing on the problem of plastic pollution in the Tisza River. Its success led to the creation of a non-profit environmental initiative called Plastic Cup, which has since become a registered trademark and the official name of the society. Currently, Plastic Cup stands out as one of the most influential and effective river cleanup initiatives in the Danube River Basin due to its impressive results, large number of participants, and substantial outputs. This initiative goes beyond the simple act of cleanup. By emphasizing monitoring, education and recycling, it addresses different aspects of river litter and tailors its approach to each stage. These collective efforts have resulted in the removal of over 300 tons of river litter and the recycling of 200 tons of river litter, mostly plastics. While these activities have successfully raised awareness and engaged local stakeholders, the ultimate solution lies in preventing waste from entering the river. This requires the implementation of preventative measures and proper waste management systems. The Plastic Cup has therefore taken proactive measures in upstream countries, particularly in

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Ukraine. Along the Latorica and Uzh rivers, the initiative has established collaborative partnerships with local environmental activists and waste management companies. Together, they have effectively diverted more than 700 tons of household waste from the river.

The General Directorate of Water Management (OVF) is an independently operating institute and a central governmental body under the direction of the Minister of the Interior. OVF is based in Budapest, however the activities of the General Directorate of Water Management (OVF) cover the entire country. OVF coordinates the professional activities of the 12 local water directorates in Hungary.

2.8.1. General Overview

In DALIA, the DPS 8 site area includes the Hungarian section of the Bodrog River, from the border between Hungary and Slovakia to the mouth of the river at Tokaj, covering a distance of 51 kilometers along the river (abbreviated as "rkm"). The Bodrog River is one of the tributaries of the Tisza River, recognized as the longest (966 km) tributary of the Danube. The region is of particular importance from the project perspective due to the severe impact of transboundary litter pollution on the Tisza River, resulting in extensive contamination with various forms of plastic waste, including microplastics and macroplastic particles. In addition, the issue of legacy pollution, involving toxic substances leaking from abandoned mines, is equally significant. In 2000, the Somes River experienced a catastrophic cyanide spill, described by the BBC as "the worst environmental disaster since the Chernobyl nuclear leak in 1986". In 2022, the Slana River suffered months of poisoning that turned the entire river red. Both the Slana and Somes rivers flow into the Tisza, as does our pilot site, the Bodrog River, which collects water from tributaries such as the Latorica in Ukraine. To understand the severe plastic pollution of these waterways from improperly managed household waste, especially plastic, you can watch a **VIDEO** illustration filmed in March 2023 in the city of Munkachevo, Ukraine.



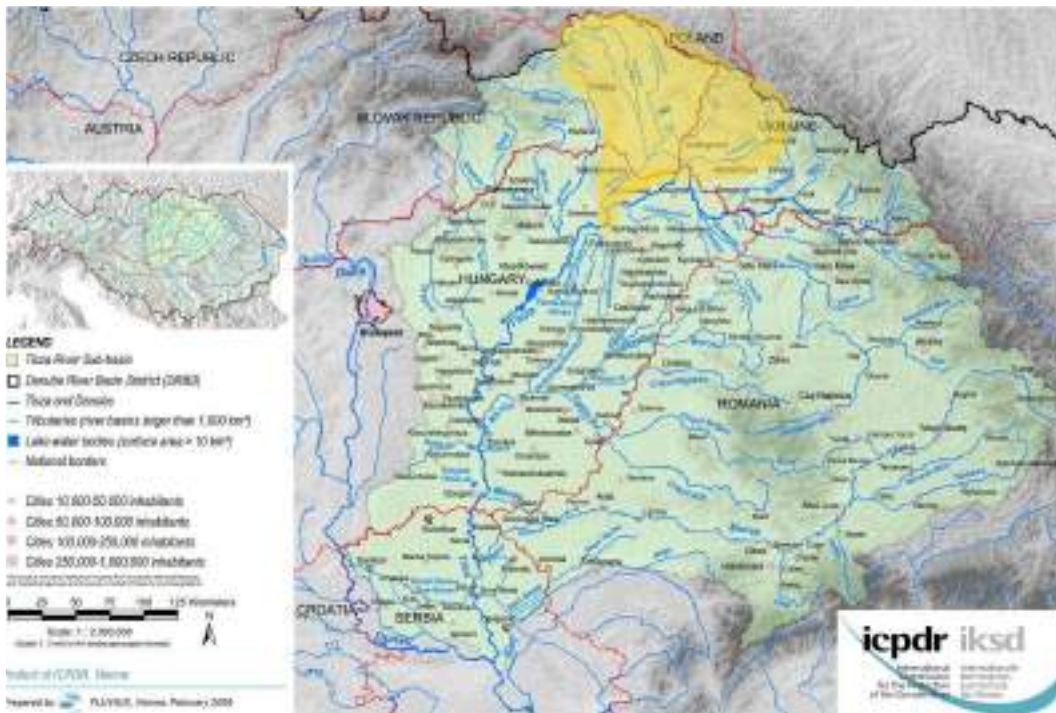


Figure 59: Overview of the Tisza sub-basin, with the Danube on the left, the Tisza and Bodrog Rivers, and their approximate catchment areas highlighted in yellow (map source: www.icpdr.org, graphics: M.A., Plastic Cup Society).



Figure 60: The Bodrog river basin. The activities of the pilot site will be carried out in the zone highlighted with yellow color (map: www.icpdr.org)

The Bodrog River is part of the Tisza River sub-basin and the Bodrogköz planning sub-basin within the Hungarian River Basin Management Plan (RBMP). The surface water body (SWB) code for the Hungarian section of the Bodrog River is HUAEP334. This water body belongs to the natural category and has specific typological characteristics, such as being a lowland river with a low gradient, a calcareous geochemical character with a medium-fine bed material. It

also collects water from a relatively large catchment area. In Hungary, the Bodrog has a length of 51.2 km and a catchment area of 969.1 km². Its total catchment area is 12338 km². The average flow of the river from 1971 to 2000 was 119.6 m³/s. The Hungarian section of the Bodrog is a class III navigable waterway of regional importance. The Tiszalök dam on the Tisa River impounds the Bodrog from Tokaj (0 km) to Sárospatak (37 km). This dammed section is well adapted to the development of holiday cruises. From 2020, the section of the waterway between river kilometer 51 (HU/SK border) and 0 (Tokaj) can be navigated by a motorboat, small boats such as canoe, kayak, pedal boat, etc. (57/2011 (XI.22.) NFM decision), and thus also serves tourist purposes. Naturally a meandering type with an index of 0.85, although 32% of the riverbed is from the development of natural meandering progression constrained by reinforcement and 10% regulated: straightened and 19 groynes protect the riverbank from erosion. Nearly 35% of the river has an artificial barrier to protect deeper areas from flooding, thus reducing interaction with the floodplain. As there were no infrastructure or riverbed alterations associated with the pilot project, a standard map can be used. In addition, a hydrological model of the river is available to predict the spread of plastic pollution in the river (Fleit, G. et al 2023).

Several sections of the Bodrog River are under **protection**. In Hungary, the Aggtelek National Park manages the Tokaj-Bodrog River **Protected Landscape Area**, which is one of the most beautiful wetlands in the country. Any activity in the area requires a permit. This is the only area in the country that is regularly flooded. Apart from its natural values and undisturbed nature, this is one of the reasons why it was included in the list of internationally significant waterbird habitats under the Ramsar Convention in 1989. The area was declared protected in August 1986 and covers an area of 5318 hectares. It consists of two main parts. One is the Nagy-Kopasz, which belongs to the Tokaj-Hegyalja region, famous for its flavorful wines, and is part of the UNESCO World Heritage. With a height of 513 meters, it is one of the largest volcanic hills in the country. The other important area of the protected landscape is the Bodrog-Tisza floodplain, which is silvery in spring due to the swollen and glistening waters of the two rivers. As a result, the vegetation here is dominated by plant species associated with water and wet habitats. Because of the spring floods, the floodplain remains inaccessible until mid-summer, providing undisturbed nesting habitat for the rich waterfowl population. Numerous species of ducks and waders, such as the elegant great egret, its smaller and rarer cousin the little egret, or the elusive bittern, which nests in the sedge and wet meadows, have made the Bodrogzug internationally famous. During the fall migration, large flocks of southward-migrating waterfowl pass through or congregate in the area. The list of basic data concerning the Tokaj-Bodrogzug Protected Landscape Area includes the following: Registration number: 183/TK/86 Legal regulation declaring the protection: 165/2007 (XII. 27.) Government Decree on the Protection of the Tisza-Bodrog-Tisza Corridor Number of areas covered by international agreements: HUBN10001 Bodrogzug-Kopasz-hegy-Taktaköz Special Area of Conservation for Birds Natura 2000, HUBN20072 Tokaji Kopasz-hegy, HUBN20071 Bodrogzug and Bodrog floodplain Special Area of Conservation for Birds Natura 2000; RAMSAR site (3782 ha) Area: 5058 ha (strictly protected: 724 ha) County name: Borsod-Abaúj-Zemplén County Names of settlements: Bodrogkeresztúr, Bodrogkisfalud, Olaszliszka, Szegi, Tarcal, Tiszaladány, Tokaj, Zalkod Geographical coordinates (EOTR) N: 48° 15'; E: 21° 25' Height above sea level: max.: 513 m, min.: 93 m.

2.8.2. History of transformations

The Bodrog is a unique river with special cultural significance. The river is fed by the surface waters of the Carpathian Mountains. Despite its relatively short length, it is an international river, collecting water from as many as 3 countries (namely Ukraine, Slovakia and Hungary) and discharging into a major tributary of the Danube called the Tisza River. The Bodrog-Tisza estuary is an iconic place and a UNESCO World Heritage Site known worldwide as Tokaj. The Tokaj region, famous for its special wines, owes its unique microclimate to these two rivers - mainly the Bodrog and partly the Tisza.



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Figure 61: Tokaj wineries in 1908, with the Bodrog River in the background, on the right side. Picture of: Fortepan.hu, Erdélyi Mór.

The Bodrog River has been a rich **fishing ground** for centuries. The main river bed and the wide floodplains along the river banks provided a good catch. There are many known fish dishes from the region, including stuffed pike and fish soup made from sterlets. The water quality in the main stream was very good, suitable for drinking or in the winter, for making fresh ice. The vast wetlands between the Tisza and the Bodrog (often called the Bodrog branch) were difficult to navigate and the water quality was not suitable for drinking. Nevertheless, these areas were traditionally used for hunting and gathering, for example, the freshwater turtles collected in the region were sold among the nobility as an exquisite delicacy.



Figure 62: A fisherman in a traditional boat, called a "ladik" in the region, and a special type of net used to catch small schoolfish. Image courtesy of: Fortepan.hu

In the last three centuries the Bodrog River has undergone **significant changes and challenges**. It began in 1846, when the regulation of the downstream Tisza River had an intermediate effect on the water level and quality of the Bodrog. However, the most dangerous impact came with the heavy **industrialization** of the communist countries, beginning in 1946. Factories and production plants discharged an alarming amount of pollutants into the river, to the extent that it stopped freezing in the winter. Locals along the Bodrog River used to joke: "Do you need antifreeze for your car? Just get some water from the Bodrog!" The color of the water also changed dramatically, becoming very dark brown, and key species sensitive to good water quality, such as freshwater crayfish and crabs, became extinct.

The next major challenge for the river was the **construction** of the Tiszalök **Dam**, which fundamentally changed the flow characteristics of the river. The water level rose and the flow slowed down. Before the regulation of the Tisza,

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the Bodrog was a relatively small waterway. The settlements along the river depended on fishing, shipping and agriculture in the floodplains, which were flooded for months every year. After the regulation, there was a decrease in the flowrate of the Bodrog and a rise in the water level. The topographical features and the water retention effect of the Tiszalök dam allowed for the accumulation of flotsam from upstream countries in the floodplain. This polluted the river and the surrounding floodplain forests with plastic and other types of river debris. Plastic waste has managed to invade the floodplain despite its high ecological value, which includes protected areas such as the Long Forest above Sárospatak and nature parks such as the Bodrog Draught. Fortunately, the protected areas are mostly protected from plastic flooding. The Long Forest has a dam structure along the river, which has no bends, so there are few trapping sites. It is an old floodplain forest, originally a hunting area, where dams were built to allow game to escape during floods. These dams now help keep the forest clean. The Bodrog water system is controlled by sluices and canals, creating bottlenecks for pollution to enter the area. Transboundary pollution of the river continues to have widespread and damaging effects on economic sectors such as tourism, fishing and shipping. Today, all settlements along the Bodrog are protected by dikes, and water quality has improved throughout the region thanks to EU investment in the construction and maintenance of wastewater treatment plants. Many species returned from the Tisza River and tourism has experienced an upswing.

A 2018 citizen science river pollution survey in Ukraine revealed that **illegal dumping along rivers** in the region is not occasional, but regular, due to a lack of alternatives. Most unfortunately, this illegal dumping **is a widely accepted method of waste disposal** (field report: https://petkupa.hu/hu_HU/hulladekmonitoring-a-tisza-karpataljai-szakaszan). Along a short 60-kilometer stretch of river, volunteers reported 17 illegal coastal dumping sites, or hotspots. Before the invasion by neighbouring Russia, 400 million tons of household waste weren't properly disposed of each year in Ukraine, a serious environmental problem that is likely to worsen as the war escalates (Oksana, C. et al. 2018). Illegal coastal landfills can also be found across the EU. According to the Water Authority, coastal hotspots in Romania can dump up to 300 cubic meters of mistreated waste into the Somes River during a single flood event. Close to natural waterways, the mistreated and illegally dumped waste is swept away by rising water levels, allowing hotspots to further contribute to the overall mass of riverine litter. Drifting river litter can travel long distances and easily cross borders. Consequently, transboundary river pollution is a matter of international concern. The bad news is that the floating fraction of riverine litter is only the tip of the iceberg. Of all the mismanaged waste - household and industrial - that enters natural waters, about 70% sinks to the bottom, 15% is washed onto the banks, and only 15% continues to drift in the water column (Hanke, G. et al 2013). In other words, most of the trash disappears from view the moment the area is flooded. Rivers are known not only to transport waste to the sea, but also to act as traps and deposition sites for riverine litter (Shruti, V. C., et al. 2019).

2.8.3. Implemented measures

On October 03, EURONEWS released the latest episode of OCEAN magazine. The environmental program presented the Bodrog plastic cup as a flagship initiative. To see the video and the interview with DALIA colleague Miklós Gyalai Korpos please follow this link: <https://www.euronews.com/green/2023/10/03/cleaning-europes-rivers-meet-the-teams-looking-to-turn-the-plastic-tide>.

DALIA partner **Plastic Cup Society**, originally founded in 1996 under the name Naturefilm.hu, began as a team of passionate nature filmmakers. The society produced an environmental television documentary series focusing on plastic pollution in the Tisza River. Its success led to the creation of a non-profit environmental initiative known as the Plastic Cup (PC), which has since become a registered trademark and the official name of the Society. For more



than a decade, the PC has actively collaborated with numerous international partners and participated in river clean-ups throughout the Danube River Basin. Currently, the PC stands out as **one of the most influential and effective river cleanup initiatives in the Danube River Basin**, due to its impressive results, large number of participants and substantial outputs. This initiative goes beyond the simple act of cleaning. By emphasizing monitoring, education, and recycling, the PC addresses different aspects of river litter and tailors its approach to each phase. These collective efforts have resulted in **removing over 300 tons of litter and recycling 200 tons of litter**, mostly plastics. While these activities have been successful in raising awareness and engaging local stakeholders, the ultimate solution lies in the prevention of waste entering the river in the first place. This requires the implementation of preventative measures and proper waste management systems. For this reason, the Plastic Cup has taken proactive measures in the upstream countries, in particular in the Ukraine. Along the Latorica and Uzh rivers, the initiative has established collaborative partnerships with local environmental activists and waste management companies. Together, they have effectively **diverted more than 700 tons of household waste from the rivers**. This concerted effort not only mitigates environmental damage, but also reduces plastic pollution in the Bodrog River. As part of DALIA, we intend to use this expertise to tackle litter accumulation in coastal and floating rivers through prevention, mitigation and education.



Figure 63: Plastic Cup actions are based on three pillars: Research, River Cleanup Actions, and Environmental Education. Graphic by: Emese Silimon, Plastic Cups.

Research

From our perspective, restoration activities include the extensive **pollution mapping activities** conducted to date and those planned for the pilot implementation phase. We firmly believe that any habitat restoration effort must begin with a rigorous and meticulous data collection process. We have been pioneers in this regard. In recent years, Plastic Cup has become increasingly involved in research activities related to plastic pollution in rivers. In the Bodrog area, three interrelated developments related to research and monitoring have played and will continue to play an important role. They are described below.

As its first development, Plastic Cup began the creation of an **online river pollution map** to monitor the largest accumulations of litter in the rivers and to determine the extent of plastic pollution in the floodplains and along the banks. The goal of this monitoring was to gain a better understanding of the extent of river litter and identify opportunities for further prevention and cleanup efforts. In more than 5 years, volunteers from 5 countries recorded and registered 3216 accumulations of litter along the banks of the Tisza River after covering 4500 km on foot. The most polluted waterway in the TRB was the main river Tisza with 2667 polluted sites. The tributary rivers of the Somes and the Bodrog were also strongly affected by transboundary riverine litter pollution. The online pollution map can be found in the beta version at www.tiszatizaterkep.hu. The results of this activity were first reported at the

World's Large Rivers Conference in Vienna in 2023 (A.D.Molnár et al. 2023). In DALIA, this low-cost method will be replicated prior to clean-up efforts in the pilot area.

The second research advancement involves integrating hydrological modeling with **GPS-based tracking** to monitor plastic pollution dispersal during flooding events. In cooperation with the Budapest University of Technology and Economics, we have developed a hydrological model that is tailored to improve our understanding of the dynamics of plastic pollution in the Bodrog River. Our ongoing efforts in this area have yielded partial results, and some of our findings have already been published. The Budapest University of Technology and Economics continues to refine the model. However, in order to ensure the accuracy of the model and to account for factors (such as vegetation) that are not adequately represented, validation by field data and results is essential. In pursuit of this validation, the Plastic Cup Initiative has introduced the GPS bottle - a specially designed technology that is seamlessly integrated into a standard wide-mouth commercial plastic bottle. This innovative system serves as a location tracker equipped with GPS and a cellular communication unit using narrowband IoT network technology. Waterscope Inc. was contracted by the Plastic Cup Initiative to design and build the system's electronics and software. The system transmits forward data, including location, number of GPS satellites in use, and battery voltage, over the cellular network, enabling real-time visualization on a publicly accessible map. The tagged GPS bottle, a collaboration between Plastic Cup and Waterscope Inc., is currently in the testing phase and is not commercially available. Plastic Cup chose to design this tracking technology to fit into a standard plastic bottle to replicate real life conditions. By placing the technology inside an empty plastic bottle, both the material and dimensions closely resemble those of actual items found in the river.

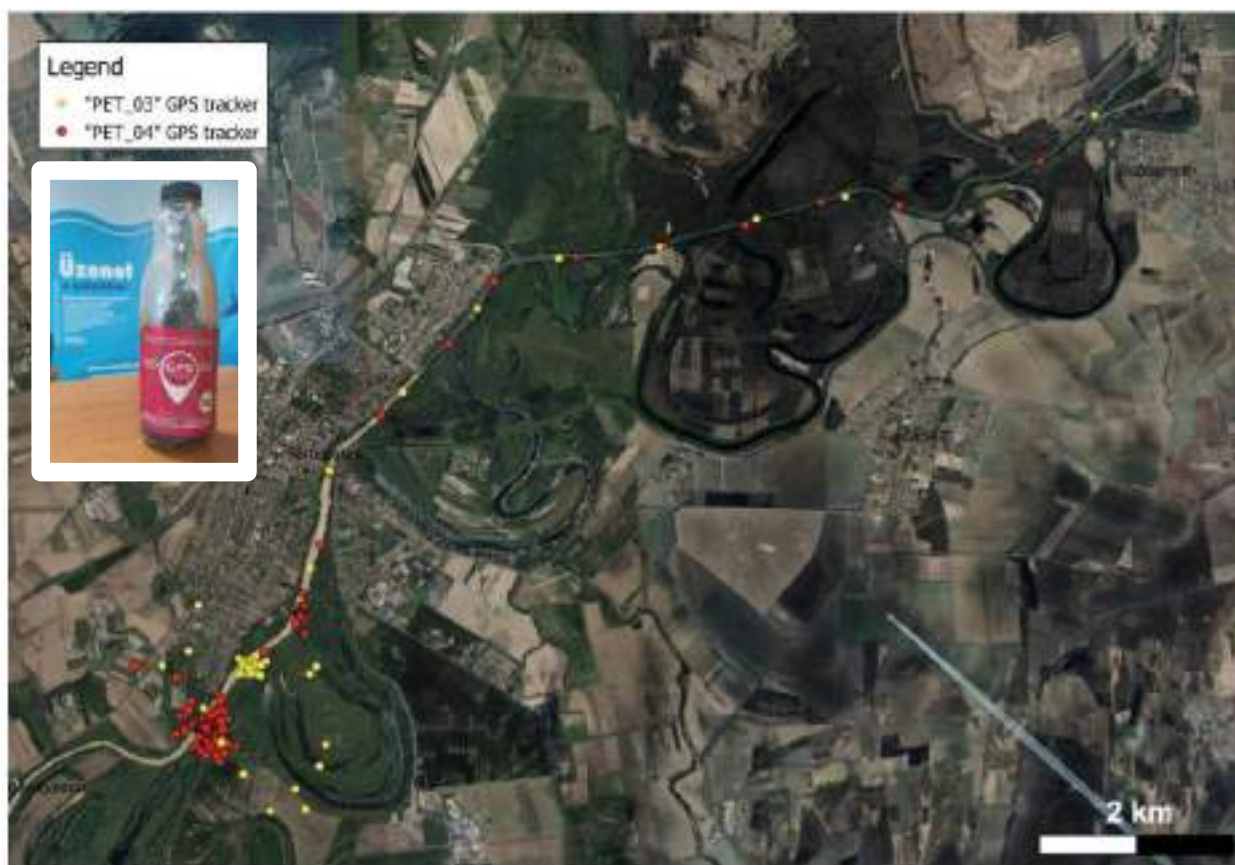


Figure 64: GPS tagging has been developed into a robust and affordable method of monitoring plastic flooding events in real time. Plastic Cup has set additional development goals for the upcoming prototype version to be used



during the DALIA pilot implementation. Further testing will be conducted to provide valuable input to modeling efforts and to improve our understanding of the dynamics of plastic pollution in the Bodrog River, particularly with regard to the formation of floating and coastal litter accumulations.

The third advance in research activities in DPS8 is the use of **remote sensing**. Floating macroplastic accumulations are formed in several stages during the migration of riverine litter from its source to the marine environment. Preliminary PC data show that floating riverine debris accumulations that are NOT covered by vegetation can be detected from the air and from space. Earth observation satellites equipped with medium- and high-resolution multispectral sensors have undergone major technological developments. Remote sensing of floating debris formation has been tested using Sentinel-2 and PLANETSCOPE satellite imagery and machine learning. As part of the research, an automated debris monitoring and change detection evaluator was developed. The program provides a simple and robust solution for configuring areas for continuous monitoring. The application downloads satellite images from the above sources on a daily basis (provided a new image is available for the selected area). It compares the amount of litter covered area with previous images. Further experiments will be conducted in DALIA to provide valuable input for modeling efforts and to improve our understanding of the dynamics of plastic pollution in the Bodrog River. Especially regarding the early detection and warning system related to impending plastic floods. For this purpose, ICPDR has been offered professional assistance from IT experts.

Cleanup actions

The Plastic Cup began over a decade ago with the launch of a plastic bottle boat race on the upper Tisza River. The concept was inspired by prestigious ocean sailing competitions such as the America's Cup. The idea was to use waste as a valuable resource and draw attention to the intrinsic value of our rivers. In these so-called Community River Cleanups (CRCs), teams compete with specially designed boats made of plastic bottles and earn points for the amount of waste they collect. This innovative approach was recognized and even promoted on the UNEP website after its experts participated in one of the races (<https://www.unep.org/news-and-stories/story/worlds-rivers-and-streams-need-more-plastic-cup>). Thanks to active networking and local support, the first Plastic Cup CRC on the Bodrog River took place in 2020 and became an annual tradition held every September. The second CRC, in 2021, developed into a transnational cleanup, starting in Slovakia and moving downstream each day with active waste collection. The fourth CRC, from August 30 to September 3, 2023, was an important platform for the launch of the DALIA project and the development of transferable protocols. This event stretched from Olaszliszka to the Tokaj estuary of the Bodrog River. It set records in terms of the number of participating teams (10 teams with approximately 160 people on the water collecting waste) and the amount of waste collected (11 tons in 3.5 days of cleanup). Notably, in line with Plastic Cup's official partnership with Plastic Pirates in Hungary, a Plastic Pirates sampling initiative was also conducted during the event. In addition, the Euronews crew documented the event: <https://www.euronews.com/green/2023/10/03/cleaning-europes-rivers-meet-the-teams-looking-to-turn-the-plastic-tide>. In the course of four years of multi-day clean-up events, approximately 30 tons of waste were removed from the floodplains of the Bodrog River and sorted and recycled according to Plastic Cup's practice. Experience shows that in addition to Community River Cleanups (CRCs), professional river cleanup efforts can also yield significant results. At DALIA, we are in the process of fine-tuning and then creating the first open-access blueprints for the well-tested Rapid Response River Cleanup Workboat. This will enhance our ability to respond quickly to pollution incidents in river environments.



Figure 65: The Fast Response River Cleanup Workboat in action on the Bodrog River during a winter plastic litter event (left) and a summer community river cleanup event (right). The plans for this boat will be published in an open access paper in DALIA. Photos by Zsolt Tamás and Vanda Molnár, Plastic Cup

The boat concept does not require any additional investment. Instead, DALIA's partner PC will refine the design and produce the open-access blueprints. PC will conduct further testing of the low-cost, high-impact river litter skimmers in cooperation with OVF and its local directorate, ÉMVIZIG. We strongly believe in the significant potential of skimmers, not only within DPS8, but also for wider application in related regions, both for multiplying and replicating. Therefore, we are providing a detailed description of this solution:

The multi-snake-headed Hydra (hereafter referred to as HYDR) is a serpentine water monster of Greek and Roman mythology. Its legendary regenerative abilities inspired the scientific name of the genus Hydra, a unique group of cnidarians with multiple tentacles around their mouths. HYDR's sustainable solution relies entirely on the flow of the river to target floating/submerged debris. Much like members of the Hydra genus, HYDR sucks in its "prey" (collected debris) and delivers it to its "mouth" (collection zone) with its "tentacles" (modular booms). In operation, HYDR causes no additional stress or pollution (noise, fumes, etc.) to the environment (above or below the surface). The solution is based on the use of long, rigid, modular booms. There are 2 versions (surface and submerged) of the HYDR boom. Due to their lightweight design, surface HYDR booms have a maximum draft of 5 cm. Unlike traditional containment booms that have a deeper draft to contain waste and/or oil, the HYDR boom skims the surface of the water, not to contain the pollution, but to create a series of vortices on the downstream side of the boom. Upon contact with the HYDR, large particles of organic debris (driftwood) are slightly deflected by the rigid structure, but the current pushes them onward. For smaller and lighter debris (inorganic waste, synthetic, anthropogenic pollution), the changed flow conditions at the water's surface have a significant impact on how they move after contacting the boom. The suction created by the series of eddies diverts the floating debris towards the collection zone for gathering. The angle between the boom and the main flow direction, as well as the velocity of the current, determine the strength and direction of the suction force generated. The solution is adaptable as it can be mounted either on a workboat or on the river bank. The implementation of the Hydra Riverine Litter Skimmer solution, called HYDR, offers several advantages. First, it does not require significant infrastructure changes, shoreline alterations, or the construction of permanent coastal facilities. HYDR works as a passive waste filtration system, using the natural power of the river current to filter and skim debris from the water's surface. Unlike other methods, HYDR does not rely on machinery or built-in propulsion systems. The basic components of HYDR consist of rigid, semi-submerged booms that can be easily linked together as needed. These modular units form an extended arm that reaches the main flow of the river



surface. Research shows that the majority of floating debris is transported within the main stream. This allows HYDR to effectively address the problem without requiring a complete closure of the riverbed. Guidelines for the use of HYDR depend on whether it is being used in a waterway or in a work zone supervised by hydraulic engineers. In both cases, safety measures such as light and colored signs must be implemented. Separate permits are only required if the water quality intervention affects a navigation channel. In such cases, licenses from the shipping authority must be obtained in addition to the operator's license for the specific water area (water authority). Since HYDR is used periodically, the permits only need to be valid for the duration of the waste flow. With regard to personal safety, after a short training session, personnel must comply with the rules and regulations for working on water (e.g. mandatory safety equipment). The application of HYDR does not require continuous supervision, the collected river litter can be treated within a period of 24-48 hours, depending on the level of pollution and the intensity of the plastic flood.

In summary, the list of economic sectors and industries affected by marine litter includes: agriculture, aquaculture, fisheries, commercial shipping and recreational boating, coastal communities, coastal tourism, and emergency rescue services. Water authorities and water engineering companies (e.g. hydroelectric power generation) are also adversely affected in the case of river litter. In general, those who benefit from the implementation of river restoration measures are the riparian communities along the lower reaches of the waterways concerned, the wildlife of the river and its floodplains, and the affected industries. In particular, the use of sustainable river cleaning solutions, such as the HYDRA River Debris Skimmer, is especially beneficial to the operators of artificial water engineering structures (hydropower plants, dams). It makes the separation, collection and recycling/depositing of river debris cost-effective and environmentally friendly.

Environmental education

Within the context of DALIA DPS8, environmental education has a distinct place, allowing Associate Regions the flexibility to replicate and adapt practices according to their unique needs. They can choose from a wide range of options tailored to their specific needs, capabilities and conditions. DALIA partner Plastic Cup (PC) has consistently focused its awareness activities on the unifying theme of “**RiverSaver**”. Educational materials have been developed to engage both students and teachers in the process of becoming a RiverSaver. In essence, a RiverSaver is an individual who has a fundamental understanding of the interrelationship between human actions and rivers, and how rivers, in turn, shape our way of life. As part of the 5 Countries 1 River Erasmus+ project, a comprehensive guide detailing the journey to becoming a RiverSaver is currently being published. This guide will soon be available in all Tisza languages as well as in English, facilitating wider access to this valuable resource.

The **River Litter Lab** is a mobile co-working and workshop space designed to resemble a pirate ship, both inside and out. Upon boarding, visitors are greeted by experienced plastic pirates who guide them through an immersive experience. Here, visitors learn about the origins, formation and composition of river litter. They gain hands-on knowledge of how to sort and bring new life to these materials. Visitors engage in activities such as grinding, melting, and molding, using recycled plastics to create fresh, useful objects. They learn effortlessly while having a great time. The River Litter Lab ensures that no one leaves empty-handed. Each child leaves with tangible memories and a wealth of knowledge. This knowledge not only empowers individuals to contribute to river cleanups, but also equips them to effectively manage household waste. As part of the 5in1 project, educational materials have been developed to guide RiverSavers in the creative selection, reuse and recycling of both household and river plastics. DALIA partner PC also has a floating exhibition called FLEX. It does exactly the same work as the River Litter Lab, but travels around the region on the river.



Figure 66: The river Litter Lab on the banks of the Bodrog River in the historic town of Sárospatak. Photo by: Alíz Bódiszné Hajnal

As described above, educational program participants can gain first-hand experience in co-working spaces when it comes to river litter and creative recycling. However, to really get the full picture, a visit to a **RiverSaver Center** is highly recommended. The first operational center, established by DALIA partner PC, is located in Kisköre, developed in close cooperation with the local OVF directorate, KÖTIVIZIG. Within the framework of DPS8, another RiverSaver Center is currently under construction in the project area, specifically in Olaszliszka. Here, visitors will have the opportunity not only to observe, but also to actively engage with a range of RiverSaver innovations, including a pontoon, a fleet of kayaks, canoes and various other water-related items made from recycled river debris. To fully appreciate these innovations, participants in educational programs gain insight into the meticulous processes of collecting, sorting and recycling river debris. By examining selected samples, they see firsthand how environmental waste can be transformed into a circular raw material and ultimately a finished product.





Figure 67: Volunteers empty the flagship of trash bags after a successful community river cleanup at the Kisköre RiverSaver Center. The facility, run jointly by Plastic Cup and the local OVF branch in KÖTIVIZIG, has inspired the establishment of other centers in the Tisza River Basin. Photo by: Attila D. Molnár, Plastic Cup

The full understanding of the **RiverSaver concept** is realized when all facets of the educational program are visualized on an online platform. In the "Research" section of this paper, we have already discussed the benefits of the online river pollution map and how it can serve as a valuable tool for research and cleanup efforts. However, the online map also has unique potential from an environmental education perspective. The map will provide opportunities to engage various stakeholders, including water authorities, conservation experts, NGOs, schools, etc., within these activities. The availability of multilingual and easily accessible protocols will facilitate the participation of third parties in becoming part of the solution to combat plastic pollution in our rivers. Schools can access educational materials and explore extracurricular activities such as **river adoption**. Restaurants and buffets can learn about the requirements and conditions to establish venues that can be recognized as **RiverSaver restaurants**. NGOs, local communities and fishermen can access vital information about plastic pollution and even initiate their own community river clean-ups. Water authorities and water engineering experts can access real-time information and forecasts to help them prepare for potential plastic flooding. Throughout the implementation of the DALIA pilot, our goal is to further strengthen our awareness efforts in the region and develop transferable protocols. These protocols will focus on involving local stakeholders in the process of cleaning and preserving our rivers, rather than just raising awareness. To achieve this, Plastic Cup has been working on the **RiverSaver toolkit**, which is designed to instill a sense of responsibility for the local environment among people living along the rivers. These protocols will be developed and refined during the pilot implementation and then promoted for knowledge transfer.

2.8.4. Impact of the measures on the environment

The socio-economic importance of rivers is undeniable. For a millennia, we have relied on them as sources of water and food, for irrigation, for recreation, and more recently for hydropower generation, among many other uses. As a result, quantifying the true costs of the increasing amounts of improperly managed domestic and industrial waste in natural waters is a complex task. River litter has a profound impact on various industries such as fishing, shipping and tourism, resulting in economic losses often referred to as financial costs. The direct economic costs of cleaning up European beaches alone are staggering. According to a 2010 study, the annual cost of cleaning each kilometer of coastline in the UK averaged between €7,000 and €7,300. To mitigate the negative effects of marine debris, the EU spends €630 million annually on beach cleanup. Other costs include the degradation of ecosystems, the decline of species and habitats, and the resulting loss of environmental values and ecosystem services. The range of economic sectors and industries affected by marine litter includes agriculture, aquaculture, fisheries, commercial shipping, recreational boating, coastal communities, coastal tourism, and emergency response services. In the case of river litter, water authorities and hydraulic engineering companies, such as those involved in hydropower generation, are also

adversely affected. In general, the beneficiaries of river restoration initiatives include downstream communities along the affected waterways, wildlife in the river and its floodplains, and industries affected by the problem. The ecological services provided by rivers are affected in many ways by transboundary river pollution. The effects of marine debris on biota have been scientifically studied for decades, while the same relationships between riverine debris and wildlife have not been fully documented. However, we have reliable data and reports that show that the accumulation of litter in rivers has a negative impact on the lives of native species in the area. Plastic pollution causes all kinds of damage to the environment. The list includes ingestion, entanglement, aesthetic/visual pollution (shiny bottles disturb some birds), noise pollution (plastic bottles break in their thousands depending on daily temperature changes, plastic in the undergrowth makes stalking predators difficult if not impossible), and degradation (abrasion, photodegradation), which leads to the formation of secondary microplastics and special additives that pollute the lower trophic levels in freshwater habitats.

Through our previous river cleanup initiatives in the Bodrog River Basin, we have already seen remarkable improvements in habitat conditions in over **tens of hectares**. The total amount of plastic and other forms of river debris removed exceeds **25 tons**. Local communities, municipalities, and schools have actively participated in the cleanup efforts, demonstrating such remarkable effectiveness, that if not for the war in Ukraine, much of the floodplain would likely be free of plastic pollution by now. Preliminary results suggest that by focusing on monitoring, cleanup, and environmental education, we can significantly improve the water quality of the Bodrog River. This, in turn, would lead to an improvement in the conditions of the natural habitats, while raising awareness and addressing the root causes of the environmental problem. To achieve this goal, we propose to involve upstream regions, especially those that contribute to pollution, as demonstration sites. In this way, we can implement and refine best practices and ultimately reduce or prevent future plastic floods. Our ambition extends to replicating these activities in upstream regions of Ukraine, where these initiatives can serve as candidates for demonstration sites, allowing for adaptable activities. By initiating research, cleanup and education efforts in these regions, we expect to achieve impressive results in reducing plastic pollution and improving overall environmental quality.

Preventive measures are taken by THU in upstream countries, especially in Ukraine. Along the Latorica and Uzh rivers, we have expanded cooperation with local environmental activists and waste management companies. Together we have successfully diverted **more than 700 tons of household waste from the rivers**. The Russian invasion of Ukraine has jeopardized these efforts to some extent.

2.8.5. Summary and recommendations

On March 2, 2022, a landmark resolution was adopted by representatives of 175 nations at the UN Environment Assembly in Nairobi. The resolution established an Intergovernmental Negotiating Committee (INC)¹¹ to finalize a legally binding agreement to end plastic pollution by the end of 2024. This agreement will address the entire life cycle of plastics, including the design of reusable and recyclable products and materials, and the need for enhanced international cooperation. At the EU level, the European Green Deal, the Zero Pollution Action Plan, aims to protect European citizens and ecosystems from various forms of water pollution. The EU must improve its prevention, monitoring and reporting practices, as well as restoration efforts for contaminated natural habitats. Recognizing the fact that the EU must invest directly in sustainable projects and activities, a common language and clear definition of what constitutes " sustainable " in practice are needed.



The EU Taxonomy was developed to create a level playing field for stakeholders and to provide a classification system for environmentally sustainable activities. The Commission has established lists of environmentally sustainable activities by defining technical screening criteria for each environmental objective through " delegated acts. " The Taxonomy can play a crucial role in redirecting investment towards sustainability and help implement the European Green Deal. Current and future directives that support these efforts include the Corporate Social Responsibility Directive, the Waste Framework Directive, the European Plastics Strategy and the Single Use Plastics Directive, the Water Framework Directive and the Plastic Bags Directive. It is an urgent matter for all EU countries to implement the listed directives and regulations. Recognizing the difficulties in implementing the directives and the magnitude of the societal and environmental pressures, the European Economic and Social Committee (EESC) has started to develop a legal framework for the protection and management of our freshwater and marine resources. The **Blue Deal** is a comprehensive approach to European water policy, and the EESC will adopt a series of own-initiative opinions addressing the issue from a sectoral perspective and making concrete proposals. Ahead of the Blue Deal, however, there is a comprehensive recommendation paper prepared by DALIA partner THU at the request of the International Commission for the Protection of the Danube River (ICPDR). The document, entitled *Policy Guidance on Managing Transnational Riverine Litter Pollution*, deals with micro and macro plastic pollution in great detail and includes a list of recommendations as well as top 10 findings. The Policy Guidance will soon be published in paper form in the ICPDR and DALIA partner THU (Plastic Cup Society) edition.

2.9. DPS 9

Authors: Ioan-Alexandru Morgovan, Laura-Linda Iuhasz & Simona-Gabriela Andrişca

Location: "Crişuri" River Basin, Romania

Short form of the organization: The Crisuri Water Basin Administration (CWBA - DPS 9) proposed to implement three intervention sections at the hydrographic basin scale for waste management and watercourse cleaning through the installation of three litter traps. The aim is to reduce pollution with PET's (floating plastic bottles or similar) in the transboundary zone on three main watercourses. The three main watercourses are the Barcău River with a length of 134 km, the Crişul Repede River with a length of 71 km and the Crişul Negru River with a length of 164 km.

2.9.1. General Overview

The Crisuri Water Basin Administration (DPS 9) proposed to implement some intervention sections at the basin scale for waste management and watercourse cleaning through the installation of three litter traps. The aim is to reduce pollution from PET (floating plastic bottles or similar) in the transboundary zone on three main watercourses. The three main watercourses are the Barcău River with a length of 134 km, the Crişul Repede River with a length of 71 km and the Crişul Negru River with a length of 164 km.

They are all 1st and 2nd order tributaries of the Hármas Körös, which in turn is a tributary of the Tisza.

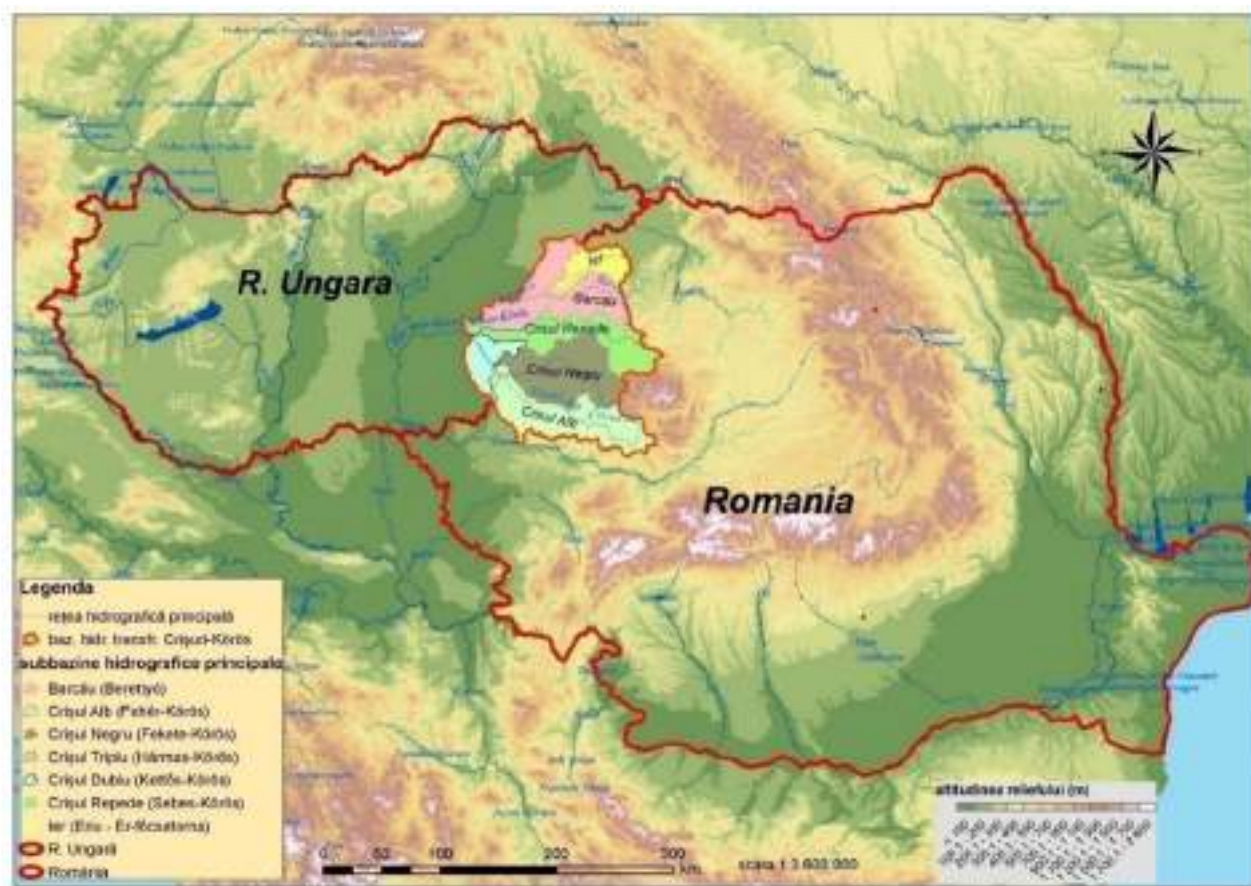


Figure 68: Crişuri Catchment Area related to Tisa, tributary to Danube



Figure 69: Proposed litter trap placements in Crișuri Catchment Area (DPS 9)

All three rivers covered by this DPS intersect **Natura2000 sites** (<https://natura2000.eea.europa.eu/>) along their course, but for the purposes of our work in Dalia, we'll only mention those that fall within our 'zone of interest'.

The location of the **Barcău river litter trap** doesn't overlap with any Natura 2000 sites, as it is located 3.5 km upstream of **ROSPA0067 Lunca Barcăului - Barcău's meadow** (protected under the Birds Directive).

On the other hand, the **Crișul Repede river litter trap** overlaps with 2 Natura2000 sites, the **ROSCI0104 Lunca Inferioară a Crișului Repede - Crișul Repede's inferior Meadow** (protected under the Habitats Directive) and **ROSPA0103 Valea Alceului - Alceu's Valley** (protected under the Birds Directive).

Lastly, the **Crișul Negru river litter trap** is located within the Natura2000 site **ROSCI0049 Crișul Negru** (protected under the Habitats Directive).

2.9.2. History of transformations

In recent years there has been a significant increase in urban waste pollution in the riverbeds, with the biggest problem being floating PET bottles, which are picked up and transported with other waste by the tidal waves, especially in spring and autumn.

Over the last two decades, the fact that many products are packed and made of plastic has meant that after use they end up as waste and are not properly disposed of. Public negligence and poor enforcement of laws also contribute to this problem. This is despite the fact that dumping and disposal of waste is only allowed in designated areas.

At present, the results of water pollution control measures have limited effectiveness due to deficiencies in waste management with diffuse domestic sources and insufficient collective mentality, especially in rural areas. As a result, in spring and autumn, when water levels rise sharply, waste is discharged into the hydrographic network via various routes.

It becomes necessary to remove the waste, otherwise fauna, flora and even human health may be affected. There are no studies on this subject in our region.

In addition, Romania must subscribe to the framework of obligations and responsibilities assumed in the RO-HU bilateral relations regarding water management - Bilateral Agreement between the Government of Romania and the Government of the Republic of Hungary regarding cooperation for the protection and sustainable use of border waters - Budapest 2003.

Last but not least, as a European country, we have to apply the **Water Framework Directive (Directive 2000/60/EC - WFD)**, which is the fundamental European directive in the field of water. It promotes the concept of river basin management and provides a framework for the protection of water bodies. The main objectives are to prevent deterioration, maintain and improve the status of aquatic ecosystems, promote the long-term sustainable use of water resources and ensure the progressive reduction and prevention of groundwater pollution.

2.9.3. Planned measures

The task in the area is to reduce floating pollution by installing three litter traps for efficient recovery of plastics from the Barcau, Crisul Repede and Crisul Negru watercourses in the transboundary sector. In addition, the development



of decision-making tools for the sustainable management of aquatic ecosystems will be discussed by transboundary stakeholders and local actors (Grant Agreement).

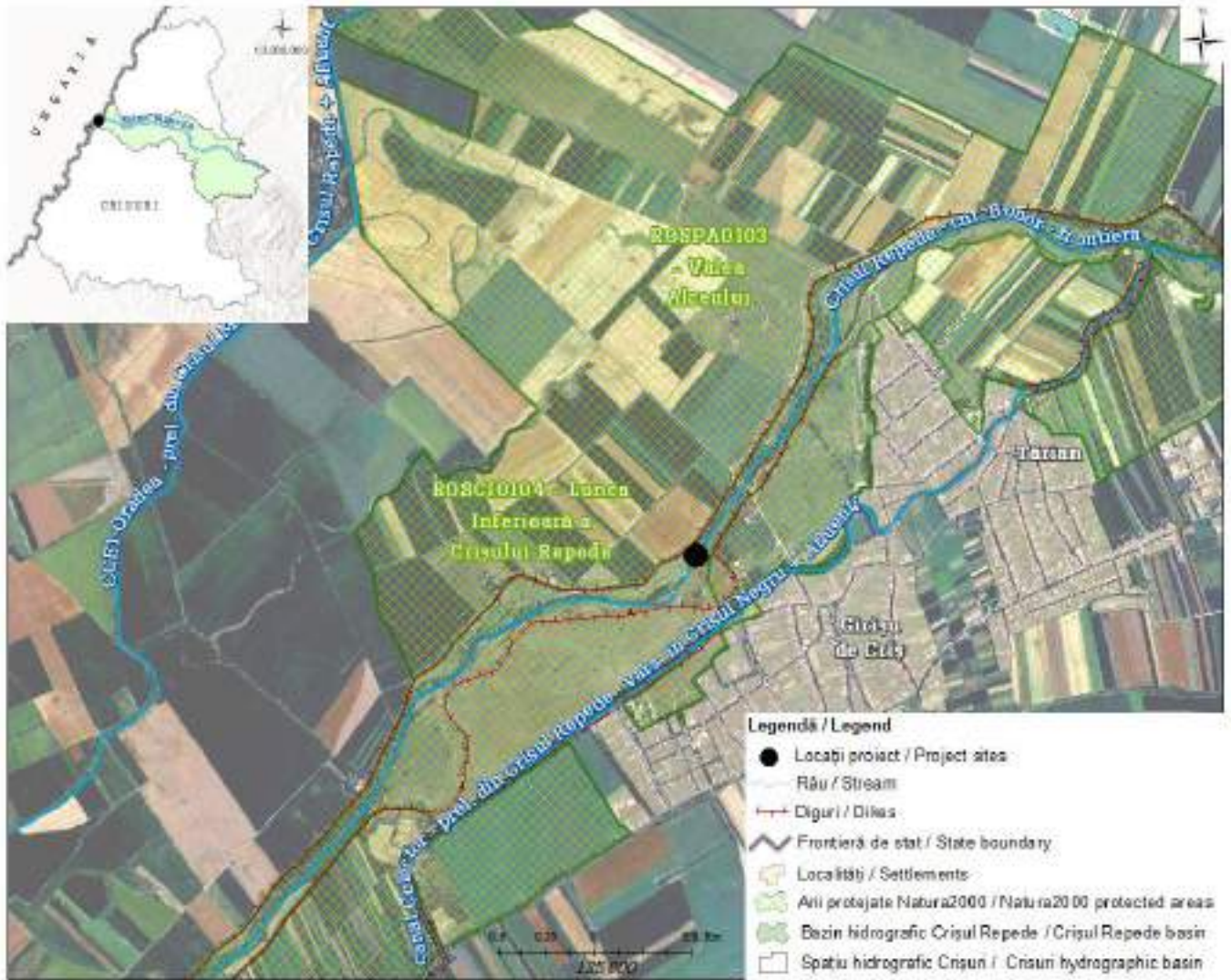


Figure 70: Detailed map of the proposed placement area of Crișul Repede river litter trap

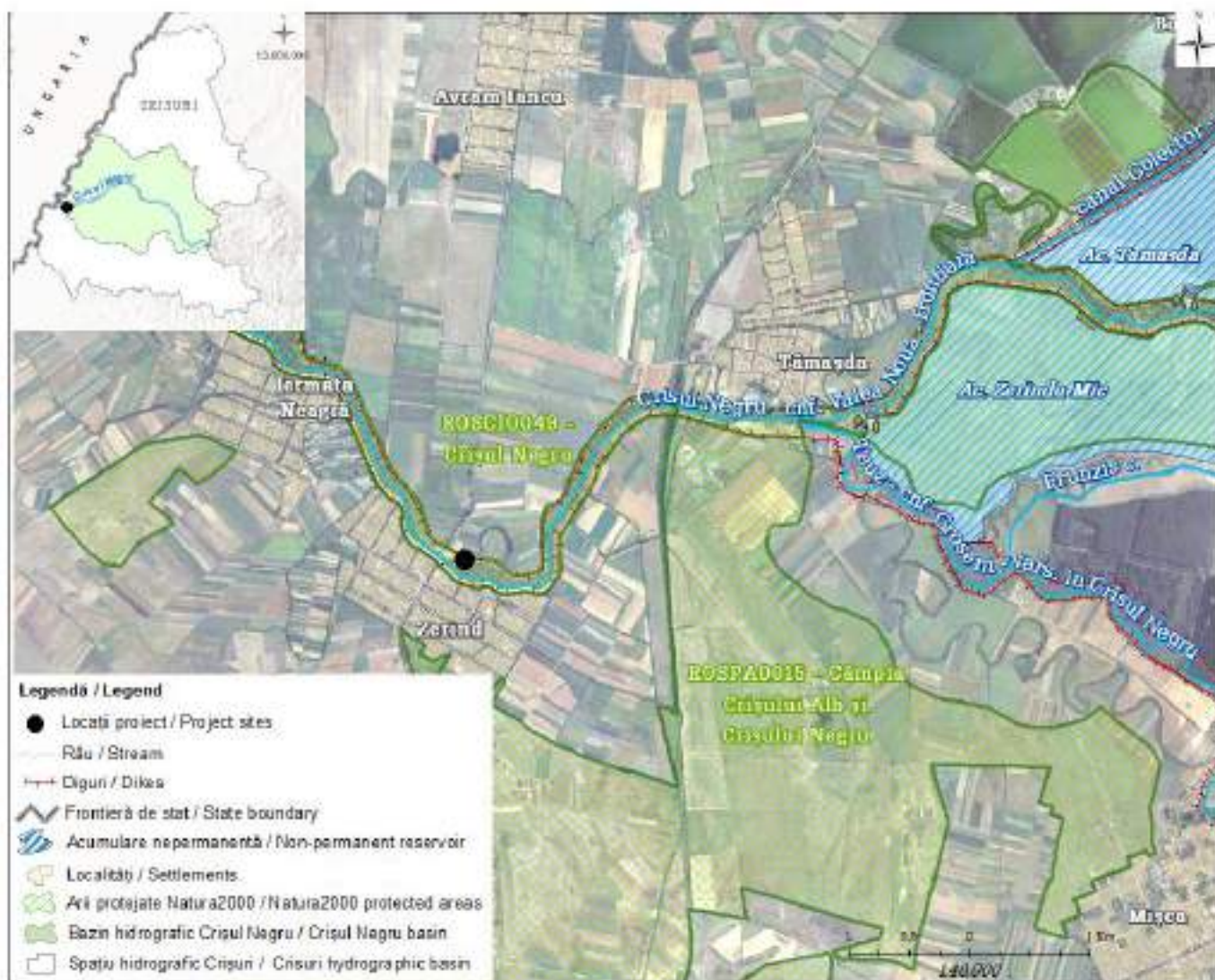


Figure 71: Detailed map of the proposed placement area of Crişul Negru river litter trap

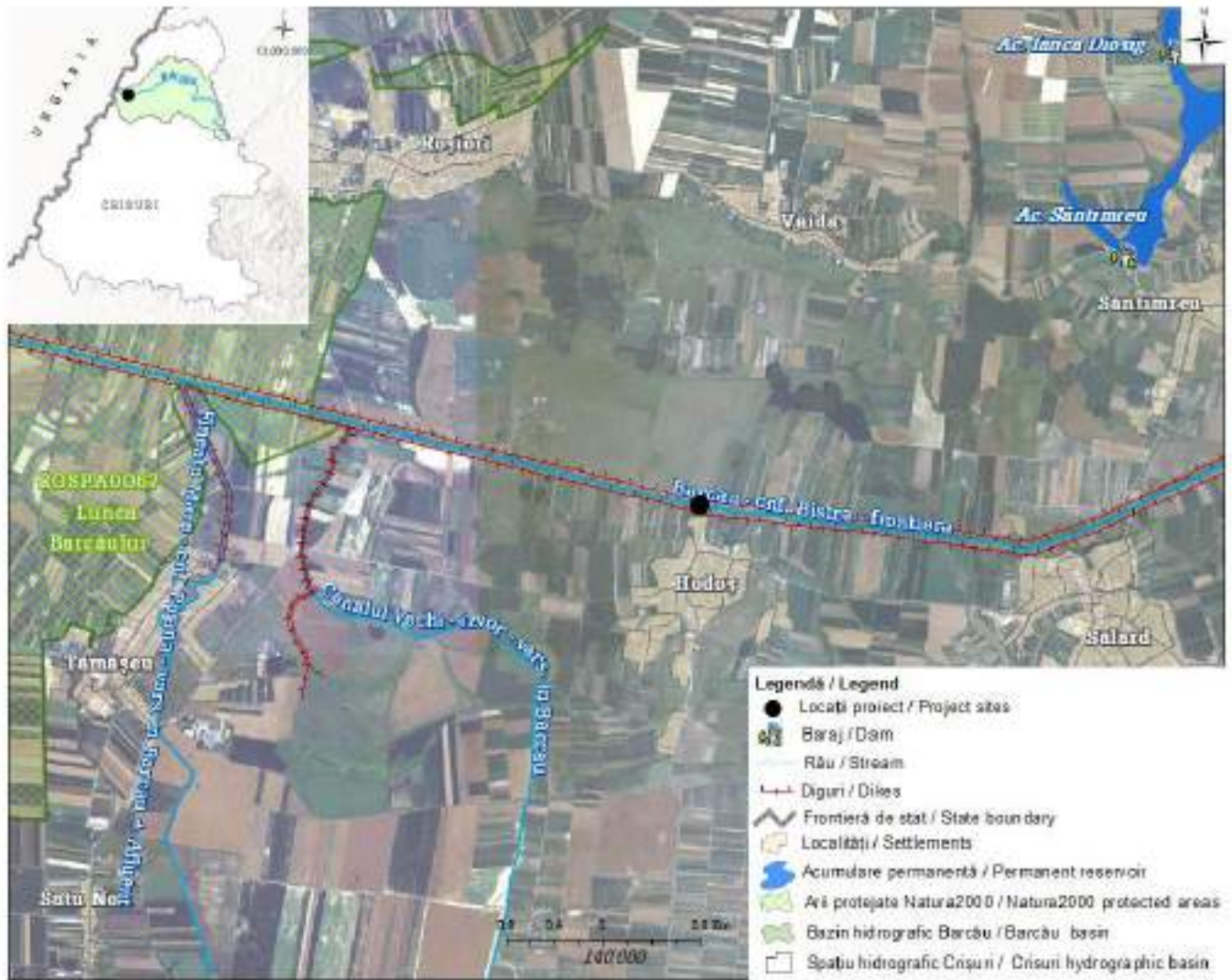
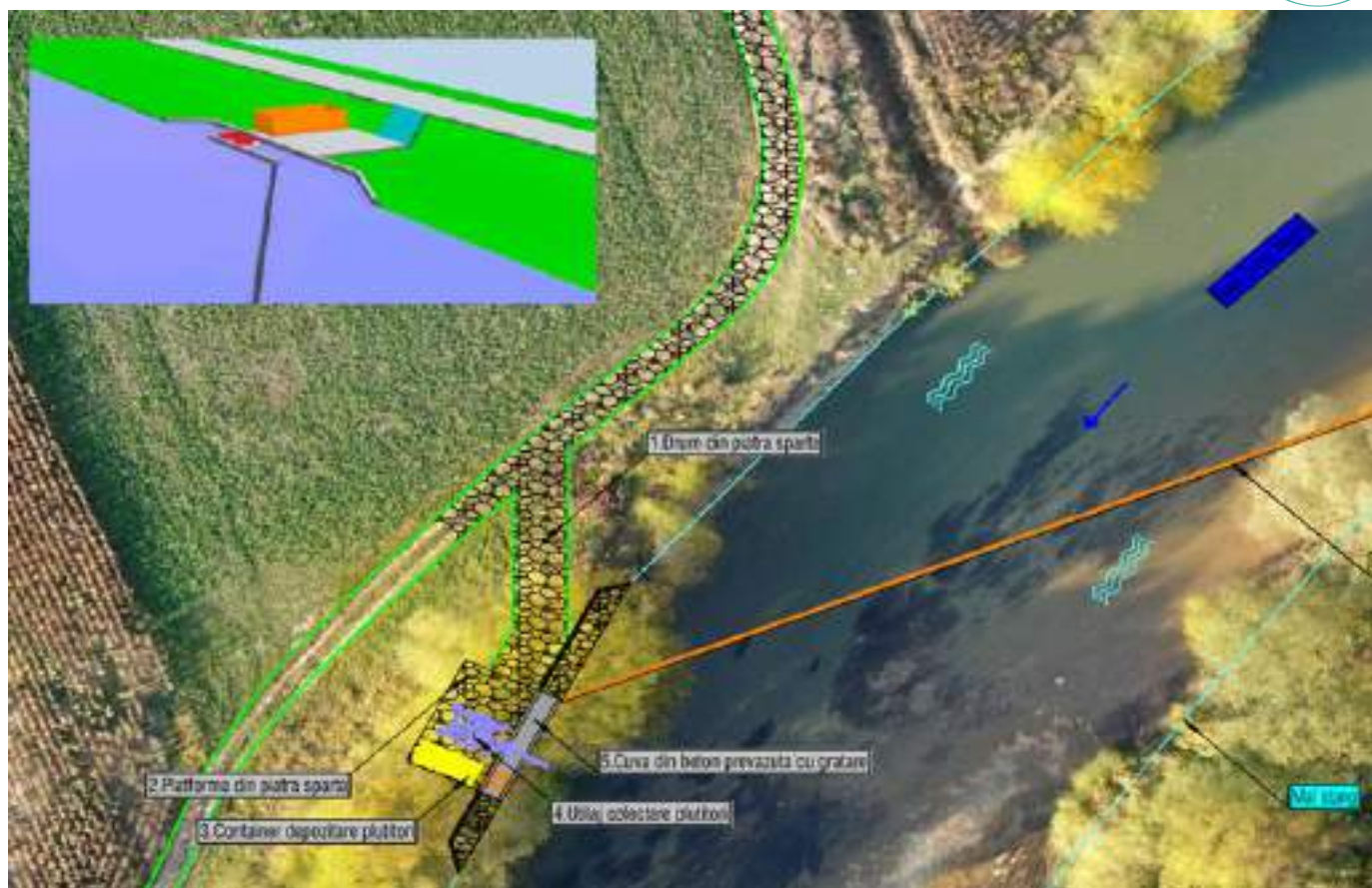


Figure 72: Detailed map of the proposed placement area of Barcău river litter trap



The principle of a litter trap is relatively simple. Strain the water and the litter remains. While the principle is simple, there are several variables that add to the complexity. Is it possible if the riverbed is too narrow and shallow, or if it's too wide? Is the amount of water, and therefore the water level, always the same, or can the flow sometimes be too high? Can the device be emptied? These questions require an analysis of the required functions of the screen. Once the functions are known, the trap can be designed.

In our case, the technical solution consisted of several elements. The first was to build an access road to the platform where the debris would be collected. The next step was to install the litter trap system, which is a passive method of collecting floating debris. It is anchored using metal piles which are hammered into the ground using a special machine. Buoys are used to guide the floats, which then land in a container in the litter trap, and finally the container is lifted by crane and emptied into a transport vehicle.

The estimated cost per site is 100,000 euros. There's no guarantee that all the rubbish will be collected in advance and won't sink, but it will definitely have an impact. That's why there are clean-up campaigns every year.





Figure 73: Proposed litter trap system

2.9.4. Impact of the measures on the environment

Information is not available currently due to the fact that the litter traps aren't placed at this moment.

We expect the impact of the measures on the environment in the border region with Hungary to be positive, but at this stage we cannot say by how much, as all the sites proposed in this current project are currently before the construction/implementation phase. Nevertheless, it is expected to reduce the amount of litter in the waterways, both in Romania and in downstream areas within Hungary.

2.9.5. Summary and recommendations

As a closure, litter traps are considered a cost-effective and passive way to remove floating debris from rivers around the world. They don't require large numbers of people to maintain them, they use no energy during their lifetime and they can be dismantled and moved to another area if necessary.

Before considering the implementation of a litter trap, a few **recommendations** should be taken into account. Firstly, the site should be chosen in the sub-catchment of a main watercourse, so that the water velocity is slow and a higher amount of waste can be transported from a large area. Secondly, an area with little or no vegetation should be chosen upstream of the site. The site should also be easily accessible for hourly, daily or weekly operations and easily accessible for transport vehicles.

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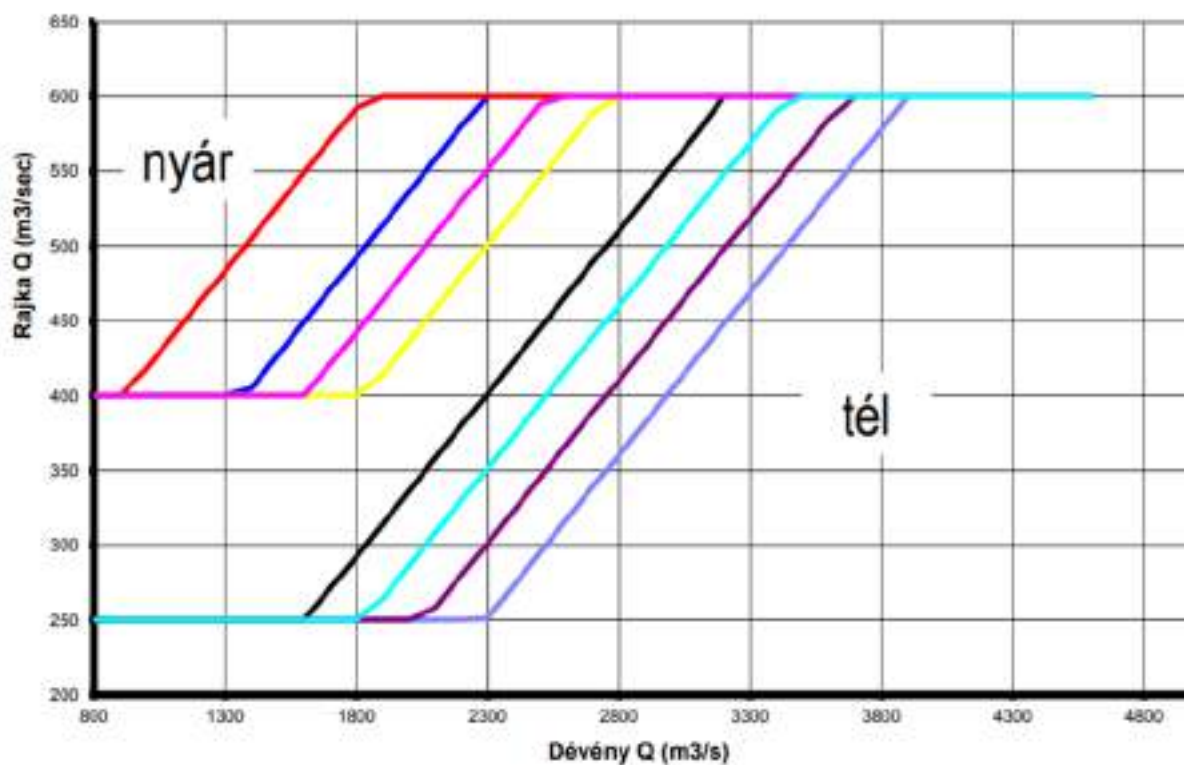
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4. ANNEX

ANNEX NO 1.

D.1.1 – Detailed Analysis of Demonstrators Ecosystems

Dynamic control of the system



ANNEX NO 2.

Main parameters of fish-passes built in the Szigetköz area:

Three different types of fish passages, or a combination of those were built in the area (Pannonhalmi Miklós – Halátjárók (2018)):

1.) Fish ladder

2.) Nature-like fish passage

3.) Fish ramp



Table 9:

Dunakiliti submerged weir – fish ramp

| | | | |
|-----------------------|---------------------------------------|--|------------|
| Watercourse | Old Danube | Constructor: | ÉDUVÍZ Kft |
| Location | Dunakiliti, Old Danube 1843+00 rkm | Difference in water level (Δh)(m) | 3,5 |
| Year of construction | 1995 | Discharge (m ³ /s) | 1,2 (0,6) |
| WFD water course type | 9F | Length (m) | 60 |
| WFD fish species | Danube | Slope (‰) | 58 |
| Fish-pass type | Fish ramp | Costs: | 1 113 000€ |
| Material | rip-rip, gravel | Cost/length (€/m) | 18 550 |
| Design | Observator Kft. | Cost/ Δh (€/m) | 318 000 |



Table 10:

Mosoni-Danube – Homoki fishpass:

| | | | |
|-------------|-------------------------------------|--|---------------|
| Watercourse | Mosoni Danube | Constructor: | DD konzorcium |
| Location | Rajka, Mosoni-Danube 122+539 rkm | Difference in water level (Δh)(m) | 2,7 |

| | | | |
|-----------------------|----------------------|-------------------------------|----------|
| Year of construction | 2015 | Discharge (m ³ /s) | 3,2-2,2 |
| WFD water course type | 9F | Length (m) | 4360 |
| WFD fish species | Danube | Slope (‰) | 0,62 |
| Fish-pass type | nature like fishpass | Costs: | 206 000€ |
| Material | riprap | Cost/length (€/m) | 47 |
| Design | SOLVEX kft | Cost/ Δ h (€/m) | 76 300 |



Table 11:

Active floodplain – Denkpál fishpass:

| | | | |
|-----------------------|--|---|------------|
| Watercourse | Barkási- Danube (active floodplain branch) | Constructor: | ÉDUVÍZ Kft |
| Location | Dunasziget, Barkási-Danube 3+280 | Difference in water level (Δh)(m) | 3,80 |
| Year of construction | 1997 | Discharge (m ³ /s) | 1,2 (0,6) |
| WFD water course type | 9F | Length (m) | 271 |
| WFD fish species | Danube | Slope (‰) | 14 |
| Fish-pass type | fish ladder + nature-like fishpass | Costs: | 597 000 € |
| Material | riprap, reinforced concrete, steel | Cost/length (€/m) | 2 200 |
| Design | AWE Consulting Kft | Cost/ Δh (€/m) | 157 000 |



Table 12:

Active floodplain - Ásványi fishpass:

| | | | |
|-------------|------------------------------------|--------------|------------------------|
| Watercourse | Ásványi-branch (active floodplain) | Constructor: | SzKK Vízép. konzorcium |
|-------------|------------------------------------|--------------|------------------------|

| | | | |
|-----------------------|---------------------------------------|--|------------|
| Location | Ásványráró, Ásványi-branch 0+464 | Difference in water level (Δh)(m) | 2,4 (2,9) |
| Year of construction | 2015 | Discharge (m ³ /s) | 1,5 (0,65) |
| WFD water course type | 9F | Length (m) | 70 |
| WFD fish species | Danube | Slope (‰) | 34,2 |
| Fish-pass type | nature-like fish-pass | Costs: | 1355 000€ |
| Material | riprap, concrete, reinforced concrete | Cost/length (€/m) | 19 400 |
| Design | K+K Kft. | Cost/ Δh (€/m) | 542 000 |



Table 13:

Active floodplain – Bagaméri fishpass:

| | | | |
|-----------------------|-----------------------------------|---|------------------------|
| Watercourse | Bagaméri -branch | Constructor: | SzKK Vízép. konzorcium |
| Location | Győrzámoly, Bagaméri-branch 0+464 | Difference in water level (Δh)(m) | 3,35 (2,0) |
| Year of construction | 2015 | Discharge (m ³ /s) | 2,3 (0,5) |
| WFD water course type | 9F | Length (m) | 79 |
| WFD fish species | Danube | Slope (‰) | 42,5 |
| Fish-pass type | nature-like fish pass | Costs: | 1 513 000 € |
| Material | riprap, concrete | Cost/length (€/m) | 19 150 |
| Design | K+K Kft. | Cost/ Δh (€/m) | 452 000 |



Table 14:

Mosoni-Danube - Mosonmagyaróvári Barrage fishpass:

| | | | |
|-------------|---------------|--------------|---------------|
| Watercourse | Mosoni-Danube | Constructor: | DD konzorcium |
|-------------|---------------|--------------|---------------|

| | | | |
|-----------------------|--|--|-----------|
| Location | Mosonmagyaróvár, Mosoni-Danube 85+934 | Difference in water level (Δh)(m) | 1,7 |
| Year of construction | 2015 | Discharge (m ³ /s) | 1,5 |
| WFD water course type | 9F | Length (m) | 1132 |
| WFD fish species | Danube | Slope (‰) | 1,5 |
| Fish-pass type | nature-like fish pass, fishramp | Costs: | 458 000 € |
| Material | riprap | Cost/length (€/m) | 405 |
| Design | SOLVEX Kft | Cost/ Δh (€/m) | 269 500 |

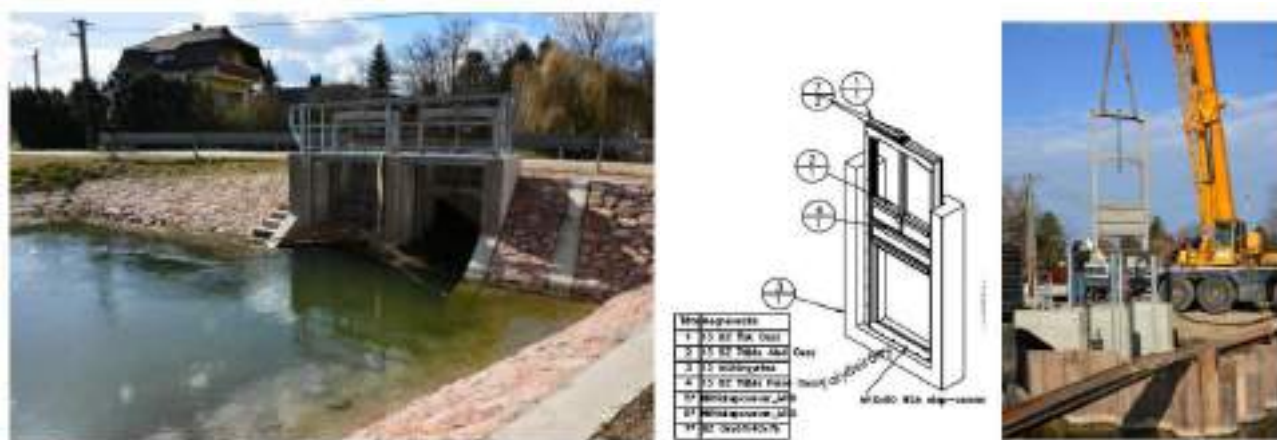


Some fishpasses were built between the historic floodplain system and the Mosoni-Danube as well:



Underpass sluice on historic floodplain

There are about 100 sluices in the historical floodplain. During the 2014-2015 project expanding the water replenishment systems, more than half of those were equipped with a double gate. The advantage of the double gate is that the two gates can be operated separately to allow both overflow and underflow. Thus the precise controlling of the system is ensured while aquatic fauna can migrate as well.



ANNEX NO 3.

WFD status

According to the River Basin Management Plans there are 6 different river water bodies in the Szigetköz area. Five of those are considered to be heavily modified water-bodies mainly due to hydromorphological alterations which caused ecological changes in the system. The quality status of the water bodies throughout the 3 RBMP cycles can be seen in the following table:

| WATER BODY | TYPE | RBMP-1 (2010) | | | | RBMP-2 (2015) | | | | RBMP-3 (2021) | | | |
|---|---------|---------------|----------|--------------|--------------|---------------|----------|--------------|--------------|---------------|--------------|--------------|--------------|
| | | Hydromorph | Chemical | Biological | OVERALL | Hydromorph | Chemical | Biological | OVERALL | Hydromorph | Chemical | Biological | OVERALL |
| Danube at Szigetköz (Old Danube) | HMWB | Moderate (3) | Good (2) | Moderate (3) | Moderate (3) | Moderate (3) | Good (2) | Moderate (3) | Moderate (3) | Good (2) | Good (2) | Moderate (3) | Moderate (3) |
| Active Floodplain Water Replenishment | HMWB | Moderate (3) | Good (2) | Moderate (3) | Moderate (3) | Good (2) | High (3) | Moderate (3) | Moderate (3) | Good (2) | Moderate (3) | Good (2) | Moderate (3) |
| Historical Floodplain Water Replenishment | HMWB | Poor (4) | No Data | Moderate (3) | Moderate (3) | Moderate (3) | Good (2) | Moderate (3) | Moderate (3) | Good (2) | Good (2) | Poor (4) | Poor (4) |
| Mosoni-Danube upper | HMWB | Moderate (3) | No Data | Moderate (3) | Moderate (3) | Good (2) | Good (2) | Moderate (3) | Moderate (3) | Good (2) | Moderate (3) | Moderate (3) | Moderate (3) |
| Mosoni-Danube middle | NATURAL | Moderate (3) | Good (2) | Moderate (3) | Moderate (3) | Moderate (3) | Good (2) | Moderate (3) | Moderate (3) | Good (2) | Good (2) | Moderate (3) | Moderate (3) |
| Mosoni-Danube lower | HMWB | Poor (4) | No Data | Moderate (3) | Moderate (3) | Moderate (3) | Good (2) | Moderate (3) | Moderate (3) | Good (2) | Good (2) | Moderate (3) | Moderate (3) |

Table 15:
Biological status of river water bodies in the Szigetköz

| Waterbody | | Biological quality elements | | | | | Overall evaluation |
|----------------|---|----------------------------------|----------------|---------------|------------------------|---------------|--------------------|
| | | Makrozoobenthos | Phyto-plankton | Phyto-benthos | Macrophytes (RBMP 2-3) | Fish | |
| RBMP -1 (2010) | Danube at Szigetköz * (HMWB) | Good ecological potential (E.P.) | High E.P. | Good E.P. | No data | Moderate E.P. | Moderate E.P. |
| | Szigetköz Historical Floodplain Water Replenishm. System (HMWB) | Good E.P. | High E.P. | Good E.P. | No data | Moderate E.P. | Moderate E.P. |
| RBMP -2 (2015) | Danube at Szigetköz (HMWB) | Moderate E.P. | High E.P. | Moderate E.P. | No data | No data | Moderate E.P. |
| | Szigetköz Active Water Replenishm. | Moderate E.P. | High E.P. | Moderate E.P. | No data | Moderate E.P. | Moderate E.P. |



| | | | | | | | |
|-------------------|--|------------------|-----------|-----------|---------|------------------|------------------|
| | System (HMWB) | | | | | | |
| | Szigetköz <u>Historical</u> Floodplain Water Replenishm. System (HMWB) | Moderate E.P. | Good E.P. | Good E.P. | No data | Moderate E.P. | Moderate E.P. |
| RBMP -3 (2021) | Danube at Szigetköz (HMWB) | Moderate E.P. | High E.P. | Good E.P. | n.a. | High E.P. | Moderate E.P. |
| | Szigetköz <u>Active</u> Water Replenishm. System (HMWB) | Good E.P. | High E.P. | High E.P. | n.a. | No data | Good E.P. |
| | Szigetköz <u>Historical</u> Floodplain Water Replenishm. System (HMWB) | Poor E.P. | Good E.P. | High E.P. | n.a. | Good E.P. | Poor E.P. |

* In 2010 Danube main riverbed and the Active floodplain branch system was handled as a single water body. In later RBMP-s (2015, 2021) they were considered as separate water bodies.

** HMWB – Heavily modified water body – due to hydromorphological changes.

ANNEX NO 4.

Monitoring systems

D.1.1 – Detailed Analysis of Demonstrators Ecosystems

FISH SPECIES: There is a significant change in the number of **fish species**. The evaluation of the 2018 national report on the effects of water replenishment states the following: During the surveys carried out in 2018, almost 8 thousand fish were collected in Szigetköz, among which 32 fish species were identified. The surveys covered more locations so a more comprehensive picture of the current situation of the fish fauna was achieved.

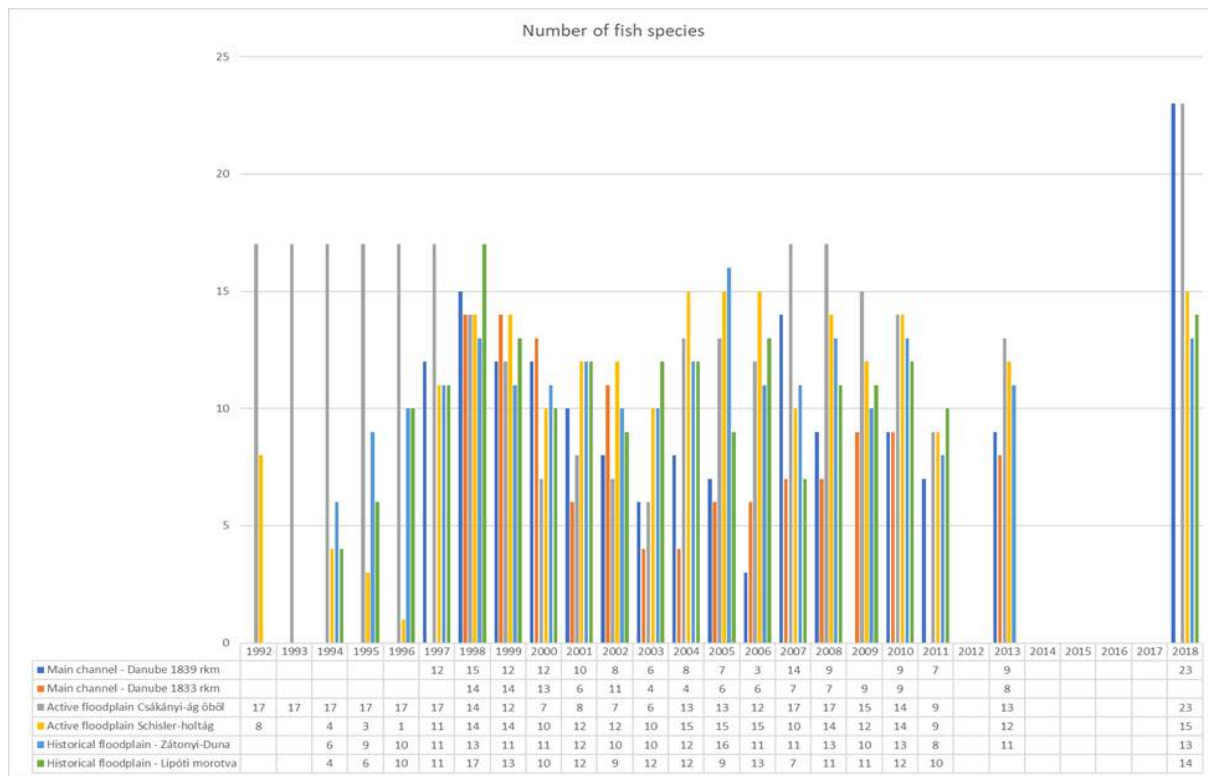
In the **Danube main channel (Old-Danube)** 28 species were found, more than in other water bodies of the Szigetköz (floodplain systems, Mosoni-Danube.) Some rheophilic species, (*Ballerus ballerus*, *Barbus barbus*, *Rutilus rutilus*, *Zingel zingel* and *Zingel streber*) were only present in habitats with intensive flowing water in the main channel. The species with the largest number of individuals collected in the main channel are *Alburnus alburnus*, *Chondrostoma nasus*, and *Rutilus rutilus*. Some more limnophilic species were found in more stagnant, vegetated areas of the Old-Danube, such as *Scardinius erythrophthalmus*, *Ameiurus melas*, and *Lepomis gibbosus*. The presence of several rheophilic fish species that had previously been detected several times could not be detected in 2018: such as *Romanogobio vladykovi*, *Lota lota*, *Leuciscus leuciscus*, *Cottus gobio*, *Gymnocephalus baloni*, and *Gymnocephalus schraetser*.

Sampling sites in the **active floodplain** are characterized by diverse habitat conditions, and accordingly there was a significant number of detected fish species (26 species). In places where mixed habitats of faster flow velocity and stagnant wetlands are both present, (e.g. Cicolai branch system), both rheophilic and limnophilic fish species were found, therefore larger species richness was determined. The species collected in the largest number of individuals on the active floodplain were similar to previous years: *Alburnus alburnus*, *Rutilus rutilus*, and *Rhodeus sericeus*. The number of *Blicca bjoerkna* specimens however has become rarer, compared to its mass occurrence in the 1990s. It can be clearly established that many rheophilic fish species, such as *Barbus barbus*, *Chondrostoma nasus*, *Leuciscus idus*, and *Squalius cephalus* formed a significant population in the faster-flowing branches. Other rheophilic species (*Romanogobio vladykovi*, *Lota lota*, *Leuciscus leuciscus*, *Gymnocephalus baloni*) were on the other hand missing in the samples collected in 2018.

Fewer fish species (16 species) occurred at the sites studied on the **historical floodplain** branches. No fish species were found that were not found in the active floodplain. At the sampling sites, mostly very slow or stagnant water was observed. Accordingly the frequency of limnophilic species dominated: *Rutilus rutilus*, *Alburnus alburnus*, and *Scardinius erythrophthalmus*. Before the diversion of the Danube, and before water replenishment, the historical floodplain was characterized by many swamps which were fed mostly by groundwater. Some of the characteristic fish species of that time (*Umbra krameri*) are no longer present in the Upper Szigetköz. The occurrence of the species has been verified however in the active floodplain areas of lower Szigetköz in recent years.

The number of fish species changed significantly since the diversion of the Danube due to continuous rehabilitation activities from 1993-2015. Earlier monitoring data from before the diversion of the Danube was not available.





ANNEX NO 6.

Table 16:

Protected areas within Iron Gates National Park directly influenced by the Iron Gates system

| Nr. Crt. | Protected area | Species | Area (ha) |
|----------|--|--|-----------|
| 1. | Balta Nera-Danube Natural Reserve | The fauna is exceptionally diverse, from invertebrates to mammals. Due to the bioecological conditions necessary for feeding, reproducing, and nesting, waterbirds are the most prominent fauna in the area. As expected, ichthyofauna is also very well represented: <i>Umbra krameria</i> , <i>Aspius aspius</i> , <i>Barbus meridionalis</i> , <i>Gobio kessleri</i> , <i>Cobitis elongate</i> , <i>Cobitis taenia</i> , <i>Zingel zingel</i> , <i>Cottus gobio</i> , <i>Misgurnus fossilis</i> . | 10 |
| 2. | Baziaș Natural Reserve | The fauna is diverse, from invertebrates to mammals. The ichthyofauna is poorly represented due to fluctuating water levels. | 170.9 |
| 3. | Calinovăț Island Special Avifaunistic Protection Area | During seasonal migration or nesting, the island is a veritable oasis for an abundance of avian species. As expected, ichthyofauna is also very well represented: <i>Umbra krameria</i> , <i>Aspius aspius</i> , <i>Barbus meridionalis</i> , <i>Gobio kessleri</i> , <i>Cobitis elongate</i> , <i>Cobitis taenia</i> , <i>Zingel zingel</i> , <i>Cottus gobio</i> , <i>Misgurnus fossilis</i> . | 24 |
| 4. | Râpa cu lăstuni Natural Reserve | The reserve has been designated for the preservation of nests and colonies of the <i>Riparia riparia</i> (sand martin, "lăstun de mal" in romanian), which have been established in Quaternary leosoid deposits on shores. The species is protected by the Bern Convention due to its rarity. | 5 |
| 5. | Divici – Pojejena Special Avifaunistic Protection Area | During seasonal migration or nesting, the area is a veritable oasis for an abundance of avian species. As expected, ichthyofauna is also very well represented: <i>Umbra krameria</i> , <i>Aspius aspius</i> , <i>Barbus meridionalis</i> , <i>Gobio kessleri</i> , <i>Cobitis elongate</i> , <i>Cobitis taenia</i> , <i>Zingel zingel</i> , <i>Cottus gobio</i> , <i>Misgurnus fossilis</i> . | 498 |
| 6. | Valea Mare Natural Reserve | Each category of fauna is highly well-represented. The presence of diverse habitats, including forest, rocky habitats, and even permanent and transient water courses, results in a high level of biodiversity within each group. | 1179 |



| | | | |
|----|---|--|------|
| 8. | Moldova Veche Island Special Avifaunistic Protection Area | During seasonal migration or nesting, the area is a veritable oasis for an abundance of avian species. As expected, ichthyofauna is also very well represented: <i>Umbra krameria</i> , <i>Aspius aspius</i> , <i>Barbus meridionalis</i> , <i>Gobio kessleri</i> , <i>Cobitis elongate</i> , <i>Cobitis taenia</i> , <i>Zingel zingel</i> , <i>Cottus gobio</i> , <i>Misgurnus fossilis</i> . | 1627 |
|----|---|--|------|

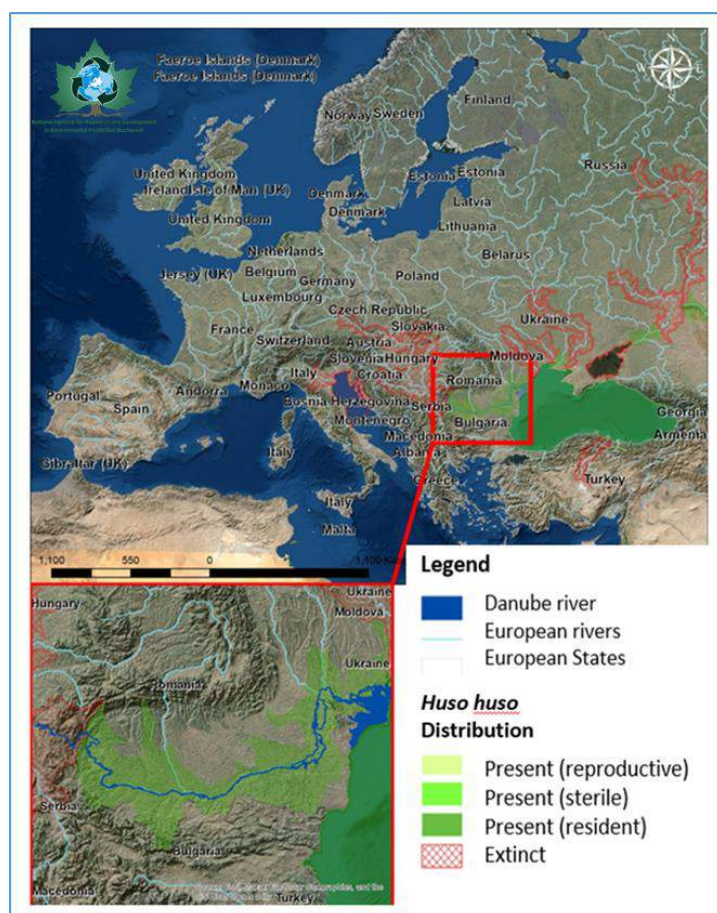
1. *Huso huso*

The historic range of this species included the Black Sea, the Caspian Sea, the Azov Sea and the Adriatic Sea areas. The beluga sturgeon migrated in large numbers from the Black Sea to the upper portion of the Hungarian section of the Danube and sporadically also ascended to the Austrian section (Hensel & Holčík, 1997).

It was one of the most significant components of fishing in Hungary during the Middle Ages, as evidenced by numerous historical archives: In November of 1553, 77 specimens were obtained at the fishing site of Aszód; in 1746, the annual catch on the 55-kilometer-long Danube section between Paks and Szeremle was 27 tons.

Current distribution of *Huso huso* is restricted to the Black Sea according to IUCN and INCDPM data (Figure 80). Individuals complete their natural reproductive cycle exclusively in the Danube and Caspian Sea, where it is believed that they also spawn in the Ural and Volga rivers. It is essential to note that the population in the Adriatic Sea became extinct in the 1970s and that the Azov sea population has been considered extinct since the end of the 20th century.

Since the commissioning of Iron Gate I dam, only two captures have been reported in Hungary (Guti, 2006). Based on the historical presence of migratory sturgeons in the Danube River system, it is reasonable to assume that traditional spawning sites for these anadromous species were located in the Middle Danube River as well as along some major tributaries, such as the Tisza, Sava, and Drava Rivers (Hensel & Holčík, 1997). No spawners of the hiemal form, with the possible exception of a few beluga sturgeon 55 years and older, would persist upstream of Iron Gates II (Friedrich et al., 2019).



According to INCDPM informational volume, the individuals that migrate during autumn remain in the Lower Danube until the end of the spring season (DEÁK & Georgescu, 2023).

2. *Acipenser gueldenstaedtii*

The historic range of *Acipenser gueldenstaedtii* included the Black Sea, the Caspian Sea and the Azov Sea. Currently, this species is extinct in the Azov Sea basin, but still extant in the Caspian Sea basin.

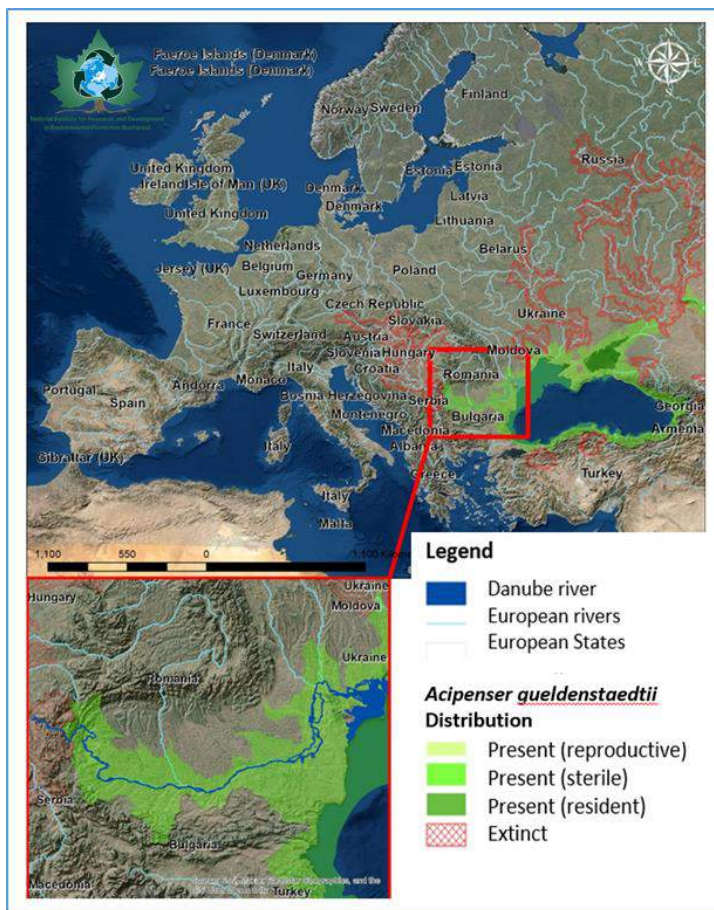
The Russian sturgeon was extensively distributed in the Danube Basin, migrating from the Black Sea to Bratislava and the major tributaries of the middle Danube. It occurred as both resident and migratory species (Hensel & Holčík, 1997). Beginning with the 20th century, Hungary started to record only sporadic captures. (Guti, 2006).

It has been reported that after the completion of Iron Gates I, catches of *H. huso* and *A. gueldenstaedtii* attained a peak due to the large number of migrating sturgeons trapped below the dam. During the five-year period from 1972 to 1976, a total of cca. 116 metric tonnes of *H. huso* and *A. gueldenstaedtii* were captured, representing an increase of nearly 25 percent compared to the five-year period preceding dam construction. After 1976, catches began to decline, reaching a low of cca. 37 metric tonnes from 1980 to 1984 during the construction of Iron Gates II (Jankovic, 1993).

Regarding the Danube area, it can be seen in Figure 81 that only fragmented reproductive populations can be identified.



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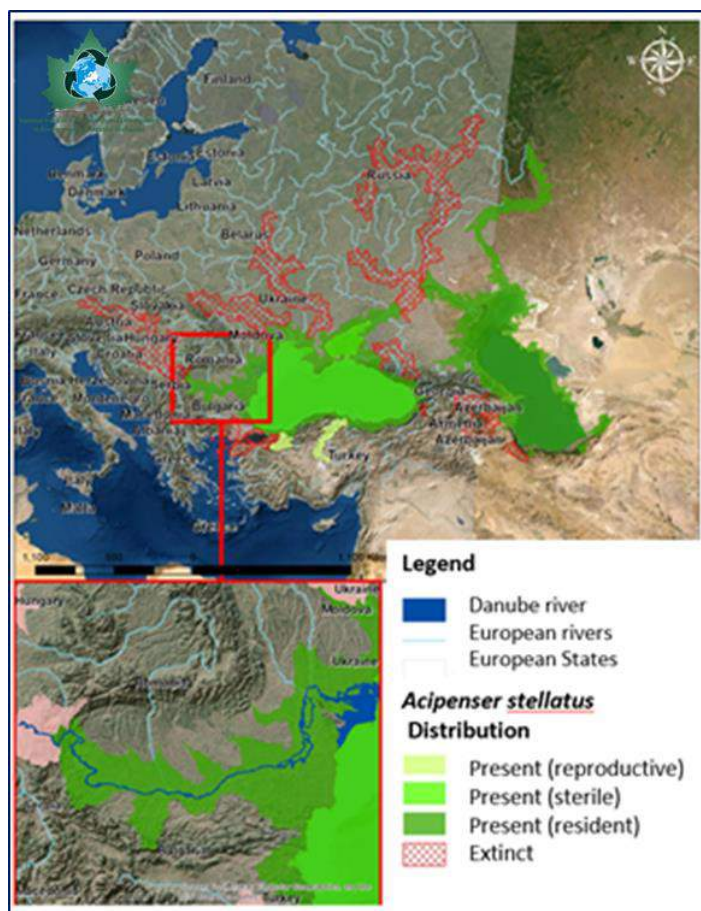


The last confirmed natural reproduction at national level (Romania) occurred in 2006, and the limited number of individuals captured, tagged, released and monitored by INCDPM between 2011 and 2022 (DEÁK & Georgescu, 2023) confirms this information.

3. *Acipenser stellatus*

In Figure 82 can be observed that this species inhabits coastal regions, especially the Caspian Sea, the Black Sea and the Azov Sea. *Acipenser stellatus* was also present in the northern Aegean basin in the past. Historically, this species migrated to the Upper Danube, but the Iron Gates hydropower system now obstruct its migration routes.

The stellate sturgeon ascended from the Black Sea to Bratislava on the Danube and to Tokaj in the Tisza, but it was always uncommon and played a minor role in historical fisheries (Hensel & Holčík, 1997). This anadromous species is presumably extinct in Hungary due to the dams Iron Gate I and II, which restrict its migration to the middle Danube (Guti, 2006).



In the present, there are reproductive populations in the Danube, Sakarya and Rioni rivers, the Black Sea and the Ural and Sefid rivers in the Caspian Sea. Juveniles migrate to the sea during their first calendar years for feeding purposes and they remain there until they reach maturity (DEÁK & Georgescu, 2023).

4. *Acipenser ruthenus*

Figure 83 presents the potamodromous character of *Acipenser ruthenus*, as it is only found in rivers and estuaries. This species has been documented in the littoral regions of the Black Sea, Azov Sea and Caspian Sea. It inhabits large rivers, preferring areas with difficult hydrodynamic conditions.

Acipenser ruthenus was once abundant in the Lower to Middle Danube and now plays a significant role in the fisheries of the Middle Danube and Tisza. In the 1950s and 1960s, sterlet captures in Hungary indicated a population decline (Jaczó, 1974), but an upturn was observed from the early 1970s to the latter half of the 1990s. Population increases were likely due to the emigration of individuals from the Iron Gate Dam reservoir (Hensel & Holčík, 1997).





The species is currently regarded as present in the Volga, Ural and Danube rivers. *Acipenser ruthenus* is mostly sedentary and migrates infrequently. Considering INCDPM volume of information obtained from the monitoring activities and the data validated by IUCN Red list of Threatened Species, it can be concluded that the population trend is currently declining (DEÁK & Georgescu, 2023).

5. *Acipenser sturio*

According to the scientific literature, *Acipenser sturio* inhabits the North and Baltic Seas, the English Channel, the European Atlantic coasts, the northern Mediterranean west of Rhodes (Greece), and the southwestern Black Sea.

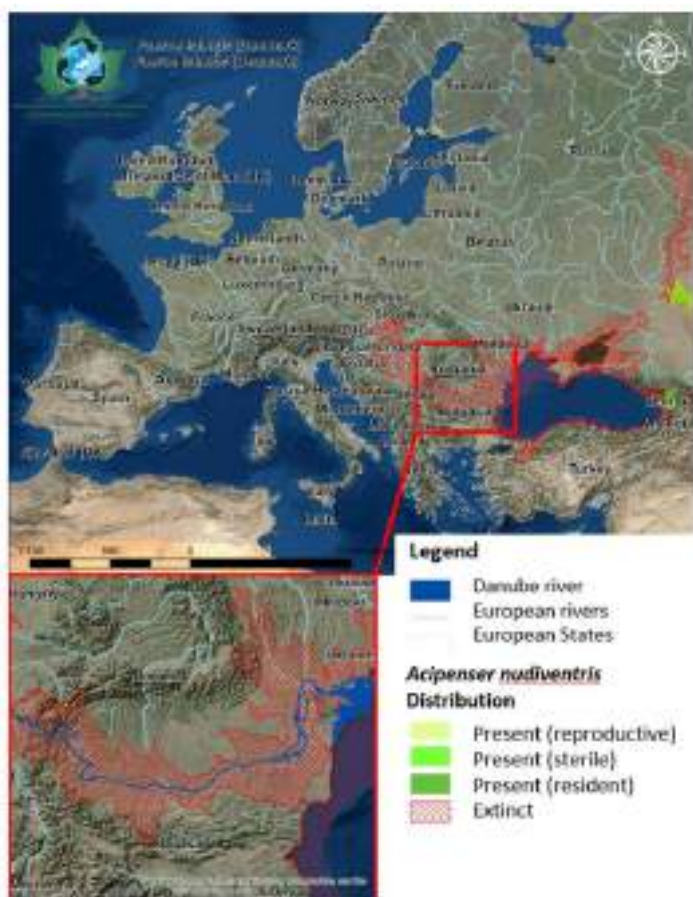


However, based on the findings of the INCDPM team of experts, this species has been declared extinct (DEÁK & Georgescu, 2023). Therefore, it was considered necessary to map the species' current distribution in order to represent its extinction in the Black Sea basin.

6. *Acipenser nudiventris*

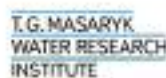
Historically, this species has been identified in the Black Sea, the Azov Sea, the Caspian Sea and the Aral Sea, as well as in the large tributaries: the Danube to Bratislava, Volga to Kazan, Ural to Chkalov, Don, Kuban, Rioni, Sakarya.





Wild populations of *Acipenser nudiiventris* are observed as being extinct from the following basins: the Azov Sea, the Black Sea (confirmed by INCDPM monitoring activities) and the Caspian Sea (DEÁK & Georgescu, 2023). Thus, it was considered necessary to map the current distribution of the species in order to show that it is extinct in the Black Sea basin.

PARTNERS



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