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Report

From Vision to Action: Co-identifying a Safe Water Operating Space for the Danube basin

March 5, 2025, Vienna, Austria

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[6 June 2025]

SOS Water

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ZVR 524808900

The authors gratefully acknowledge funding from European Union's Horizon EUROPE Research and Innovation Programme under Grant Agreement N° 101059264 (SOS-WATER). Views and opinions expressed are those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Abstract

As water-related challenges intensify under the combined pressures of climate change, land use change, and competing water demands, the SOS-Water project seeks to define a Safe Operating Space (SOS) for water resources that ensure sustainable, equitable, and resilient water systems. Supported by the European Union's Horizon Europe Framework Programme, SOS-Water applies a transdisciplinary methodology—integrating modeling, monitoring, and participatory stakeholder engagement—across four diverse case studies in Europe and beyond, including the ecologically and socio-economically complex Danube River Basin.

The second stakeholder workshop for the Danube case study, held in Vienna on 5 March 2025, brought together key stakeholders from across the basin to evaluate and refine a common objectives framework and to explore scenario-based adaptation pathways. Building on the results of the first workshop, participants provided detailed feedback on indicators and thresholds representing various water functions—such as state, regulatory, productive, supply, and chemical carrier functions. Discussions highlighted the importance of robust data, contextual definitions, and system-specific thresholds, as well as cross-cutting challenges such as connectivity, habitat degradation, and water quality.

In the second half of the workshop, stakeholders examined three global socio-economic scenarios and co-designed adaptation strategies tailored to the Danube Basin. Using participatory mapping and structured discussion, they identified risks, opportunities, and viable adaptation options to maintain water system resilience across a range of plausible futures.

This workshop marks an important step in the co-creation of the Danube Basin's Safe Operating Space by integrating scientific insights with local knowledge and stakeholder perspectives. The results will inform the refinement of indicators, threshold setting, and the development of scenario-specific adaptation pathways in the next phases of the SOS-Water project.

About the authors

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Barbara Willaarts is a Senior Researcher in the Water Security Research Group of the IIASA Biodiversity and Natural Resources Program. Her research is driven by two main principles: one is collaborative and interdisciplinary research aiming to understand complex problems and find joint solutions to support the development of pathways to sustainability; and the other is impact-oriented research in- and beyond academia to enhance the social and policy relevance of science and her research in particular. Her work covers a broad range of topics relevant to water and food sustainability transitions. It also benefits from an international reach through geographical settings ranging from Europe to Latin America, and more recently, Africa and Asia. As part of her interest in enhancing the social impact of science, she has also devoted substantial efforts to research approaches for stakeholder engagement to address complex sustainability challenges. Outside of the lab, she dedicates her time to ensuring the availability of scientific knowledge to all relevant stakeholders, including policymakers to support informed decision-making, the next generation of scientists through teaching, and the public through engagement on social media (willaart@iiasa.ac.at).

Acknowledgments

We are deeply grateful to the participants of the second Danube case study workshop. Stakeholders once again shared their valuable knowledge and insights about the Danube Basin, actively contributing to the refinement of the objectives hierarchy, the evaluation of indicators and thresholds, and the co-design of adaptation pathways. Their continued engagement is instrumental in advancing the modelling work and shaping a robust Safe Operating Space for the Danube.

1. Introduction

1.1 Background

Over the last century, rapid increases in water withdrawals have driven significant environmental challenges worldwide, including water scarcity, pollution, and the degradation of freshwater ecosystems. With climate change and societal developments expected to intensify these pressures, urgent action is needed to ensure sustainable water use aligned with the Sustainable Development Goals (SDGs) and the 2030 Agenda. A key part of this response is to define a Safe Operating Space (SOS) for water resources that guarantees sufficient water of appropriate quality for human needs and ecosystem integrity in the face of environmental and socio-economic change.

SOS-Water is a four-year project funded by the European Union's Horizon Europe programme. Coordinated by the Water Security Research Group at IIASA, the project adopts a multidisciplinary approach that integrates advanced modelling, Earth observation data, and co-designed stakeholder processes. Its goal is to operationalise the SOS concept across four diverse case studies—Danube, Rhine, Jucar, and Mekong river basins—by combining modelling, monitoring, indicators, and participatory scenario building to support sustainable water management.

The project's outcomes aim to strengthen our understanding of water availability and use, improve water planning, and promote equitable water distribution that balances ecological, social, and economic priorities.

On 22 November 2023, the SOS-Water project held its first stakeholder workshop for the Danube Basin in Vienna. This event brought together key stakeholders from across the basin to engage in collaborative discussions about water-related values, goals, and challenges. Participants contributed to identifying key objectives and priorities for both the wider Danube basin and the Danube Delta, helping to develop objective hierarchy maps that reflect diverse stakeholder perspectives. The workshop highlighted the importance of integrated approaches that consider climate change, ecological preservation, and socio-economic development.

Building on the success of this first workshop, the project has established a strong and inclusive stakeholder network and promoted an ongoing dialogue involving all significant interest groups related to freshwater in the Danube basin. This report documents our continued stakeholder engagement for the Danube case study, summarizing key discussions and outcomes from the second stakeholder workshop, held in Vienna on 5 March 2025.

1.2 Danube case study

The Danube River is the second longest river in Europe, stretching nearly 3,000 kilometers from the Black Forest in Germany through the Alps and Central European plains to the Black Sea. Spanning approximately 800,000 km² across 19 countries, it is also the largest river basin in Europe and the most international river basin in the world. Due to its size and diverse conditions, the basin is commonly divided into three sections: the Upper

(1,066 km), Middle (860 km), and Lower Danube (931 km; see Figure 1), each with distinct ecological and socio-economic characteristics and exposure to varying environmental pressures. Annex 2 of the first workshop report (Artuso *et al.*, 2024; https://pure.iiasa.ac.at/id/eprint/19926/) contains supplementary maps with additional detail on the basin's hydrological network, country boundaries, and sub-basin delineations.
The Danube basin faces a range of stressors, notably hydromorphological alterations from barriers, embankments etc., navigation infrastructure, pollution and water quality issues in the mid-lower course, and the spread of invasive species.

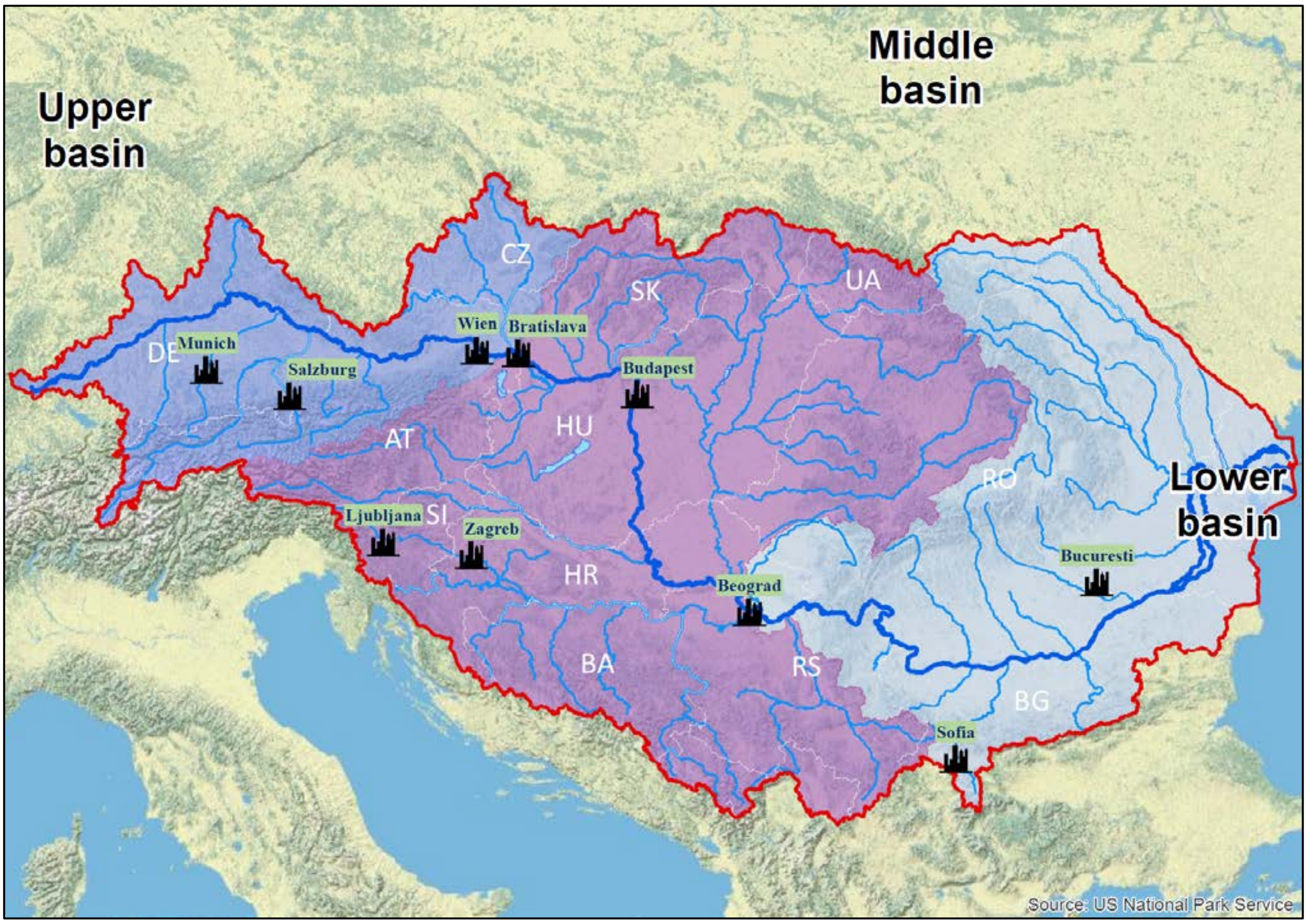


Figure 1. Danube basin map

Within the SOS-Water project we consider the whole basin with special attention to the Upper and Lower Danube sub-basins, due to their ecological importance and specific management challenges.

The Upper Danube, located across southern Germany, Austria, Switzerland, and parts of the Czech Republic, is recognized as a major freshwater source for Europe. It holds significant hydropower potential and supports rich biodiversity. Its runoff regime is dominated by snowmelts, but significantly altered by extensive regulation for navigation, settlements, agriculture, and energy production. These alterations affect flood dynamics, sediment transport, and water availability downstream, often leading to competing interests between hydropower, agriculture, environmental conservation, and tourism.

At the opposite end, the Lower Danube includes the Danube Delta in Romania, a critical wetland ecosystem at the river's outlet into the Black Sea. This region supports a wide range of flora and fauna but is highly sensitive to upstream activities. Agricultural runoff and energy production influence flood regimes, sediment transport and water quality, which have cascading effects in the Delta. Attempts to mitigate sediment loss, for example through channel engineering, have led in the past to unintended consequences such as pollution, eutrophication, and coastal erosion. Tensions in the region reflect competing priorities between upstream resource use and downstream goals such as ecological preservation, tourism, and community resilience.

In both the first and second stakeholder workshops, we engaged key representatives from across the Danube basin, encompassing all major water-related sectors, along with dedicated participants from the Danube Delta. These stakeholders have played an active role in the SOS-Water participatory process and continue to collaborate closely with researchers from IIASA and other partner institutions. Together, we are co-developing a Safe Operating Space (SOS) framework that reflects the region's specific challenges, priorities, and opportunities.

2. Second stakeholders' workshop for the Danube case study

2.1 Workshop objectives

During the second workshop, we presented the objective hierarchy map for the Danube Basin developed based on the outcomes of the first stakeholder engagement (see Annex 3: Revised objective hierarchy for the Danube Basin) and we gathered feedback on the identified indicators and thresholds used to quantify the fulfilment of the hierarchy's objectives. Additionally, we shared preliminary modelling results and provided baseline insights into the basin's future challenges. These insights were used to co-identify possible adaptation options and co-develop adaptation pathways.

Results from the second stakeholder workshop will inform a series of adaptation pathways to cope with climate change impacts. The pathways will then be simulated across the basin to assess their impacts and trade-offs across various dimensions of the water system. This process will help identify the safe operating space for the Danube basin, ensuring efficient, equitable, and resilient water management in the future for both the people and the environment. The culmination of this collaborative dialogue will be a case-study-specific SOS-Water framework, which together with a fine-tuned, spatially optimized management plans will be presented to stakeholders in a final workshop, where their feedback will be collected.

The workshop was structured as a one-day event comprising several activities (Fig. 2, see Annex 1 for the Agenda) aimed to achieve the following expected outcomes:

- Continue and reinforce the dialogue between the leading key players in the Danube basin

- Validate and refine the results of the earlier workshop, including the delineation of the Danube water functions and indicators
- Discuss preliminary model runs and future trends, risk and opportunities under no action scenario
- Elicit transformational adaptation pathways to restore and maintain Danube Water Functions

Figure 2. System Mapping tools and materials utilized for the workshop activities

A total of 25 people located in 3 countries attended the workshop, including the organizers. Stakeholders represented a wide range of freshwater-related institutions listed in Table 1.

Table 1. List of institutions participating

International Commission for the Protection of the Danube River (ICPDR)
National Agency for Land Improvements (ANIF)
WWF Central and Eastern Europe
Danube Delta Biosphere Reserve Administration (ARBDD)
Austrian Development Agency (ADA)
International Institute for Applied Systems Analysis (IIASA)
Federal Ministry of Agriculture, Forestry, Regions and Water Management (BML)
Eutema Research Services
Viadonau
University of Natural Resources and Life Sciences (BOKU)
Leibniz Institute of Freshwater Ecology and Inland Fisheries (IGB)

National Authority of Romanian Waters (ANAR)
International Association of Water Service Companies in the Danube River Catchment Area (IAWD)
Verein fur Okologie un Umweltforschung (VÖU) / Tiwag
The National Institute for Research and Development of Marine Geology and Geoecology (GeoEcoMar)

2.2 Introduction of stakeholders

Participants were invited to briefly introduce themselves and their institutions to the audience, highlighting the role of their institution in the Danube. This activity helped set the overall mood and created a welcoming atmosphere, encouraging networking and the exchange of ideas, emphasizing the collective commitment to the sustainable development and preservation of the Danube River basin.

2.3 Refined objectives hierarchy map presentation: the water functions

Based on the results from the first workshop (see Artuso *et al.*, 2024), the objectives hierarchy's maps for the Danube Basin were redefined to integrate the insights given by the stakeholders (Annex 3). While we initially created two separate maps for the whole basin and the Delta, we decided afterwards to integrate the specific objectives for the Delta in the main map and work with one general framework for the entire basin.

The objectives hierarchy map is organized as a hierarchy of goals and sub-goals that reflect the stakeholders' values and priorities for the Danube. At the top level are the Water functions in the Danube Basin, which describe the essential roles water plays in regulating, sustaining, and stabilizing hydrological, ecological, and socio-economic systems across this transboundary region. This concept is grounded on the paper of Falkenmark et al. (2021). To maintain the resilience of the basin, these water functions must remain within a safe operating space; meaning, ensuring they operate within boundaries that prevent ecological and socio-economic destabilization. Each water function is associated with one response variable (second level) that describes its state. The response variables are in turn depending on one or more control variables, which describe a measurable state or property of the response variable which can be influenced by human water management (third level). Finally, at the bottom of the hierarchy, there are the indicators and their thresholds. The indicators are measurable and quantifiable parameters or variables used to assess the status, performance, or condition of the water system. For each indicator, a threshold (i.e., boundary) is defined, beyond which the system is considered to be operating unsafely. Crossing such thresholds may lead to dysfunction in the corresponding water function, systemic instability, and increased risks for both humans and ecosystems. These indicators will be evaluated at the sub-basin scale and aggregated into a composite metric that will reflect the state or performance of each Water Function, and, ultimately, the overall SOS of the Danube Basin. The defined thresholds serve as reference points for assessing whether the basin operates within a safe operating space under various future scenarios and management pathways, supporting a multidimensional evaluation of system sustainability.

Danube Water Functions

Water functions in the Danube Basin describe the essential roles water plays in regulating, sustaining, and stabilizing hydrological, ecological, and socio-economic systems across this transboundary region. These functions are categorized into five main types: regulatory, state/storage, supply, productive, and carrier and chemical load functions, each defined below. The Water Functions are adopted from Falkerman et al. (2021).

Function Type	Definition and examples
REGULATING	Natural processes that depend on flow regimes, and control and moderate the movement and availability of water and sediments within its ecosystem and surrounding landscape. Examples: • Creation of habitat and refugia, such as maintaining riparian buffers, wetlands, and healthy floodplains. • Sediment transport through the preservation of natural sediment transportation processes and natural infrastructure, such as meandering rivers. • Baseflow maintenance and water availability in the dry season by enabling water infiltration through soils and natural vegetation, which is then slowly released. • Support for species migration through fish passages and dam management that mimics natural flows.
STATE/STORAGE	Natural and managed processes that regulate the retention, availability, and distribution of water within a system, ensuring both sufficient water resources for ecological and human needs and resilience to hydrological extremes such as droughts and floods. Examples: • Aquifer storage capacity, ensuring sufficient groundwater reserves for long-term water availability • Lake storage capacity, regulating water levels for supply, ecosystems, and seasonal variability. • Channel storage, maintaining streamflow and buffering fluctuations in water availability. • Water levels and depth regulation, supporting aquatic and floodplain habitats for biodiversity and ecosystem stability.
SUPPLY	Hydrological processes, infrastructures, and governance and management strategies that ensure water demands are met.

	Examples: • Demands for domestic, industry and agriculture are fully or almost fully met • Water demands are met with renewable water resources
PRODUCTIVE	(Blue) water productive function refers to the role of surface and groundwater in sustaining aquatic biomass production and supporting socio-economic activities that depend on in-channel water availability like navigation and recreation (i.e., without withdrawal). Examples: • Sustaining aquatic biomass production, includes supporting fisheries, aquaculture, and ecosystems that rely on in-channel water availability. • Enabling inland navigation, providing sufficient water depth and flow for transport and commercial shipping on rivers and canals. • Supporting recreational activities, such as boating, swimming, and fishing, which depend on stable water levels and quality
CARRIERS AND CHEMICAL LOADS	(Blue) water carrier and chemical functions refer to the role of rivers, lakes, and groundwater in transporting sediments, nutrients, and pollutants, thereby influencing water quality, ecosystem health, and socio-economic activities Examples: • Dilution and dispersion of pollutants, reducing concentrations of contaminants through natural hydrological processes and mitigating water quality impacts. • Retention and transformation of substances, including the natural breakdown of organic matter, denitrification, and chemical interactions that improve water quality.

2.4 Preliminary modelling results

Slides from presentations on preliminary modelling results for the Danube basin are provided in Annex 2.

Task 1: Validation and refinement of indicators and thresholds

After having presented the revised objectives hierarchy map to the participants (see above and Annex 3), stakeholders were invited to participate in an in-depth discussion using a *World Café* format. Three thematic tables were prepared, each focusing on a set of indicators belonging to specific water functions. Each table was supported by a facilitator and a note taker from the organizing team, who provided explanations on the indicators and their corresponding thresholds, and guided the discussion.

Stakeholders were divided into three groups and assigned to a starting table. At each table, they were asked to reflect and provide input on the following points:

- Appropriateness of the indicator
- Appropriateness of the thresholds
- Potential data sources for the indicator

Workshop task 1: Specific goals

1. *Discuss the* ***relevance and appropriateness of the indicators*** *selected to measure the performance of the different water functions*
2. *Discuss and* ***validate thresholds*** *i.e. value or ranges above/below which the indicator might be out of the safe operating space*
3. *Discuss* ***additional data sources relevant*** *to define indicators and/or thresholds*

After 20 min, each group moved clockwise to the next table and replicated the discussion. This was done for three rounds, until every group visited every table.

Figure 3. Photos from the first task of the workshop

Afterwards, the facilitators of each table summarized the main discussion points to the whole group.

Task 2: Identify current challenges, risks and opportunities

For the second exercise, we prepared three tables, each with a map of the Danube basin (Figure 1) alongside a set of cards illustrating pre-identified challenges and risks currently faced by the water functions in the Danube, and opportunities for further development and/or improvement (Figure 4; see complete list in Annex 4). Stakeholders were divided into three groups based on their expertise and assigned to one or more Water Functions:

- Group 1: State/Storage
- Group 2: Regulatory and Productive
- Group 3: Supply and Chemical loads

Participants were invited to collectively assess the current status of water functions in the Danube Basin. They did so by placing the provided cards on the basin map in the locations they considered most relevant, whether in the Upper, Middle, or Lower Danube, or across the entire basin. If a particular challenge, risk, or opportunity was not represented in the pre-printed cards, participants were encouraged to add new ideas by writing them on blank cards and placing them on the map.

Figure 4. Examples of system elements and processes used to map risk, challenges and opportunities for the water functions in the Danube basin. The full list can be found in Annex 4.

Task 3: Identify future adaptation pathways

In the third exercise, the same groups received a set of adaptation measures, each fit to specific water functions, selected from Catalogue of adaptation measures Climate ADAPT (https://climate-adapt.eea.europa.eu/en/knowledge/adaptation-information/adaptation-options). The full list is provided in Annex 5.

To guide the discussion, we introduced three future scenarios for the Danube Basin, inspired by the global Shared Socioeconomic Pathways (SSPs). Each scenario was presented with a short video simulating a fictional "Danube News" broadcast from the year 2050, helping participants envision the societal and environmental context of each potential future.

Scenario I: Pessimistic – SSP5: Fossil-Fuelled Development ("Taking the Highway")
high challenges to mitigation, low challenges to adaptation

- Great trust in competitive markets, innovation and participatory society
- Rapid economic growth and development of human capital
- Global population peaks and declines in the 21st century
- Free, global trade sustained by carbon-intensive fuels
- High technological development
- Local environmental issues successfully managed
- Trust in technological development to manage ecological systems

Scenario II: Middle of the Road – SSP3: Regional Rivalry ("A Rocky Road")
high challenges to mitigation and adaptation

- Nationalism drives competition among regions and focuses on domestic issues.
- Low technological development and decline in investments in education
- Low priority for social and environmental goals, an increase in inequality
- Focus on domestic resources and national and security matters
- High population growth in developing countries, low growth in industrialised ones
- Slow economic growth of developing countries and material-intensive consumption
- Low priority of environmental issues leads to degradation in some regions

Scenario III: Sustainability – SSP1: Sustainability ("Taking the Green Road")
low challenges to mitigation and adaptation

- Global, gradual cooperation towards sustainability
- Rapid and inclusive technological development
- Global commons management improves slowly but steadily
- Educational and health investments drive low population growth
- Inequity declines, and economic growth shifts towards human well-being
- Use of renewable energy sources and development of efficient energy and resource systems

Following the scenario presentations, participants were asked to review the adaptation measures and identify those they found relevant to the Danube Basin, either at the sub-basin level or for the basin as a whole. They then evaluated which measures aligned best with each of the three future scenarios by placing them on the basin map using color-coded post-its corresponding to each scenario. Through this exercise, stakeholders contributed to the co-design adaptation pathways to maintain and restore water functions and enhance Danube's water resilience in the light of different global Scenarios.

Figure 5. Photos from one of the tables during the third task

Task 4: Reporting back to everyone

A selected representative from each group was then invited to report the main discussion points to the whole group.

3. Results and discussions

Stakeholders responded positively to the workshop and the scheduled activities, actively engaging, and contributing to the discussions. Building on the foundation laid during the first workshop, participants reviewed and discussed the revised objectives hierarchy map, critically revising the relevance, clarity, and feasibility of proposed indicators and thresholds. In the second task, stakeholders mapped current challenges, risks and opportunities across the basin using thematic cards, identifying region-specific risks such as sediment disruption, habitat degradation, and water quality issues. The final task introduced three future scenarios for the Danube basin, under which participants co-designed adaptation strategies aligned with each scenario. Together, these activities deepened stakeholder involvement and advanced the co-creation of a Safe Operating Space for the entire Danube basin.

3.1 Indicators and thresholds

During the World Café session, stakeholders discussed the indicators and thresholds proposed for assessing the Danube Basin's water functions. Key insights and recommendations for some of the discussed indicators and thresholds are summarized below by water function:

Water State Function

- *Environmental flows (Eflows)* were critically assessed. Stakeholders recommended renaming the indicator to "natural flow" or "minimum flow" and aligning it with the Common Implementation Strategy guidance under Article 31 of the Water Framework Directive (WFD). Some questioned whether eflows sufficiently capture floodplain and habitat conditions, and whether land-use-based indicators might be more representative.
- The *Aquifer Recharge Rate* also raised questions, with stakeholders asking for clearer definitions and possible renaming.

Water Regulatory Function

- For the *Natural Flow and MMFA* indicator, stakeholders requested clearer definitions and better communication of its role in assessing human impacts. The need for reliable datasets and methods to account for sediment continuity, especially below the Iron Gates, was stressed. Agricultural land use trends, potentially affecting flow regimes, were also discussed.
- Regarding the *Structural Connectivity index*, stakeholders advocated for integrating ecological criteria, such as habitat suitability, and simplifying terminology by referring to the indicator simply as "connectivity." They also highlighted the importance of addressing riverbed degradation and morphological alterations, suggesting floodplain reconnection and multipurpose reservoirs as potential solutions.

Water Productive Function

- For *Navigation*, one stakeholder offered detailed input including navigation day thresholds and percentile metrics. This information will be followed up for potential integration into the indicator design.
- For *Key Fish Habitat Suitability* stakeholders emphasized including temperature impacts, expanding the reference period, and integrating observational data. They stressed that restoration of connectivity is essential, although existing fishways are often inefficient. Projects like "Vpass2" were highlighted as successful examples, but it was also noted that habitat restoration must be coupled with efforts to combat poaching, pollution, and habitat degradation.

Water Supply Functions

- For *Water Supply Reliability*, stakeholders noted the challenge of defining historical thresholds due to temporal and geographic variability in water demand. They recommended disaggregating industrial and domestic supply, and emphasized the importance of reducing water losses, which are currently estimated at 64% in the whole Danube basin region.
- For the *Agricultural Water Demand* indicator, discussions focused on understanding actual water use and future irrigation trends. No threshold was proposed, but it was emphasized that policies and planned irrigation expansions—especially in Romania—will play a major role.

Water Chemical Carrier Function

- The indicator about pollutants and nutrient loads (*P and N concentrations*) was generally accepted due to the availability of clear thresholds (e.g., from the WFD). However, stakeholders highlighted the importance of expanding the range of substances considered to include emerging contaminants like PFAS and active hormones, if possible, and clarifying the control variable name as referring to nutrients (instead of chemical water status). Reference materials such as the Nitrate Directive, SIMONA project, and Danube sediment restoration efforts were proposed as data sources.

3.2 Current challenges, risks and opportunities

Figure 6. Danube Basin Map with the post-its and cards from the second and third task, listing stakeholders' identified challenges, risk, opportunities for the basin, and adaptation measure for scenario SSP5

In the second activity, participants worked in groups to identify spatially relevant risks and opportunities affecting the Danube's water functions (Fig. 6). Results can be found in Annex 6 and are here summarized as follows:

- In the Upper Danube, key risks included floods, droughts, climate variability, riverbed degradation, habitat fragmentation, and hydropower impacts. Opportunities were identified in restoring riparian wetlands and improving dam management.
- In the Middle Danube, biodiversity loss, pollution, riverbed degradation, increasing drought frequency and water overexploitation emerged as major concerns, alongside pressures from industry, tourism, and irrigation systems.

- The Lower Danube was highlighted for its vulnerability to pollution, coastal erosion, sediment disruption, and sea level rise. Stakeholders emphasized the importance of sediment management, wetland restoration, and water quality improvement.
- At the basin-wide level, common concerns included inefficient infrastructure, climate variability, and disrupted sediment transport.

4.3 Adaptation Pathways

The third task explored potential adaptation options under three plausible future scenarios for the Danube, based on the global Shared Socioeconomic Pathways (SSPs).

We here summarize some of the main points for each scenario. The full list of identified, spatially explicit adaptations is given in Annex 6.

- Under the **SSP5 (fossil-fuelled development)** scenario, adaptation options centered on high-tech but costly solutions, such as advanced fish pathways at major hydropower dams (e.g., Iron Gate I & II). Limited environmental ambition makes implementation of broad restoration strategies unlikely.
- In the **SSP3 (regional rivalry)** scenario, governance gaps and weak cooperation were major concerns, such as the absence of basin-wide allocation schemes. Participants suggested better enforcement of existing regulations, bilateral cooperation, and the creation of forest strips for water protection.
- The **SSP1 (sustainability)** scenario generated the most engagement. Proposed strategies included large-scale land use change and afforestation with compensation schemes, circular economy promotion (e.g., PET recycling in Romania), restoration of sediment flows, education initiatives, and implementation of the EU Nature Restoration Law. Other suggestions included restoring old fishing ponds and reconnecting floodplain areas in Romania.

Adaptation priorities varied across sub-basins (see Annex 6), but consistently emphasized the need for combined technological, ecological, and policy measures. The exercise provided a structured basis for aligning future actions with diverse development trajectories and resilience goals for the Danube Basin.

4. Next steps and outlook

The ongoing project is running until September 2026. One last workshop is planned where we will present the co-developed SOS framework for the Danube basin to the stakeholders.

The next steps are:

- Publication of this workshop report on the IIASA's publication repository PURE with access links to download the PDF presentations of the workshop (June 2025);

- Modelling of the Danube scenarios based on the results of the stakeholders' engagement;
- Evaluation of the different adaptation pathways;
- In the fourth and final workshop, the adapted SOS-Water framework and fine-tuned spatially optimized adaptation pathways will be presented to the stakeholders, along with exploring possibilities for ongoing partnerships and collaborations (tentatively scheduled for Autumn 2026).

ANNEX

Annex 1: Detailed Agenda

Annex 2: Preliminary modelling results

Annex 3: Revised objective hierarchy for the Danube Basin

Annex 4: List of challenges, risks and opportunities for the water functions in the Danube basin

Annex 5: List of potential adaptation measures, per group and water function

Annex 6: Results from workshop Task 2 and 3

Annex 1: Detailed Agenda

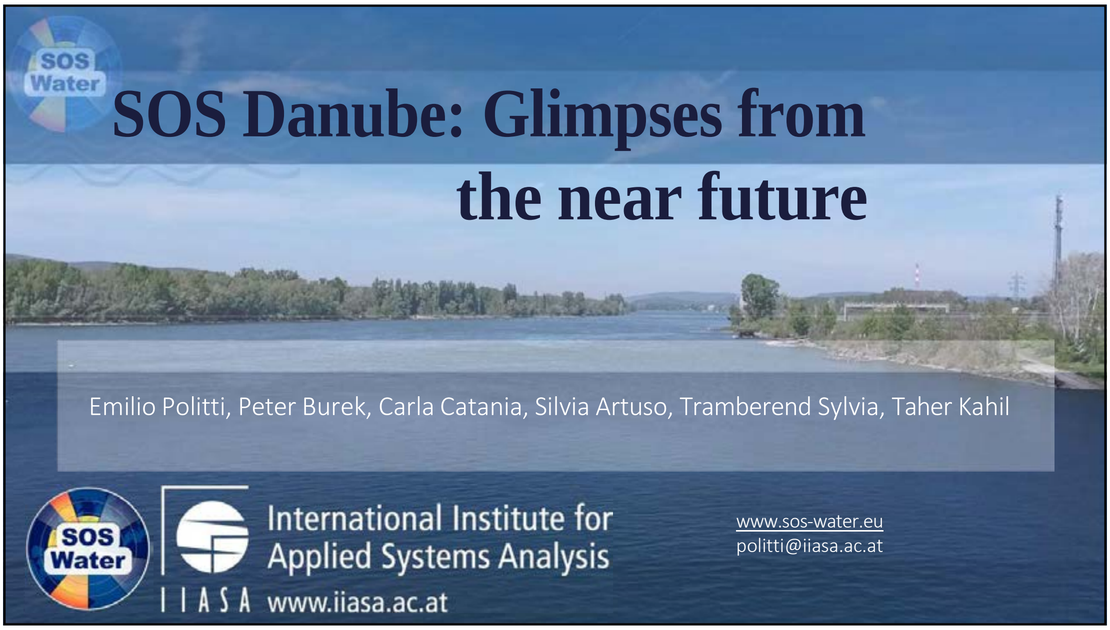
SOS-Water
Stakeholders' Engagement 2nd Workshop

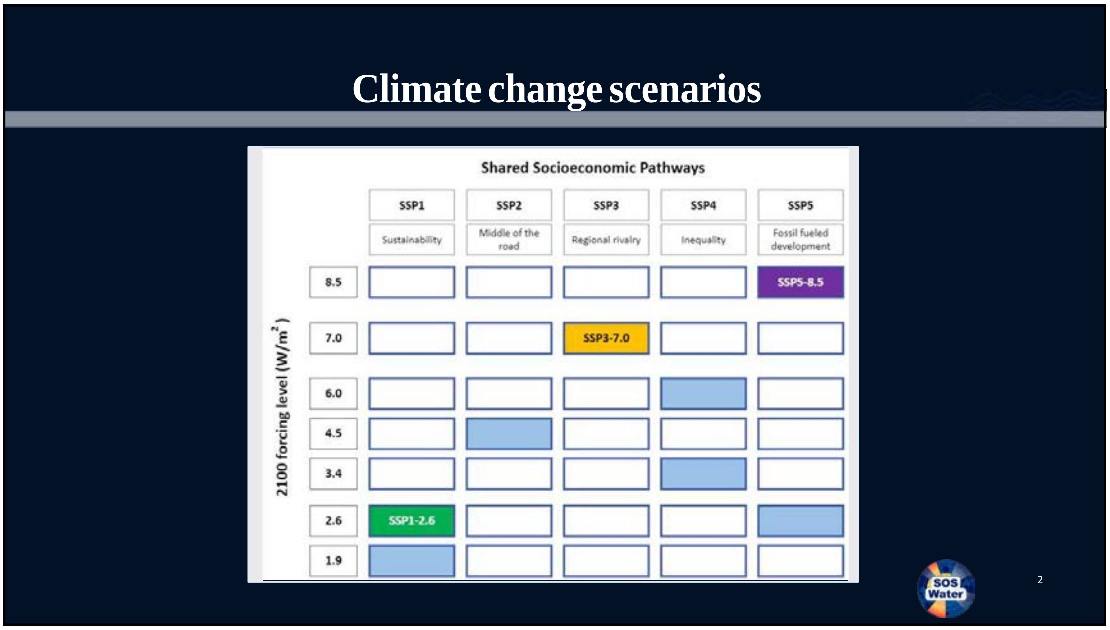
Wednesday 5th of March 2025, Vienna
Venue: Your office - Room Rhein (1st floor), Europlaza, Am Euro Platz 2, 1120 Wien

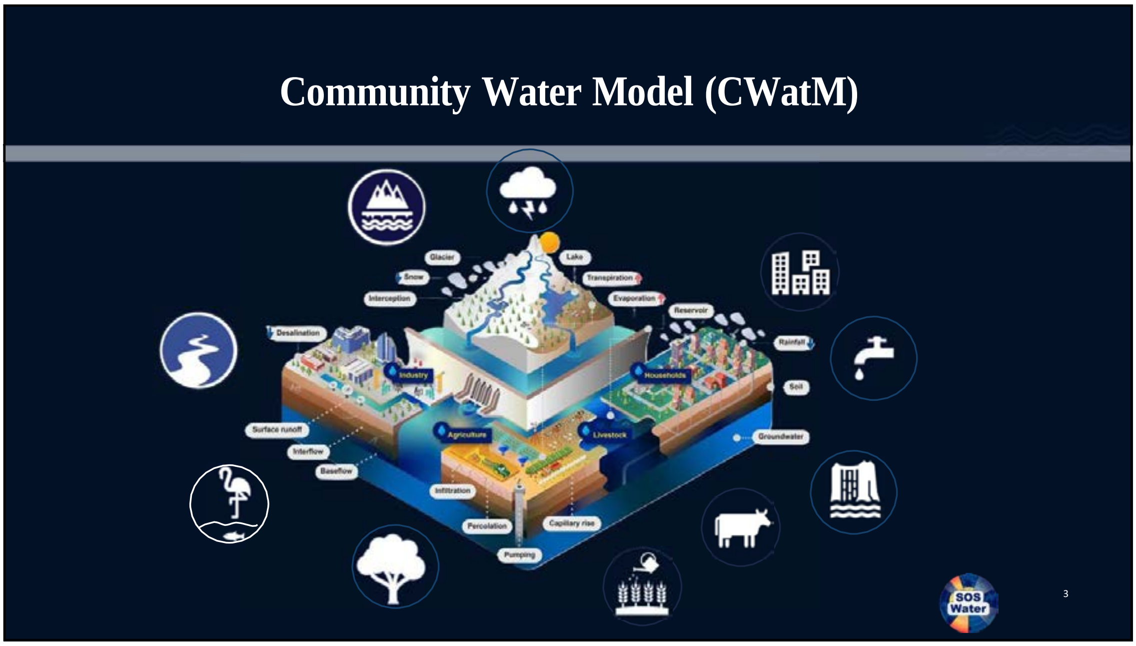
Agenda

From	To	
9:00	9:15	Registration and welcome coffee
9:15	9:30	Official welcome, participant introduction and agenda
9:30	9:45	SOS-Water project presentation
9:45	10:15	Main outcomes from the first workshop and presentation of the objectives hierarchy map for the Danube basin
10:15	11:00	Overview of the Danube basin modelling results
11:00	*11:20*	*Coffee break*
11:20	**12:35**	**First task: Validation and refinement of indicators and thresholds**
12:35	*13:15*	*Light Lunch*
13:15	**14:00**	**Second task: identify current challenges, risks and opportunities**
14:00	**14:45**	**Third task: identify future adaptation pathways**
14:45	15:15	Reporting back to the plenary
15:15	15:30	Conclusion and outlook

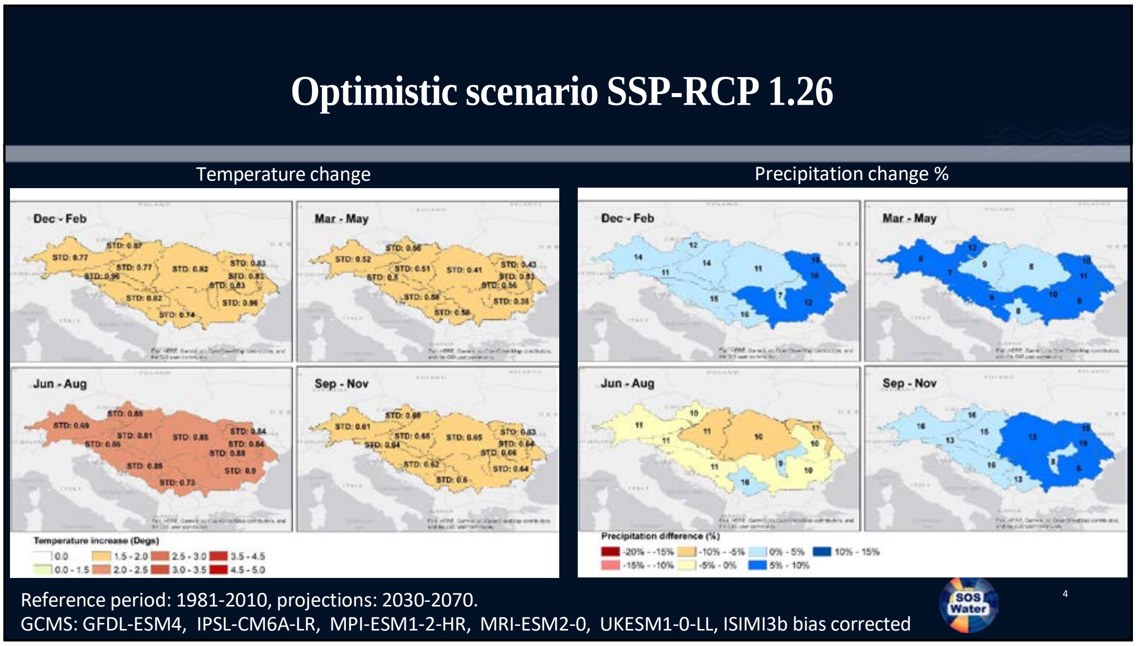
Annex 2. Preliminary modelling results







Community Water Model (CWatM)
Glacier
Snow
Interception
Lake
Transpiration
Evaporation
Reservoir
Desalination
Industry
Households
Rainfall
Soil
Surface runoff
Interflow
Baseflow
Agriculture
Livestock
Groundwater
Infiltration
Percolation
Capillary rise
Pumping
SOS Water
3

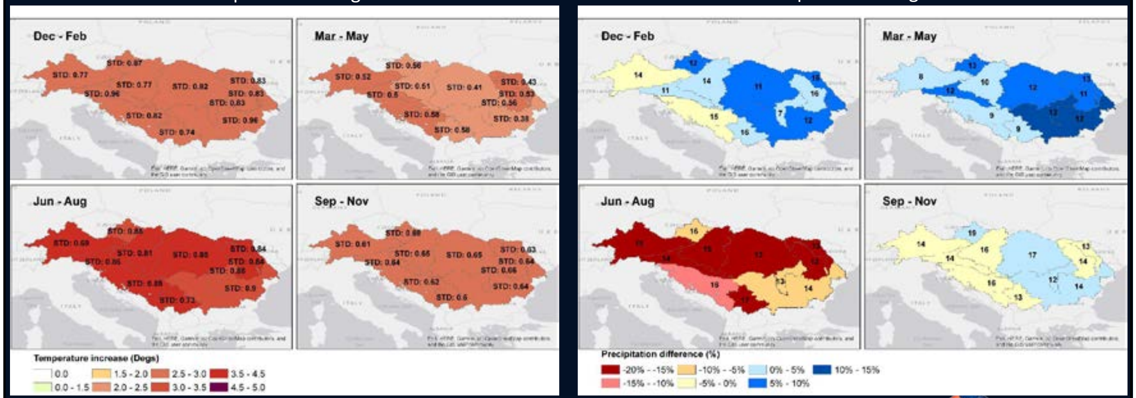


Optimistic scenario SSP-RCP 1.26
Temperature change
Precipitation change %
Dec - Feb
Mar - May
Jun - Aug
Sep - Nov
Temperature increase (Degs)
0.0
0.0 - 1.5
1.5 - 2.0
2.0 - 2.5
2.5 - 3.0
3.0 - 3.5
3.5 - 4.5
4.5 - 5.0
Precipitation difference (%)
-20% - -15%
-15% - -10%
-10% - -5%
-5% - 0%
0% - 5%
5% - 10%
10% - 15%
Reference period: 1981-2010, projections: 2030-2070.
GCMS: GFDL-ESM4, IPSL-CM6A-LR, MPI-ESM1-2-HR, MRI-ESM2-0, UKESM1-0-LL, ISIMI3b bias corrected
SOS Water
4

Pessimistic SSP-RCP 5.85

Temperature change

Precipitation change %

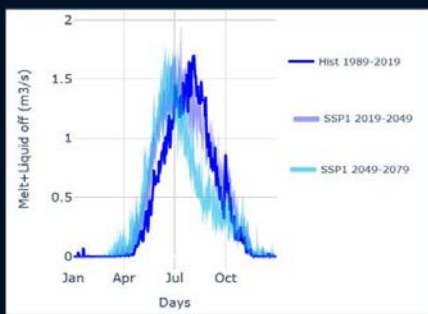


Reference period: 1981-2010, projections: 2030-2070.
GCMS: GFDL-ESM4, IPSL-CM6A-LR, MPI-ESM1-2-HR, MRI-ESM2-0, UKESM1-0-LL, ISIMI3b bias corrected

SOS Water

5

Glacier melting effect on yearly discharge



SOS Water

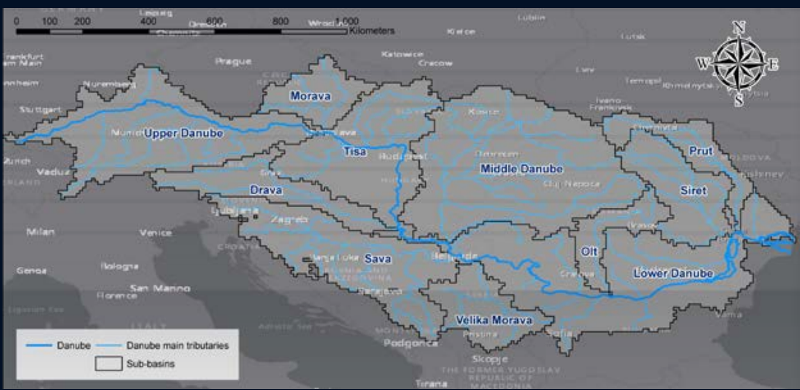
6

Indicators

Function	Process	Indicator
Regulatory functionality	Natural flow regime	Monthly mean flow alteration
	Longitudinal connectivity	Structural connectivity
Water state	Uphold state	Aquifers recharge
	Drought resilience	Resilience index
	Extreme flood events	High pulses duration
	Ecosystem state	Implemented eflows
Water supply	Sectoral water demand	Met demand
	Agricultural demand	Met demand
	Renewable supply	Share of demand met by renewable
Productivity	Navigation	Navigable days/year
	Habitat	Habitat availability
Chemical loads	Chemical status	WFD limits

7

Sub-basins analysis scale



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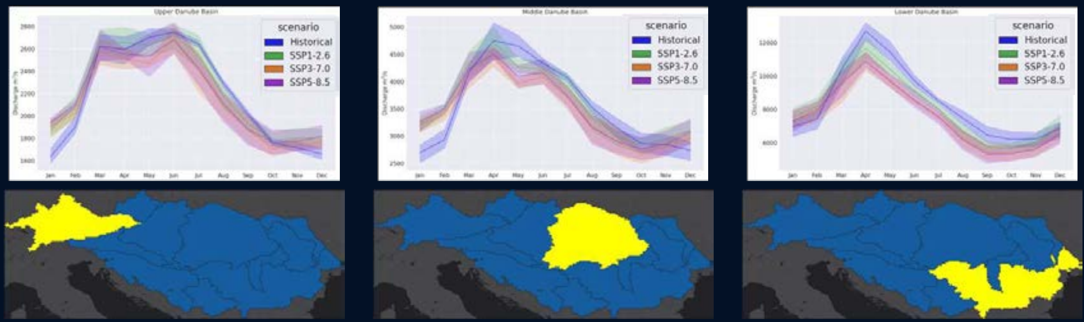
Mean monthly discharge

Upper Danube | Middle Danube | Lower Danube

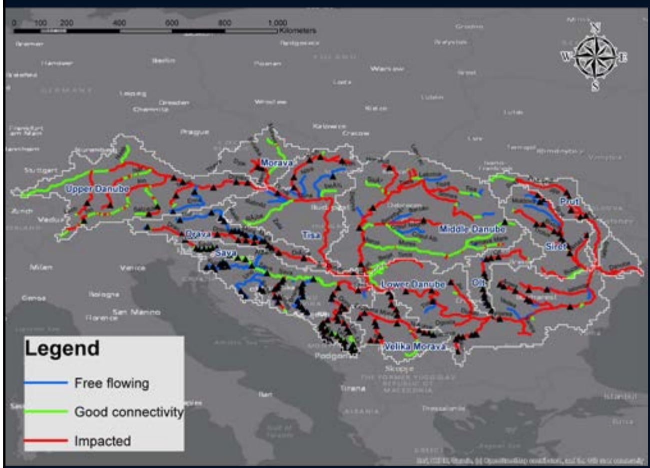


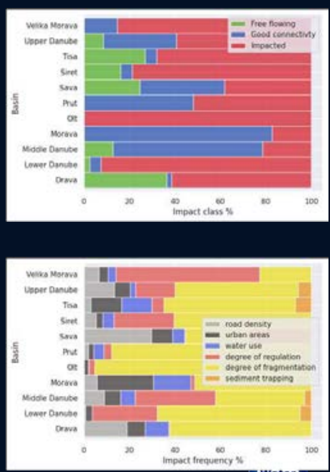
Reference period: 1981-2010, projections: 2030-2070

9

Regulatory

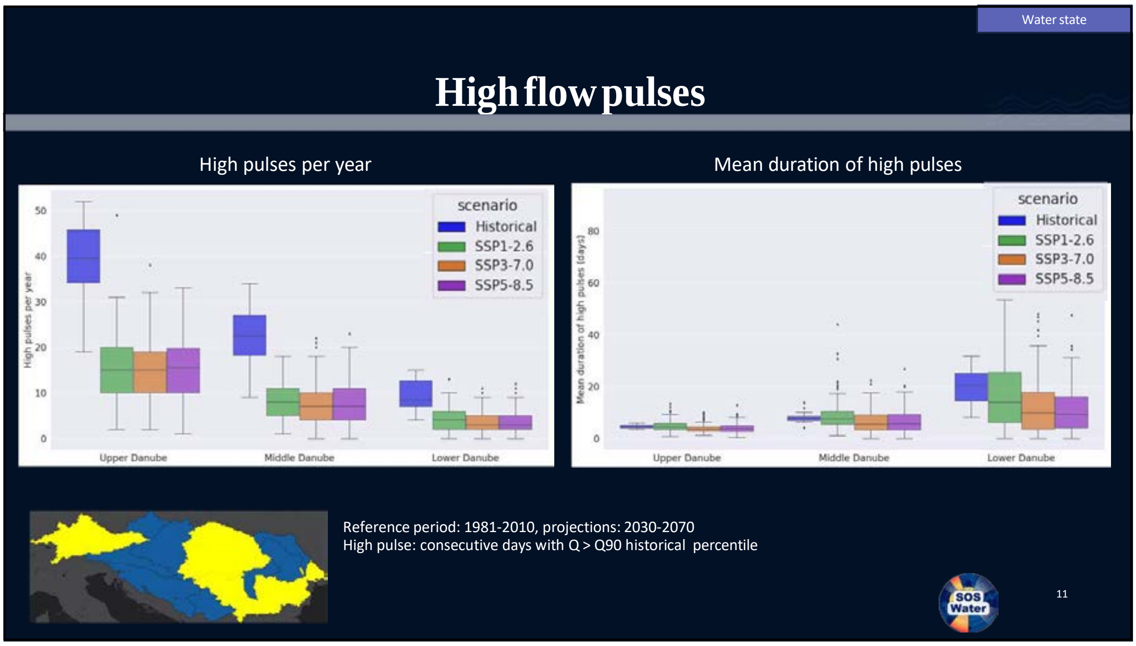
Connectivity Status Index



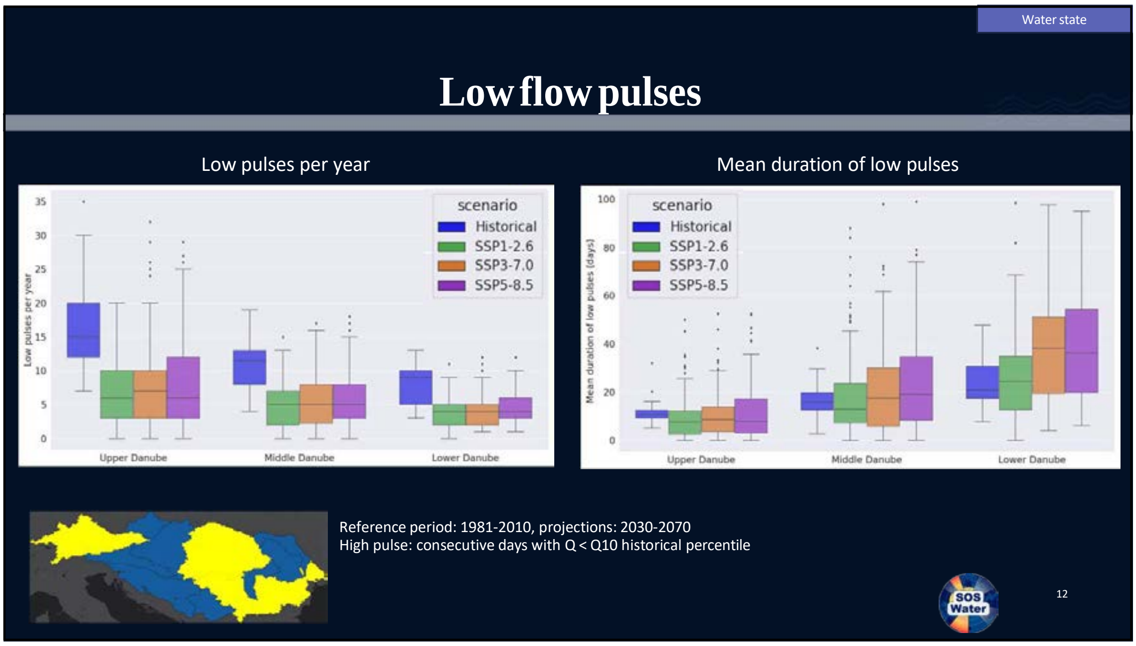


10

Grill, G., Lehner, B., Thieme, M. et al. Mapping the world's free-flowing rivers. Nature 569, 215–221 (2019). https://doi.org/10.1038/s41586-019-1111-9



Water state
High flow pulses
High pulses per year
Mean duration of high pulses
scenario
Historical
SSP1-2.6
SSP3-7.0
SSP5-8.5
Upper Danube
Middle Danube
Lower Danube
Reference period: 1981-2010, projections: 2030-2070
High pulse: consecutive days with Q > Q90 historical percentile
SOS Water
11



Water state
Low flow pulses
Low pulses per year
Mean duration of low pulses
scenario
Historical
SSP1-2.6
SSP3-7.0
SSP5-8.5
Upper Danube
Middle Danube
Lower Danube
Reference period: 1981-2010, projections: 2030-2070
High pulse: consecutive days with Q < Q10 historical percentile
SOS Water
12

Water supply

Water supply reliability

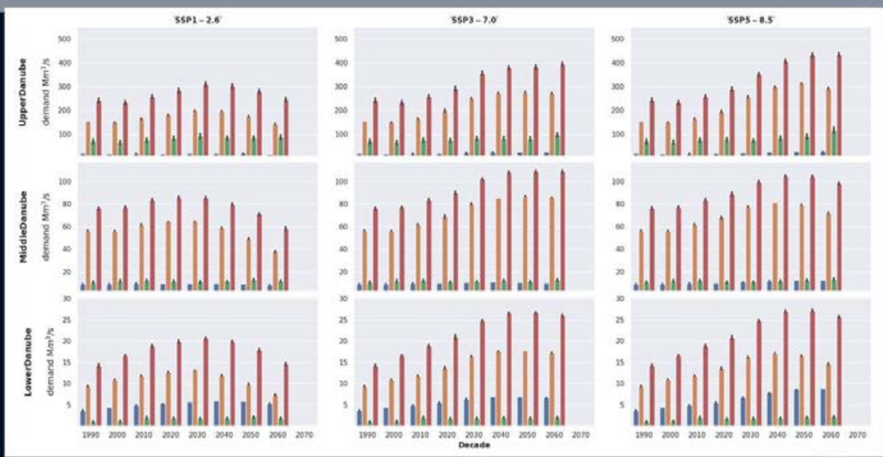
Sub basin	Scenario	Mean deficits year	std
Sava	Historical	0.1	0.0
	SSP126	0.0	0.0
	SSP370	0.1	0.1
	SSP585	0.2	0.2
Upper Danube	Historical	0.0	0.0
	SSP126	0.0	0.0
	SSP370	1.4	0.6
	SSP585	1.6	0.4
Velika Morava	Historical	0.3	0.2
	SSP126	0.0	0.0
	SSP370	0.2	0.2
	SSP585	0.3	0.3

Months in a year when water demand in the basin exceeds the supply

13

Water supply

CWatM projected withdrawal



Estimated mean decadal withdrawal by sector and total

14

Carrier

Total N and P – without policies

- SWOT global runs
- 30 ArcMins (~50 km)
- 4 GCMs
- WFD thresholds

Total N GFDL-ESM2M

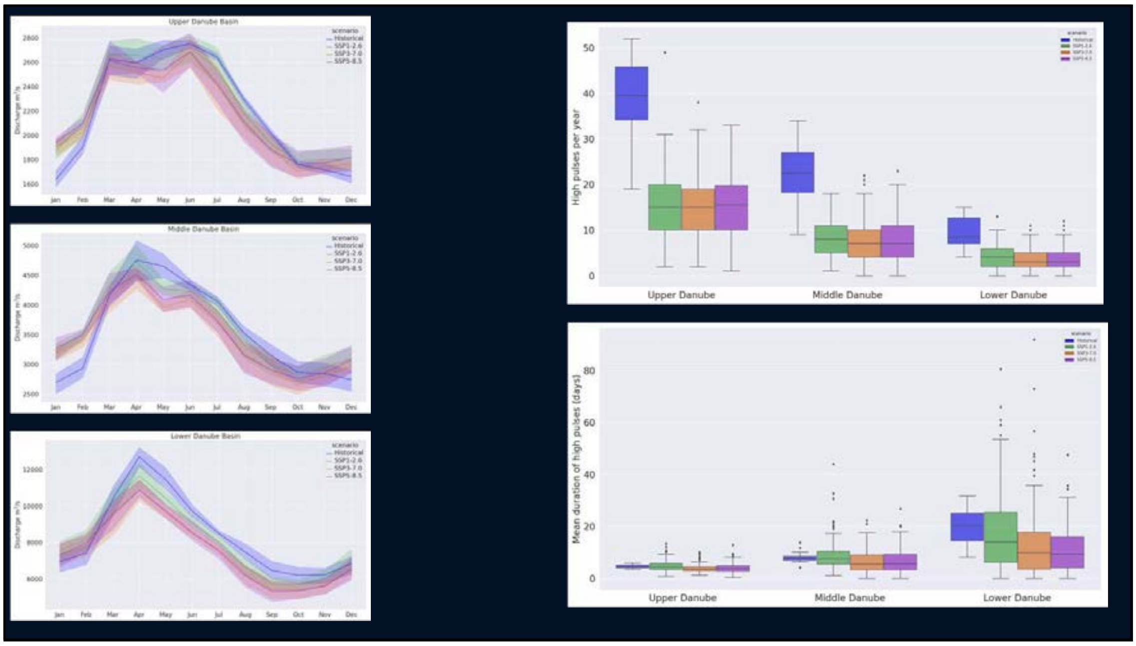
15

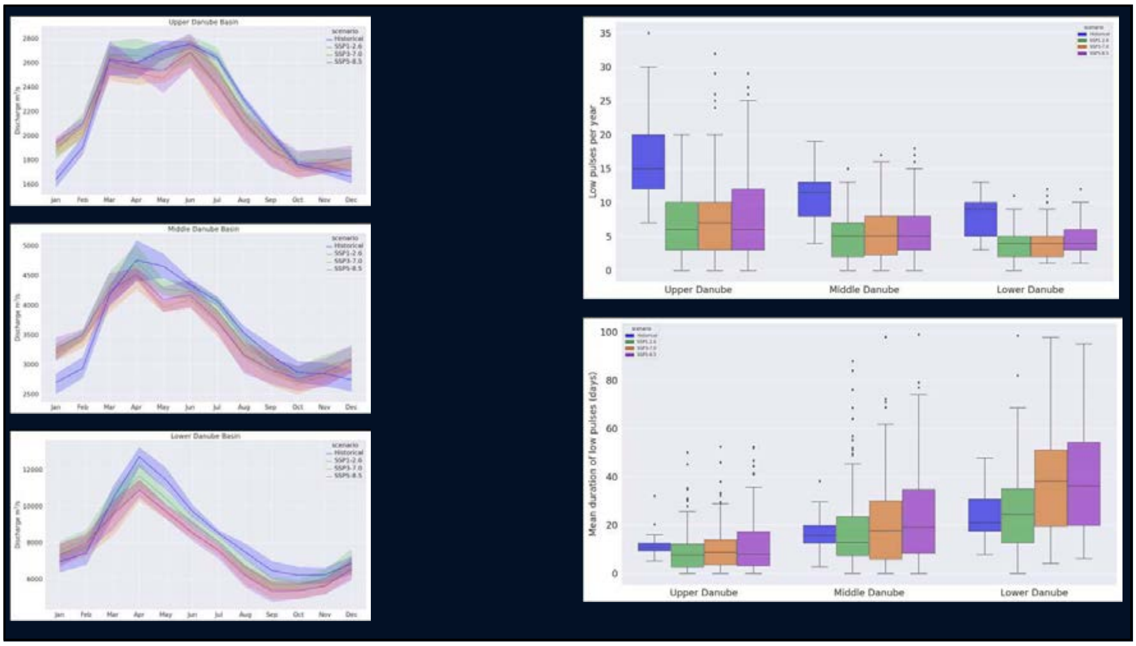
Key points for SSPs

Impact	SSP1-2.6			SSP3-7.0			SSP5-8.5		
	Up	Mid	Low	Up	Mid	Low	Up	Mid	Low
Temperature rise									
Higher but erratic precipitation									
Less high flows									
Lower high flows duration									
Less low pulses									
Higher variability of low pulses duration									
Higher low flow pulses duration									
Industry and domestic supply reliability									
Water quality is at high risk									
Connectivity is a major impact									

High
Med
Low
Positive

16


Upper Danube Basin
Middle Danube Basin
Lower Danube Basin
High pulses per year
Mean duration of high pulses (days)
Upper Danube
Middle Danube
Lower Danube


Upper Danube Basin
Middle Danube Basin
Lower Danube Basin
Low pulses per year
Mean duration of low pulses (days)
Upper Danube
Middle Danube
Lower Danube

Fish in the Danube: habitat suitability modelling and impacts of climate change

Jaime García (IGB), Sami Domisch (IGB), Katarina Cetinic (NIVA)

www.sos-water.eu

SOS WATER – Stakeholder Workshop
Vienna, 5 March 2025

IGB
Leibniz Institute of Freshwater Ecology and Inland Fisheries

NIVA
Norwegian Institute for Water Research

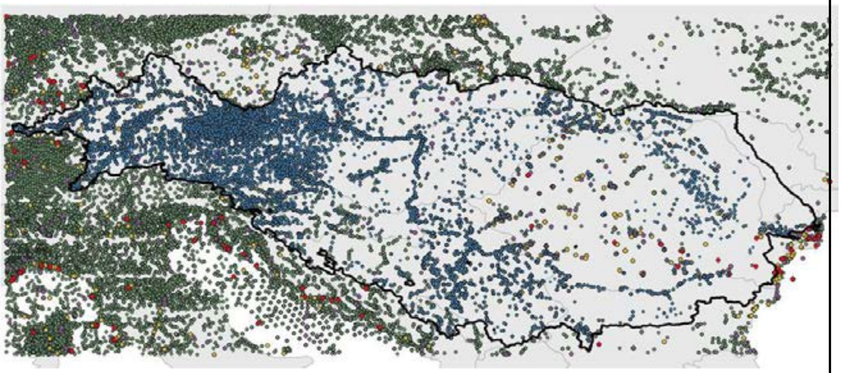
OBJECTIVES

- **Map the habitat suitability of key f sh species in the whole basin**
- **Quantify the impacts of environmental change scenarios on fish habitat suitability**
- **Incorporate the results as a component to identify the Safe Operating Space**

2

Species selection & fish occurrence location

- 52 fish species
- Status in red list
- Endemic
- Migratory
- Economic / cultural value



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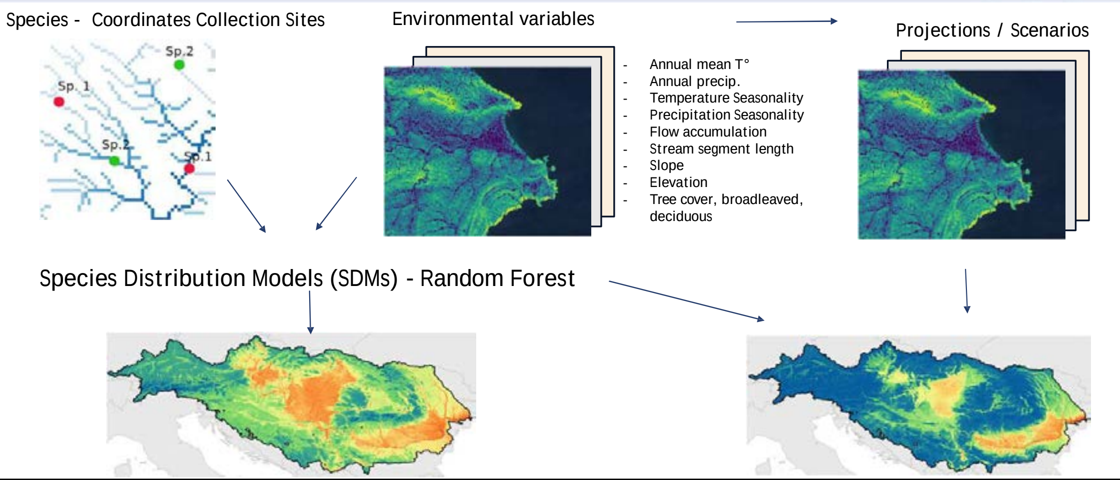
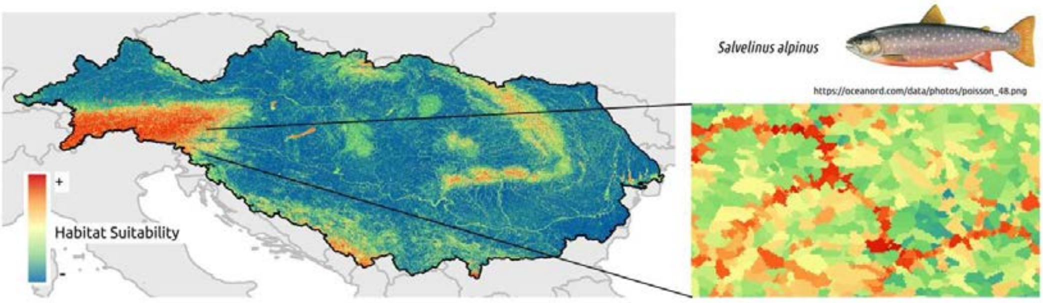
Habitat suitability mapping of fish species



Habitat Map Salvelinus alpinus

The arctic char, saibling



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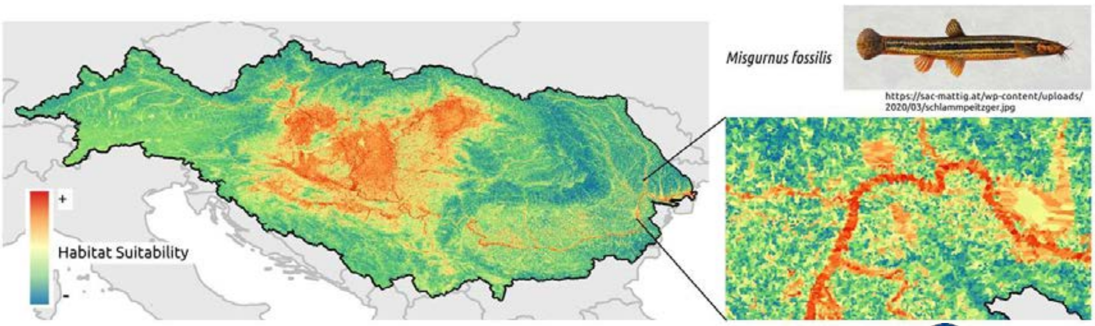
Habitat Map Misgurnus fossilis

weatherfish, schlammpeitzger



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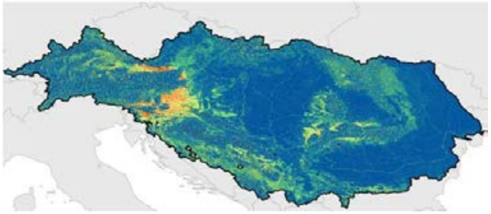
Impacts of climate change **Hucho hucho**

Danube salmon or redfish

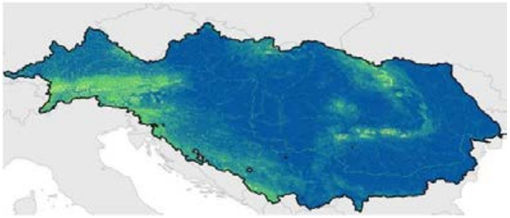
https://es.wikipedia.org/wiki/Hucho

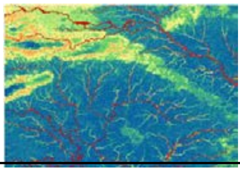
Example with climate scenarios 2071-2100 ukesm1-0-ll ssp5

Reference condition



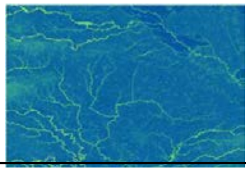
Future projections





High Hab Suitability

Low Habitat Suitability



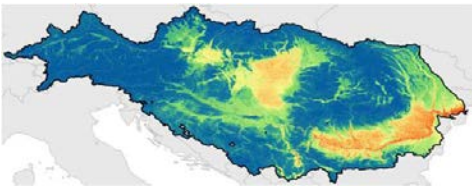
7

Huso huso

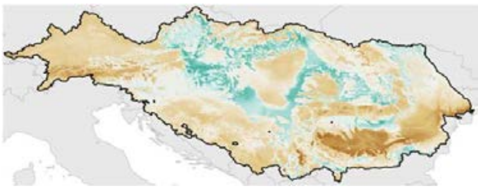
European Sturgeon; Giant Sturgeon

https://animaldiversity.org/accounts/Huso_huso/

Reference condition



Future projection - Reference condition



High Habitat Suitability

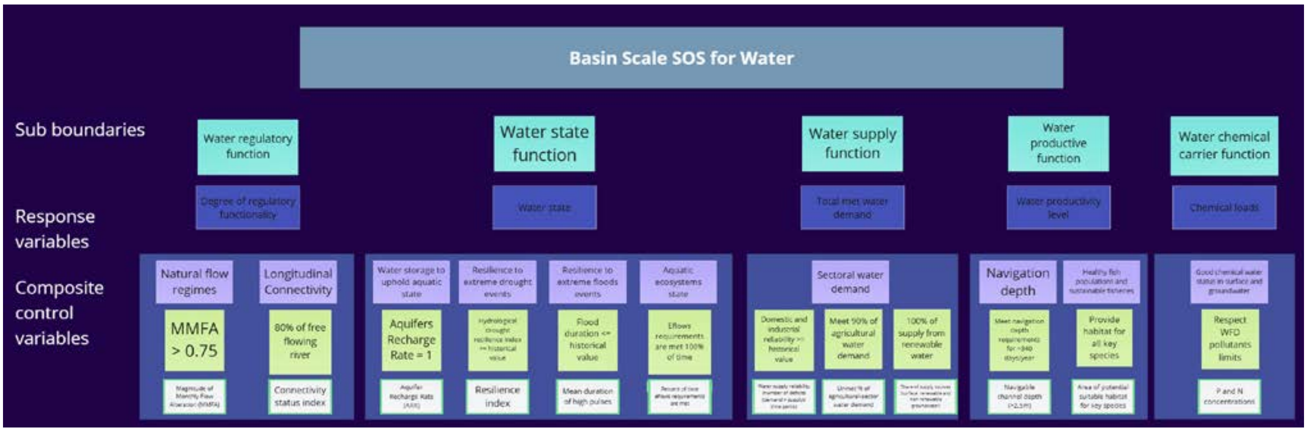
Low Habitat Suitability

Gains in Habitat Suitability

Losses in Habitat Suitability

8

Annex 3: Revised objective hierarchy map for the Danube basin



Annex 4: List of challenges, risks and opportunities for the water functions in the Danube basin

Type of Variables	Sub-types	Cards
Resources	Water resources	Surface water
Resources	Water resources	Groundwater
Resources	Water resources	Reclaimed water
Resources	Land Use	Forest
Resources	Land Use	Wetland
Resources	Land Use	Irrigated area under irrigation
Resources	Land Use	Protected area & Biodiversity Site
Socio-economic activities	Services	Transportation
Technologies and infrastructure	Water	Dams
Technologies and infrastructure	Energy	Hydropower
Technologies and infrastructure	Agriculture	Gravity irrigation
Technologies and infrastructure	Agriculture	Drip irrigation
Technologies and infrastructure	Agriculture	Sprinkler irrigation
Technologies and infrastructure	Agriculture	Center pivot irrigation
External drivers/risks	Environmental	Drought
External drivers/risks	Environmental	Floods
External drivers/risks	Environmental	Aridity
External drivers/risks	Environmental	Intra-annual variability
External drivers/risks	Environmental	Inter-annual variabiluty
Internal drivers/risks	Environmental	Biodiversity loss
Internal drivers/risks	Environmental	Water Pollution
Governance	Management	Irrigation use efficiency
Governance	Management	Water supply and sanitation efficiency
Governance	Management	Surface water storage
Governance	Management	Groudnwater storage
Governance	Management	Nature-based solutions
Governance	Management	Wastewater
Governance	Management	Non-conventional sources of water
Governance	Governance	Water fee
Governance	Governance	Irrigation development
Governance	Governance	Irrigation modernization
Governance	Governance	Protected area

Note: each card could be used either as risk/challenge or as an opportunity, depending on stakeholders perspective.

Annex 5: List of potential adaptation measures, per group and water function

Group 1: LIST OF MEASURES LINKED TO WATER STATE/STORAGE FUNCTIONS

Category	#	Measure
Improved water retention capacity in the agricultural landscape	3	AO-05.04 – On-farm water storage (soil moisture, groundwater, surface)
	4	AO-05.05 – Restoring natural water retention spaces (ponds, lakes, reservoirs)
	5	AO-05.06 – Setting up flood control reservoirs or water impoundments
	6	AO-05.07 – Terracing and contour ploughing
Rehabilitation and restoration of rivers and floodplains	11	AO-13.01 – Adaptation of dredging practices
	12	AO-13.02 – Improving water storing capacity in floodplains (Natural Water Retention Measures)
	13	AO-13.03 – Removal of damming, levees, embankments, constructions and infrastructure on the floodplain
	14	AO-13.04 – Floodplain reconnection for flood attenuation (Room for the River, Re-Meandering)
	16	AO-13.08 – Natural retention ponds in headwater areas
Establishment and restoration of riparian buffers	18	AO-15.01 – Riparian Buffers and Wetland Restoration
Restoration and management of coastal wetlands	20	AO-16.01 – Diverting waterways, dredging sediments, and maintaining natural canals and channels
	22	AO-16.03 – Rewetting of Wetlands Drained in the Past
Water sensitive forest management	24	AO-17.05 – Peak flow control structures in forest areas
Groundwater management	28	AO-22.01 – Conjunctive management of water sources
	29	AO-22.02 – Managed Aquifer Recharge
	30	AO-22.03 – Techniques to Restore and Increase Natural Infiltration Capacity

GROUP 2: LIST OF MEASURES LINKED TO WATER REGULATORY AND PRODUCTION FUNCTIONS

Category	#	Measure
Rehabilitation and restoration of rivers and floodplains	11	AO-13.01 – Adaptation of dredging practices
	13	AO-13.03 – Removal of damming, levees, embankments, constructions and infrastructure on the floodplain
	14	AO-13.04 – Floodplain reconnection for flood attenuation (Room for the River, Re-Meandering)
	15	AO-13.06 – Implementing and enforcing environmental flows
	17	AO-13.09 – Removal or lowering of old dams and weirs

Establishment and restoration of riparian buffers	18	AO-15.01 – Riparian Buffers and Wetland Restoration
	19	AO-15.04 – Natural Bank Stabilization
	21	AO-16.02 – Waterway Diversion and Sediment Transport Management
	22	AO-16.03 – Rewetting of Wetlands Drained in the Past
Improve the functional connectivity of ecological networks	25	AO-18.01 – Green Infrastructure for Ecological Connectivity
	26	By-Pass Channels
Groundwater management	29	AO-22.02 – Managed Aquifer Recharge
	30	AO-22.03 – Techniques to Restore and Increase Natural Infiltration Capacity
Adaptation of hydropower plants	9	AO-10.04 – Hydropower Spillway Flow Regulation
Governance	37	AO-31 – Water Allocation Frameworks
Management	38	AO-00 – Adjusting Dam Operations

GROUP 3: LIST OF MEASURES LINKED TO WATER SUPPLY AND CARRIER AND CHEMICAL LOADS

Category	#	Measure
Improvement of irrigation efficiency	1	AO-03.01 – Improved conveyance efficiency (irrigation)
	2	AO-03.02 – Shift from gravity irrigation to pressurized systems
Improved water retention capacity in the agricultural landscape	6	AO-05.07 – Terracing and contour ploughing
Water sensitive urban and building design	7	AO-07.06 – Upgrading infrastructures (urban)
	8	AO-07.07 – Water conservation measures in urban areas (e.g., water efficiency and awareness raising)
Desalinisation	27	AO-21.01 – Desalination
Groundwater management	28	AO-22.01 – Conjunctive management of water sources
	29	AO-22.02 – Managed Aquifer Recharge
Water reuse	33	AO-25.01 – Water Reuse
	34	AO-25.03 – Grey Water Recycling
	35	AO-25.04 – Closed Water Reuse Circuits in Industries
Capacity building	36	AO-30 – Capacity Building on Water Management Strategies
Governance	37	AO-31 – Water Allocation Frameworks
Management	38	AO-00 – Adjusting Dam Operations

Annex 6: Results from workshop Task 2 and 3

Upper Danube

Risks and opportunities	Climate variability Droughts Floods Habitat fragmentation Hydropower Important biodiversity sites Industrial pollution Industry cooling Intensive agriculture (nutrient load) Irrigated land Lodging Multipurpose dams Riparian wetlands Riverbed degradation Water pollution

Adaptation measures

SSP5	Adjusting Dam Operations Flexible low water repopulation infrastructure Multipurpose reservoirs On-farm water storage (soil moisture, groundwater, surface) Peak flow control structures in forest areas Riparian Buffers and Wetland Restoration Setting up flood control reservoirs or water impoundments
SSP3	Adjusting Dam Operations
SSP1	Floodplain reconnection for flood attenuation (room for the river, re-meandering) Improving water storing capacity in floodplains (Natural Water Retention Measures) Natural retention ponds in headwater areas Removal of damming, levees, embankments, constructions and infrastructure on the floodplain Restoring natural water retention spaces (ponds, lakes, reservoirs) Riparian Buffers and Wetland Restoration

Middle Danube

Risks and opportunities	Biodiversity loss Climate variability Droughts Extraction industry Floods Groundwater Hydropower Important biodiversity sites Industry Irrigation Irrigation channels Military (soil pollution, infrastructure destruction) Multipurpose dam, Navigation Non-conventional sources of water Riparian wetlands Riverbed degradation Tourism Waste management (floating plastic) Water overexploitation Water pollution

Adaptation measures

SSP5	Adjusting Dam Operations Flexible low water repopulation infrastructure Floodplain enlargement (wider) and floodplain reconnection Managed Aquifer Recharge (through lateral connectivity and vertical) On-farm water storage (soil moisture, groundwater, surface) Peak flow control structures in forest areas Riparian Buffers and Wetland Restoration Sediment management through effective dam management Shift from gravity irrigation to pressurized systems
SSP3	Grey Water Recycling Multipurpose dams On-farm water storage (soil moisture, groundwater, surface) Public water supply-specific plans (water restriction)
SSP1	Adaptation of dredging practices Detached groins and rip raps

	Floodplain reconnection for flood attenuation (Room for the River) Gravel island Managed Aquifer Recharge (Re-Meandering) Restoring natural water retention spaces (ponds, lakes, reservoirs) Riparian Buffers and Wetland Restoration Sidearm reconnection Techniques to Restore and Increase Natural Infiltration Capacity

Lower Danube

Risks and opportunities	Biodiversity restoration Chemicals Climate variability Coastal erosion Droughts Extraction industry Floods Gravity irrigation (if using groundwater) Groundwater Habitat fragmentation Hydropower Important biodiversity sites Industry Irrigation Irrigation channels Military (soil pollution, infrastructure destruction) Multipurpose dams Navigation Nuclear powerplant Primary wastewater treatment Riparian wetlands Risk of sprinkler irrigation Sea level rise Sediment management Tourism Water overexploitation Water pollution Water quality degradation and pollution

Adaptation measures

SSP5	Adjusting Dam Operations Desalinization (if cheaper) Diverting waterways Dredging sediments, and maintaining natural canals and channels, Flexible low water repopulation infrastructure Floodplain enlargement (wider) and floodplain reconnection Managed Aquifer Recharge (through lateral connectivity and vertical) On-farm water storage (soil moisture, groundwater, surface) Sediment management through effective dam management Setting up flood control reservoirs or water impoundments Shift from gravity irrigation to pressurized systems Strengthen regulatory framework Water reuse
SSP3	Adaptation of dredging practices Area reconnections (Green Infrastructure for Ecological Connectivity) Center pivot irrigation Drip irrigation Floodplain reconnection for flood attenuation (Room for the River, Re-Meandering) Forest curtains to stop diversification Gravity irrigation Groundwater Implementing and enforcing environmental flows Improving water storing capacity in floodplains (Natural Water Retention Measures) Increase biodiversity sites Increase forest Increase riparian wetlands Natural Bank Stabilization On-farm water storage (soil moisture, groundwater, surface) Reducing water consumption for cooling thermal generation plants Removal of damming, levees, embankments, constructions and infrastructure on the floodplain Rewetting of Wetlands Drained in the Past Terracing and contour ploughing

	Use more local and small water resources (not from the main river) Hydropower Spillway Flow Regulation
SSP1	Diverting waterways, dredging sediments, and maintaining natural canals and channels Floodplain reconnection for flood attenuation (Room for the River, Re-Meandering) Improving water storing capacity in floodplains (Natural Water Retention Measures) On-farm water storage (soil moisture, groundwater, surface) Preserving and restoring reproduction sites for sturgeons Removal of damming, levees, embankments, constructions and infrastructure on the floodplain Restoring natural water retention spaces (ponds, lakes, reservoirs) Restoring sediments supply Rewetting of Wetlands Drained in the Past Riparian Buffers and Wetland Restoration Stop poaching (this could be achieved through education but in general with a higher quality of life for the people) Water reuse

Whole Danube

Risks and opportunities	Climate variability Inefficient water infrastructures (loss) Sediment transport and morphology Surface water Transportation

Adaptation measures

SSP5	100 % domestic water recycling, High technological wastewater systems Select primarily the high-technical measures
SSP3	Better enforcement of current regulations Bilateral meetings take place Conjunctive management of water sources Generate forest strips (curtains) next to surface water

	Improve international cooperation
	Improving science-policy interface
	Lack of water allocation schemes on Danube River
	Reducing water consumption for cooling thermal generation plants
	Resilient hydropower management for different discharge regimes
	Rewetting of Wetlands Drained in the Past
	Riparian Buffers and Wetland Restoration
	Small restoration projects
	Strengthening education and capacity building
	Wastewater reuse
	Water allocation framework
	Water conservation measures in urban areas (e.g., water efficiency and awareness raising)
	Water retention efficiency
SSP1	Adaptation of dredging practices
	Adopt the Polluter Pays Principle
	Build community-based activities and water treatment plants
	Capacity building
	Compensation schemes
	Easy access to funds for efficient water management
	Easy financing
	Ecological training in schools
	Economic incentives for individuals
	High degree of digitalization and modernization
	Improved weather forecasting systems
	Improving water quality
	Increase education
	Introducing longer and larger bypass systems
	Large scale land use changes to increase forest cover with compensation schemes during the first years
	Large scale river restoration projects
	PET recycling factory
	Precision farming and irrigation using remote sensing soil information
	Promote Circular Economy
	Promote other forms of green energy
	Reducing water consumption for cooling of thermal generation plants
	Replace harmful chemicals in industry
	Sewage treatment plants become resource recovery units

	Substitute/dismantle old and obsolete dams and barriers
	Terracing and contour ploughing
	Water conservation measures in urban areas (e.g., water efficiency and awareness raising)