SOS-Water deliverable report

D1.1 Case study-specific stakeholder engagement roadmaps

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Authors

Authors	Partner no	Partner organisation	Name of author
Main author	10	NIVA	Katarina Ana Cetinic
Contributing author(s)	10	NIVA	Simone Daniela Langhans
	5	IGB	Jaime Garcia Marquez
	5	IGB	Sami Domisch

Review

Authors	Partner no	Partner organisation	Name of author
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Publishable Executive Summary

The SOS-Water project addresses the escalating pressure on global freshwater resources due to rising demands and climate change-induced impacts. The central objective of SOS-Water is to define a safe operating space (SOS) for water resources by engaging stakeholders in developing a comprehensive framework that assesses the environmental, social, and economic dimensions of water systems. This is achieved by co-creating objectives hierarchies and indicators that will be integrated into hydrological models.

The project focuses on five case studies – four in Europe (the Júcar River Basin, the Rhine River and the Rhine-Meuse Delta, the Upper Danube, and the Danube Delta) and one in Asia (the Mekong Delta). Case study leaders were selected within each case study to establish a local stakeholder community. Stakeholder engagement is a core component of SOS-Water, involving both high-level (e.g., policymakers) and low-level stakeholders (e.g., local communities). The engagement process is based on Multi-Criteria Decision Analysis (MCDA) – a community-driven decision-making framework that fosters trust, transparency, and inclusivity, ensuring that diverse perspectives and needs are considered in decision-making. Using this framework, stakeholder engagement in the SOS-Water project follows a series of systematic steps (problem framing, stakeholder mapping, and the co-

development of objectives hierarchies) to define objectives and indicators that reflect the stakeholders' values and concerns.

The SOS-Water case studies are in varying stages of progress. The case studies in the Danube, as well as the Mekong case study are advanced and planning stakeholder workshops. The Rhine case study is currently in the early stages of identifying key stakeholders, while the Júcar River Basin case study is leveraging the GoNEXUS project to streamline stakeholder engagement.

In conclusion, the SOS-Water project employs stakeholder engagement and MCDA to develop a holistic framework for sustainable water resource management. By co-creating objectives hierarchies and integrating stakeholder input into hydrological models, the project aims to create actionable solutions that balance environmental, social, and economic considerations, safeguarding water resources for future generations.

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1. Description of the SOS-Water Project

The pressure on water resources worldwide has been increasing due to factors such as rising food and energy demands, improving living standards, and challenges in water governance. This has led to severe environmental consequences, including water scarcity, degradation of ecosystems, and conflicts between nations and communities. Climate change is expected to exacerbate these issues by reducing water availability and increasing the frequency of extreme events like droughts and floods[1].

To address these challenges and achieve sustainable development goals, there is a need to define a safe operating space (SOS) for water resources. The SOS concept aims to identify tipping points leading to large-scale and irreversible environmental changes, while at the same time maintain equitable levels of well-being for mankind. Various analytical frameworks have been developed to assess the SOS for water resources globally, but their implementation at local and regional scales has been limited[2]. These frameworks often lack comprehensive integration of relevant dimensions of the water system and fail to consider multiple objectives and stakeholder engagement.

The SOS-Water project will follow an inclusive and iterative participatory approach, involving stakeholders in defining visions, values, and management options. The project will develop a comprehensive set of indicators to assess the environmental, social, and economic aspects of the water system and enable the evaluation of trade-offs and feedbacks between different dimensions.

The goal of SOS-Water is to create an accessible and actionable framework that addresses water scarcity, quality degradation, biodiversity loss, governance inefficiencies, and equity issues. It will consider various spatial and temporal scales to provide a comprehensive understanding of the complex natural-human water system. The project brings together expertise from multiple disciplines and aims to foster collaboration and co-development of scenarios and management pathways.

[1] Garrote, L. (2017). Managing water resources to adapt to climate change: Facing uncertainty and scarcity in a changing context. *Water Resources Management*, *31*(10), 2951-2963. doi:10.1007/s11269-017-1714-6

[2] Bunsen, J., Berger, M., & Finkbeiner, M. (2021). Planetary boundaries for water – A review. *Ecological Indicators, 121,* 107022. doi:10.1016/j.ecolind.2020.107022

2. Description of the SOS-Water Case Studies

2.1. The Júcar River Basin

Case study leader(s): *Manuel Pulido-Velazquez (Technical University of Valencia – UPV, Spain)*

Considered study area for SOS-Water: *Entire catchment*

Involved countries: *Spain*

Previous engagement with stakeholders in the area: *IMPADAPT, ADAPTAMED (previous projects); GoNEXUS, eGROUNDWATER (ongoing projects)*

The Júcar River Basin (JRB) is a significant watercourse in Eastern Spain, flowing through the autonomous communities of Castilla La Mancha and Valencia. It stretches over a length of 512 km from its source at Ojuelos de Valdeminguete in Montes Universales, a mountain range in the Sierra de Albarracin, and has a drainage area of 22,260 km^2 (Figure 1). Its main tributaries are the Cabriel, Albaida, and Magro rivers[3].

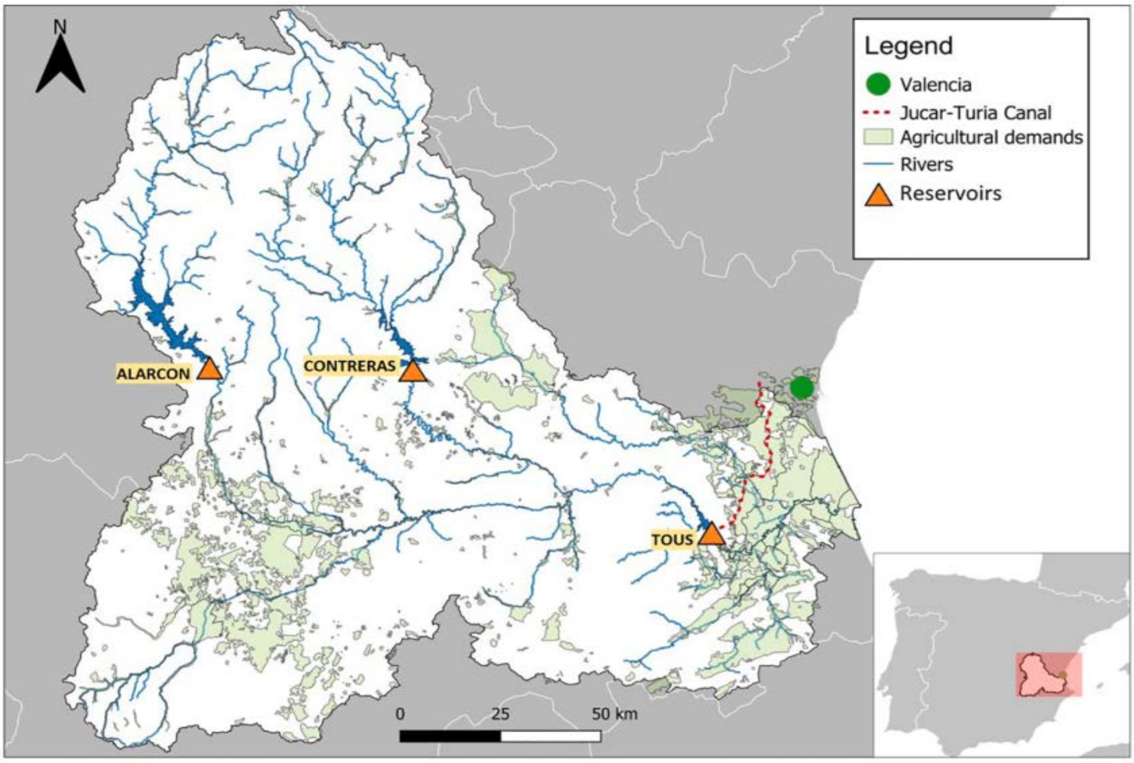

Figure 1. The location of the Júcar River Basin.

From its upper reaches, the Júcar descends and flows through the middle part of the basin (La Mancha Plateau), and then further to the lower basin and coastal area. The La Mancha Plateau and the coastal plains account for a significant portion of irrigated agricultural production, supporting crops such as

[3] Confederación Hidrográfica del Júcar (CHJ). (2018). River Basin Management Plan of the Júcar River Basin District 2016 – 2021: Informative Document. Available online at: https://www.chj.es/es-es/medioambiente/planificacionhidrologica/Documents/Plan-Hidrologico-cuenca-2021-2027/Libros-divulgativos/Libro_Divulgativo_PHJ15_21_English.pdf

cereals, olives, grapes, and citrus. The lower basin also encompasses lagoons, coastal dunes, and wetlands, such as the l'Albufera de Valencia wetland – a Nature Park of significant cultural and environmental value. The preservation of vital ecosystems such as these, which are heavily impacted by reduced inflows and diminished water quality, is essential for the conservation of diverse bird species and aquatic life[3].

The most recent climate projections indicate that the region will experience higher average and maximum temperatures and reduced rainfall, as well as increased evapotranspiration that will alter the water balance in the area, impacting vegetation and water bodies. Moreover, increased water scarcity and droughts will pose risks to ecosystems and impact sectors such as water supply, agriculture, energy, and transportation[4]. Balancing water demand with available resources, achieving good status for water bodies, and implementing cost recovery measures are crucial for the region's water security and environmental preservation. Collaborative efforts between different stakeholders and government authorities are necessary for the successful implementation of hydrological planning and conservation measures. By addressing these challenges and adhering to the objectives of the EU Water Framework Directive (WFD), the Júcar River basin can move towards a more resilient and sustainable water future (Figure 2).

[4] Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kolli, W.-T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, A. Sarr and P. Whetton, 2007: Regional Climate Projections. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Available online at: https://www.ipcc.ch/site/assets/uploads/2018/02/ar4-wg1-chapter11-1.pdf

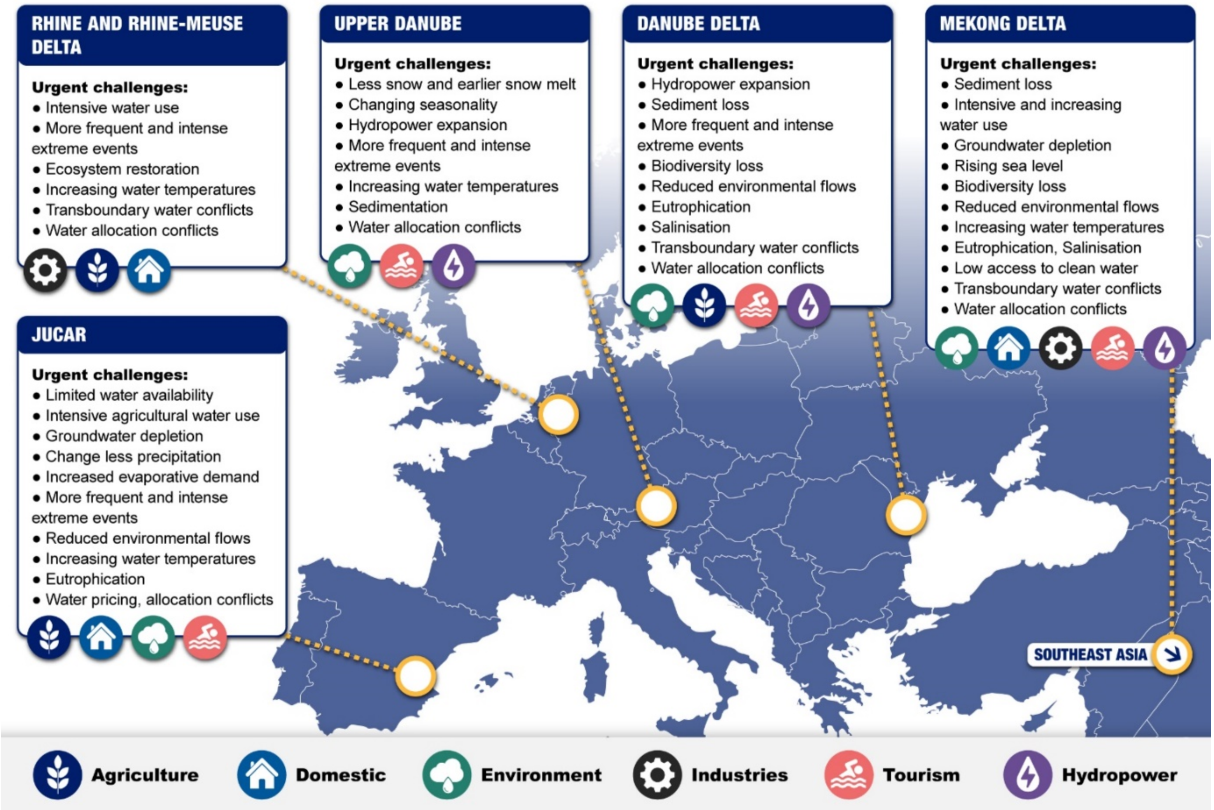

Figure 2. Overview of the case studies in SOS-Water and a list of urgent water challenges and key sectors impacted.

2.2. The Mekong Delta

Case study leader(s): *Nam Nguyen Trung; Thanh Lam Dang (Southern Institute for Water Resources Planning – SIWRP, Vietnam)*

Study area for SOS-Water: *Delta and **Considered area**: Entire Mekong River Basin*

Involved countries: *Vietnam*

The Mekong River, one of the longest rivers in Asia, originates from the Tibetan plateau and spans approximately 4,350 km. The hydrological dynamics of the Mekong are heavily influenced by seasonal variations and monsoon rains, resulting in distinct wet and dry seasons. Tidal processes and saline intrusions also strongly impact the hydrology of the region[5].

At the southern tip of Vietnam, the Mekong River flows into the East Sea of Vietnam, forming the Mekong Delta, a vast area of around 40,000 km^2 characterized by an intricate network of channels and marshes (Figure 3). [5]The Mekong Delta is home to roughly 17.318 million inhabitants, with an average density of 424 people/km^2. About 26 % of the population lives in urban areas, while about 74% are in

[5] Mekong River Commission (MRC). (2021). The integrated water resources management–based Basin Development Strategy for the Lower Mekong Basin 2021–2030 and the MRC Strategic Plan 2021–2025. Vientiane: MRC Secretariat. Available online at: https://www.mrcmekong.org/assets/Publications/BDS-2021-2030-and-MRC-SP-2021-2025.pdf

located in rural areas[6]. The fertile soils that characterize the area, coupled with a complex hydrological system, make the Mekong Delta a vital agricultural region that supports the cultivation of rice, fruits, vegetables, and aquaculture[5]. Widely recognized as the "Rice Bowl of Vietnam," the Mekong Delta plays a pivotal role in the agricultural landscape of Vietnam, contributing 54% of the rice yield, accounting for about 90% of the rice export; 70% of the seafood production; and 36,5 % of the fruit production of the nation[7].

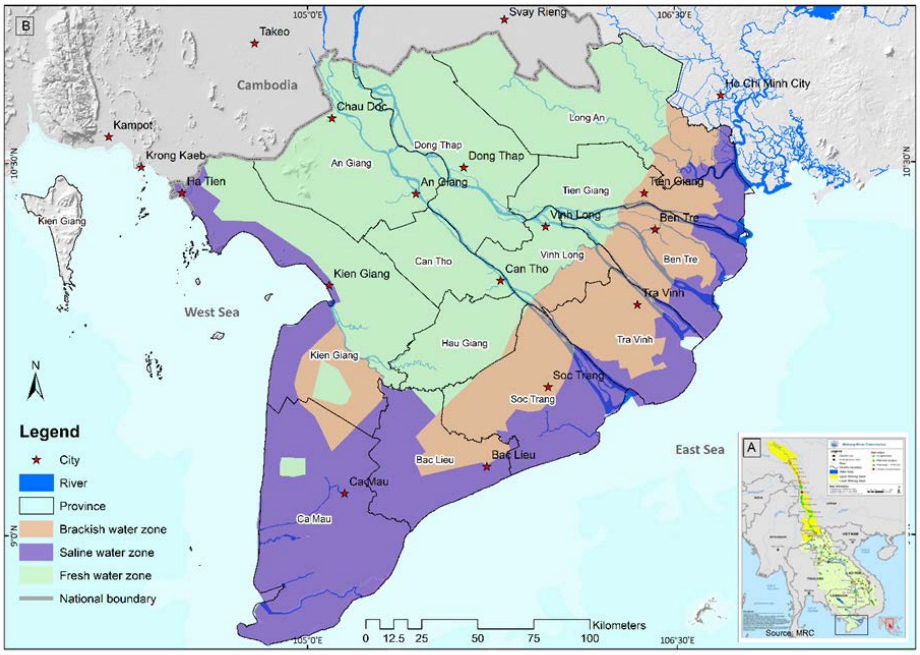

Figure 3. The location of the Mekong Delta in the Mekong River Basin (A) and the Mekong Delta administrative map (B).

The Mekong Delta is renowned for its diverse and unique ecological habitats, comprising mangrove forests, freshwater swamps, marshes, and submerged forests. These habitats support a rich biodiversity, including numerous fish species, migratory birds, and endemic flora and fauna. However, rapid population growth, urbanization, and intensive agricultural practices have resulted in habitat loss, deforestation, and water quality degradation and pollution. The construction of dams and water infrastructure upstream due to increases in energy demands has altered the natural flow regime of the Mekong River, impacting sediment transport and nutrient cycling downstream. Moreover, increases in water consumption have led to changes in water allocation, water shortage and groundwater depletion[5].

Climate change further exacerbates these challenges, increasing the risks of sea-level rise, saltwater intrusion, and extreme weather events. These ecological changes in the Mekong Delta have significant socio-economic implications. They can affect the livelihood of local communities dependent on

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[6] Ministry of Natural Resources and Environment (MONRE). (2023). River basin master plan for the Mekong Delta in the 2021-2030 period with a vision to 2050.

[7] United Nations Development Programme (UNDP) & the Vietnam Chamber of Commerce and Industry (VCCI) (2022). Agricultural transformation model adapting to climate change in the Mekong Delta. Available online at: https://www.undp.org/vietnam/publications/agricultural-transformation-model-adapting-climate-change-mekong-delta

agriculture and fisheries, as well as the region's food security. The loss of natural habitats and biodiversity also undermines the resilience of the Delta's ecosystems and their ability to provide essential services, such as flood regulation and water purification[8] (Figure 2).

Efforts are being made to address these challenges and promote the sustainable management of the Mekong Delta. At the regional scale, Mekong River Commission Procedures have been implemented based on the 1995 Mekong Agreement (i.e., Procedures for Data Information Exchange and Sharing; Procedures for Water Use Monitoring; Procedures for Notification, Prior Consultation and Agreement; Procedures for the Maintenance of Flows on the Mainstream; Procedures for Water Quality). These procedures have helped implement stronger regional coordination on technical support and information sharing.

At the national scale, the Vietnam government has undertaken a wide array of solutions, encompassing both policy and technical measures, which have supported the Mekong Delta effectively mitigate compounding impacts of human activities and climate change. Notably, in 2017, the government issued Resolution 120/NQ-CP on sustainable and resilient development of the Mekong Delta in the climate change context, highlighting the critical role of the Mekong Delta in the nation's growth, a strategic vision grounded in a nature-based approach that proactively addresses challenges caused by climate change and human-induced pressures to unlock the potential and strengths of the Mekong River Delta, driving its developmental progress[8]. A series of strategic plans and programs have been implemented to realize this vision. Notable examples include the 2022 Master Plan for the Mekong Delta Region (2021-2030, with a vision to 2050), the 2023 River Basin Master Plan (2021-2030, with a vision to 2050), and the 2020 Overall Program for Sustainable and Climate-Resilient Agriculture Development in the Mekong River Delta (2020-2030, with a vision to 2045). These initiatives reflect dedicated efforts towards the comprehensive development of the Mekong Delta region. Furthermore, several laws have been put into place (i.e., the Law on Water Resources, the Natural Disaster Prevention and Control, Irrigation, and Environmental Protection). In addition to implemented laws and regulations, several technical measures have been set to mitigate impacts on the Mekong Delta (e.g., restoration of mangrove forests, implementation of monitoring stations and warning systems, water diversion and water source alternatives for groundwater, etc.).

Despite various regional and national initiatives aimed at addressing water-related challenges, the Mekong Delta continues to grapple with significant gaps in effectively managing transboundary concerns and confronting internal issues within the delta exacerbated by the impacts of climate change. Pursuing sustainable development in the Mekong Delta necessitates an investigation of a safe operating space for water management in the context of changes in climate and society at a basin-wide scale.

[8] Vietnam Government Portal. (2021). Preliminary Outcomes of Three-year Implementation of Resolution on Climate-resilient Development of Mekong Delta. Available online at: https://en.baochinhphu.vn/preliminary-outcomes-of-three-year-implementation-of-resolution-on-climate-resilient-development-of-mekong-delta-11140641.htm.

2.3. The Rhine River and the Rhine-Meuse Delta

Case study leader(s): *Niko Wanders; Jen Steyaert (Utrecht University)*

Considered study area for SOS-Water: *Rhine River Basin and the Rhine-Meuse Delta*

Involved countries: *The Netherlands, Germany, Switzerland, France*

The Rhine River, spanning a length of approximately 1,230 km, is a major watercourse in Europe. It has a vast drainage area of around 185,000 km^2, encompassing various sub-basins and tributaries (Figure 4). The source of the Rhine River is in the Swiss Alps in the canton of Graubünden, from which it flows through diverse landscapes, including mountainous regions, fertile valleys, and urbanized areas[9].

Together with its tributaries, the Rhine forms a diverse range of ecological habitats, including mountain streams, floodplains, wetlands, and estuaries, supporting a rich biodiversity in the region. Moreover, the Rhine plays a crucial role in maintaining ecological connectivity, allowing for the migration and dispersal of species[9].

In addition to serving as an essential navigation route, facilitating trade and commerce within Europe, the Rhine River is also a significant source of water resources, providing drinking water, supporting industrial processes, and facilitating agriculture in the region. The water flow of the upstream parts of the Rhine is regulated through a system of dams and reservoirs to ensure water availability throughout the year. The lower reaches have no man-made obstacles to enable shipping of large volumes of cargo from Germany to the port of Rotterdam and back.

The Rhine-Meuse Delta, also known as the Rhine Delta or the Dutch Delta, is the vast coastal plain formed by the convergence of the Rhine and Meuse rivers in the Netherlands. It extends from the city of Rotterdam to the North Sea and covers an area of approximately 8,000 km^2. The Delta, with its complex network of channels and wetlands, is a dynamic environment influenced by tidal processes, sediment deposition, and human interventions. The diversity of its habitats supports unique flora and fauna, and serves as an important breeding ground for birds, as well as a stopover site for migratory species.

The Rhine River and its delta currently face various ecological challenges. Human activities, including land reclamation, urbanization, and agriculture, have led to habitat loss, fragmentation, pollution, and a reduced water availability in summer. The construction of dams and flood defences has altered the natural hydrology of the river, affecting fish migration, sediment transport and water quality. Additionally, climate change poses risks such as sea-level rise increased storm surges, droughts, and changes in precipitation patterns, which can impact the stability and biodiversity of the river basin[4,9] (Figure 2).

Integrated river basin management approaches aim to balance the needs of different sectors while preserving and restoring natural ecosystems and maintaining water resource availability and quality.

[9] International Commission for the Protection of the Rhine (ICPR). (2022). Internationally Coordinated Management Plan 2022–2027 for the International River Basin District of the Rhine. ICPR. Koblenz, Germany. Available online at: https://www.iksr.org/fileadmin/user_upload/DKDM/Dokumente/BWP-HWRMP/EN/bwp_En_RMBP_2021_01.pdf

Restoration projects, floodplain reconnection, and nature conservation initiatives play crucial roles in maintaining the ecological integrity of the region and ensuring its long-term sustainability. International collaboration, such as the Water Framework Directive, Agreements for Transboundary Water Cooperation, and Low Water Navigation Agreements, are key to addressing these challenges effectively.

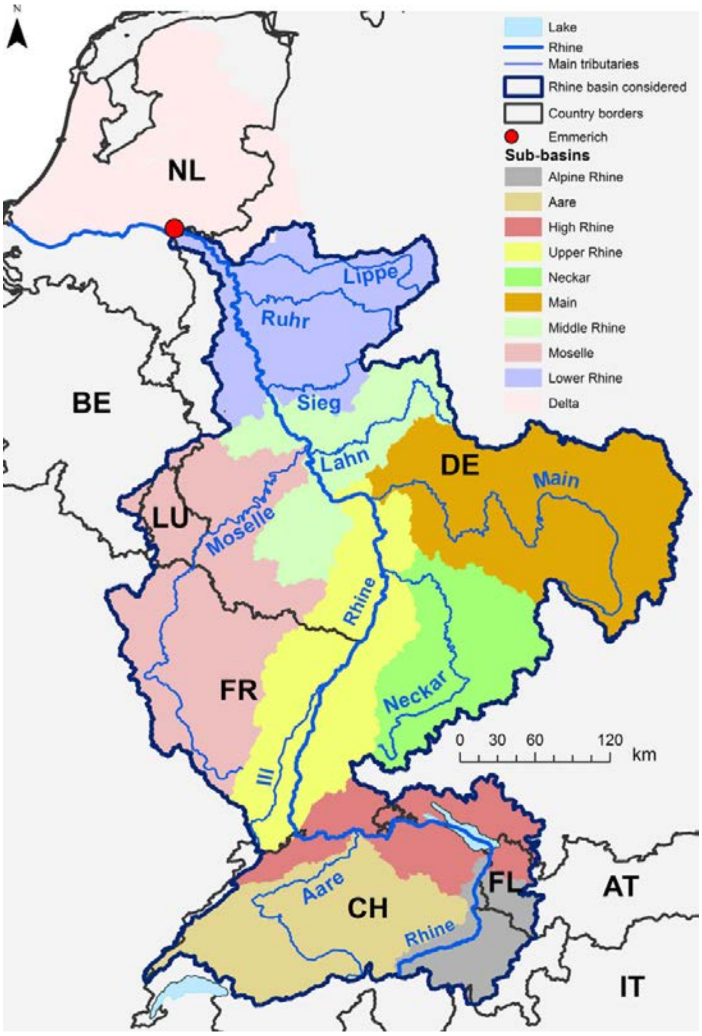

Figure 4. Map of the Rhine River Basin and its sub-basins. Country codes – AT: Austria, BE: Belgium, CH: Switzerland, DE: Germany, FL: Liechtenstein, FR: France, IT: Italy, LU: Luxembourg, NL: the Netherlands[10].

2.4. The Danube River Basin

The Danube, the second longest river in Europe, stretches approximately 2,850 km from its source in the Black Forest Mountains in Germany to where it flows into the Black Sea (Figure 5; Figure 6). Its vast basin (approximately 79,000 km^2) extends into the territories of 19 countries, making it the most

[10] Moser, A., Wemyss, D., Scheidegger, R., Fenicia, F., Honti, M., & Stamm, C. (2018). Modelling biocide and herbicide concentrations in catchments of the Rhine basin. *Hydrology and Earth System Sciences*, 22(8), 4229-4249. doi:10.5194/hess-22-4229-2018

international river basin in the world[11]. Today, the Danube is a symbol of European unity and cooperation. This river is subject to both floods and droughts. The Danube homes diverse wildlife, including sturgeon, otters, and rare birds like the white-tailed eagle and serves as a vital energy source and transportation artery for goods and people.

Floods in the Danube can be caused by heavy rainfall, melting snow, or a combination of both. When the river's water level rises above its banks, it can cause extensive damage to surrounding areas. There have been several major floods in the Danube Basin in recent years, including in 2002 and 2013. These floods caused widespread damage to infrastructure, homes, and agriculture and resulted in significant economic losses.

During a drought, water levels can drop significantly, affecting navigation, power generation, and water supply for agriculture and drinking. Droughts can also lead to the deterioration of water quality due to higher concentrations of pollutants and reduced dilution of wastewater[11]. Recently the Danube has experienced several droughts, including a severe drought in 2012 that affected large parts of the region. This drought was caused by a combination of low rainfall and high temperatures, which led to reduced water levels in rivers and lakes and increased water demand from agriculture and industry.

Climate change is expected to exacerbate the frequency and intensity of floods and droughts in the Danube basin. Therefore, the countries in the region will benefit from collaborating to develop strategies for managing water resource opportunities and reducing the risks. This includes improving early warning systems, implementing flood and drought resiliency measures, and promoting sustainable water use practices[4,11] (Figure 2).

[11] International Commission for the Protection of the Danube River (ICPDR). (2021). Danube River Basin Management Plan. ICPDR Secretariat. Vienna, Austria. Available online at: https://www.icpdr.org/flowpaper/viewer/default/files/nodes/documents/drbmp_2021_final_hires.pdf

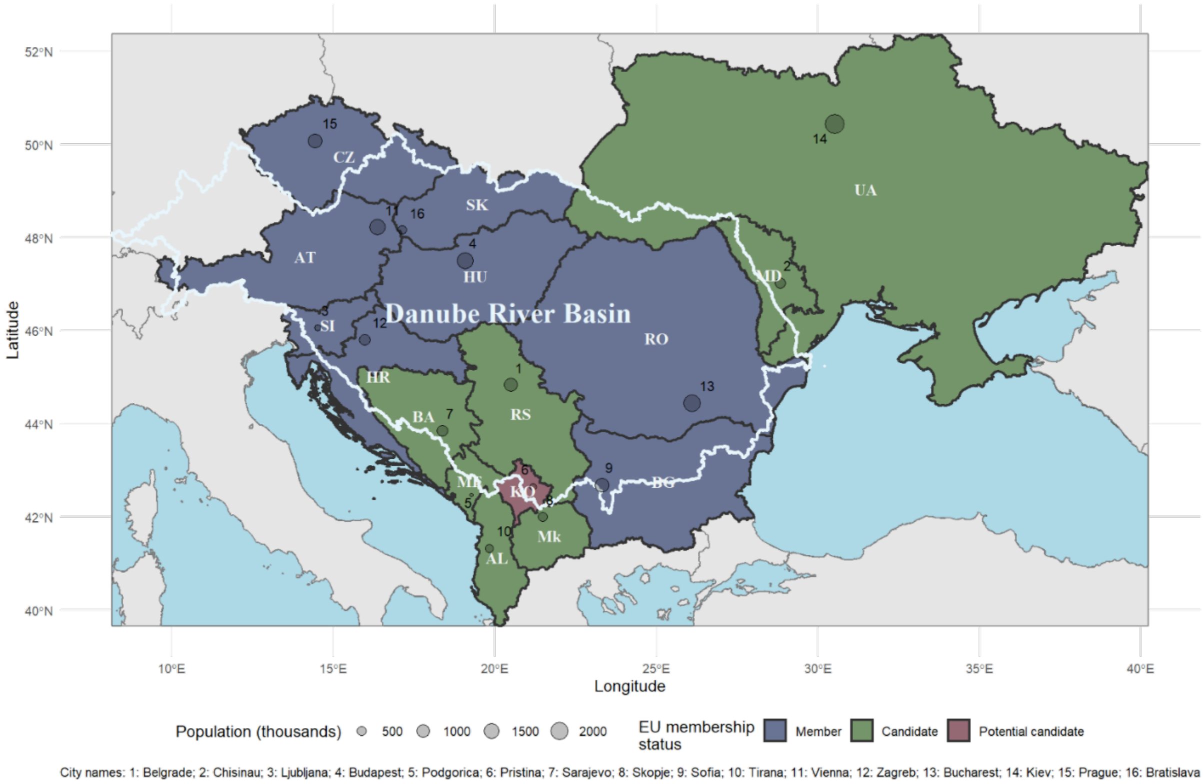

Figure 5. The DWP countries, main cities, and the Danube River basin borders[12,13,14].

12 Global administrative areas (GADM). (2022). GADM database of global administrative areas, version 4.1. Available online at: https://gadm.org/

13 Lehner, B., and Grill, G. (2013). Global river hydrography and network routing: baseline data and new approaches to study the world's large river systems. *Hydrological Processes, 27*(15): 2171-2168.

14 Natural Earth data. 14/09/2023. Available online at: https://www.naturalearthdata.com

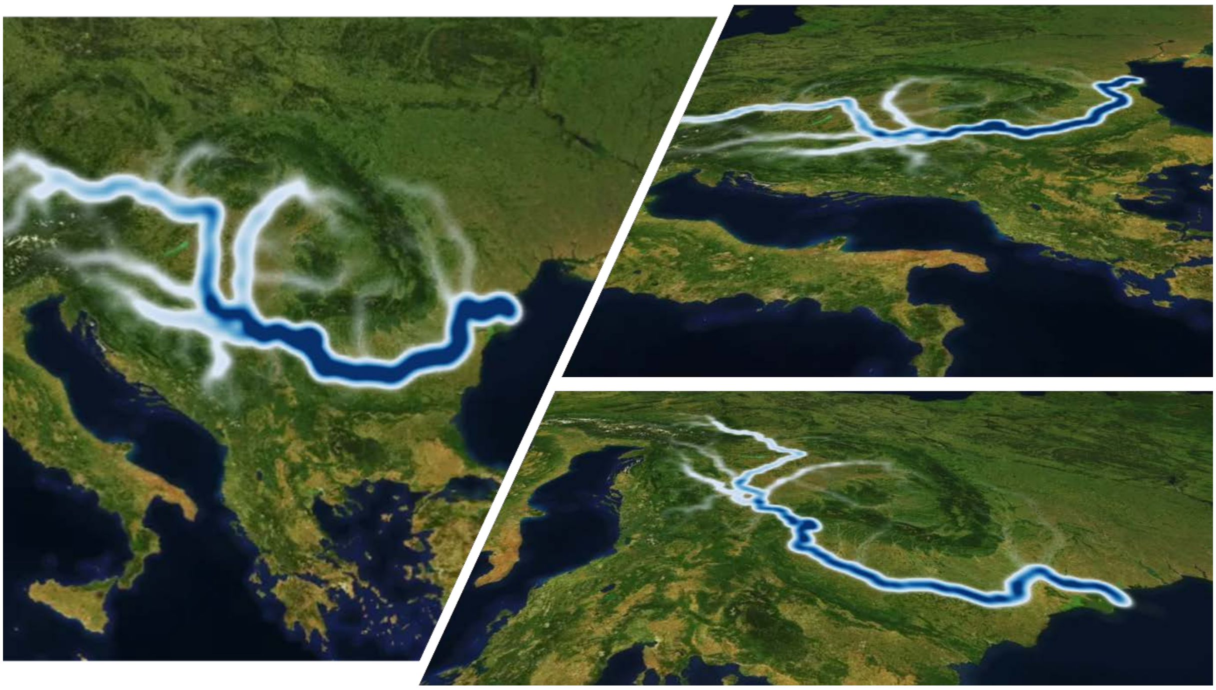

Figure 6. River flow in the Danube basin from three perspectives. These density maps show the strongest points of flow from deep blue lighter flows in white to transparent. The images were created using the Community Water Model[15].

2.4.1. The Upper Danube

Case study leader(s): *Mikhail Smilovic; Sylvia Tramberend (International Institute for Applied Systems Analysis – IIASA, Austria)*

Considered study area for SOS-Water: *Danube River Basin*

Involved countries: *High-level approach involving all countries in the Danube catchment*

Previous engagement with stakeholders in the area: *WaterStressAT; Water Security assessment of the Eastern European and Central Asian region*

The upper reaches of the Danube begin at the river's source and extend to the Carpathian Mountains near Bratislava, Slovakia. This section is characterized by high flow velocities and low temperatures, and is influenced by a glacial-nival flow regime. Compared to the middle and lower reaches of the river, the Upper Danube is highly altered by dams, navigation channels, and bank constructions for flood protection[11]. The geographical diversity of the Upper Danube Basin results in the formation of different ecological habitats along that river's course, including alpine meadows, wetlands, forests, and riparian zones, all of which support a rich biodiversity.

[15] Burek, P., Y. Satoh, T. Kahil, T. Tang, P. Greve, M. Smilovic, L. Guillaumont, F. Zhao, Y. Wada. (2020). Development of the Community Water Model (CWatM v1.04) A high-resolution hydrological model for global and regional assessment of integrated water resources management. *Geoscientific Model Development, 13*, 3267–3298.

The volume of water resources generated within the Upper Danube Basin is substantial, with an average annual discharge of around 1,700 m^3/s. However, the consumptive demand for water resources, including irrigation, hydropower generation, industrial processes, and municipal water supply, poses a significant challenge in the region[11].

Climate change impacts, reduced water provisions, loss of river connectivity, and flood risks all present significant ecological and socio-economic challenges to the Upper Danube Basin. Achieving good status for water bodies while ensuring the sustainable use of water resources requires careful planning and implementation of effective measures, which can be achieved through collaborative efforts among stakeholders, government authorities, and the public[4,11] (Figure 2).

2.4.2. The Danube Delta

Case study leader(s): *Sabin Rotaru (National Institute for Research and Development on Marine Geology and Geo-ecology – GeoEcoMar, Romania))*

Considered study area for SOS-Water: *Delta*

Involved countries: *Romania*

Previous engagement with stakeholders in the area: *FP7 ARCH; H2020 CERTO; H2020 CERES*

The Danube Delta is a unique and ecologically rich region, formed on the eastern end of the Danube River, where it separates into three main branches: the Chilia, Sulina, and Sfântu Gheorghe, before flowing into the Black Sea. It is one of the largest and best-preserved river deltas in Europe, covering an area of approximately 4,150 km^2. The Delta is characterized by a network of channels, lakes, marshes, brackish lagoons, sandy spits, and extensive reed beds that are subject to tidal changes, saltwater intrusion, and seasonal variations in water levels. These complex hydrological dynamics form a diverse and dynamic ecosystem that sustains a high biodiversity, supporting over 300 bird species, and a diverse range of fish species, amphibians, reptiles, and mammals. This rich biodiversity has earned it the status of a Biosphere Reserve and a UNESCO World Heritage site[11,16].

The Danube Delta is a natural water purification system, filtering and retaining sediments and pollutants carried by the river before they reach the Black Sea. It plays a crucial role in maintaining water quality and mitigating the impacts of human activities upstream. The Delta also provides essential ecological services, including flood regulation, nutrient cycling, and carbon sequestration.

However, the Delta faces numerous challenges. Human interventions, such as drainage for agricultural purposes, dredging for navigation, and unsustainable and illegal fishing practices, have impacted the balance of the Delta. These activities have led to habitat loss, altered hydrological regime, and the decline of species abundances. Climate change poses additional challenges to the Danube Delta. Rising sea levels, increased frequency of extreme weather events, and changes in precipitation patterns can influence the hydrology and salinity of the Delta, potentially affecting its ecosystems and biodiversity[4,11] (Figure 2).

[16] International Union for Conservation of Nature (IUCN) and UN Environment World Conservation Monitoring Centre. (2017). World Heritage Datasheet – Danube Delta. Available online at: http://world-heritage-datasheets.unep-wcmc.org/datasheet/output/site/danube-delta/

3. Stakeholder Engagement in Freshwater Management

3.1. Stakeholder Engagement Mechanisms

Stakeholder engagement in water management involves a range of formal and informal mechanisms that facilitate the participation and collaboration of diverse stakeholders. Formal mechanisms often have a legal or institutional basis and include, for example, public consultations and advisory committees (e.g., the Danube River Basin Management Expert Group – RBM EG). These methods offer a platform for stakeholders to share their knowledge and perspectives, provide feedback, or even co-create proposed policies, plans or projects related to water management.

On the other hand, informal mechanisms of stakeholder engagement include community-based organizations (e.g., NGOs or citizen-led groups), collaborative partnerships, and social media platforms. Informal collaborations and partnerships among stakeholders involve information-sharing and joint problem-solving, encouraging dialogue and building trust among all participants. By utilizing a combination of formal and informal engagement mechanisms, stakeholders can actively contribute to water management strategies, fostering inclusivity in decision-making processes[17].

3.2. Benefits of Engaging with Stakeholders: Fostering Trust, Transparency, Inclusivity, and Equity

Active collaboration with stakeholders promotes the development of trust in the decision-making process. By including the input of diverse stakeholders from the initial stages of the SOS-Water project for each case study, we ensure that their values and interests are considered and integrated into the decision-making framework.

Increasing transparency and openly sharing information and data with stakeholders deepen stakeholders' understanding of the complex ecological and socio-economic dynamics of freshwater systems. The co-creation process also includes collaborative learning, i.e., including local knowledge and expertise from stakeholders in the decision-making process. Furthermore, engaging stakeholders through transparent communication channels builds credibility and public confidence, while enabling them to hold decision-makers accountable[17].

As freshwater management initiatives impact a wide range of stakeholders, including local communities, indigenous groups, industrial sectors, and recreational users, engaging these stakeholders (particularly those who are historically marginalized or underrepresented) ensures that their unique perspectives and needs are considered, leading to more equitable and fair decision-making processes.

[17] Organization for Economic Co-operation and Development (OECD) (2015), Stakeholder Engagement for Inclusive Water Governance, OECD Studies on Water, OECD Publishing, Paris. Available online at: http://dx.doi.org/10.1787/9789264231122-en

3.3. Obstacles to Stakeholder Engagement

While stakeholder engagement holds immense potential for sustainable freshwater management, several obstacles can hinder effective participation and collaboration. This section highlights four key obstacles: lack of interest of concern, poor legal frameworks, stakeholder fatigue, and resistance to change.

Lack of interest or concern

Some stakeholders may not recognize the importance of their involvement in freshwater management processes or may underestimate the potential impact of management decisions on their lives and livelihoods. Lack of awareness or interest, or perceived disconnection from the issues at hand can deter stakeholders from actively engaging in the planning process. Overcoming this obstacle requires targeted efforts to raise awareness, educate stakeholders about the ecological and socio-economic benefits of sustainable freshwater management, in turn emphasizing the relevance of their contributions[17].

Poor legal frameworks

Stakeholder engagement can be undermined by legal frameworks that lack clarity or do not provide adequate mechanisms for stakeholder participation. Absence of a legal framework for embedding engagement in institutional practices may result in stakeholders being excluded from the decision-making process or only being involved at a superficial level, limiting the potential for meaningful contributions. Overcoming this obstacle requires the development and implementation of robust legal frameworks that explicitly prioritize and mandate stakeholder engagement, providing clear guidelines and mechanisms for their active involvement throughout the freshwater management process[17].

Stakeholder fatigue

Stakeholder fatigue can arise when there is an information overload or when several projects or initiatives with similar objectives require engagement from the same stakeholders. Moreover, a lack of clarity concerning the outcome of the information and time stakeholders put into the engagement process can lead not only to stakeholder fatigue, but also disillusionment about the role and usefulness of stakeholder engagement[17]. This can hinder the quality and depth of engagement, resulting in disengagement or superficial involvement. To address stakeholder fatigue, coordination and collaboration among different projects and initiatives is crucial. Streamlining efforts, ensuring efficient information sharing, and avoiding duplication of engagement activities can help alleviate fatigue and maintain stakeholders' interest and commitment.

Resistance to change

Stakeholders may have concerns or resistance to change, especially if it impacts their established workflows or roles. This obstacle can hinder stakeholder engagement and create roadblocks in project implementation.

Addressing the lack of interest or concern among stakeholders, mitigating stakeholder fatigue through coordination and efficient information sharing, and establishing robust legal frameworks that mandate meaningful participation are critical steps towards overcoming these obstacles. By recognizing and addressing these challenges, stakeholder engagement can enhance freshwater initiatives, leading to more effective and inclusive decision-making processes.

4. Multi-Criteria Decision Analysis (MCDA) in Stakeholder Engagement

Active collaboration with stakeholders is a cornerstone of effective freshwater management. The implementation of Multi-Criteria Decision Analysis (MCDA) as a community-driven decision-making framework can offer a robust and structured approach to ensure transparent, unbiased, and objective decision-making. In essence, MCDA uses quantitative data and rigorous steps to evaluate and prioritize alternative management strategies based on multiple criteria or objectives. In the context of freshwater management, MCDA enables stakeholders to understand and compare the trade-offs and uncertainties associated with water allocation, infrastructure development, and environmental conservation[18,19]. By actively engaging stakeholders in the decision-making process, MCDA promotes transparency, inclusivity, and shared responsibility, ultimately leading to more informed and balanced decisions that align with the long-term sustainability of freshwater resources and the diverse values and perspectives of stakeholders[20]. The steps of MCDA in stakeholder engagement are shown in Figure 7.

4.1. Step A: Problem Description

Reaching a consensus on a common problem definition can occur prior to engaging stakeholders or in collaboration with them – the timing of which will depend on the scope of the project and the decision challenge. Establishing a shared understanding of the nature of the problem and scope provides a solid foundation for effective stakeholder involvement in subsequent steps (steps B and C; see below).

[18] Langhans, S. D., Jähnig, S. C., & Schallenberg, M. (2018). On the use of multicriteria decision analysis to formally integrate community values into ecosystem-based freshwater management. *River Research and Applications*, *35*(10), 1666-1676. doi:10.1002/rra.3388

[19] Schuwirth, N., Honti, M., Logar, I., & Stamm, C. (2018). Multi-criteria decision analysis for integrated water quality assessment and management support. *Water Research X*, *1*, 100010. doi:10.1016/j.wroa.2018.100010

[20] Langhans, S. D., & Schallenberg, M. (2021). Accounting for diverse cultural values in freshwater management plans by using a transparent and collaborative decision support system based on multi-criteria decision analysis. *New Zealand Journal of Marine and Freshwater Research*, *57*(3), 309-335. doi:10.1080/00288330.2021.1987932

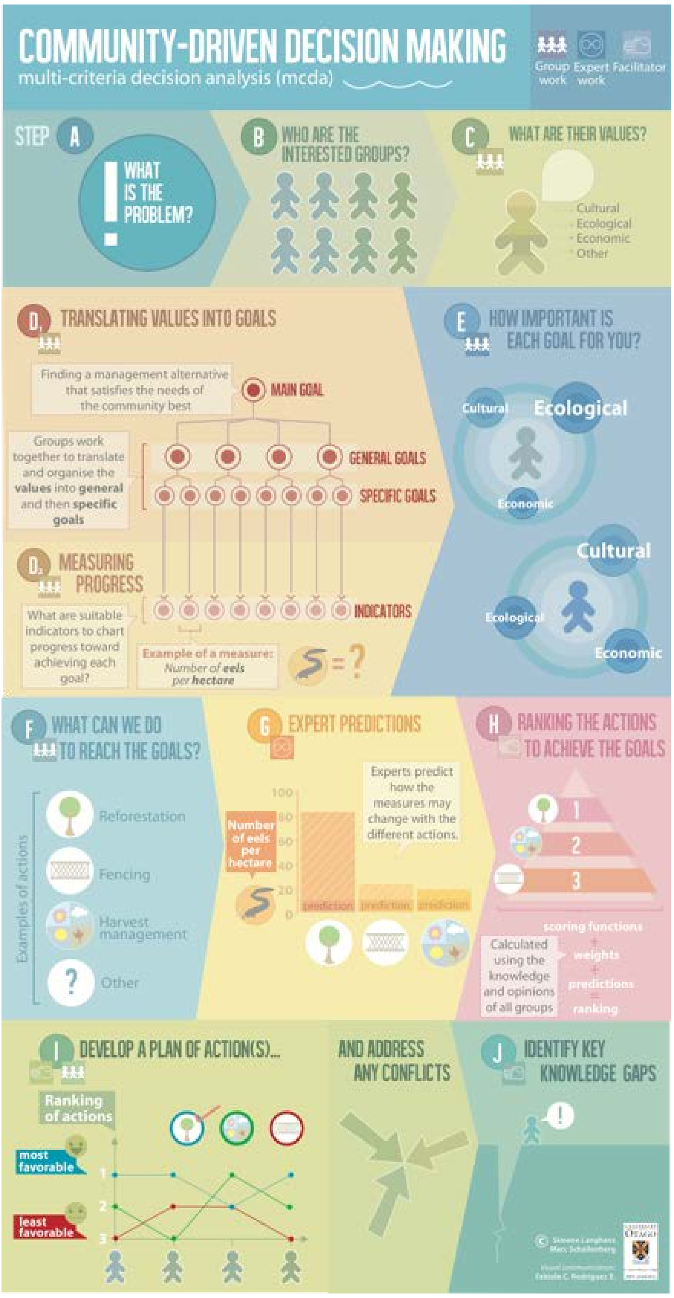

Figure 7. Infographic highlighting the different steps involved in the MCDA-framework for each of the case studies in the SOS-Water project[18].

4.2. Step B: Stakeholder Mapping

A crucial step in stakeholder engagement involves stakeholder mapping – identifying and categorizing individuals, groups, organizations, and institutions that have a vested interest in or are affected by water resources management decisions, and determining their core motivations and responsibilities. During this process, it is important to include a carefully thought-out and strategic selection of stakeholders to develop successful collaborative case study-specific freshwater management strategies.

Stakeholder mapping can occur at different scales through the inclusion of both high-level (e.g., intergovernmental bodies or government agencies) and low-level stakeholders (e.g., local watershed groups or indigenous communities). Involving a broad range of stakeholders at different levels allows for their diverse needs and interests to be addressed and enables the identification of power dynamics within and between stakeholder groups. If not dealt with in an equitable and effective way, these power dynamics can lead to challenges and an under-representation of less powerful stakeholders[17].

At the national and international levels, stakeholders may include policymakers, intergovernmental bodies, government agencies, non-governmental organizations (NGOs), and research institutions. These stakeholders shape policy and regulatory frameworks, allocate resources, and influence decision-making processes on a larger scale. Engaging with these higher-level stakeholders is essential for aligning freshwater management plans with national and international regulations and goals, leveraging funding opportunities, and ensuring policy coherence[20].

At the local level, stakeholders may comprise local communities, indigenous groups, farmers, fishermen, recreational users, and local businesses. These stakeholders have direct interactions with freshwater ecosystems and possess valuable traditional knowledge and expertise, allowing for a better understanding of local ecosystem dynamics and challenges. The involvement of local stakeholders in freshwater management initiatives can enhance social acceptance, promote local ownership, and foster sustainable practices that are based on the current needs of local communities[20].

Some methods for stakeholder mapping can include: (i) consultations with experts (e.g., scientists, policymakers, researchers, and professionals with extensive knowledge of local water resources); (ii) network analysis (i.e., analyzing existing networks and collaborations within the river basin management domain); and (iii) research and literature review (i.e., identifying key organizations and agencies involved in freshwater management through a revision of existing reports and documents)[17].

Understanding the diverse range of stakeholders involved in the SOS-Water case studies is paramount to achieving effective and equitable decision-making. By recognizing the distinct perspectives, concerns, and values of each stakeholder group, freshwater management strategies can create solutions that harmonize ecological, social, economic, and institutional considerations. The list of stakeholders involved in each of the SOS-Water case studies can be found in Table 1.

Table 1. List of stakeholders involved in each of the SOS-Water case studies.

	Category	Stakeholder	Description
DANUBE RIVER BASIN (UPPER DANUBE AND DANUBE DELTA)	**NGOs and non-profits**	DANUBEPARKS	The DANUBEPARKS Association is the platform for coordinated and extensive collaboration among the various administrations of the Danube Protected Areas.
		The Danube Civil Society Forum	The Danube Civil Society Forum is the platform for civil society dialogue and networking in the Danube basin under the EU Strategy for the Danube Region

			(EUSDR). It functions as the interface for structured consultations between civil society and public and private authorities on the regional, national and EU level as well as to international and intergovernmental organisations active in the region.
		WWF	
		International Commission for the Protection of the Danube River	The International Commission for the Protection of the Danube River (ICPDR) works to ensure the sustainable and equitable use of waters in the Danube River Basin.
		Sava Commission	
	Academia	University of Natural Resources and Life Sciences (BOKU), Vienna	
		Verein fur Okologie um Umweltforschung	A platform for the exchange of interests between energy industry and experts in applied research in the field of ecology.
	Industry	Tiwag	Tiroler Wasserkraft AG is a Tirolean power company established in 1924 in which most of the generated electricity comes from hydropower.
		Viadonau	Viadonau is the leading international waterway operator in the Danube region. Its responsibilities include waterways and bank management and maintenance. Viadonau engages also in national and international projects, whereby the interests, ideas and inspirations from politics, business, science, and the environment are brought together.
		Donau Soja	Donau Soja supports its partners and members in progressing change to address social, environmental, and economic challenges in the soya value chain.
		International Association of Water Service Companies in the Danube River Catchment Area	IAWD, the International Association of Water Service Companies in the Danube River Catchment Area, is the prime association of water and wastewater utilities in the Danube region – an international cooperation network with a shared vision, a shared mission, and a shared approach.
		Danube Commission	The primary goals of the Danube Commission are to ensure unrestricted navigation on the Danube River for commercial vessels from all states, while

			respecting the interests and sovereign rights of its Member States. Additionally, the Commission aims to promote economic and cultural relations among its Member States with other nations.
	IGO	World Bank	
MEKONG DELTA	**NGOs and non-profits**	International Center for Environmental Management (ICEM)	An international organization specializing in environmental consultancy and management, ICEM provides expertise in addressing complex environmental challenges in the Mekong Delta and beyond, contributing to sustainable development and conservation efforts.
		Mekong Delta Climate Resilience Program of GIZ (MCRP)	This program, initiated by the German development agency GIZ, aims to enhance the climate resilience of the Mekong Delta by implementing projects and initiatives that address climate-related challenges and promote sustainable development.
	Academia	Water Resources Research Institute	An academic institution dedicated to research and studies on water resources, contributing to informed decision-making for sustainable water management in the Mekong Delta.
		University of Natural Resources and Environment (HCMUNRE)	An educational institution dedicated to training and research on water resource engineering and environment, contributing to capacity building for sustainable water management in the Mekong Delta.
		Thuy Loi University	An educational institution dedicated to training and research on water resource engineering and risk prevention, contributing to capacity building for sustainable water management in the Mekong Delta.
		Can Tho University	An educational institution dedicated to training and research on water and ecology, contributing to capacity building for sustainable water management in the Mekong Delta.
		Institute for Environment and Resources	An academic institution dedicated to research and studies on water environment, contributing to informed decision-making for sustainable water management in the Mekong Delta.
	Public administration	Southern Regional Hydrometeorological Center (SRMC)	A governmental center providing meteorological and hydrological information to support decision-making, including flood and drought management, in the Mekong Delta region.

		Mekong River Commission Secretariat (MRCS) – Regional Flood and Drought Management Center (RFDMC)	The Mekong River Commission Secretariat (MRCS) is a regional body focused on enhancing the capacities of Mekong countries to manage and respond to flood and drought events in the Mekong Delta, playing a vital role in disaster risk reduction and water resource management.
		Vietnam National Mekong Committee (VNMC)	A governmental body responsible for coordinating Vietnam's policies and activities related to the Mekong River Basin's sustainable development and management.
		Southern Institute of Water Resources Planning (SIWRP)	A government-affiliated institute involved in planning and research related to water resources management and development in the Mekong Delta.
		Sub-National Institute of Agricultural Planning and Projection (Sub-NIAPP)	A government agency focusing on agricultural planning and projection, contributing to sustainable land use and water resource management in the Mekong Delta.
		Central Project Management Office (CPO)	The Central Project Management Office is a government office responsible for coordinating and managing development projects in the Mekong Delta, aiming to enhance infrastructure and socio-economic conditions.
		Ministry of Transport (MOT) – Inland Navigation Department	A government department overseeing navigation and water transport activities in the Mekong Delta, contributing to economic development and waterway management.
		Ministry of Transport (MOT) – Transport Development and Strategy Institute (TDSI)	An institution focused on transportation planning and strategy, contributing to efficient transport networks within the Mekong Delta.
		Ministry of Construction (MOC) – Infrastructure Department; Rural Planning Institute	A governmental body engaged in the planning and development of infrastructure projects, including those related to water management and transport in the Mekong region.
		Ministry of Construction (MOC) –	A government-affiliated institute involved in rural development planning, addressing socio-economic and environmental challenges in the Mekong Delta.

		Rural Planning Institute	
		Ministry of Planning and Investment (MPI) – Planning Management Department	A government department responsible for coordinating planning and management activities to support sustainable development in the Mekong Delta.
		Southern Economic Research Center (SVEC)	SVEC, the Southern Economic Research Center, is a research center focusing on economic studies and analysis, contributing to informed decision-making for socio-economic development in the Mekong Delta.
		Department of Agriculture and Rural development (An Giang, Ca Mau, and Kien Giang provinces)	Governmental departments overseeing agriculture and rural development activities, addressing livelihoods and environmental challenges in specific provinces within the Mekong Delta.
		Water Technical Coordination Group for Long Xuyen Quadrangle irrigation system and Quan Lo-Phung Hiep irrigation system	A coordination group overseeing water-related technical aspects of irrigation systems in specific regions of the Mekong Delta.
	Industry	Southern Company for Irrigation Management (SIMC)	An entity overseeing irrigation infrastructure and management in the Mekong Delta, playing a role in agricultural productivity and water resource utilization.
		Royal Haskoning DHV	An international engineering and project management consulting firm.
The Júcar River Basin	**NGOs and non-profits**	Xúqer Viu (environmental NGO)	Civic Association for the Defense of Xúque river. Their main objectives include raising awareness of the importance of the Xúquer River Basin, promoting sustainable water management practices, and advocating for the protection of the river and its ecosystems.
		AEMS Ríos con Vida	Environmental NGO dedicated to conserving and restoring rivers while actively advocating for the sustainable management of fluvial fish resources through the application of scientific principles.

	Academia	University of Valencia	Spanish public university.
		Polytechnic university of Valencia	Spanish public university.
	Industry	Iberdrola	Energy company responsible for hydropower production. They are a member of USUJ and the owner of all the main hydropower facilities in the basin. They also own the hydropower reservoirs in the middle Júcar.
	Civil organisation	Júcar Users Union (USUJ)	The USUJ acts as a representative body for the users of the Júcar River Basin and works towards ensuring fair and sustainable water use in the region.
		Acequia Real Del Júcar (ARJ)	The ARJ is one of the oldest irrigation communities in Spain. It ensures compliance with ordinances and good order in the use of water. It carries out the functions of policing, distribution, and administration of the assigned waters.
		Junta Central de Regantes de la Mancha Oriental (JCRMO)	The JCRMO is an irrigation community that manages and supervises the coordinated use of groundwater and surface water for irrigation and other purposes to ensure that the resources are used in a sensible manner maintaining their sustainability and preventing overuse.
	Public Administration	Júcar Basin Agency (CHJ)	The Júcar Basin Agency (CHJ) is a public organization responsible for the integrated management and regulation of water resources in the Júcar River Basin. Its primary functions encompass the development of hydrological plans for the basin and their periodic revision, rigorous monitoring of its water systems, and the effective management of the Public Hydraulic Domain.
		Canal Júcar-Turia (CJT)	Canal system that regulates the general operation of the Júcar-Turia Canal in relations with irrigation and supply users.
		City of Valencia	Municipal government.
		City of Albacete	Municipal government.

		Government of the Valencian Region	Regional government.
		Government of Castille – La Mancha	Regional government.

4.3. Step C: Objectives Hierarchies

One of the main goals of SOS-Water is to co-develop comprehensive objectives hierarchies, which enable a systematic approach to decision-making and resource allocation. These objectives hierarchies provide a structured framework that organizes objectives into a logical sequence, starting from broad, overarching goals, and refining them into specific actionable targets whose degree of success is assessed using measurable indicators.

When co-developed with stakeholders, objectives hierarchies offer several key benefits. First, they foster active participation and inclusivity, engaging stakeholders from diverse backgrounds and interests in the decision-making process. Stakeholders' inputs lead to more accurate and comprehensive representations of their concerns, needs and values, thereby enhancing the legitimacy and acceptability of the proposed objectives[18,20]. Furthermore, stakeholder involvement ensures that the objectives hierarchies are aligned with local contexts and the unique challenges faced by each case study region. Overall, this will help stakeholders and decision-makers clarify priorities, understand trade-offs, and harmonize diverse perspectives for effective and sustainable freshwater resource management. It is important to note that stakeholders do not need to unanimously agree on every objective. Rather, the hierarchies offer a comprehensive overview of objectives that stakeholders can later adjust through the assignment of weights. If there are particular objectives that certain stakeholders do not wish to include, they have the flexibility to assign a weight of zero to those specific objectives. This circumvents the challenges involved in including a wide range of stakeholders (particularly those with conflicting values/objectives) that can sometimes hinder engagement processes. Instead, the co-creation of objectives hierarchies allows progress to continue even if stakeholders cannot immediately agree on the objectives to be included[18].

As the engagement process evolves, stakeholders begin to gain a deeper understanding of each other's objectives. Through co-learning and multiple in-person interactions, stakeholders can develop relationships and insights that oftentimes lead to compromised solutions. Over time, the likelihood of finding middle ground increases, promoting consensus-building that might not have been likely or feasible at the outset.

To ensure progress and maintain momentum towards the SOS-Water project goals, provisional objectives hierarchies were created independently for each of the five case studies together with the case study leaders, taking into consideration the main challenges identified for each basin (Figures 8-11). These tentative hierarchies and associated indicators were built upon a foundation of extensive research, relevant expertise, and an in-depth understanding of the specific challenges faced by each case study region. During the upcoming workshops, stakeholders will devise their own objectives hierarchies according to the values and needs of the individuals or sectors they are representing, while the previously constructed hierarchies will serve as a provisional framework to facilitate discussions with stakeholders.

4.3.1. Utilizing the DPSIR Framework for the Development of Objectives Hierarchies

Developed by the European Environment Agency (EEA), the DPSIR (*Driver-Pressure-State-Impact-Response*) framework is used to better understand interactions between human activities and the health of the environment[21]. Through this systematic framework, social, demographic, and economic developments function as *drivers* of anthropogenic activities that exert *pressures* on the environment. These pressures alter the *state* of the environment, leading to *impacts* on human health, ecosystems, and the economy. As a *response,* a set of societal measures (e.g., regulatory, technological, practical) are put into place to mitigate negative impacts, manage pressures, and alter driving forces to promote sustainable environmental management[21]. Information provided by the case study leaders was used to help understand and highlight the main challenges in each of the respective case studies, and identify the primary objective and potential sub-objectives in the objectives hierarchies (Table 2).

[21] Song, X., & Frostell, B. (2012). The DPSIR framework and a pressure-oriented water quality monitoring approach to ecological river restoration. *Water*, *4*(3), 670-682. https://doi.org/10.3390/w4030670

A) Main Objective | 1st Level Objective | 2nd Level Objective | 3rd Level Objective | 4th Level Objective | Indicators

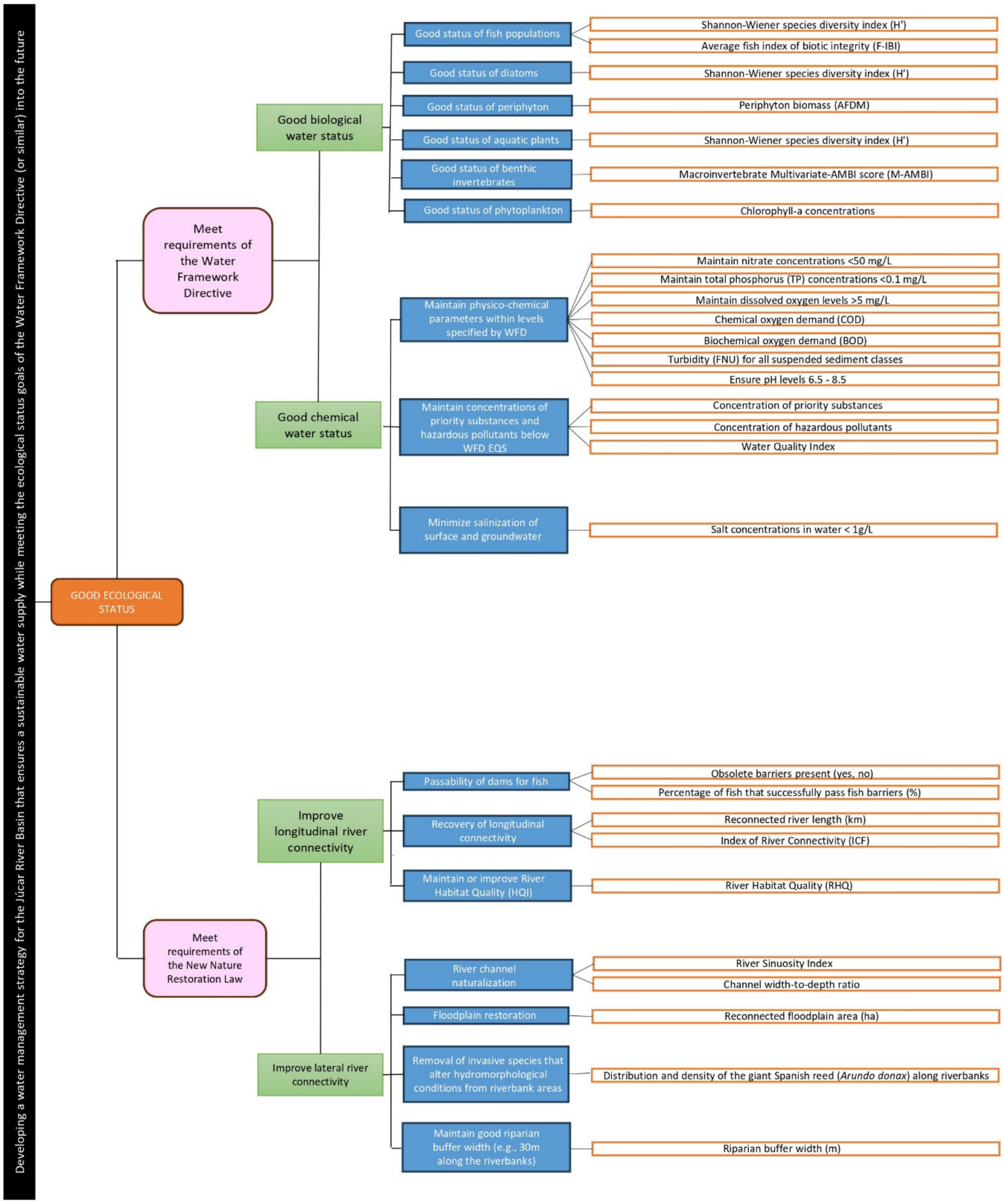

Figure 8. Objectives hierarchy for the main objective of co-developing a water management strategy for the Júcar River Basin that ensures a sustainable water supply while meeting the ecological status goals of the Water Framework Directive into the future (A-B). A) Sub-objectives for the 1st level objective Good ecological status, B) for the 1st level objective Sustainable water use.

B)

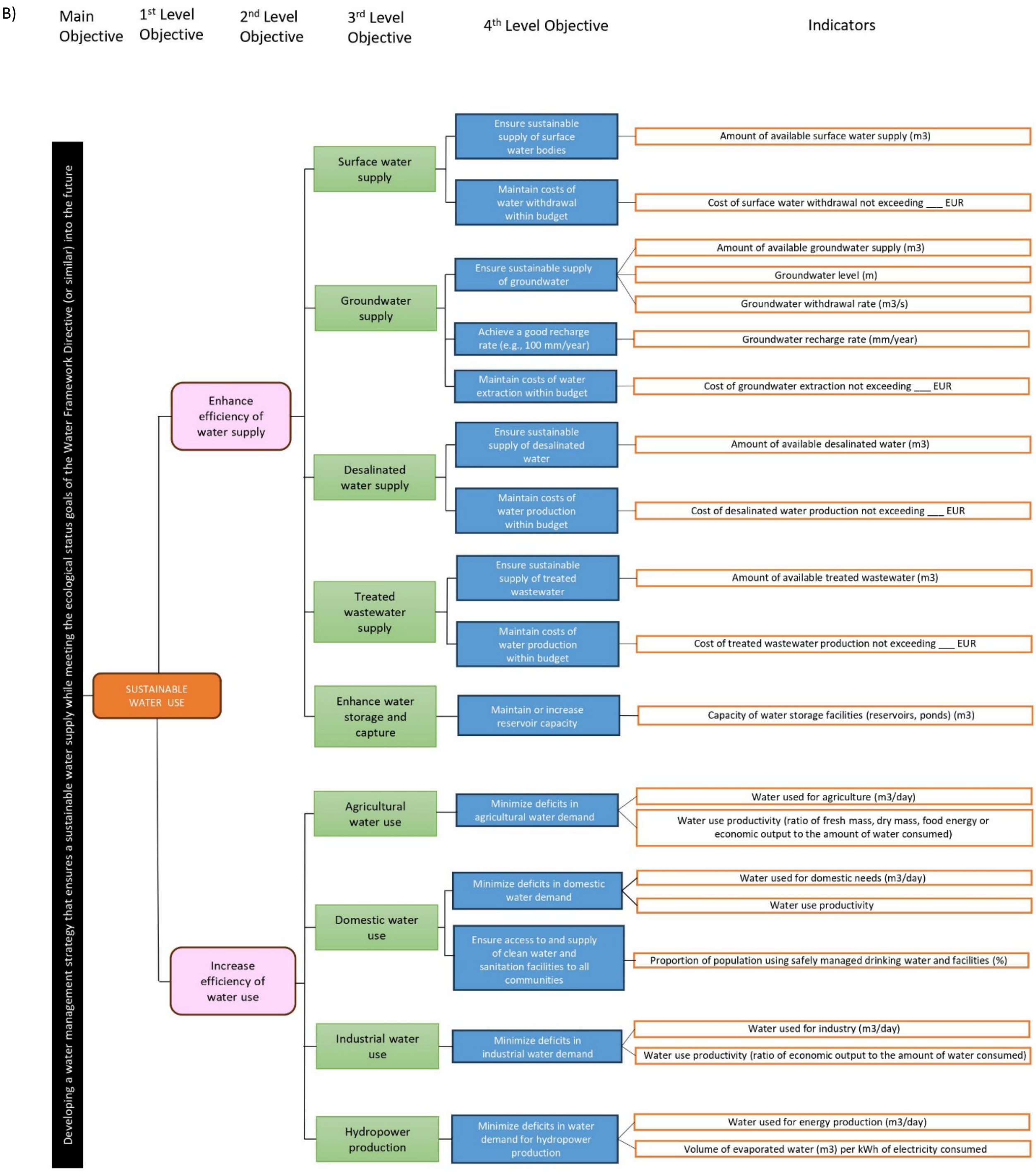

Figure 8. Continued

A)

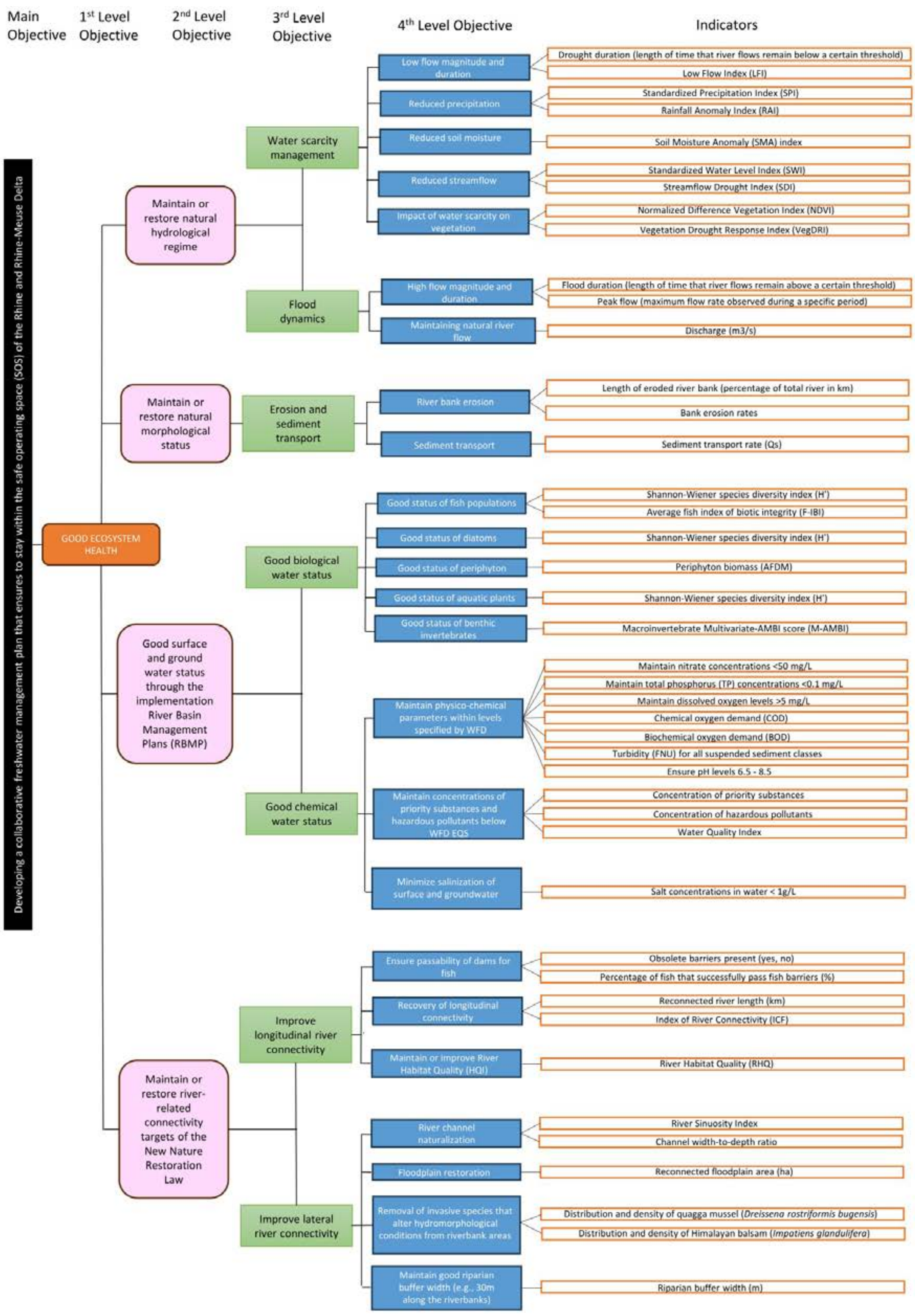

Figure 9. Objectives hierarchy for the main objective of co-developing a water management strategy for the Rhine and Rhine-Meuse Delta that ensures to stay within the safe operating space (SOS) (A-B). A) Sub-objectives for the 1st level objective Good ecosystem health, B) for the 1st level objective Good human well-being.

B)

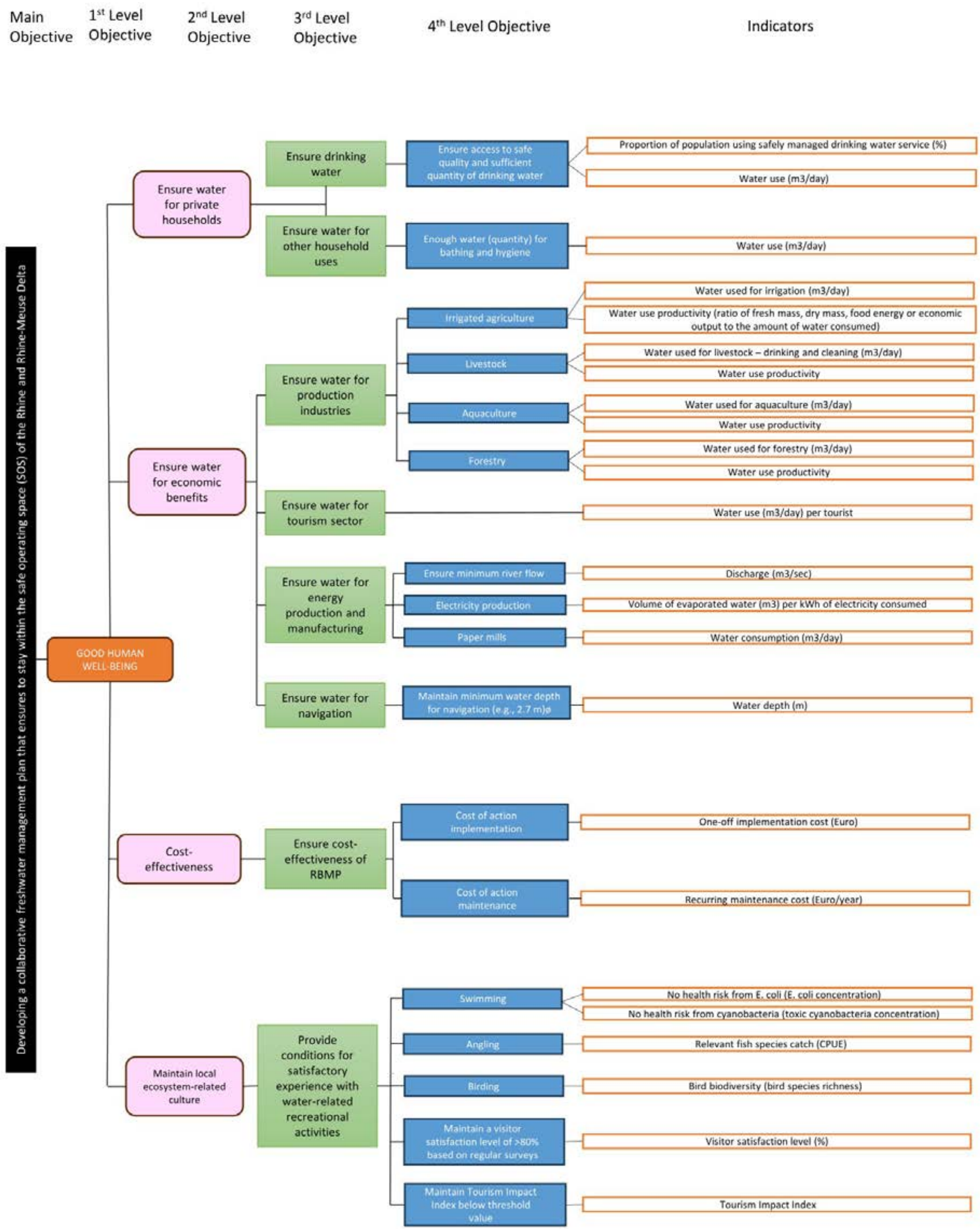

Figure 9. Continued

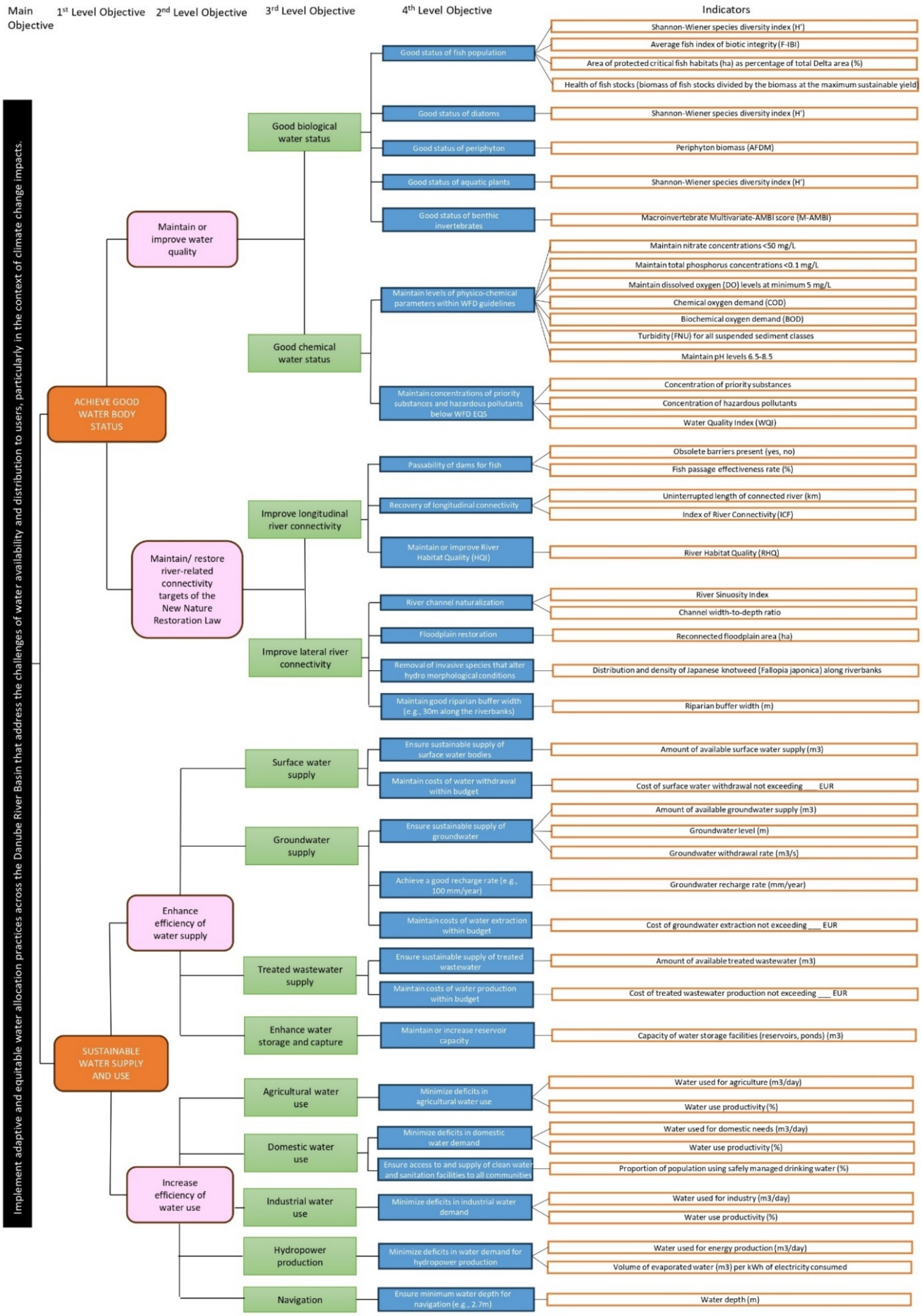

Figure 10. Objectives hierarchy for the main objective of implementing adaptive and equitable water allocation practices across the Danube River Basin that address the challenges of water availability and distribution to users, particularly in the context of climate change impacts.

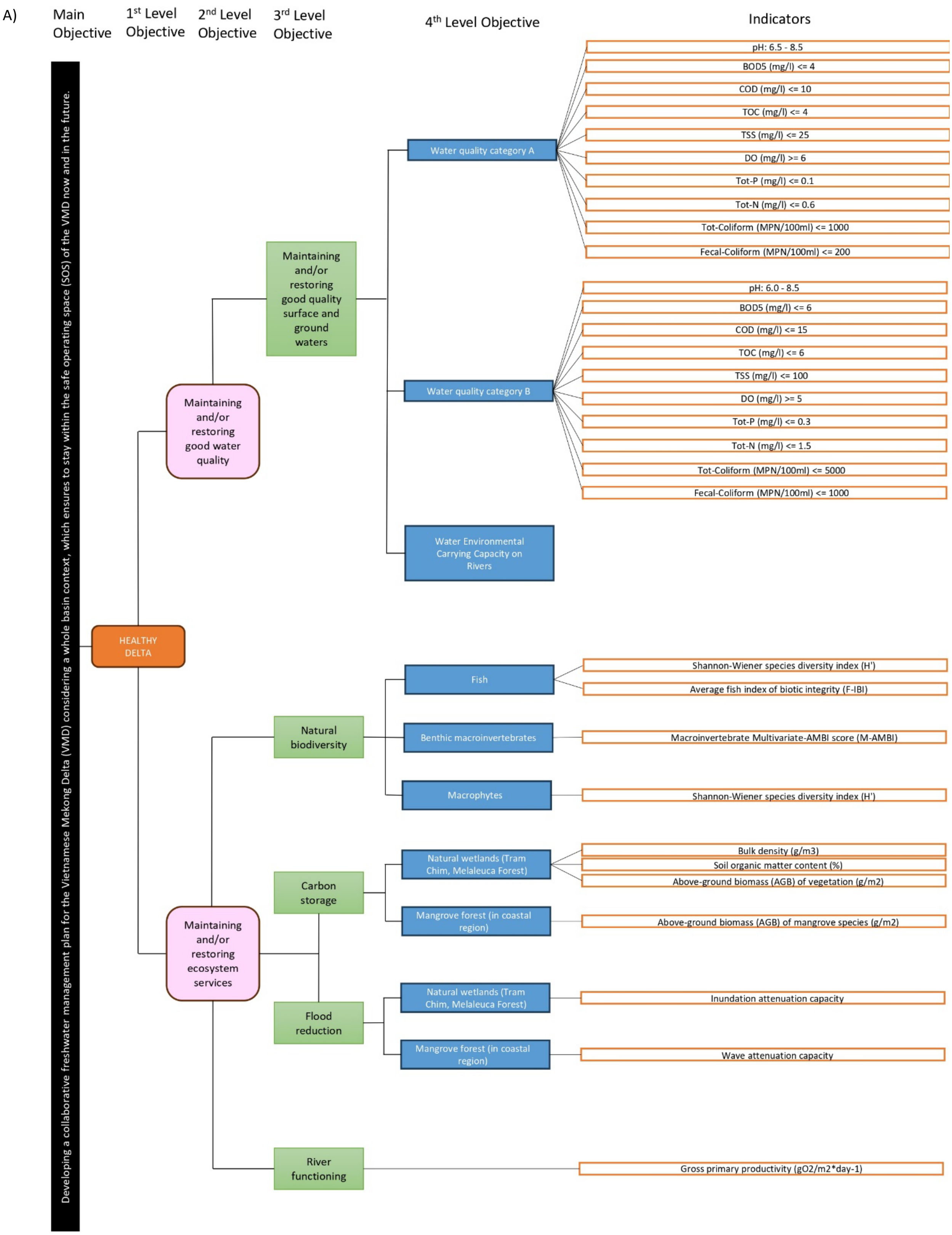

Figure 11. Objectives hierarchy for the main objective of co-developing a water management plan for the Vietnamese Mekong Delta considering a whole basin context, which ensures to stay within the safe operating space (SOS) now and in the future (A-B). A) Sub-objectives for the 1st level objective Healthy Delta, B) for the 1st level objective Liveable Delta.

A)

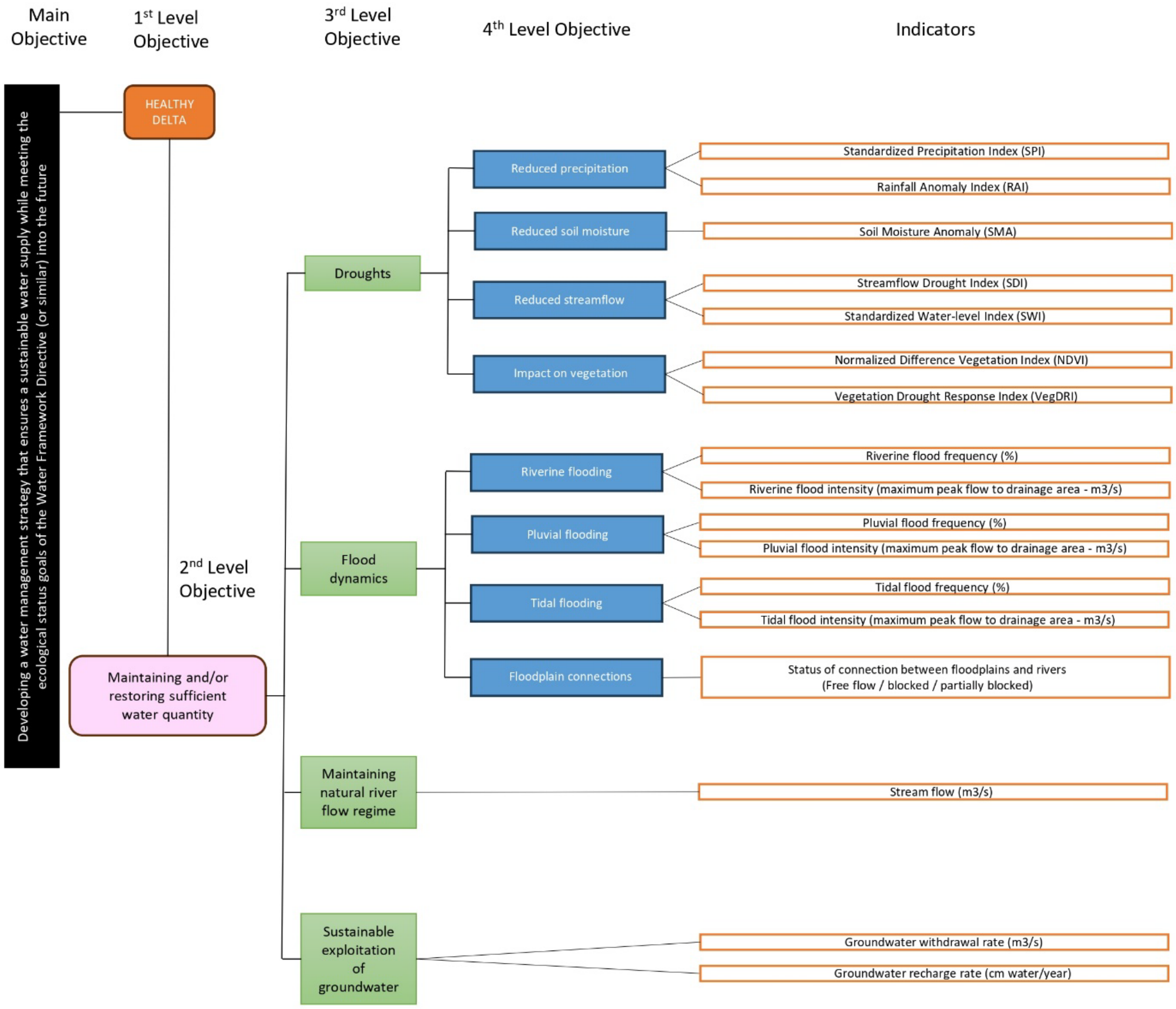

Figure 11. Continued

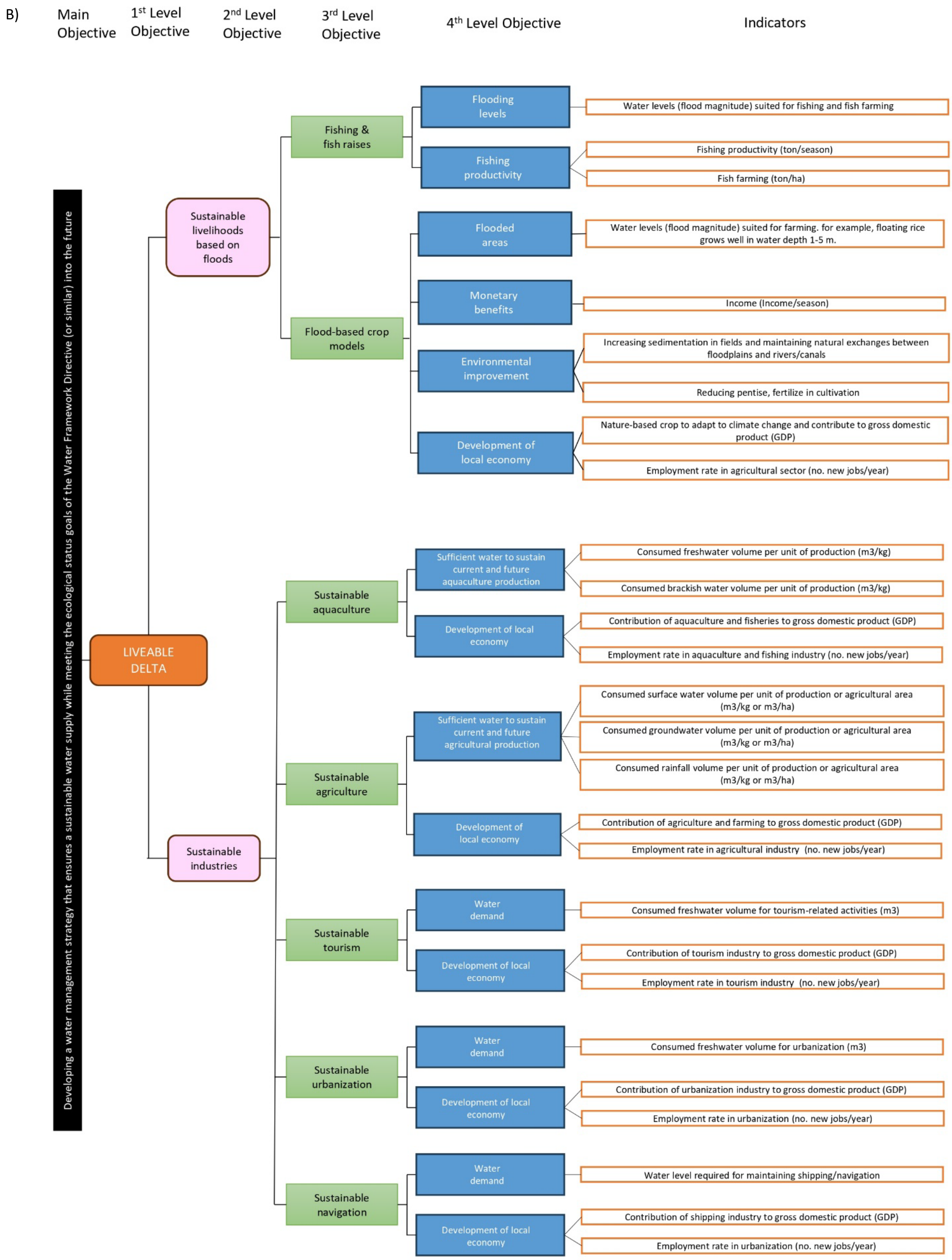

Figure 11. Continued

B) Main Objective | 1st Level Objective | 2nd Level Objective | 3rd Level Objective | 4th Level Objective | Indicators

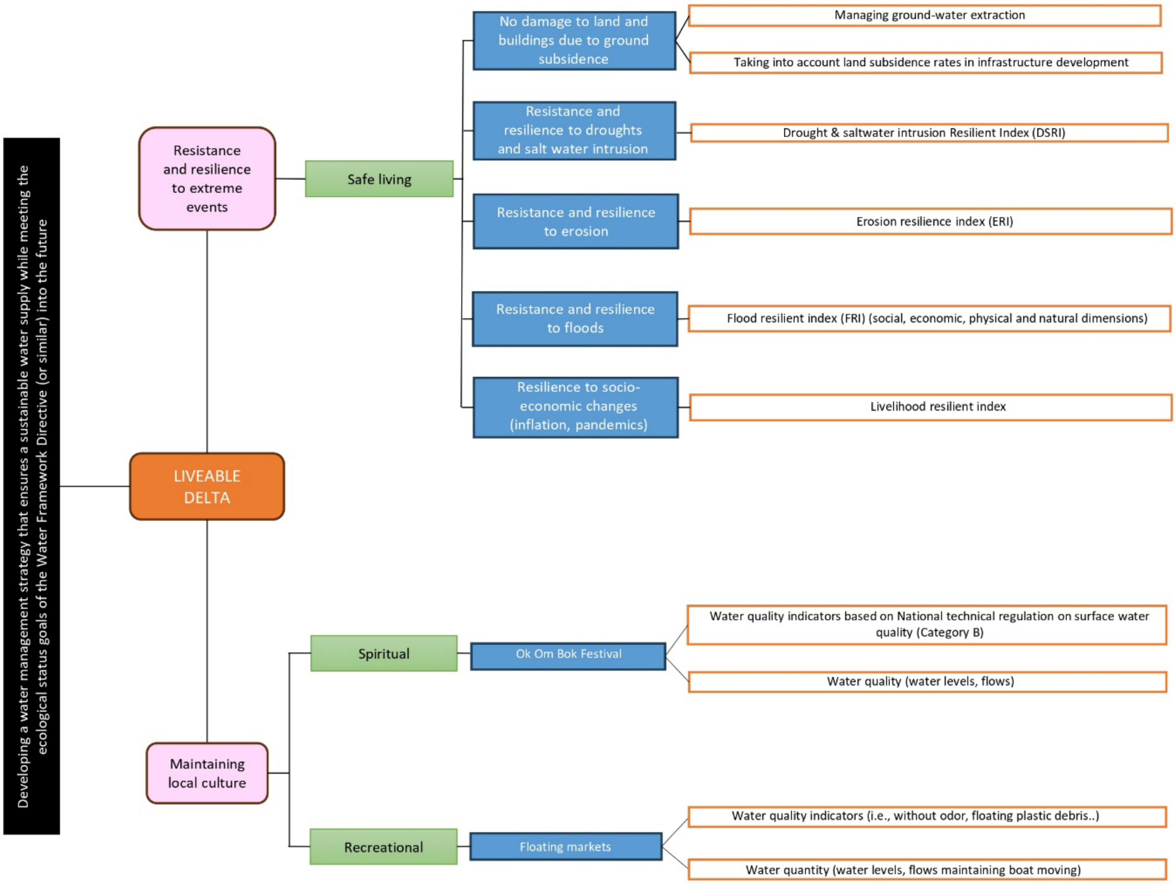

Figure 11. Continued

5. Input from Stakeholders in the Case Studies

Collaborative workshops provide a platform for constructive dialogue, enabling the synthesis of scientific knowledge with traditional and local knowledge systems, thus promoting contextually appropriate solutions and strategies. Stakeholder engagement workshops in SOS-Water will be case study-specific and will require a high level of flexibility and adaptability from the case study leaders. However, a tentative agenda following the general structure of the MCDA framework was set in place to guide the case study leaders and facilitate effective discussion between stakeholders (Figure 7).

Below is the MCDA-driven agenda for the SOS-Water stakeholder engagement workshops[18].

1. Welcome and Introduction

At the start of the first workshop, case study leaders will explain the purpose of the workshop to the participants. They will use visual aids to introduce the MCDA framework and its role in facilitating objective and inclusive stakeholder discussions.

2. Identifying Water Values and Visions

The next part of the workshop will involve problem-framing, i.e., defining case study-specific water management challenges and the overall goal, as well as collating stakeholders' water values. Stakeholders will present their visions for the future of each river basin or delta and engage in a collective discussion to identify and group similar values thematically.

3. Creating Objectives Hierarchies

Following the identification of water values and visions, stakeholders will collaboratively draft an objectives hierarchy for each case study, arranging the objectives at different levels, from general to sub-objectives, becoming more specific at each level.

4. Defining Measurable Indicators and Value Functions

To each of the lowest-level sub-objectives at least one measurable system attribute, or indicator, will be assigned. These indicators, that will later serve as model inputs, will be defined through a collaborative effort between the case study leaders and the stakeholders.

5. Determining Value Functions

The stakeholders will then be introduced to the concept of value functions and their importance in quantifying the relationship between objectives and attributes. Value functions allow for the direct comparison of the degree of fulfilment between objectives by normalizing the levels of attributes measured in different units into a standardized score between 0 and 1 (Figure 12)[18]. In practice, value functions are derived from various sources, including regulatory (e.g., WFD) guidelines, technical literature, monitoring data, and local knowledge and information, ensuring a comprehensive and well-informed basis for decision-making.

Following the workshops, stakeholders will be asked to assign weights to the objectives at the higher levels (e.g., water quality, environmental health, economic growth, and cultural significance) through one-on-one interviews. Alternative management actions will then be proposed to achieve the set goals, taking into consideration stakeholder input. Experts will then analyze how these actions may impact the measures associated with different management scenarios. By integrating the knowledge and opinions of all stakeholder groups, alternative management actions will be ranked to achieve the proposed goals[18].

Utilizing the MCDA approach for stakeholder engagement in SOS-Water ensures that the values and preferences of all participants are acknowledged, resulting in the creation of cohesive and effective freshwater management plans.

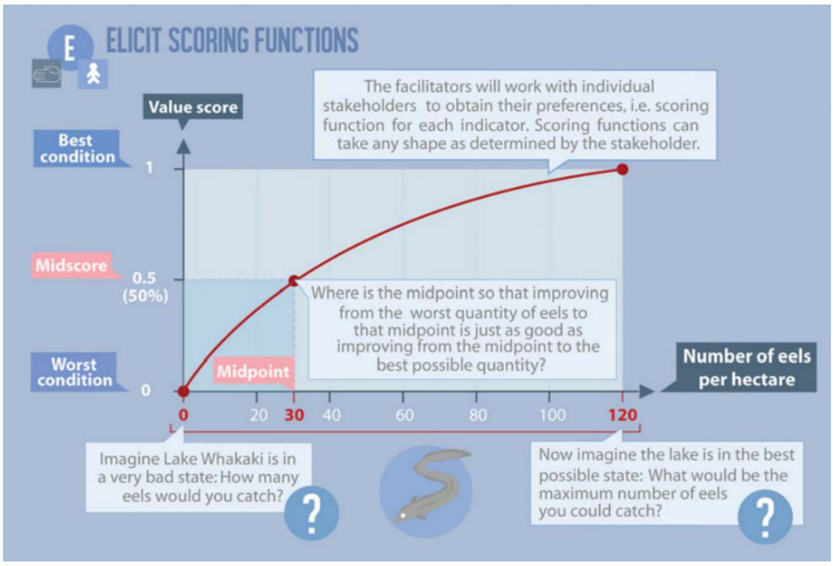

Figure 12. Illustration depicting the quantification of value preferences using a scoring function (also called value function). The scoring functions employs a continuous scale ranging from 0 to 1 along the y-axis, while the x-axis represents the attribute's original unit range (0 indicating no achievement, and 1 signifying full achievement of the goal)[18].

6. Current Progress of the SOS-Water Case Studies

The case studies in SOS-Water are progressing with different levels of advancement. The Danube River Basin case study (i.e., the Upper Danube and Danube Delta case studies) and the Mekong case study have both made notable progress and are currently in the process of planning their first stakeholder workshops. In the case of the Upper Danube and the Danube Delta, a single series of workshops is planned to be held for both case studies due to a large overlap in high-level stakeholders. Meanwhile, the Rhine and Rhine-Meuse Delta case studies are at an earlier stage, focusing on identifying and engaging key stakeholders and interested groups. In the case of the Júcar River Basin, a unique approach is being adopted. This case study will leverage an existing regional project – the GoNEXUS project – to streamline stakeholder engagement. By collaborating with the GoNEXUS stakeholders and planned workshops, the case study leaders aim to efficiently elicit water values and co-construct objectives hierarchies with the engaged stakeholders. This approach underscores the SOS-Water project's adaptability and strategic use of available resources to achieve comprehensive and sustainable water management solutions.

7. Linking Stakeholder Input to Hydrological Models

The objectives hierarchies derived from the MCDA framework will serve as a blueprint for the development and refinement of hydrological models in the SOS-Water project. More specifically, the measurable indicators identified and prioritized through the objectives hierarchies for each case study will provide valuable quantitative data that will be integrated into hydrological models. These indicators may include water quality parameters, discharge rates, groundwater levels, sediment transport, and other relevant variables that reflect the status and trends of water resources. By incorporating the insights and priorities of local stakeholders, the hydrological models can be fine-tuned to better represent real-world conditions, enhancing the accuracy and effectiveness of water resource assessments and predictions.

Through a participatory approach, modelers will work closely with stakeholders to identify suitable indicators that correspond to the identified objectives. Closely linked with Work Package 1 (*Co-developed water values and scenarios*), Work Package 4 (*Indicators and thresholds*) will finalize the development of these indicators and thresholds to fully assess the environmental, social, and economic status of the water system. This process involves 'translating' the sub-objectives into specific indicators that can be directly linked to hydrological parameters, and that will in turn provide a tangible and measurable way to gauge progress and effectiveness. Once integrated into the hydrological models, the identified indicators enhance the models' predictive capabilities. By monitoring and analyzing the indicators' trends and variations, stakeholders can make informed decisions regarding water resource allocation, infrastructure development, and policy formulation, anticipate potential issues, and develop adaptive strategies that align with their freshwater management goals.

The cooperation of case study leaders, local stakeholders, and modelers ensures that the developed models are not only scientifically robust, but also resonate with the needs and values of the communities they serve. This integrated approach, as demonstrated by the SOS-Water project, holds the potential to significantly improve water management outcomes, promote sustainability, and safeguard valuable freshwater resources.

Table 2. DPSIR Framework for each of the case studies in SOS-Water using information provided by the case study leaders.

	Rhine and Rhine-Meuse Delta	Upper Danube	Danube Delta	Júcar River	Mekong Delta
Urgent challenges	*(1) Water allocation and availability (2) Transboundary water users (3) Ecosystem restoration/water quality (4) Climate change and increasing water temperatures (5) Sediment transport*	*(1) Hydropower and river fragmentation (2) Water scarcity and management (3) Sediment management and erosion (4) Transboundary cooperation (5) Hydromorphological alterations (6) Water quality and pollution (7) Flood risk management (8) Droughts*	*(1) Erosion and land subsidence (2) Biodiversity loss and habitat degradation (3) Water management and pollution (4) Climate change and sea level rise*	*(1) Water scarcity and allocation (2) Drought and climate variability (3) Erosion and habitat loss (4) Increase in energy demand*	*(1) Salinization and freshwater scarcity (2) Sediment loss and erosion (3) Climate change and sea level rise (4) Biodiversity loss and habitat degradation (5) Riverine plastic pollution (6) Groundwater abstraction and land subsidence (7) Flooding*
Drivers	*(1) Increased water demand (2) Climate change (3) Population growth (4) Increased irrigation demand (5) Snowpack reduction (6) Sea level rise (7) Glacier melt (8) Transportation*	*(1) Agriculture (2) Hydropower development (3) Industrial activities (4) Urbanization (5) Navigation*	*(1) Population growth (2) Urbanization (3) Agriculture (4) Industry (5) Water infrastructure development*	*(1) Generational shifts out of agriculture (2) Globalization (3) Climate change (4) Water demand (5) Urban development*	*(1) Water infrastructure (2) Agricultural development (3) Urbanization (4) Flood security (5) Population growth (6) Risk reduction (7) Climate change*

Pressures	*(1) Alterations in land use (2) Hydropower production (3) Climate change (4) Agricultural expansion (5) Groundwater abstraction (6) Nutrient runoff (7) Navigation infrastructure and river engineering*	*(1) Altered flow patterns (2) Alterations in land use (3) Impacted water quality (4) Altered connectivity*	*(1) Pollutants and waste generation (2) Disruption of natural hydrological patterns and habitat connectivity (3) Alterations in land use*	*(1) Increase in energy demand (2) Increasing water demand*	*(1) Increases in energy demands (2) Increases in water consumptions (3) Deforestation and land use changes (4) Release of substances (5) Climate change (6) Flood proofing and flood control*
State	*(1) Decreasing trends in natural water availability (2) Increasing water temperatures (3) Reduced water quality (4) Pharmaceuticals and emerging contaminants*	*(1) Altered flow patterns and sediment transport (2) Loss of habitat connectivity*	*(1) Erosion (2) Eutrophication and pollution (3) Saltwater intrusion (4) Biodiversity loss and habitat degradation*	*(1) Groundwater depletion (2) Eutrophication of water bodies (3) Urban water quality reduction (4) Riparian ecosystem deterioration (5) Deficit in environmental flows*	*(1) Altered flow regimes (2) Land subsidence, river erosion, and land loss in coastal region (3) Saltwater intrusion (4) Water quality degradation and riverine plastic pollution (5) Extreme sediment and nutrients loss (6) Fish diversity decline (7) Reduction of flood plain and wetland areas*
Impacts	*(1) Loss of biodiversity (2) Provisioning of water (3) Sediment loss (4) Altered hydrological patterns and habitat connectivity (5) Reduced cooling water potential*	*(1) Decline in water quality (2) Reduced biodiversity/species endangerment (3) Altered riverbed morphology (4) Altered sediment transport*	*(1) Disruptions in aquatic food webs (2) Loss of biodiversity (3) Alterations in the hydrological regime (4) Reduced suitability for fisheries and tourism (5) Habitat loss and degradation*	*(1) Degradation of the Albufera freshwater lagoon (2) Reduction of agricultural activities, farming abandonment (3) Reduction of tourism in areas of ecological interest (4) Reduced biodiversity (5) Flooding*	*(1) Freshwater scarcity in coastal regions (2) Reduction of fishing productivity (3) Decline of rice productivity (4) Higher frequency of pluvial and tidal floods (5) Decline in regulation services of the ecosystem (6) Loss of biodiversity and decreased resilience to climate change*

		(5) Changes in hydrological patterns and habitat connectivity *(6) Loss of habitat* *(7) Neobiota invasions* *(8) Loss of cultural heritage*		*(6) Habitat loss*	*(7) Reduced income of farmers* *(8) Reduced attractiveness of tourism* *(9) Challenges to navigation maintenance* *(10) Increased carbon footprint*
Responses	*(1) EU Water Framework Directive* *(2) Transboundary agreements* *(3) Low water navigation agreements*	*(1) EU Water Framework Directive* *(2) International Commission for the Protection of the Danube River* *(3) Danube Transnational Program* *(4) National laws and regulations*	*(1) Ramsar Convention* *(2) Danube Delta Biosphere Reserve* *(3) EU Habitats Directive* *(4) Romanian legislation* *(5) International Commission for the Protection of the Danube River* *(6) Bilateral agreements*	*(1) EU Water Framework Directive* *(2) Water Law of Spain* *(3) The Júcar River Basin Management Plan* *(4) Natura 2000 Network* *(5) Relocation of agricultural production and changes in crop selection* *(6) Shift towards clean energy production* *(7) Better monitoring and control*	*(1) Mekong River Commission procedures (regional scale)* *(2) Water Resources Act; Environmental Protection Act; Irrigation Act; Natural Disaster Prevention and Control Act (national scale)* *(3) restoration and monitoring measures for technical measures* *(4) water diversion and water source alternatives*

8. Conclusions

The SOS-Water project aims to address complex challenges posed by water scarcity, quality degradation, biodiversity loss, governance inefficiencies, and equity issues. The approach to developing sustainable freshwater management strategies is built upon stakeholder engagement and the integration of stakeholder input into hydrological models. The integration of stakeholder input, from both high- and low-level stakeholders, helps create a decision-making framework that is transparent, inclusive, and responsive to diverse perspectives. The project recognizes obstacles such as stakeholder disinterest, fatigue, and legal limitations, emphasizing the need for efficient coordination and robust legal frameworks to overcome these challenges.

Utilizing the Multi-Criteria Decision Analysis (MCDA) framework as a structured approach to decision-making allows stakeholders to co-create objectives hierarchies and prioritize trade-offs, enhancing transparency and ensuring that decisions are based on the collective values and concerns of stakeholders. Furthermore, by integrating stakeholder values and knowledge into hydrological models, the SOS-Water project bridges the gap between local perspectives and scientific models. This integration paves the way for effective, equitable, and sustainable freshwater management practices that account for the complexities of water systems and the needs of various stakeholders.

Disclaimer

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