STARS 4 Water

Climate change impacts: water challenges in European river basins

Policy brief 2

Deliverable D6.6

May 2026

Policy brief 2 - Climate change impacts: water challenges in European river basins

Lead beneficiary	DELTARES & SEVEN
Lead author(s)	Harm Duel, Maggie Kossida, Michiel Blind
Work Package	6: Dissemination and Communication
Due Date	September 2025
Submission date	September 2025
Update	May 2026
Contributers	Trine Jahr Hegdahl (NVE), Hege Hisdal (NVE), Virginie Keller (UKCEH), Nathan Rickards (UKCEH), Maria-Helena Ramos (INRAE), Africa de la Hera Portillo (IGME), Pedro Martinez Santos (UCM), Helmut Habersack (BOKU), Mario Klösch (BOKU), Albert Scrieciu (GeoEcoMar), Norbert Cremers (RWS), Judith ter Maat (Deltares)

Dissemination Level		
PU	Public	X
SEN	Confidential, only for members of the consortium and the granting authority (including other EU institutions and bodies)	
CI	Classified, as referred to EU Decision 2015/444 and its implementing rules	

Version log			
Version	Date	Released by	Nature of Change
0.1	3-9-2025	Harm Duel	Outline
0.7	16-8-2025	Harm Duel	Draft version
0.8	18-8-2025	Maria-Helena Ramos	Review draft version
0.9	29-9-2025	Harm Duel	Final draft, incorporated comments of internal review
1.0	30-9-2025	Judith ter Maat	Approval final version
1.1	18-5-2026	Harm Duel	Update

Citation

STARS4Water (2026): Climate change impacts: water challenges of European river basins. Policy Brief 2. Horizon Europe project STARS4Water. Deliverable D6.6. Update.

The STARS4Water project has received funding from the European Union's Horizon Europe research and innovation program under the Grant Agreement No 101059372

Disclaimer

Table of contents

Introduction

Climate change is rapidly altering hydrological cycles, leading to more frequent and severe floods and droughts across Europe. Freshwater resources are increasingly under pressure and its availability becoming more limited due to shifting precipitation patterns, and higher evapotranspiration rates and glacier retreat due to rising temperature, while demand for water continues to grow. Together, these trends act as a systemic risk multiplier, exacerbating vulnerabilities across societies, economic sectors, and ecosystems. At the same time, adapting water management to changing water cycles at river basin scale from source-to-sea offers a strategic opportunity to strengthen resilience. When effectively governed, water can become a stabilising factor that underpins economic activity, societal well-being, and ecosystem health. The launch of the EU Water Resilience Strategy in June 2025 signals a recognition by the European Commission that water resilience is not only an environmental concern, but a prerequisite for economic stability, security of supply, human well-being, healthy ecosystems, and long-term sustainability.

River basins are the natural unit for operationalising this ambition. However, delivering water resilience requires a structural shift in the management of interconnected water systems, including rivers, lakes, reservoirs, and groundwater. Bridging the gap between strategic objectives and on-the-ground implementation remains a key challenge. There is a need for clearer guidance, stronger coordination mechanisms, and more consistent application of policy instruments to reduce implementation risks at basin scale.

This policy brief sets out actionable recommendations for EU institutions, national governments, and river basin organisations to advance water resilience through collaborative approaches, tools and shared knowledge and expertise. It builds on practical insights from the EU Horizon STARS4Water project, which collaborated with stakeholders across seven European river basins, highlighting shared understanding in climate vulnerabilities and co-created pathways and solutions for effective adaptation to changing hydrological cycles.

STARS4Water

STARS4Water is a Horizon Europe research project dedicated to advancing tools and data services through co-creation with river basin stakeholders. The project aims to deepen our understanding of future hydrological cycles and the evolving hydrological regimes of catchments and aquifers, including extreme events such as floods and droughts. By fostering collaboration and innovation, STARS4Water supports better adaptation strategies for a resilient, sustainable, and prosperous future.

Key messages

- **Climate change is already altering the hydrological cycle** in European river basins, with more frequent and intense drought and flood events expected in the coming decades.
- **Future water availability and flow regimes will vary significantly** across river basins due to both climatic and socio-economic factors, requiring basin-specific approaches.
- **Integrating scientific insights with the practical experience of river basin managers** is essential to understanding future water dynamics and co-designing effective resilience strategies.
- **The safe-operating-space concept is a valuable framework** for supporting evidence-based decision-making on solutions addressing climate risks and opportunities.
- **STARS4Water provides actionable knowledge, tools, and guidance** to support strategic planning and implementation of solutions for water-resilient river basins across Europe.

Climate change impacts in Europe

Climate change has intensified in recent years, resulting in an alarming trend of global warming and extreme weather events[1]. This calls for urgent action to adapt faster to its cascading impacts and to respond to the needs of society and economic sectors to secure water, food and energy supplies for today and the next generations. According to the European State of Climate[2], Europe is experiencing the fastest rate of warming among all continents, with temperatures rising at approximately twice the global average. This accelerated warming contributes to an increase in the frequency and intensity of extreme weather events, including heatwaves, droughts and floods. Furthermore, climate change is significantly altering the availability of natural freshwater resources. These changes are driven by melting glaciers, shifts in precipitation patterns, and increased evapotranspiration. As a result, the impacts on freshwater systems are profound, leading to economic losses, threats to food and energy security, disruption of inland shipping, degradation of ecosystems, loss of biodiversity, increased exposure to wildfires and challenges in ensuring a reliable supply of drinking water. In addition, climate change is causing ocean warming, which contributes to rising sea levels and deterioration of marine ecosystems. These developments pose serious risks to deltas and coastal communities and economic sectors, exposing them to flooding, erosion, and the salinization of freshwater sources. These multifaceted climate change impacts call for urgent action to adapt faster to its impacts and the needs of society and economic sectors to secure water, food and energy supplies for today and the next generations.

Across Europe, the impacts of climate change vary significantly between regions and river basins. To advance the understanding of these impacts within European river basins, STARS4Water collaborated closely with basin stakeholders to assess climate and socio-economic scenarios through the application of co-developed data services and analytical tools. This policy brief outlines the key findings of this work and provides recommendations aimed at strengthening water resilience across European river basins.

[1] IPCC Sixth Assessment Report (AR6, 2023)

[2] Copernicus Climate Change Service (C3S) and World Meteorological Organization (WMO), 2025: European State of the Climate 2024, climate.copernicus.eu/ESOTC/2024, doi.org/10.24381/14j9-s541

Impact Reporter

Sharing experiences is essential to improve understanding of the biophysical and socio-economic impacts of climate change. To facilitate information sharing on climate change impacts STARS4Water has developed the Impact Reporter. This application will support creating better insights in vulnerabilities and risks of a rapid changing climate, and ex-post evaluations of applied adaptation measures by different categories of stakeholders related to climate change. The Impact Reporter is openly accessible online (https://ir.stars4water.eu/).

European river basins under stress: cases across Europe

Climate change is affecting water resources availability across Europe in diverse ways. Some river (sub)basins are experiencing more frequent and more intense droughts, while other (sub)basins are becoming overall wetter or more prone to flooding. These regional disparities lead to differing effects on river flow regimes and the availability of water resources from one river basin to another. As a result, existing water management practices need to adapt to these evolving conditions to remain effective and become resilient.

STARS4Water has collaboratively explored future water resource availability and water use across seven diverse European river basins, ranging from small to large, through co-creation with local stakeholders (Figure 1). These basins span a broad spectrum of hydrological and socio-economic contexts across Europe, including Drammen (Norway), East Anglia (UK), Rhine, Danube, Seine (France), Duero (Spain), and Messara (Crete). Findings are presented in a STARS4Water report on improved projections on water resources availability and related risks[3].

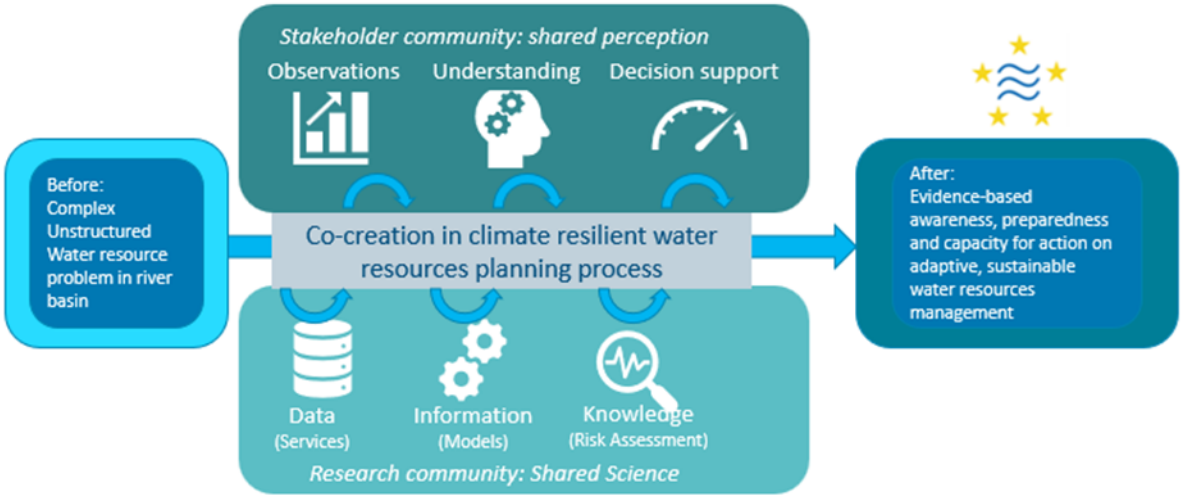

Figure 1: STARS4Water's Stakeholder driven approach to create a shared understanding of current and future flow regimes and water resources availability and the associated impacts on ecosystems and societal and economic sectors at river basin scale.

[3] Ramos, M.H., et al., 2026. Improved projections on water resources availability and risks in selected river basins. STARS4Water. Deliverable D4.2.

- ***Rhine river basin***

Alpine glaciers are melting at an alarming rate due to climate change. The loss of glaciers and the decline of snowfall in winter is significantly altering the flow regimes of main European rivers, such as Rhine and Danube. The hydrology of the Rhine River is shifting from a glacier-fed to a rain-fed river, altering its flow regime and seasonal water resources availability. Evidence from simulations and stakeholder consultations points out to increased low-water conditions during summer, and flood risk during winter. Less water from glaciers has significant impact on the hydropower production in the Alps and causes additional pressures to the alpine river ecosystems and habitats. State-of-the-art assessments made by STARS4Water predict a decline in the summer average flow in the lower and middle Rhine River of around 10% in the next decades due to climate change and increased water consumption. The intensifying low-flow conditions diminish the navigability of the River Rhine and are expected to generate adverse economic impacts as inland water transport declines. The drought events and low flow conditions also affect the aquatic ecosystems and riparian wetlands, the drinking water supply and the abstraction of water for irrigation and industrial processes. Sea-level rise combined with increased low flows conditions exacerbates saltwater intrusion in the Rhine delta and complicates freshwater management across the delta.

- ***Danube river basin***

The retreat of alpine glaciers and shifts in precipitation patterns are altering flow regimes and seasonal water availability in the Danube River basin, mirroring similar trends and risks projected in the Rhine River basin. These changes are expected to intensify low-flow conditions, creating growing bottlenecks for inland water transport along the Danube River, reducing the hydrological conditions for river ecosystems and riparian wetlands and limiting the abstraction of water. As major rivers in Central and Western Europe, hydrological changes in the Danube and Rhine have widespread impacts on water-dependent sectors, such as agriculture, hydropower, industry, and inland navigation, as well as on ecosystems and water supply.

- ***Messara river basin***

In the Mediterranean region, water scarcity will increase in many river basins as water availability will decline due to less precipitation and unsustainable water use, mainly by the agricultural sector. In the Messara River basin, the main agricultural area of the island of Crete in Greece, water scarcity is already significant and is expected to worsen, increasing pressure on the water consuming economic sectors and the environment. Water demand for irrigation often exceeds the annual rainfall, leading to overexploitation of the aquifers and depletion of freshwater resources. The cascading impacts of water scarcity are clearly linked to environmental decline and socio-economic instability. Climate-smart farming practices and other measures to reduce the irrigation demand need to be implemented.

- ***Duero river basin***

In the Duero River basin, in the Iberian Peninsula, the runoff and recharge will significantly decline due to changing climate and interannual variability and the frequency of droughts will increase. Groundwater-dependent ecosystems will experience more stress, and lowland irrigation will face

limitations. The projected further increase of drought risks calls for transition towards climate-smart farming practices and reducing the vulnerability of water-depending ecosystems through improved storage and operational rules of reservoirs.

- ***Seine river basin***

The Seine River basin presents a unique challenge for water managers, as it is situated at the transitional boundary between two contrasting European climate zones: the drying southern regions and the increasingly wetter northern areas. This geographic position amplifies uncertainty around future water availability and extreme events, challenging the development of adaptation strategies. Climate projections consistently point to more frequent and prolonged summer low-flow conditions, driven by rising temperatures, increased evapotranspiration, and reduced summer precipitation. In contrast, trends in annual precipitation and high-flow events remain uncertain, with no clear consensus among climate models. For river basin management, this requires giving more attention to how upstream reservoirs in the Seine basin operate during summer to sustain downstream flows. It also underscores the need for planning under uncertainty, requiring flexible and adaptive strategies to ensure long-term water resilience.

- ***East Anglia***

East Anglia is one of England's more water-scarce regions, due to relatively low rainfall, with high agricultural/irrigation demand and several protected environmental sites and peatlands. This makes the area extremely sensitive to climate change and any reductions in summer water availability. As such, East Anglia's water resources are likely to become increasingly strained in the future due to hotter, drier summers and wetter winters, leading to more frequent droughts and floods. Rising sea levels and storm surge risk will also increase flood risk and salinisation for low lying coastal areas. This will likely reduce water supply and worsen raw water quality, impacting the region's vulnerable ecosystems and high agricultural water demand. In response, basin stakeholders are collaborating on projects such as reservoir management, aquifer storage, water reuse, strategic transfers, and shared water efficiency standards to build resilience against these escalating challenges.

- ***Drammen river basin***

In the snow dominated Drammen River basin, future higher temperatures and more precipitation will significantly alter the flow regime of the river. Earlier and fewer snowmelt floods are already observed. Rain-induced floods have become more frequent, and their magnitude will increase as precipitation amounts and intensity rise even more in the decades to come. Climate projections indicate an increase in the duration of summer low-flow events, primarily driven by rising temperatures leading to a longer summer season with increased evapotranspiration. Like many rivers in Norway, the Drammen River plays an important role in hydropower production. Increasing precipitation may enhance hydropower potential; however, reservoir operating rules will need to be adapted to manage higher flows. Such adjustments are necessary to minimise flood risks, prevent both flood- and drought-related damages, and reduce the vulnerability of ecosystems and habitats.

Challenges in mainstreaming water resilience in river basins

Climate change can be a threat to water resources management with the potential to intensify socioeconomic and environmental risks, and challenge best practices in water management. Scenario studies in STARS4Water river basins reveal critical situations regarding water sharing and tensions among different users, and these pressures could be further exacerbated in the future. Our findings underscore the urgent need for data and tools that support an integrated modelling approach to water management, where physical factors, socio-economic dimensions and management operations come together. This is not only a key issue at the local or river basin scale, but also at regional scales, across neighbouring basins linked through surface and groundwater interdependencies, or across regions linked by shared services, such as those offered by hydropower grids in the energy sector.

The European Water Resilience Strategy acknowledges that well-functioning water cycles from source to sea are essential for water resilience. Water cycles are complex interactions between atmospheric processes and hydrological processes on land, rivers, lakes, aquifers, seas and oceans. To manage freshwater resources, healthy soils and wetlands are playing a key role in the hydrology of rivers, lakes and groundwater.

River basin organisations and basin stakeholders are essential for mainstreaming actions and water resilience solutions. European Water Resilience Strategy faces critical implementation gap risks in understanding the changes in hydrological cycles at river basin scale, evolving flow regimes in catchments and aquifers, and the complex human-water interactions that shape water availability. The implementation strategy of the EU Water Resilience Strategy requires a multi-governance approach, each with clearly defined roles and responsibilities. This includes the specific role of river basin organisations in mainstreaming actions and solutions that support the restoration of hydrological cycles from source-to-sea. While the strategy does not create new formal roles for river basin organisations, it strongly reinforces their importance as the operational level where water resilience is delivered. Many river basin organisations face systemic, institutional, financial, and technical challenges that can significantly hinder implementation. STARS4Water has identified several challenges in mainstreaming actions and solutions supporting water resilience at river basin scale.

River basin water management involves multiple sectors, such as agriculture, energy, industry, and urban planning, often with competing water uses. Fragmented governance is recognised as a major barrier to effective water management. In transboundary river basins, the additional governance challenge is the coordination across countries, as it is usually politically sensitive. Water resilience is inherently cross-sectoral. This also implies that agricultural practices, land use planning, water infrastructure development, and hydropower production need to integrate with river basin management objectives regarding water resilience. Achieving water resilience relies upon the active involvement of basin stakeholder representing economic sectors and societal organisations. Thus, we need to ‘mainstream’ working with all sectors of society to deliver water resilience solutions.

The STARS4Water Safe-Operating-Space framework is a valuable tool to enhance the understanding of future water resources availability at the river basin scale under changing

climate and socio-economic developments and to identify risks of the current operations. Applying the SOS concept in river basin management is not straightforward. Effective stakeholder engagement is crucial to build a shared understanding of the concept and to clarify how it complements existing approaches, such as risk assessments and scenario-based analyses used in climate impact assessments and adaptation planning.

Setting clear limits on water abstraction from groundwater, rivers, and lakes is fundamental to safeguarding a sufficient, reliable, and sustainable water supply for both human use and ecosystems, under current conditions and future pressures related to climate change, population growth, and economic development. These limits should be grounded in robust assessments of ecological and hydrological needs to prevent overexploitation.

Across European river basins in STARS4Water, responses to water scarcity and drought vary in their level of coordination. While some countries have established national frameworks to prioritise water use during low-flow periods (e.g. the Netherlands' *verdringingsreeks*), recent reviews highlight the need for stronger mechanisms to enable fair and sustainable water allocation[4]. Overall, significant challenges remain in transitioning societies and economic sectors towards more sustainable and climate-resilient water-sharing approaches, particularly in regions facing higher levels of water scarcity or drought vulnerability[5].

Many river basin organisations face limited expertise and capacity to address the system complexity and climate uncertainty to support decision making on cross-sectoral trade-offs and implement effective water resilience solutions. Data, tools and knowledge limitations at river basin organisations constitute a significant gap in the understanding of basin dynamics and how climate change and future water use will impact the availability of water resources.

To enhance water resilience, strategic actions must go beyond current challenges and anticipate future dynamics. Insights from STARS4Water activities across European river basins show that science-stakeholder partnerships are key to develop adaptive pathways that prepare for uncertain climate impacts. By linking scientific knowledge with real-world water management, river basin managers and other actors can co-create solutions. These solutions proactively address new and emerging hydrological regimes and water resources availability, thus strengthening Europe's capacity to respond to future water risks. The implementation gap in water resilience strategies is not merely a technical issue but also a systemic governance challenge. From a river basin management perspective, closing this gap requires integrated approaches that bridge scales, sectors, and stakeholders. By strengthening coordination, aligning incentives, and empowering basin-level action, water resilience strategies can move from ambition to tangible impact.

[4] McCracken, M., Turgul, A., Schmeier, S., Porta, E.L., and Wolf, A.T., 2026. Transboundary water allocation in practice: global trends in international freshwater agreements. Water Policy (2026) 28 (3): 355–374. https://doi.org/10.2166/wp.2026.290.

[5] Rouillard, J., Tarpey, J., Kampa, E., Penttilä, O., Belinskij, A., Díaz, E., Berbel, J., Junjan, V., Molle, F., Ionescu, C., 2024: Review of national water allocation policies in six European countries. GOVAQUA. Deliverable 2.1.

Guidance towards water resilient European river basins

The STARS4Water project has identified six guiding principles, rooted in a stakeholder-driven approach, for enhancing water resilience at the river basin level (Figure 1). These principles are designed to support adaptive, resilient, sustainable and inclusive water resources management in the face of climate change.

1. Understanding our freshwater systems

A river basin approach is vital for understanding and managing the full hydrological cycle from source to sea. This principle is emphasized by STARS4Water. This includes recognizing the role of aquifers in river basins, as well as the role of lakes, reservoirs, wetlands, forests, and other land ecosystems in groundwater recharge, streamflow regulation, and evapotranspiration. Effective water resources management requires upstream-downstream connectivity in both hydrological and governance dimensions , especially across local, national and international jurisdictions. It should also link physical hydrological processes with societal interactions and water use priorities. This holistic understanding is essential to enhance water resilience and support sustainable water resource governance.

2. Building a water-resilient Europe through science-stakeholder partnerships

To strengthen water resilience across Europe, it is essential to establish robust partnerships between science and stakeholders to ensure that scientific advancements in modelling tools, knowledge systems, and data services are effectively translated into information for decision-making on strategies, planning and actionable solutions. Likewise, these partnerships ensure the relevance of research and development, as stakeholder needs and experience feeds into scientific development. The STARS4Water project shows that strong stakeholder engagement is critical to foster joint ownership of knowledge and information related to both current and emerging challenges in water resource availability. Stakeholder communities should be inclusive, representing upstream and downstream actors, environmental and social organisations, and water-dependent economic sectors. This diversity enables the sharing of experiences, identification of challenges, and co-development of solutions, thereby strengthening collective resilience.

3. Be better prepared for the future flow regimes and water resources availability

Climate change is driving an increase in extreme hydrological events and altering seasonal water availability across European river basins. Assessments by STARS4Water indicate that future climate conditions will significantly impact flow regimes and freshwater resources, posing risks to both ecosystems and societies. Simultaneously, growing socio-economic pressures, especially the increasing water demands from economic sectors, threaten to further strain water resources unless proactive measures are taken to reduce consumption.

To build resilience, stakeholders must be empowered to envision future scenarios through participatory and reliable frameworks integrating local concerns within coherent regional, national and European pathways. The development of narratives and future scenarios are effective approaches to explore future water resources availability under uncertain climate

conditions, to map future climate vulnerabilities and to explore opportunities for water resilience for society, ecosystems and prosperity.

4. Identify the Safe Operating Space for resilient water resources management

Reducing damages by hydrological extreme events as well as water consumption and improving water efficiency are the main pillars in European Water Resilience Strategy for building a water-smart economy. Setting limits on water allocation (groundwater, rivers, lakes) based on accurately identifying environmental requirements is essential to ensure a sufficient and reliable supply of water for both people and ecosystems, now and in the future. These limits should determine the safe operating space for water management: staying within the limits implies water management and exploitation is resilient to future water resources availability and flow regimes while safeguarding environmental flows.

5. Explore management options to enhance water resilience

A broad spectrum of management strategies and solutions are available to mitigate the impacts of a changing climate on water resources. These include measures to enhance the sponge capacity of landscapes, such as nature-based solutions and managed aquifer recharge, as well as approaches to reduce water consumption by promoting water efficiency and enabling water reuse. The relevance and effectiveness of these solutions may vary within the river basin and across river basins. Therefore, interventions should be explored and tailored as strategic components for staying within the Safe Operating Space and hence, building water resilience within the specific context of each basin. Sustainability and inclusivity must go hand in hand. Smart solutions are those that succeed on focusing on an integrative vision of meeting societal needs while also prioritising flood damage reductions and the water requirements of water-dependent ecosystems. By ensuring an inclusive sharing of safe water resources, we engage our societies on the pathway to equitable prosperity.

6. Raising awareness and information sharing

Raising societal awareness is essential as it enables behavioural change and local action, unlocks participation and innovation uptake, builds legitimacy for difficult policy choices, supports basin-wide coordination and enhances preparedness. Without societal awareness, water resilience strategies remain technocratic and under-implemented. With it, they become actionable, scalable, and durable.

Easily accessible information tools - such as the STARS4Water story-maps, the STARS4Water Impact Reporter and STARS4Water dashboards - enable river basin actors and broader audiences to monitor and raise awareness of current water resources availability and water use, as well as the biophysical and socio-economic impacts of climate change, related vulnerabilities, and the effectiveness of adaptation measures. These tools support transparent communication for informed decision-making and enhancing resilient and collaborative water resources management across regions.

Policy recommendations to close the implementation gap

European river basins are increasingly affected by climate-driven water stress, flooding, and ecosystem degradation, highlighting the need for a systemic shift toward integrated, basin-scale water governance that combines science, policy, and stakeholder action. Current responses to implement water resilience solutions based on a systemic change of river basin management remain fragmented, with gaps between EU strategies and implementation at national and basin levels. Without stronger coordinated action, risks to water security, food systems, biodiversity, and economic stability will intensify. Achieving water resilience in Europe requires a systemic shift from sectoral reactive management to integrated forward-looking basin-scale governance, supported by science-policy alignment, clear allocation limits, and robust institutions. Drawing on co-creation with river basin organisations and stakeholders, STARS4Water has developed policy recommendations to support the effective implementation of the EU Water Resilience Strategy:

- **Strengthen river basin governance:** empower national and transboundary river basin organisations as operational hubs with clear mandates and resources to facilitate river basin planning, data sharing based on FAIR principles, and implementation of water resilience solutions across economic sectors and societal organisations. Introduce multi-level governance frameworks with clearly defined EU–national–basin roles.
- **Align policies** across water, agriculture, energy, and spatial planning sectors to enable the development of climate adaptation strategies and water resilience actions across sectors at river basin scale.
- **Institutionalise stakeholder co-creation:** embed participatory processes in river basin planning cycles, through permanent science–basin interfaces and engagement of key actors: farmers, industries, cities, and civil society. Use participatory scenario-building and adaptation pathways for water resilience as standard practice.
- **Invest in knowledge, tools and data systems:** strengthen technical capacity of water authorities and stakeholders through co-creation with science community by unlocking (global) data services, data-sharing, developing basin-oriented data services, and scaling up existing hydrological modelling approaches and targeted decision support tools at basin scale. Strengthen capacity-building programmes for water authorities and basin stakeholders.
- **Embed the "Safe Operating Space" concept within water resources management frameworks:** apply this approach to define and establish basin-specific thresholds for water abstraction and ecological flows; support prioritisation frameworks for water allocation that balance trade-offs across sectors; and integrate these limits into both operational management (including forecasting) and long-term strategic planning. Water allocation decisions should be systematically and consistently aligned with ecosystem requirements and projected climate impacts.