STARS 4 Water

Climate change impacts: water challenges of European river basins

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Lead beneficiary	DELTARES & SEVEN
Lead author(s)	Harm Duel, Maggie Kossida, Michiel Blind
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Contributors	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)

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Table of contents

Key Messages

- Climate change is already changing 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 understand future water dynamics and to co-design effective resilience strategies.
- STARS4Water provides actionable knowledge, tools, and guidance to support strategic planning and implementation of solutions for water-resilient river basins across Europe.

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.

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[3]. 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

[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

[3] 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

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.

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 areas are experiencing more frequent and more intense droughts, while other areas 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 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 in seven diverse European river basins, ranging from small to large, through co-creation with local stakeholders (Figure 1). These basins include Drammen (Norway), East Anglia (UK), Rhine, Danube, Seine (France), Duero (Spain), and Messara (Crete), representing a broad spectrum of hydrological and socio-economic contexts across Europe.

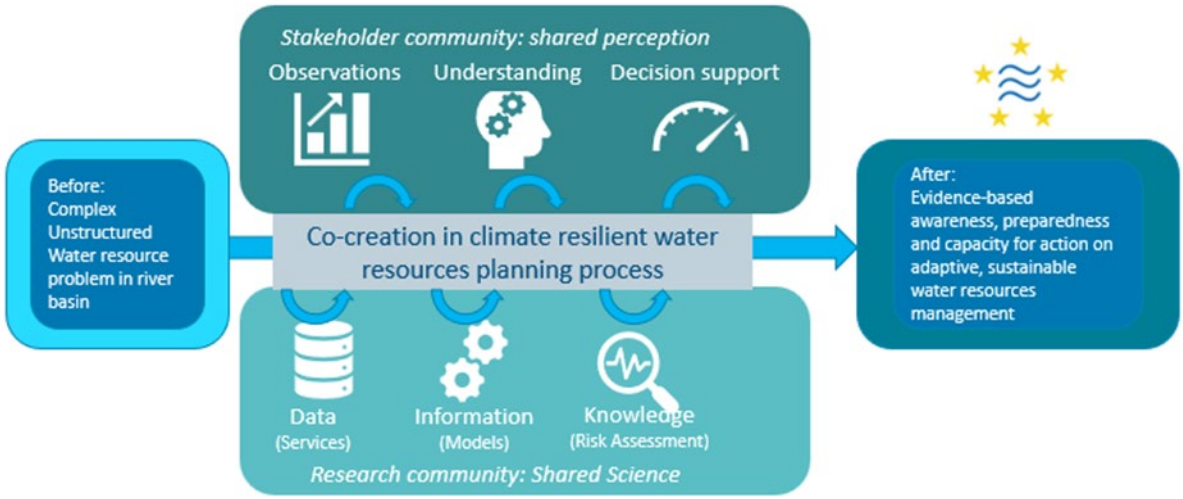

Figure.7¿STARS0Water¾.Stakeholder.driven.approach.to.create.a.shared.understanding.of.current.and.future.flow.regimes.and.water.resources.availability.and.the.associated.impacts.on.ecosystems.and.societal.and.economic.sectors.at.river.basin.scale¡

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 European rivers, such as the Rhine and the Danube rivers. The hydrology of the Rhine River is shifting from a glacier-fed to a rain-fed river, resulting in a shift in 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. State-of-the-art assessments made by STARS4Water predicts 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. 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. In the middle and lower parts of the catchment, increased low flow conditions reduce the navigability of the Rhine River. The low flow conditions also affecting the aquatic ecosystems and riparian wetlands, the drinking water supply and the abstraction of water for irrigation and industrial processes.

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 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.

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 floods have become more frequent, and their magnitude will increase as precipitation amounts and intensity increases even more in the decades to come. Climate projections indicate a slight increase in the duration of summer low-flow events, primarily driven by rising temperatures leading to a longer summer season with increased evapotranspiration.

More water means a higher hydropower production potential, but changes in reservoir operation rules will be required to avoid flood losses, prevent flood and drought damages and reduce the vulnerability of ecosystems and habitats.

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, which is the main agricultural area of Crete Island in Greece, water scarcity is already significant and will increase further, putting higher pressure on the water consuming economic sectors and the environment. The 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.

In the Duero River basin, 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.

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 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 is one of England’s more water-scarce regions, due to relatively low rainfall, with high agricultural/irrigation demand and a number of protected environmental sites and peatlands. That baseline scarcity 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.

STARS4Water and the European Water Resilience Strategy

In June 2025, the European Commission launched the European Water Resilience Strategy. The strategy aims to adapt society to the hydrological impacts of the rapidly and intensifying changing climate. To enhance water security across Europe, the strategy is based on three pillars: (1) restoring and protecting the water cycle, (2) building a water-smart economy, and (3) securing clean and affordable water and sanitation for all.

The European Water Resilience Strategy acknowledges that a well-functioning water cycle is 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. Overexploitation and mismanagement of water resources, pollution as well as climate change and degradation of ecosystems, crucial for natural hydrological process in catchments, have deeply affected the hydrological cycle, flow regimes of rivers, the retention capacity of aquifers and severely reduced water quality of Europe's freshwater resources. To ensure resilience against floods, droughts and water scarcity, the European Water Resilience Strategy aims to restore and protect the water cycle from source to sea by adopting water smart practices and green infrastructure to improve water retention on land, reducing water consumption, introducing innovative water technologies, preventing water pollution and effectively implementing the already existing EU laws for freshwater.

The European Water Resilience Strategy is timely as the intensified flood and drought events and alterations in flow regimes in Europe clearly demonstrate the urgency for boosting actions to adapt the management of the freshwater systems to the changing climate. In many European regions, water use practices are not sustainable and water stress will increase due to increasing water demand. This also calls for urgent actions aiming to reduce use and consumption of water resources. National and international river basin organisations play a crucial role in implementing the water resilience strategy.

Europe faces a critical implementation gap in understanding future hydrological cycles, evolving flow regimes in catchments and aquifers, and the complex human-water interactions that shape water availability. 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.

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 the STARS4Water initiative. 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, both hydrology and governance-related, 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 use (groundwater, rivers, lakes) and 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 society needs while flood damage reductions and water requirements for water-dependent ecosystems are also priorities. By ensuring an inclusive sharing of safe water resources, we engage our societies into the pathway to equitable prosperity.

6. Raising awareness and information sharing

Story-map approaches and easily accessible information tools, such as 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, and the biophysical and socio-economic impacts of climate change and related vulnerabilities, and the effectiveness of adaptation measures. These tools support transparent communication for informed decision-making, enhancing resilient and collaborative water resources management across regions.