Engineering the Resilience and Sustainable Development of the European Water Infrastructure

Current Challenges, Risks and Recommendations

efca
European Engineering Consultancies

Content

Foreword

The resilience of the European water sector, and in particular of its physical infrastructure, is a critical factor in ensuring the continent's socio-economic stability, public health, and its capacity to meet long-term climate ambitions. This document has been produced by EFCA's Future Trends Committee in association with Marburg University. It provides a comprehensive analysis of the current state of the European water sector, identifying key vulnerabilities arising from both internal structural deficits and external pressures, and proposes strategic solutions to enhance its resilience. It highlights the consulting engineering sector's vital role in addressing structural and operational challenges, mitigating geopolitical and climate-related risks, and ensuring a secure and sustainable water future for Europe.

With a number of recommendations addressing both policy and operational aspects of water infrastructure management, as well as the relevant parts of the EU legal framework governing the sector, we hope that this paper, part of our 2025 Future Trends Report, will stimulate further dialogue with EU and national policy makers as well as with other relevant stakeholders. We look forward to sharing EFCA's expertise at this pivotal moment. Due to the accelerating impact of climate change on hydrological systems across the continent, and the growing exposure of water infrastructure to cyber threats and supply chain disruption, the importance of strengthening and modernising Europe's water infrastructure cannot be overstated.

I would like to extend my gratitude to all the contributors who have dedicated their time and expertise to this important work, which are listed below. Their invaluable insights and collaborative efforts have been instrumental in shaping this comprehensive study.

Emmanuelle Frénéat
Chair of the EFCA Future Trends Committee

EFCA FUTURE TRENDS COMMITTEE MEMBERS

Nikola Matić (ACES - Serbia)

Iana Motovilnic (ARIC - Romania)

Pavlina Mladenova
(BACEA - Bulgaria)

Anders Persson
(FSIC – Innovationsföretagen - Sweden)

Despina Kallidromitou
(HELLASCO - Greece)

Maddalena Rostagno (OICE - Italy)

Alexandre Vanheule (ORI - Belgium)

Richard Opsahl Resvoll
(RIF - Norway)

Marcin Mikulewicz (SIDiR - Poland)

Emmanuelle Frénéat
(SYNTEC-Ingénierie - France)

Inés Ferguson (TECNIBERIA - Spain)

Ralf Bufler (VBI - Germany)

Maximilian Grauvogl
(VBI - Germany)

Jeffrey Seeck (VBI - Germany)

CONTRIBUTING AUTHORS

Cedric Schäfer
(Phillips - University Marburg)

Rim Banu
(Phillips - University Marburg)

Mihai Barcanescu (EFCA Secretariat)

CONTRIBUTING ADVISERS

Iana Motovilnic (ARIC - Romania)

Cecilia Correia (Bentley Systems)

Bernardo Matos (Bentley Systems)

Lothar Heuser
(CDM Smith/VBI - Germany)

Despina Kallidromitou
(HELLASCO - Greece)

Rim Banu
(Phillips - University Marburg)

Torsten Wulf
(Phillips - University Marburg)

Elina Kalliala
(Ramboll/SKOL - Finland)

Peter Bassø Duus
(WSP/FRI - Denmark)

CHAIR OF THE EFCA FUTURE TRENDS COMMITTEE

Emmanuelle Frénéat
(SYNTEC-Ingénierie - France)

Executive Summary

The report examines the growing challenges facing Europe's water systems and identifies practical engineering and policy measures to strengthen resilience. Produced by EFCA's Future Trends Committee in cooperation with Marburg University, and with the help of experts' interviews, the report argues that water infrastructure has become a strategic asset that is increasingly exposed to climate, security and governance risks. Since water resilience is a very broad topic, the decision had been to focus the scope of this report on resilience via several key issues: flooding & anti-flooding measures (except coastal), water channelling and water preservation (e.g. preventing water leakage).

Europe's water sector is entering a period of profound change. Water systems that were designed under relatively stable climatic conditions are now confronting more frequent droughts, floods, water quality deterioration and competing demands from agriculture, industry, energy production and urban development. At the same time, a significant share of Europe's water infrastructure is ageing, creating maintenance backlogs, efficiency losses and growing vulnerability to extreme events.

The research identifies several major vulnerabilities. Structural water scarcity is becoming a defining issue in many regions due to declining rainfall, groundwater depletion and increasing demand. Floods remain Europe's most frequent natural hazard, while changing precipitation patterns are challenging existing flood management systems. High leakage rates, underinvestment in infrastructure and fragmented governance further reduce system resilience. The document also highlights security concerns, including cyberattacks on digital control systems, physical attacks on critical facilities and risks of deliberate contamination. These threats are increasingly relevant as water infrastructure becomes more digitalised and interconnected to other sectors.

To address these challenges, a number of engineering solutions and best practices are outlined. Precision irrigation technologies can significantly reduce water consumption in agriculture while maintaining productivity. Nature-based solutions such as wetland restoration, floodplain reconnection and river restoration can enhance water retention, improve drought resilience and reduce flood risks. Blue-green infrastructure can help cities manage stormwater while delivering environmental and social benefits. Digital technologies – including smart meters, SCADA systems, real-time monitoring and digital twins – can improve operational efficiency, enable predictive management and support leakage reduction.

Our central conclusion is that resilience requires hybrid approaches, increasingly relying on the introduction of nature-based and digital solutions. The most effective systems integrate engineered reliability with ecological adaptability and data-driven management.

Furthermore, the report makes seven key recommendations for European and national policymakers:

1. integrate uncertainty and climate resilience into infrastructure design through adaptive planning and scenario-based modelling;
2. modernise regulatory frameworks to facilitate digital monitoring and smart water management;
3. promote hybrid grey-green infrastructure through funding, standards and policy support;
4. better align water management with spatial planning and climate adaptation strategies;
5. prioritise leakage reduction as a strategic resilience objective;
6. strengthen governance coordination across sectors and administrative levels;
7. embed whole-life value and quality-based procurement in infrastructure investment decisions, moving away from lowest-price procurement for engineering services.

In conclusion, it is clear that Europe possesses many of the technical solutions required to improve water resilience. The principal challenge now lies in creating the regulatory, governance, investment and procurement frameworks that allow these solutions to be implemented consistently and on the necessary scale. Strengthening water resilience is therefore both an engineering and a governance imperative, essential for Europe's long-term economic competitiveness, environmental sustainability and societal security.

Introduction

Water shapes everyday life across Europe and remains one of its most vital, yet often under-recognised, resources. It underpins public health, economic activity, energy production and ecosystem functioning. For decades, relatively stable hydrological conditions in many parts of Europe fostered the assumption that water supply would remain reliable. This assumption is now increasingly challenged.

Water infrastructure systems across the continent are facing intensifying climate-related pressures. The frequency and severity of droughts, floods and water quality degradation are rising, placing compound stress on ageing infrastructure designed for past conditions. In some areas, structural water scarcity is emerging as a defining constraint, driven by over-abstraction[1], declining precipitation and groundwater recharge, heatwaves and saltwater intrusion into coastal aquifers. At the same time, flood risks are increasing across much of Europe, reflecting changing precipitation patterns and land-use dynamics (European Environmental Agency (EEA), 2024c). Water-related hazards are already affecting economic stability, public finances and vulnerable populations, highlighting the growing systemic importance of effective water management and flood protection (OECD, 2020). Europe thus faces a dual hydrological challenge: managing water scarcity in some contexts while addressing excess water and flood risk in others—often within the same regions at different times of the year.

Recent extreme events illustrate the scale and urgency of this challenge. Catastrophic flooding in Germany and Belgium in 2021 exposed critical limitations in flood protection and early warning systems (Junghänel et al., 2021). Severe floods in Slovenia in 2023 resulted in reconstruction costs of several billion euros, placing significant strain on public infrastructure and state finances (Slovenian Press Agency, 2023). At the same time, ageing infrastructure and deferred maintenance continue to reduce system reliability and increase vulnerability to extreme events (OECD, 2020). Without coordinated and forward-looking action, the impact of floods, droughts and declining water quality is expected to intensify further (EEA, 2024b).

While the natural/climate-issues represent the main challenges for the water sector, man-made threats are on the rise, from cybersecurity attacks to direct physical threats. As a large part of Europe's water infrastructure is also a critical infrastructure, such threats must also be addressed.

Since water resilience is a very broad topic, the decision had been to focus the scope of this report on water resilience through several key issues: **flooding & anti-flooding measures (except coastal), water channelling, water preservation (e.g. preventing water leakage, particularly in and around cities)**. Several additional topics are also briefly addressed in the report, such as the impact of the ICT sector (particularly data centres). Emphasis is placed not only on engineering solutions, but also on examples that can be replicated as much as possible across and outside Europe.

This report assesses key vulnerabilities facing Europe's water sector and outlines technical, robust and adaptable engineering approaches capable of operating under increasingly variable climatic conditions and man-made threats. Its objective is to support the transition towards a more resilient and sustainable water system across Europe.

1 *Water abstraction is the process of taking water from natural sources like rivers, lakes or underground aquifers for human use, such as drinking water, agriculture or industrial use.*

Current State of the Sector

The European water sector comprises a set of interconnected systems, including drinking water supply, wastewater treatment, stormwater management, flood protection, irrigation, energy generation and inland navigation. These systems vary widely in scale, condition, governance and exposure to risk, reflecting diverse hydro-climatic and socio-economic contexts across Europe (EEA, 2024c). The increasing pressure from climate change, rising demand and ageing infrastructure is challenging the performance and long-term sustainability of these systems. At the same time, evolving policy priorities, such as water efficiency and the substitution of potable water sources with non-potable ones (e.g. desalination plants), are beginning to reshape operational practices across the sector.

While water infrastructure has traditionally received less attention in security debates than other critical sectors, recent developments, including digitalisation, climate-related risks and emerging physical threats, are raising its strategic importance.

Consequently, the following sections focus primarily on climate-related and structural challenges, which represent the most immediate pressures on the resilience of European water infrastructure, but the security aspect is also touched upon.

CHALLENGES ACROSS EUROPE

Water infrastructure across Europe has developed under a wide range of hydro-climatic, socio-economic and institutional conditions. These differences have led to distinct system configurations and operational priorities. At the same time, shared pressures, such as climate change, ageing infrastructure and increasing sectoral competition, are creating six key thematic challenges across regions.

Water availability and scarcity patterns

Patterns of water availability across Europe range from structural scarcity to relative abundance, with increasing variability observed across all regions. In parts of Southern Europe, limited natural availability, pronounced seasonality and recurrent droughts place persistent stress on water systems. Elsewhere, historically stable conditions are becoming less predictable, with temporary shortages emerging due to rising demand from urban areas, industry and energy production (EEA, 2021c; Scholten et al., 2025). Even regions traditionally characterised by high water availability and low population density are experiencing shifts in hydrological patterns. Recent prolonged drought events highlight growing exposure to variability, suggesting that resilience challenges are no longer confined to water-scarce areas. Across parts of Eastern Europe, conditions remain heterogeneous, with some areas maintaining relatively stable supply while others face increasing drought frequency, often compounded by limited adaptive capacity (Lombana Cordoba et al., 2024).

Figure 1. Area and population affected during at least one quarter of the year by water scarcity conditions in the EU, measured by the water exploitation index plus (EEA, 2025a)

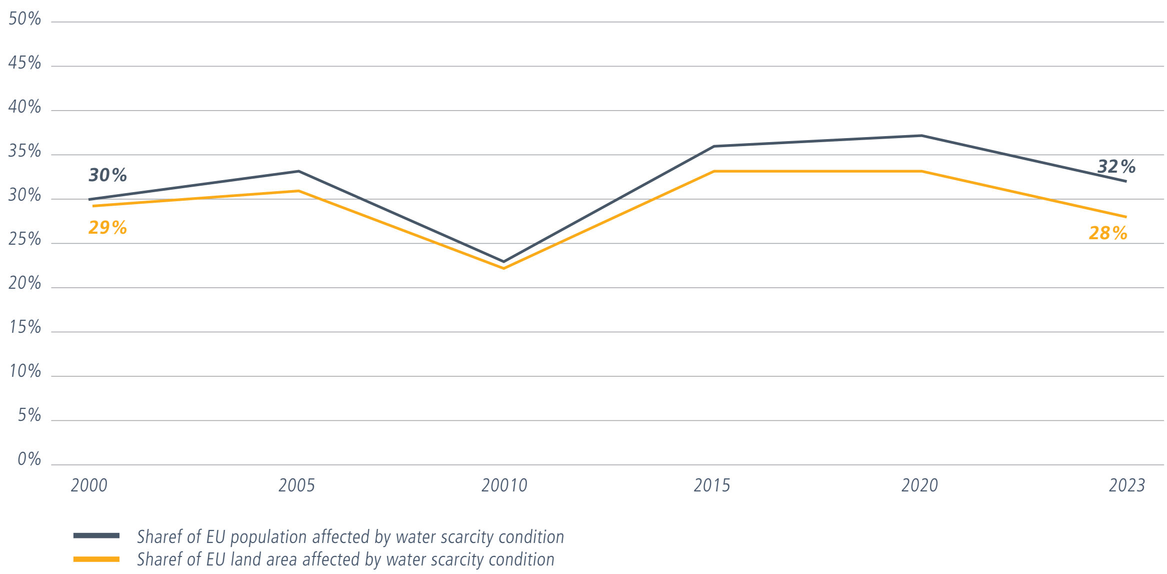
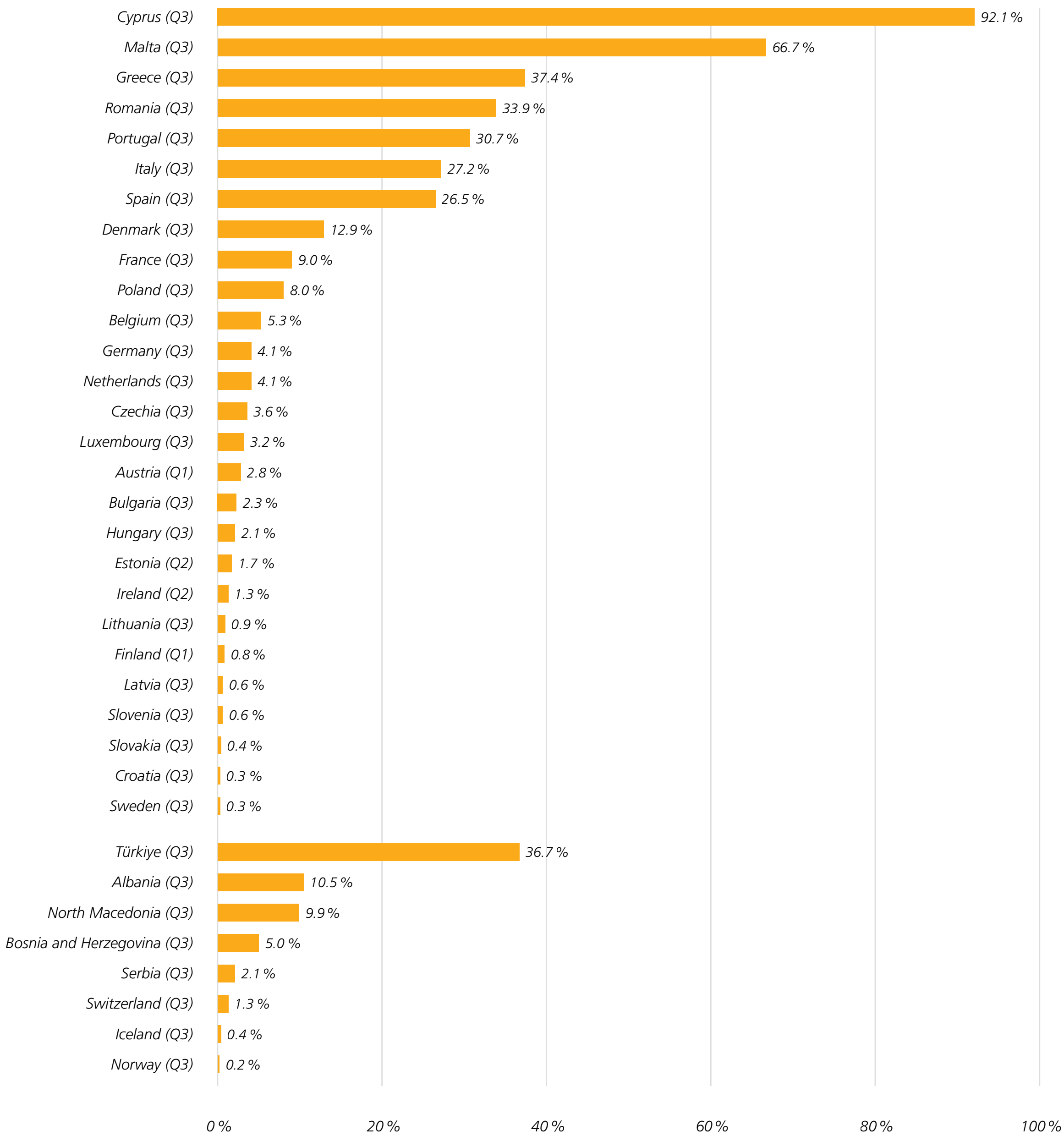


Figure 2: Worst seasonal water scarcity conditions for European countries in 2023, measured by the water exploitation index plus (WEI+) (EEA, 2025a)



Infrastructure configuration and legacy systems

Current infrastructure configuration reflects long-standing design approaches shaped by local conditions and historical priorities. In water-scarce contexts, systems have typically evolved as supply-oriented, relying on reservoirs, river regulation, inter-basin transfers and extensive groundwater use. While effective in meeting demand, such approaches often place pressure on ecosystems and limit flexibility under changing conditions (Rossi, 2019). Elsewhere, infrastructure is characterised by large-scale, centralised networks that integrate drinking water supply, wastewater treatment and stormwater management, particularly in densely populated and economically intensive areas. In regions with high runoff and seasonal flow variability, infrastructure has been designed to regulate water flows and support hydropower generation, with reservoirs and controlled river systems playing a central role (Feyen et al., 2020). Across Europe, a significant share of infrastructure was constructed decades ago and now operates under ageing conditions and a maintenance deficit. High leakage rates and declining performance in public distribution networks represent a widespread and persistent

Figure 3: Development of water abstraction in Europe since the 1990s. (Scholten et al., 2025). Use of freshwater resources in Europe. EEA Indicator Assessment, 2019.

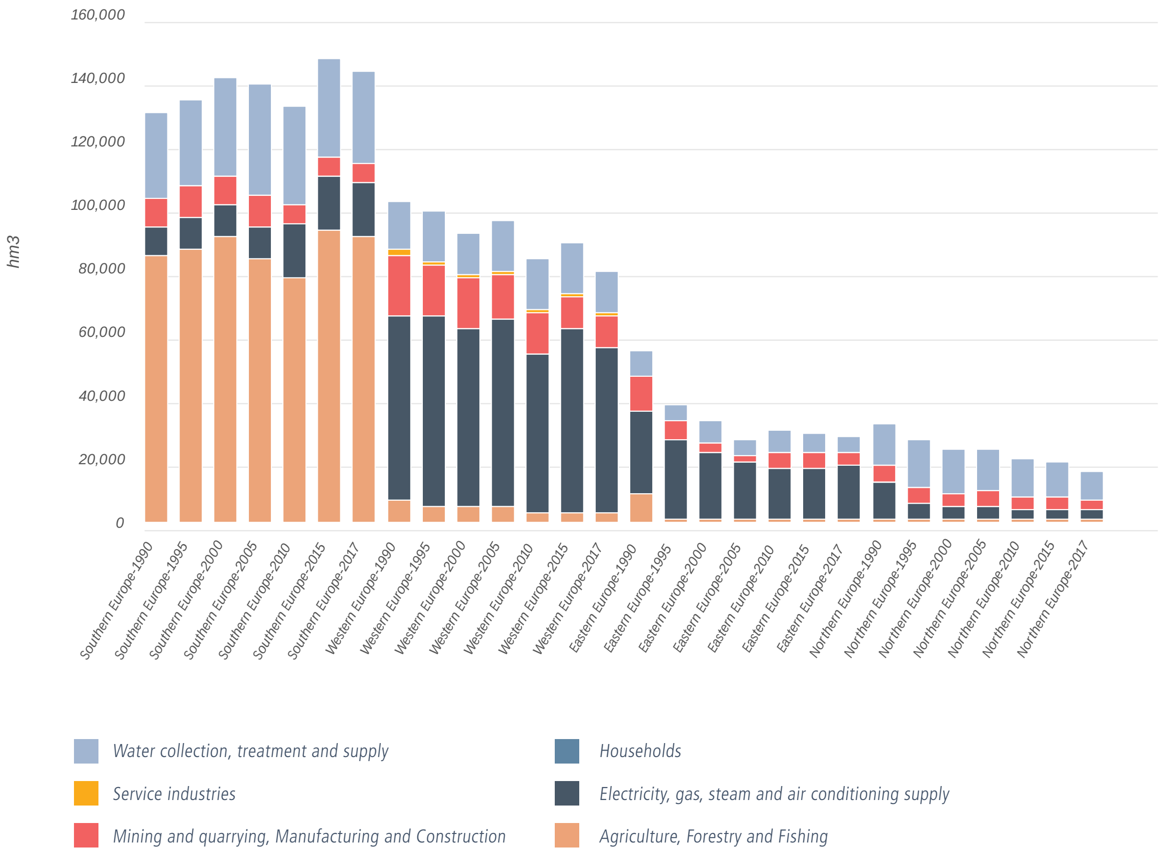
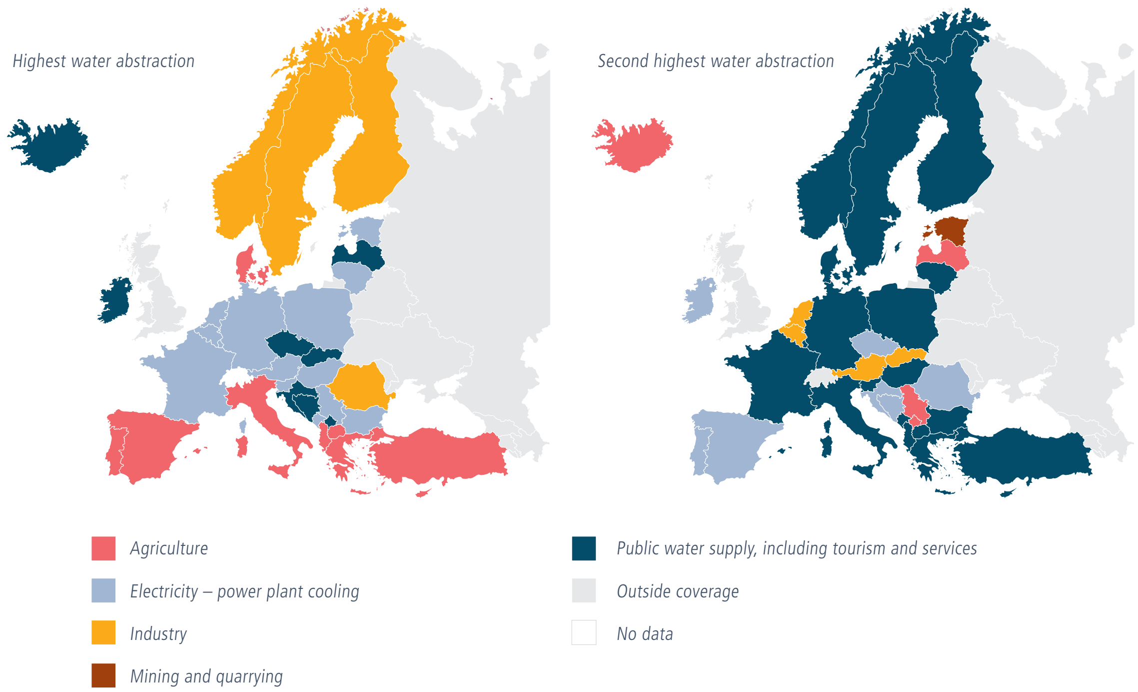


Figure 4: Economic sectors with the highest water abstraction pressure at the country level, 2000-2022 (EEA, 2025b)



challenge, with more such cases being recorded in Southern and Eastern European countries. Lastly, some regions still lack sufficient water infrastructure, a situation resulting from both population change and prolonged lack of investment. This lack of infrastructure can also impact the water system due to pollution.

Water use profiles and sectoral pressures

Water demand patterns differ considerably across Europe, reflecting varying economic structures and climatic conditions. Agricultural irrigation remains the dominant pressure in water-scarce regions, accounting for a large share of total use. At the EU level, agriculture represents approximately 28% of annual water use, with irrigation demand heavily concentrated in areas facing limited availability (Scholten et al., 2025). In more industrialised regions, water demand is driven primarily by manufacturing and energy production, and more recently by the ICT sector developments, especially due to data centre cooling requirements.

Surface water plays a key role in industrial processes and electricity generation, particularly as cooling water in thermal and nuclear power plants (EEA, 2021c; Wolters et al., 2025). In contrast, irrigation demand is comparatively low in areas with favourable climatic conditions and lower agricultural intensity. A mixed demand structure is observed across parts of Eastern Europe, where agriculture, industry and public supply all contribute to overall water use. Recent shifts toward increased groundwater use further reflect changing demand patterns and responses to drought conditions.

ICT technologies across Europe, particularly those related to AI and data centres, have recently become significant water users, as detailed in our previous report on the resilience of the European

ICT system (EFCA, 2025). Today, this is the case mostly for the Western half of Europe, but it is likely to soon become a more uniform challenge across the continent.

Groundwater dependence and associated risks

Groundwater is a critical component of water supply across Europe, providing resilience during periods of low surface water availability. Its role is particularly pronounced in regions experiencing water stress, where it supports both irrigation and drinking water supply. However, sustained high levels of abstraction raise concerns regarding overexploitation, declining water tables[2], and long-term sustainability (EEA, 2024b). In several parts of Europe, groundwater use has increased significantly in recent years, driven by prolonged droughts, the accessibility of extraction technologies and insufficient regulatory oversight (Lombana Cordoba et al., 2024). While more robust monitoring and management frameworks exist in some countries, disparities in governance and enforcement capacity remain evident. Geological conditions also influence the role of groundwater. In areas with limited aquifer productivity, reliance on surface water remains higher, reducing flexibility in times of stress (Scholten et al., 2025).

Adoption of non-conventional water sources

Non-conventional water sources, particularly reclaimed wastewater and desalinated water, are gaining importance as part of broader resilience strategies. Their adoption, however, varies significantly across Europe. Water reuse has become an established practice in regions facing chronic scarcity, where it supports the substitution of potable water with non-potable sources, particularly for urban and agricultural applications. Spain has long been a leader in municipal wastewater reuse, while countries such as Portugal (targeting 30% reuse by 2030) and France (10% target) are rapidly scaling up their infrastructure. Italy and Greece also demonstrate increasing uptake and the emergence of good practice. In other parts of Europe, water reuse is gaining momentum, supported by EU circular economy and resilience policies. France has taken a proactive approach, although overall uptake remains below its potential in many countries. Even in areas with relatively abundant water resources, recent drought events are prompting greater consideration of reuse as a complementary supply option. By contrast, uptake remains limited in regions where freshwater availability is perceived as sufficient and where policy frameworks and investment incentives are less developed.

Governance, investment and transboundary complexity

Institutional capacity, investment levels and governance structures play a decisive role in shaping the performance and resilience of water infrastructure systems. Strong regulatory frameworks and integrated river basin management approaches support effective system operation and long-term planning in many parts of Europe. At the same time, disparities in governance and financing capacity contribute to uneven infrastructure quality and performance. This is particularly evident in countries where investment levels remain insufficient and regulatory enforcement is limited (Lombana Cordoba et al., 2024). Transboundary water systems add an additional layer of complexity. Shared river basins require coordinated management across national boundaries, creating interdependencies between upstream and downstream users. A prominent example is the Danube River Basin, which spans 19 countries and supports approximately 79 million people. Its water underpins drinking water supply, agriculture, energy production, transport, and ecosystem services, while also necessitating extensive coordination to manage competing uses and risks (ICPDR, 2021a; ICPDR, 2021b).

2 *The water table is the upper surface of the phreatic zone or zone of saturation (the depth below which the ground is saturated).*

GOVERNANCE AND RESILIENCE MEASURES OF EUROPEAN WATER INFRASTRUCTURE

The governance of water infrastructure in Europe operates within a multilevel institutional framework. EU legislation provides the strategic and regulatory foundation, whilst Member States and their regional and local authorities carry responsibility for implementation, operation and investment (EC, 2025). The Water Framework Directive (WFD) sits at the centre of this framework, establishing binding objectives for water quality, ecological status and integrated river basin management (EC, 2025; EEA, 2021a). Sector-specific directives, including the Drinking Water Directive, the Urban Wastewater Treatment Directive and the Floods Directive, govern the planning, financing and operation of supply, wastewater and flood protection infrastructure. The European Green Deal further embeds these obligations, positioning water protection, climate adaptation and infrastructure resilience as cross-cutting priorities across EU environmental and investment policy (EC, 2025; EEA, 2021a).

Member States translate shared objectives into national legislation, river basin management plans and investment programmes, producing a wide diversity of governance arrangements across Europe (EEA, 2024b). Assessments of WFD implementation have repeatedly identified persistent gaps, such as: insufficient integration of water objectives into sectoral policies, fragmented responsibilities across governance levels and uneven enforcement and financing. These shortcomings have reinforced calls for closer alignment between water governance and land use planning, agriculture, energy and climate adaptation (EEA, 2021a).

The European Water Resilience Strategy responds to this challenge, aiming to restore and protect the water cycle, strengthen cross-sectoral coordination and enhance climate resilience across all water-using sectors, whilst reaffirming the central role of Member States in delivery (EC, 2025). Despite this framework, structural and regional challenges continue to constrain the performance and resilience of Europe's water infrastructure (EEA, 2024b; EEA, 2021a).

Resilience is also increasingly addressed through critical infrastructure policy. The Directive on the Resilience of Critical Entities, which entered into force in January 2023 and had to be transposed into national law by October 2024, requires Member States to identify critical entities and conduct risk assessments, including in the water sector. Relevant operators must implement technical, organisational and security measures to strengthen resilience against natural hazards, terrorism, public health emergencies and other disruptive events.

EU funding also shapes resilience measures, although the European dimension of water infrastructure remains less developed than in sectors such as energy or transport. Water-related infrastructure is often addressed through national, regional or local programmes, while cross-border elements are frequently embedded in adjacent policy areas such as transport (e.g. inland waterways or ports via the Trans-European Network of Transport - TEN-T) or environmental protection. Cohesion and regional development funds have historically been central instruments for water-sector investments, supporting upgrades in technical standards, operational performance and climate adaptation. However, security-related requirements remain less systematically integrated than climate-related considerations.

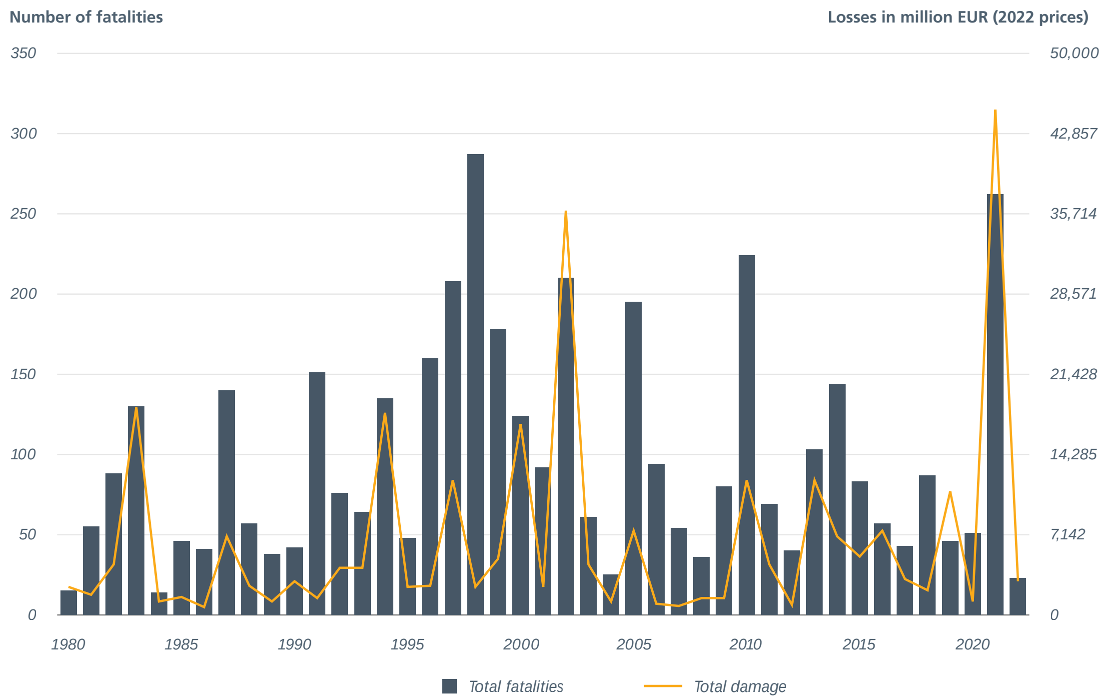
Vulnerabilities Assessment

CLIMATE PRESSURES AND HYDROLOGICAL CHANGE

The diversity of water infrastructure systems across Europe, as outlined in the previous chapter, translates into differentiated but increasingly interconnected vulnerability profiles. Systems historically designed under relatively stable hydrological conditions are now exposed to accelerating climatic shifts, rising demand and structural limitations embedded in legacy infrastructure. These pressures are converging to test the resilience of water systems across the continent. Europe is the fastest-warming continent, with increasing frequency and intensity of extreme heat, prolonged droughts, catastrophic flooding and wildfires expected to persist (EC, 2025). These developments are fundamentally altering hydrological regimes, affecting both water availability and infrastructure reliability.

Flooding remains the most frequent natural hazard in Europe, accounting for approximately 43% of all disaster events between 1998 and 2020. Around 100 major flood events caused approximately 700 fatalities, displaced roughly 500,000 people and resulted in nearly €280 billion in insured economic losses (EEA, 2024c). These impacts highlight the growing exposure of population, infrastructure and economic assets to hydrological extremes, particularly in urbanised areas where impermeable surfaces and concentrated assets amplify risks. At the same time, climate pressures interact with increasing water demand from agriculture, industry, energy production and urban development. This intensifies competition for limited resources and places additional strain on systems already shaped by regional constraints such as scarcity, ageing infrastructure or limited investment capacity.

Figure 5: Fatalities and economic damage (EUR million) attributable to floods in the EU-27, 1980-2021. Riverine and coastal floods combined. (EEA, 2024b)

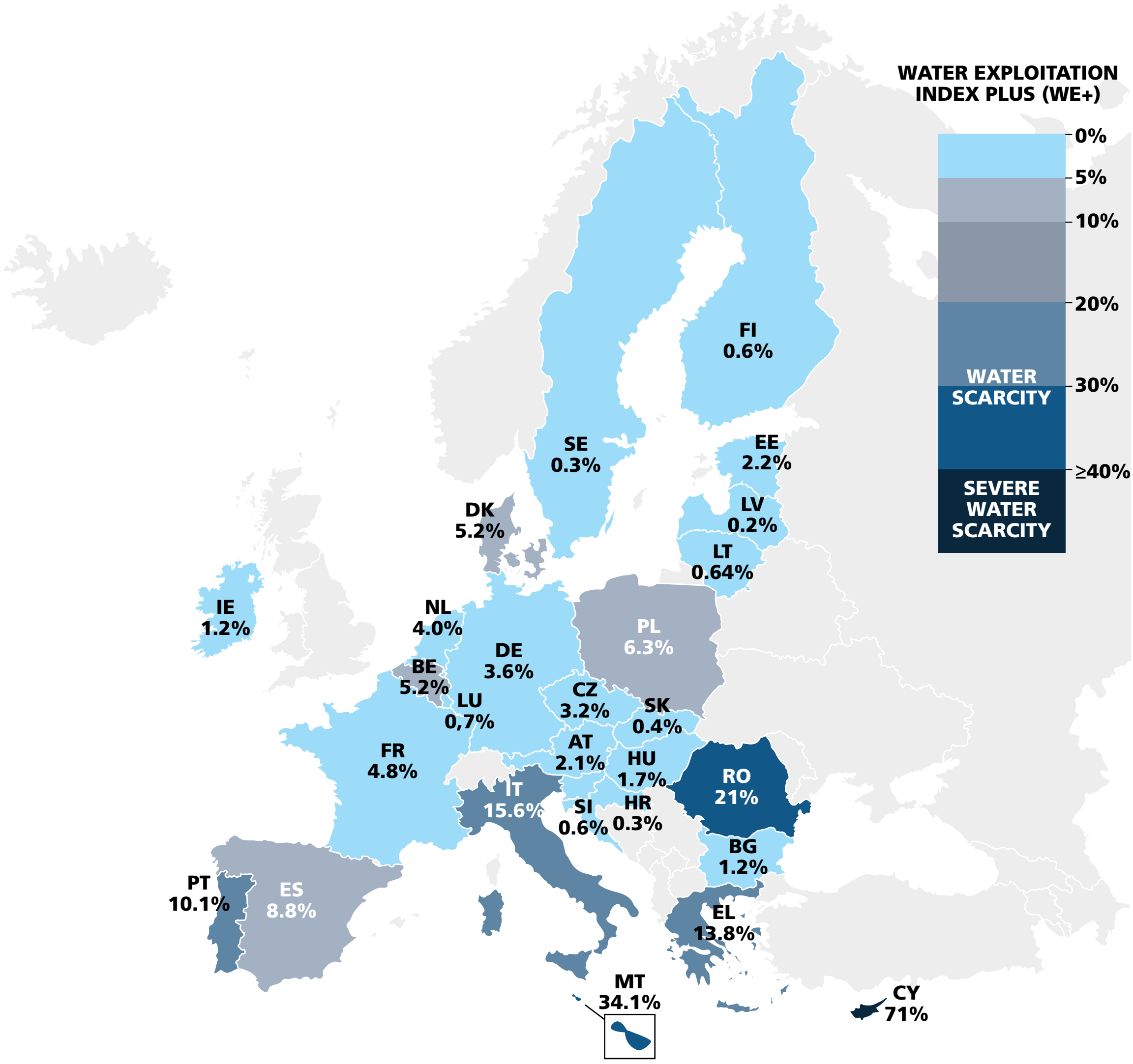


Structural water scarcity and demand imbalances

Structural water scarcity represents a critical vulnerability in parts of Europe where natural availability is limited and demand remains persistently high. As highlighted in the previous chapter, supply-oriented systems in these areas rely heavily on storage, transfers and groundwater abstraction to balance deficits. Approximately 30% of the population in water-stressed regions lives under permanent water stress conditions, with seasonal stress affecting up to 70% of the population (EEA, 2024c). Agricultural irrigation remains the dominant driver of consumptive water use, creating a structural imbalance between supply and demand. Climate change is expected to exacerbate this imbalance, as higher temperatures and longer dry periods increase irrigation requirements while reducing natural recharge.

Hydrological pressures are particularly evident in heavily exploited river basins, where abstraction levels approach or exceed sustainable limits during dry periods. Declining groundwater levels and salinisation of coastal aquifers reflect l ong-term overuse. Reservoir-based systems are also becoming less reliable, as prolonged droughts reduce storage levels while sedimentation and evaporation further limit effective capacity. These dynamics are illustrated by the Po River Basin (Italy), where severe drought conditions in 2022 led to restricted irrigation, reduced hydropower generation, saltwater intrusion

Figure 6: Water scarcity in the EU, as measured by the WEI+. (European Parliament, 2025)



and disruptions to inland navigation (Montanari et al., 2023). Similar patterns are observed across other water-scarce basins. Urban systems face additional stress from seasonal demand peaks, particularly in areas with strong tourism. While desalination and water reuse can enhance short-term supply security, they introduce new dependencies, including higher energy demand and environmental trade-offs (Scholten et al., 2025).

Infrastructure ageing and compound climate risks

A major cross-cutting vulnerability lies in the condition and performance of ageing infrastructure. Deteriorating drinking water networks, sewer systems and flood protection infrastructure lead to rising maintenance costs, increased failure risks and reduced operational efficiency (OECD, 2020). These structural weaknesses are increasingly exposed under changing climatic conditions.

Climate change is intensifying both flood and drought risks, creating compounded pressures on infrastructure. More frequent and intense short-duration rainfall events are particularly challenging in densely urbanised areas, where sealed surfaces, limited infiltration capacity and undersized drainage systems reduce the ability to manage runoff (EEA, 2024c). As a result, stormwater systems are increasingly overwhelmed, leading to surface flooding, sewer overflows and associated public health risks. At the same time, longer and more frequent droughts reduce surface water availability, increase reliance on groundwater and disrupt key economic functions, including navigation and energy production (Feyen et al., 2020). The central vulnerability arises from the growing mismatch between infrastructure designed for stable conditions and hydrological regimes that are becoming more variable and extreme.

Flood risk, hydrological variability and coastal exposure

Changing precipitation patterns and rising temperatures are significantly altering flood regimes across Europe. Increasing frequency of heavy rainfall events contributes to higher river discharge and greater variability in flow regimes, placing additional stress on flood management systems (EEA, 2024a). Flood risks are evolving in both magnitude and timing. Higher winter runoff, reduced snow storage and more frequent rain-on-snow events are increasing riverine flood risks. At the same time, shifts in seasonal patterns, such as earlier spring floods linked to accelerated snowmelt and delayed winter flood peaks in maritime regions, are challenging established protection strategies (Blöschl et al., 2017).

Coastal areas face additional pressures from sea level rise and storms, which increase the risk of coastal flooding and saline intrusion into freshwater systems. Shallow aquifers and surface water bodies used for drinking water supply are particularly vulnerable, as saltwater intrusion compromises both availability and quality (Zamrsky, 2024). These dynamics are especially critical in low-lying and deltaic areas, where water infrastructure must simultaneously manage flood protection, freshwater supply and ecological functions. The challenge lies in adapting systems originally designed to regulate predictable seasonal flows to conditions characterised by higher variability and uncertainty.

System efficiency, underinvestment and governance gaps

Beyond physical and climatic pressures, institutional and financial constraints represent a key source of vulnerability. As highlighted previously, infrastructure performance and investment levels vary considerably across Europe, with some systems facing persistent underinvestment and limited maintenance. High levels of leakage and non-revenue water remain a major issue in parts of Europe, significantly reducing effective water availability. Losses in drinking water distribution systems are often linked to ageing infrastructure, outdated materials and insufficient rehabilitation (OECD, 2020). These inefficiencies exacerbate water scarcity during dry periods and increase operational costs for utilities.

Underinvestment also affects wastewater treatment and flood protection systems, reducing their capacity to cope with extreme events. In some cases, limited regulatory enforcement and monitoring capacity further constrain effective water management (Lombana Cordoba et al., 2024). Transboundary systems add another layer of complexity, requiring coordinated governance across national boundaries. The Danube River Basin exemplifies these challenges, as upstream–downstream interdependencies influence water availability, flood risk and water quality across multiple countries (ICPDR, 2021b). Despite these constraints, improving system efficiency, particularly through leakage reduction and targeted infrastructure upgrades, offers significant potential for enhancing resilience and closing performance gaps across Europe.

SECURITY RISKS

Climate and structural vulnerabilities are increasingly intersecting with security risks. Water infrastructure has traditionally received less public and political attention than energy, transport or telecommunications, yet its disruption can affect public health, food production, energy generation, transport, emergency response and social stability. Three developments are reshaping the sector's security profile: increasing digitalisation, greater exposure to climate-related disruption and the renewed salience of physical attacks against critical infrastructure. These risks compound, rather than replace, the climate-related vulnerabilities discussed above.

Cybersecurity and other ICT aspects

Digitalisation is transforming the operation of European water infrastructure. Utilities increasingly rely on supervisory control and data acquisition (SCADA) systems, remote sensors, automated pumps, digital metering, cloud-based platforms, and data-driven asset management tools. These technologies improve efficiency and monitoring, but they also expand the attack surface across operational technology, information technology and third-party service providers. Cybersecurity risks are amplified by legacy systems, limited cyber capacity among smaller utilities and reliance on ICT hardware, software, cloud services and managed services from non-EU providers. Potential incidents include manipulation of sensor data, disruption of pumping systems, unauthorised changes to treatment processes or interruption of customer communication platforms.

Moreover, European countries have begun witnessing cyberattacks on their water infrastructure, particularly Sweden, Poland, Denmark, Norway (Euronews. 2026) and Romania (Industrial Cyber. 2026), with Russia or Russian-linked hackers being the main suspects. Cyber resilience therefore needs to be treated as an integral part of infrastructure resilience.

Physical attacks on the infrastructure and connected systems

Physical attacks remain a significant risk because water infrastructure is geographically dispersed and often difficult to secure comprehensively. Reservoirs, dams, pumping stations, treatment plants, pipelines, sewer networks and flood protection structures may be exposed to sabotage, vandalism, disruption of access, or attacks on key nodes, the failure of which could affect wider service continuity. The risk is intensified by the interdependence of water systems with electricity, ICT and their assets. Strengthening resilience requires both protective measures, such as access control and surveillance, and adaptive measures, including redundancy, backup power, alternative supply arrangements and rapid repair capacity.

Concrete examples of direct attacks on infrastructure in Europe come from the Russia-Ukraine war. Russian attacks have caused significant pollution on several rivers in Ukraine which also affected their neighbours (Erizanu, P. 2026), both via the rivers crossing the borders and by polluting the Black Sea. A telling example is the attack on Ukraine's Novodnistrovsk hydropower complex in March 2026, polluting the Dniester River which provides nearly 80% of the Republic of Moldova's drinking water in addition to the Ukrainian region. This, corroborated with the recent attacks from March 2026 on desalination facilities in Iran, Bahrain and Kuwait, show that water infrastructure is increasingly becoming a target of choice in various types of conflict, something that

the EU can no longer ignore. The spillover effects after such attacks can have long-lasting and costly consequences, especially if the groundwater will also be contaminated.

Biological and chemical attacks

Biological and chemical attacks represent a lower-probability but high-consequence risk. Deliberate contamination of water sources, treatment facilities, storage reservoirs or distribution networks could pose serious risks to public health, service continuity and public confidence, even where existing quality controls and treatment standards provide important safeguards. The consequences of suspected or confirmed contamination may include precautionary shutdowns, ‘boil water’ notices, emergency supply measures and costly remediation. Mitigation requires layered protection, including source protection, secure access to sensitive sites, continuous water-quality monitoring, emergency sampling protocols, and close coordination between utilities, health authorities and civil protection agencies.

Best Practice

ENGINEERING SOLUTIONS

Engineering approaches are central to strengthening the resilience of Europe's water systems. As outlined in earlier sections, water-related risks manifest differently across the continent, ranging from structural water scarcity to intensified flooding and growing strain on ageing assets. These differences require context-specific technical responses rather than uniform solutions. This chapter presents key engineering approaches that enhance efficiency, storage, retention and system adaptability across the water cycle.

Precision irrigation

Engineering responses to agricultural water scarcity must move beyond theoretical gains in water-use efficiency and address operational feasibility, system robustness and adaptability to diverse farm structures and climatic conditions. Precision irrigation offers a pathway to more efficient water use by enabling targeted application and reducing losses associated with conventional surface and sprinkler systems.

Recent advances focus on pressurised distribution networks and micro-irrigation technologies that allow for precise control of water delivery. These include: drip irrigation, which delivers water directly to the crop root zone; low-flow irrigation, which reduces application rates to limit evaporation and runoff; and deficit irrigation, which deliberately reduces water supply during drought-tolerant growth stages to lower overall seasonal consumption. Together, these approaches can significantly improve application efficiency and, in the case of deficit irrigation, reduce water demand by up to 50% (Leitão et al., 2025). Their effectiveness is further enhanced by sensor-based monitoring and data-driven scheduling that integrate soil moisture, crop status and climatic conditions (Price et al., 2025). However, high investment costs, technical complexity and maintenance requirements can constrain adoption, particularly among small and medium-sized farms, indicating that digitalisation, while beneficial, is not a prerequisite for achieving improved irrigation efficiency (Toscano et al., 2025).

CASE STUDY: PRECISION IRRIGATION USING THE SLECI METHOD IN PORTUGAL

This case study assesses the performance of the Self-regulating, Low Energy, Clay-based Irrigation (SLECI) method under Mediterranean climate conditions in Portugal during the 2023 irrigation season. The system was applied in cherry and peach orchards and directly compared with a conventional drip irrigation system under identical soil, climate and water supply conditions.

SLECI is a pressurised micro-irrigation approach based on underground porous clay elements installed near the crop root zone. Water is supplied through a small, elevated reservoir, which reduces hydraulic pressure and enables controlled delivery without electronic controllers or fixed irrigation schedules. Irrigation is regulated passively, responding to soil moisture and atmospheric demand through the physical properties of the clay material.

In contrast to the conventional drip system, which applied water independently of weather conditions, the SLECI system dynamically adjusted irrigation. Water delivery increased during periods of high temperature and evapotranspiration but decreased or ceased when rainfall occurred or soil moisture levels were sufficient. Despite substantially lower water use (up to 70-80%), trees irrigated with SLECI showed no visible signs of water stress, indicating adequate crop supply. While some challenges related to filtration and water quality were identified, the findings suggest that SLECI represents a promising, low-complexity precision irrigation solution for Mediterranean regions.
Source: (Frazão et al., 2025; Leitão et al., 2025)

The SLECI method demonstrates that precision irrigation does not necessarily rely on complex or automated systems, but can be achieved through well-designed micro-irrigation solutions that combine technical efficiency with practical applicability. This approach is particularly relevant in regions where water scarcity coincides with heterogeneous farm structures and ageing irrigation infrastructure (Malchev et al., 2025).

Nature-based solutions

Nature-based solutions (NbS) are interventions that harness natural processes and ecosystem functions to address societal and environmental challenges in a cost-effective and resource-efficient manner. In water management, NbS contribute to flood risk reduction, water quality improvement, drought mitigation and climate change adaptation, while delivering a range of environmental, social and economic co-benefits (EEA, 2021b). In contrast to conventional grey infrastructure, which often prioritises rapid water conveyance, NbS are typically implemented as decentralised systems that retain, store and delay water close to its source (EC, 2022).

This section distinguishes between large-scale and small-scale NbS. Large-scale interventions operate at the catchment[3], floodplain or river

3 A catchment (or drainage) basin is a land area where all precipitation—such as rain or snowmelt—drains downhill into a common body of water, like a stream, lake or reservoir.

basin level and influence hydrological processes beyond individual sites. Small-scale measures are implemented at the building, plot or street level and focus on managing runoff generation and retention within urban environments (Ruangpan et al., 2019).

Large-scale NbS are designed to modify hydrological dynamics across broader spatial and temporal scales, with key applications in flood risk reduction, drought mitigation and long-term water resource regulation. Examples include floodplain reconnection, wetland restoration, river restoration and widening, reforestation, natural water retention measures and distributed retention areas across river basins. These interventions increase storage capacity, attenuate peak flows and influence runoff timing, thereby reducing downstream flood risk (Ruangpan et al., 2019). The EEA highlights floodplain and river restoration as particularly effective measures, as they store excess water and support groundwater recharge through controlled retention and gradual release (EEA, 2024c).

Because such measures redistribute water and risk across space and time, a systems-based approach is essential. Upstream retention and controlled inundation can reduce downstream flood peaks, whereas isolated local protection measures may inadvertently increase downstream risks. This underscores the importance of coordinated planning at the catchment scale (Schröter et al., 2021). A prominent European example is the 'Room for the River' programme in the Netherlands, which adopts a "working with nature" approach. It combines measures such as floodplain lowering, riverbed deepening, removal of hydraulic bottlenecks and dike relocation to increase conveyance and storage capacity during high flows. In doing so, it reduces flood levels while enabling multifunctional land use, including ecological restoration and recreation (Dutch Water Sector, 2019; Klijn, 2013). In water-scarce basins, similar large-scale NbS, such as wetland restoration and floodplain storage can enhance natural retention and groundwater recharge, thereby improving resilience to dry periods (Ruangpan et al., 2019).

CASE STUDY: THE BRAGUE RIVER CATCHMENT, FRANCE

The Brague River catchment (68 km²), located between Nice and Cannes, was severely affected by an extreme flash flood in October 2015. The event caused fatalities and extensive damage in downstream urban areas. In its aftermath, the catchment was used as a case study to evaluate the performance of nature-based and grey flood risk management strategies under Mediterranean flash-flood conditions.

Flood hazards and associated damages were analysed using a multi-scale modelling framework that combined catchment-scale runoff modelling with a high-resolution two-dimensional hydraulic model in the lowlands. This approach enabled the integrated assessment of upstream natural water retention measures alongside downstream "giving room to the river" interventions.

Results show that upstream retention measures can reduce runoff coefficients and partially attenuate flood peaks for frequent and moderate events. In downstream areas, measures such as river widening, floodplain reconnection, wetland restoration and riparian vegetation recovery enhance conveyance capacity and lower flood levels, while also delivering ecological and recreational co-benefits. Cost–benefit analysis indicates that strategies based on nature-based solutions can reduce flood damages by approximately 30%, achieving outcomes comparable to large grey infrastructure solutions such as retention dams, while providing additional environmental and social value.

However, the storage capacity of upstream measures remains limited relative to the large flood volumes generated during extreme events, which can reach several million cubic metres. As a result, upstream retention alone is insufficient to prevent downstream flooding. The effectiveness of interventions may also be constrained by hydraulic bottlenecks, including bridges, culverts and transport infrastructure, if these are not addressed. The Brague case highlights that large-scale nature-based solutions are most effective when implemented as part of integrated, hybrid flood management strategies combining upstream retention, downstream floodplain expansion and targeted grey infrastructure measures.
Source: (Piton et al., 2023; Le Coent et al., 2023)

The implementation of large-scale NbS is often constrained by land availability, competing land uses, long planning and permitting processes, and the need for coordination across sectors and governance levels (EEA, 2021b). As a result, NbS cannot fully replace engineered protection but must be embedded within hybrid systems that combine ecological retention functions with the reliability of structural infrastructure (EC, 2020; EEA, 2021b).

Small-scale NbS operate at the building, plot, or street level and manage hydrological processes close to the source of runoff. In contrast to large-scale interventions, they target local runoff generation, short-term storage, infiltration and initial pollutant retention within the built environment. Common measures include rain gardens, bioretention systems, permeable pavements, green roofs, street trees and small infiltration facilities (EEA, 2021b). These systems rely on combinations of infiltration, evapotranspiration, interception and temporary storage to reduce runoff volumes and attenuate peak flows entering sewer and drainage networks.

Reported performance ranges indicate runoff reductions of approximately 30–65% for permeable pavements and up to 56% for infiltration-based systems, while rain gardens and bioretention systems can fully retain smaller rainfall events under favourable conditions (Ruangpan et al., 2019). Monitoring data from the International Stormwater BMP Database show that most stormwater management practices achieve statistically significant reductions in total suspended solids and particulate-bound metals, while the removal of dissolved pollutants, such as nutrients and bacteria, varies depending on system design and inflow characteristics (Clary et al., 2020).

The effectiveness of small-scale NbS depends strongly on local conditions, including soil permeability, groundwater levels, available space and maintenance practices. As standalone measures, their capacity to manage extreme rainfall is limited. Their full potential is realised when implemented as part of coordinated systems and integrated with conventional drainage infrastructure to ensure reliability at the network scale (EC, 2020).

Blue-green infrastructure

Blue-green infrastructure (BGI) represents a spatially integrated, system-level approach that connects multiple blue and green elements across neighbourhoods or districts, enabling coordinated stormwater management beyond individual plots or streets. It refers to the deliberate organisation of water and vegetation-based features into coherent urban networks that shape how stormwater is stored, routed and managed at the district scale (EEA, 2021b). These systems regulate runoff through infiltration, evapotranspiration, retention, detention and delayed conveyance, while delivering co-benefits such as water retention, enhanced urban liveability and increased biodiversity (Liu et al., 2019).

In practice, BGI reconfigures urban drainage by prioritising surface-based flow paths, distributed storage, and multifunctional public spaces over rapid underground conveyance. Open channels, adaptable streetscapes and temporary retention areas are integrated into parks, streets, and public spaces, allowing stormwater to be safely accommodated during heavy rainfall while preserving everyday urban functions.

CASE STUDY: BLUE AND GREEN INFRASTRUCTURE IN COPENHAGEN

Copenhagen is widely recognised as a leading example of a “blue-green city”, having systematically integrated green spaces and water management into its approach to climate adaptation and urban flood protection. This shift was triggered by an extreme rainfall event on 2 July 2011, when nearly 100 mm of rain (or 100 liters/m²) fell within one hour. The city’s drainage system was unable to cope, resulting in widespread flooding and significant economic damage. The event highlighted the limits of the existing sewer system, which had been designed for much less intense rainfall.

In response, the city developed the Cloudburst Management Plan (2012), which acknowledges that simply expanding underground sewers is neither sufficient nor cost-effective as rainfall becomes more intense. Instead, the plan focuses on managing excess rainwater at the surface, allowing it to be temporarily stored, slowed down or safely directed through the city. Copenhagen defined an acceptable level of flooding - around 10 cm of water on streets during very rare, extreme events - so that roads can act as temporary drainage routes while minimising damage.

To achieve this, the city prioritises solutions such as floodable parks, open basins, canals and redesigned streets that can store or guide water during heavy rainfall. Where these surface-based measures are not enough, they are supported by large underground tunnels and pipes that transport excess water to the harbour. This combined approach shows how integrating green and grey infrastructure can provide a flexible and effective response to urban flood risks.
Sources: (City of Copenhagen, 2012; Brears, 2023)

Blue-green infrastructure (BGI) delivers multiple benefits by combining water management with green space and urban design. Beyond reducing flood risk, it can enhance biodiversity, help cool cities during heatwaves, create recreational areas and improve the overall quality of urban spaces. The European Commission (2020) highlights this multifunctionality as a key advantage, particularly in dense cities where infrastructure must meet environmental, social and climate adaptation goals at the same time.

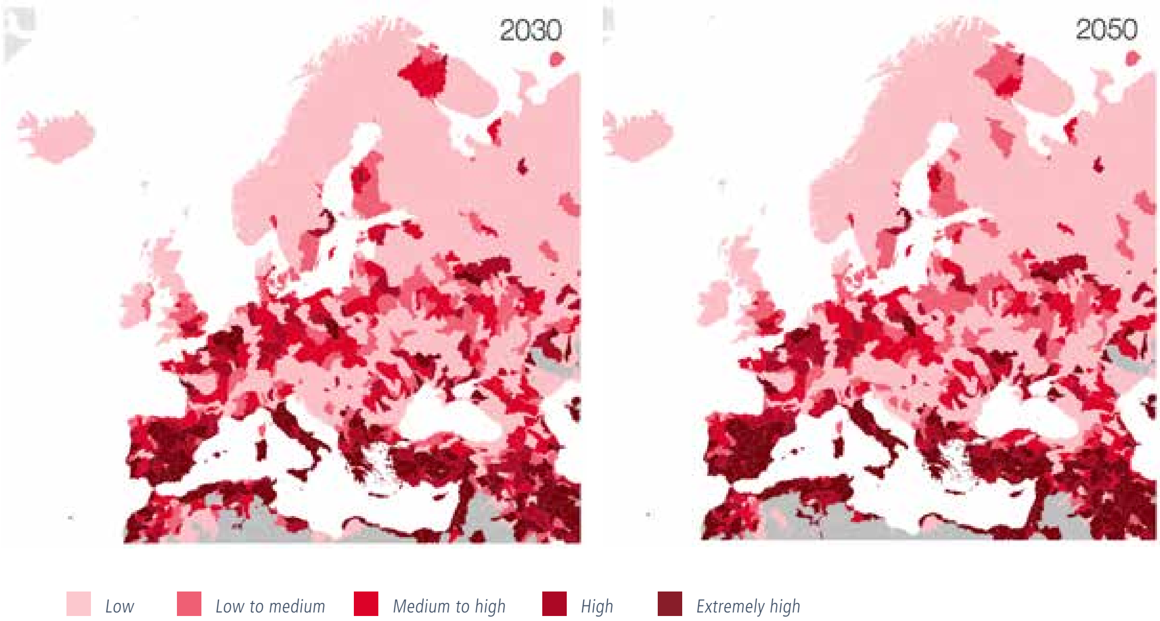
However, implementing BGI in dense urban areas can be challenging. Limited space, competing land uses and long-term maintenance responsibilities often constrain its application. Its performance also depends on local conditions, such as urban layout and institutional capacity (Ruangpan et al., 2020). BGI is therefore most effective when combined with conventional infrastructure. In such hybrid systems, small-scale nature-based measures act as building blocks, BGI provides coordination and connectivity across the urban area, and grey infrastructure ensures reliability during extreme events (Water Europe, 2021).

Smart water management and leakage control

Smart cities increasingly view urban water systems as digitally enabled socio-technical systems that combine monitoring technologies, data analytics and governance tools to improve efficiency, resilience and sustainability. Growing pressure on urban water resources calls for better monitoring, improved data availability and more adaptive management approaches. Digital tools can support demand management, optimise infrastructure performance and enable earlier detection of system stress (Water Europe, 2023).

Smart water meters allow continuous measurement and transmission of consumption data from households and industry, supporting demand forecasting, operational efficiency and more active engagement with users (Global Infrastructure Hub, 2020). Greater data availability enables a shift from reactive system operation to more predictive and adaptive management (Eggimann et al., 2017). Integrated urban drainage systems that combine upstream retention, detention basins, real-time control and SCADA-based monitoring represent an important approach to strengthening urban flood resilience. At a more advanced level, digital twins bring together real-time sensor data, hydraulic models and forecasting tools to support decision-making and simulate the impacts of extreme events in advance (Hlal et al., 2025). However, the effectiveness of these technologies also depends on their integration into governance frameworks that link data to pricing mechanisms, public awareness and regulatory enforcement (Wolters et al., 2025).

Figure 7: A water-stressed continent. The map shows the evolution of projected water stress[4] levels in 2030 and 2050 under a business-as-usual[5] scenario. (Coi G./POLITICO (2025)/World Resources Institute Aqueduct 4.0)



Leakage remains one of the most persistent inefficiencies in urban water systems. Across Europe, more than 30% of abstracted water is lost before reaching end users (Wolters et al., 2025). Smart meters and network sensors can continuously monitor flow, pressure and consumption, allowing faster detection of anomalies compared to traditional inspection methods (Global Infrastructure Hub, 2020; Water Europe, 2022). Managing operating pressure is particularly effective, as even moderate reductions can significantly reduce leakage and lower the risk of pipe failures (Puust et al., 2010).

Despite these benefits, the wider deployment of smart leakage management is constrained not only by financial aspects, but also by regulatory and institutional barriers. Current European legislation often recognises only laboratory-based measurements for compliance, limiting the use of real-time monitoring systems (Water Europe, 2022). Low monitoring frequency requirements restrict the application of advanced analytics and machine learning. In addition, insufficiently harmonised standards and challenges related to data access and privacy reduce incentives for utilities to invest in digital solutions. While smart technologies enable a shift towards proactive, data-driven management, their full potential depends on regulatory modernisation and improved data governance frameworks (Scholten et al., 2025; Vitens et al., 2018).

4 Water stress is the ratio of water demand to renewable supply and measures the competition over local water resources.

5 The business-as-usual scenario corresponds to a Representative Concentration Pathway (RCP) of 7.0 and a Shared Socio-Economic Pathway (SSP) of 3, with regional rivalries, slow economic growth and high challenges to climate mitigation and adaptation.

CASE STUDY: LEAKAGE MANAGEMENT WITH DIGITAL TWINS IN KOZANI, GREECE

The Water Utility of Kozani (DEYAK), serving around 60,000 inhabitants in Western Macedonia, provides a compelling example of how smart water technologies can address leakage at scale. In Greece, public water supply systems lose approximately 26% of abstracted water through leakage - among the highest levels in the EU. Prior to intervention, DEYAK relied on manual monitoring and fragmented operational practices, resulting in delayed leak detection, high operational effort, and limited system-wide oversight.

To address these challenges, DEYAK implemented a comprehensive digitalisation strategy aligned with Greece's National Recovery and Resilience Plan. At its core was the development of a digital twin of the Kozani water distribution network using Bentley's OpenFlows platform. This included detailed network mapping, a dynamic 3D hydraulic model and the integration of real-time data from sensors and a SCADA system measuring pressure, flow and water quality.

The results were significant. Detection time for new, unreported leaks was reduced by approximately 50%, while staff time spent on pressure management decreased by 40% through automated workflows. Improved leakage control also led to a 20% reduction in water flows through the network, indicating a substantial decrease in real losses. This case demonstrates how digital twins and smart monitoring technologies can shift leakage management from a reactive to a proactive approach, offering a scalable model for medium-sized European cities.
Source: (Bentley Systems, 2024)

Recommendations

Water infrastructure resilience in Europe is no longer defined by technical performance alone. Ageing assets, changing hydrological conditions and fragmented governance structures constrain the sector's ability to respond to growing pressures. Climate change has altered the operating environment, with intensified flooding, prolonged droughts and increased variability challenging infrastructure designed for more stable conditions.

While local conditions differ, several common priorities emerge. Hybrid infrastructure, digitalisation and improved system efficiency provide clear pathways for strengthening resilience. However, their implementation depends on enabling regulatory frameworks, coordinated governance and long-term investment strategies.

The following recommendations are addressed to European and national policymakers and focus on the conditions required to scale effective engineering responses.

CLIMATE VARIABILITY AND THE LIMITS OF TRADITIONAL DESIGN

A central lesson from this report is that uncertainty and resilience must be treated as core design parameters in water infrastructure. Traditional approaches, based on return-period calculations and historically calibrated models, assume stable hydrological conditions. This assumption is no longer valid. Shifts in rainfall intensity, seasonality, and the frequency of compound events mean that past data alone can no longer provide a reliable basis for infrastructure design

(EC, 2025; EEA, 2024c). In practical terms, this requires a shift towards scenario-based modelling, sensitivity analysis, modular system design and adaptive planning pathways. Climate resilience must be used in its full meaning, as the ability of systems to perform under a range of plausible future conditions. This also implies changes in how engineers define design, communicate uncertainty and structure long-term investment strategies. Continued reliance on historical standards alone leads to systematic underestimation.

MODERNISE REGULATORY FRAMEWORKS FOR DIGITAL MONITORING

European and national legislation should better recognise certified online monitoring systems and smart measurement technologies as valid compliance tools. Current overreliance on laboratory-based measurements limits investment in real-time monitoring and advanced analytics. Expanding regulatory recognition would support the transition towards proactive, data-driven system management.

PROMOTE HYBRID GREY-GREEN INFRASTRUCTURE

Funding mechanisms, technical standards and adaptation strategies should prioritise projects that combine conventional infrastructure with nature-based and blue-green solutions. Hybrid systems enhance reliability while increasing adaptability and delivering environmental and social co-benefits. Clear guidance and stable financing are essential to accelerate implementation.

INTEGRATE WATER MANAGEMENT WITH SPATIAL PLANNING

Water infrastructure planning should be closely aligned with spatial planning, climate adaptation and environmental policy. Integrated approaches enable multifunctional solutions that combine hydraulic performance with ecological and social value, improving both efficiency and public acceptance.

PRIORITISE LEAKAGE REDUCTION

This should be embedded as a strategic priority rather than treated as an operational issue. Performance-based regulation, targeted investment and alignment with digital monitoring can significantly increase effective water supply without expanding abstraction.

STRENGTHEN GOVERNANCE COORDINATION

Reducing institutional fragmentation is essential for effective implementation. Policymakers should establish integrated planning frameworks and cross-sector coordination mechanisms that align water management with broader policy objectives. Coordinated governance is a prerequisite for system-wide resilience.

EMBED WHOLE-LIFE VALUE AND QUALITY-BASED PROCUREMENT

Infrastructure decisions should consider the full lifecycle performance rather than initial capital cost alone. Whole-life value approaches account for maintenance, adaptability and long-term efficiency, supporting more resilient outcomes. Public procurement should prioritise quality, expertise and innovation, enabling the integration of technical, environmental and spatial considerations from the earliest stages of project development. The practice of using the lowest price criterion for engineering services in terms of design, planning etc. should be curtailed in water projects to the greatest possible extent, since it is impossible to deliver modern, robust facilities with a low-cost approach.

Conclusion

Europe's water infrastructure is entering a period of fundamental transition. As this report shows, climate change, ageing assets and fragmented governance are converging to challenge systems designed for more stable conditions. Addressing these pressures requires more than incremental improvements – it calls for a shift towards integrated, adaptive and resilience-oriented approaches to planning and delivery.

Future water systems will have to increasingly operate as connected, system-level infrastructures. Hybrid grey-green solutions should become standard practice, combining the reliability of engineered systems with the flexibility and co-benefits of nature-based approaches. At the same time, digital tools such as real-time monitoring, SCADA systems and digital twins will enable more proactive and adaptive management. Improvements in system efficiency, particularly through leakage reduction, offer immediate and cost-effective gains in resilience without increasing resource pressure.

While implementation must remain context-specific, the overall direction is clear. Integrated planning, enhanced and coordinated investments in water infrastructure and technologies, stronger alignment between water management and spatial development, integrating (cyber)security features where relevant, and improved coordination across all governance levels are essential to translate technical and operational solutions into practice. Updated regulatory frameworks, financing mechanisms and procurement rules will play a decisive role in determining whether these solutions can be deployed at scale. Strengthening Europe's water resilience is therefore both an engineering and a governance challenge. The technical and operational solutions are available; the priority now is to improve the institutional and policy conditions that enable their consistent and timely implementation.

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EFCA Secretariat
Avenue des Arts 3/4/5, B-1210 Brussels
Phone: + 32 (0)2 209 07 70
email: efca@efca.be
http://www.efcanet.org

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