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Water resources across Europe — confronting water stress: an updated assessment

European Environment Agency

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Glossary

Terms are used in this report for different types of water stress situations, as determined by their primary causes and their duration or frequency.

Available water resources	That part of surface water and groundwater resources that is available for use (EC, 2015d).
Drought	A drought refers to a temporary water shortage. A meteorological drought starts with reduced levels of precipitation compared with normal. When prolonged, this may then cause reduced levels of soil moisture in agricultural land (agricultural drought) and reduced levels of natural water flows to surface water and groundwater (hydrological drought). Long-term drought conditions (e.g. seasonal or year round) cause aridity, whereas longer periods of drought (multi-annual) may cause desertification.
Renewable freshwater resources	The average annual amount of precipitation less evapotranspiration that ends up as run-off to rivers and recharge to aquifers (internal flow), and the average amount of inflow of surface waters and groundwater from neighbouring countries minus the outflow of surface water and groundwater into neighbouring countries and into the sea (UNECE, 2020).
Water consumption	The part of water used that is not returned to groundwater or surface water because it is incorporated into products (e.g. food and beverages) or consumed by households (e.g. drinking water) or livestock. It is calculated as the difference between total water use and total supply to other sectors + returns to surface water and groundwater. Thus, it may include transpiration of water from crops, the losses due to evaporation during distribution and the apparent losses due to unauthorised tapping and malfunctioning meters. The term is equivalent to 'consumptive water use' (adapted from UN (2012)).
Water scarcity	Water scarcity defines a mid-term water stress condition (e.g. seasonal, annual or multi-annual) occurring when the water demand for human needs frequently exceeds the sustainable supply capacity of the natural system in river basins. Water scarcity is the consequence of anthropogenic impacts on the availability of water resources. Water scarcity can be measured as the ratio between renewable freshwater resources and water abstraction or water use. The occurrence of droughts in river basins exacerbates the impacts of water scarcity on both ecosystem and socio-economic conditions (as regards resilience, maintenance and restoration/development).
Water shortage	Water shortage is a short-term water stress condition (e.g. monthly or seasonal) occurring when the water demand for human needs exceeds the supply capacity of the natural system in river basins. When this happens frequently the term water scarcity is used.
Water stress	Water stress refers to the ability, or lack thereof, to meet the human and ecological demand for water. Compared with scarcity and shortage, water stress is a more inclusive and broader concept. As well as water scarcity, it also considers water quality, ecological flows and the accessibility of water (The Global Compact, 2014).
Water supply	Delivery of water to end users, including self-supply for own final use (EC, 2015d).

Water use	The total volume of water intake by a socio-economic activity (e.g. water intake for household needs, including drinking water, irrigation of crops, cooling at industrial and energy production plants). Water use includes both consumptive and non-consumptive activities. Consumptive activities result in evaporation and transpiration of water or its integration into products. Non-consumptive activities use water and then return it to surface water and groundwater but with potential changes to its physico-chemical properties. Water use may incorporate excess water intake ('water waste'), which does not serve the needs of the activity (adapted from UN (2012).
Water use efficiency	The ratio of either the net or the gross value added of a socio-economic activity and its water consumption.

Summary overview schema

Duration or frequency of water stress	Causes of water stress					
	Volumetric availability of water is lower than long-term average		**Demand for water exceeds available water**			
	Natural	**Anthropogenic**	**Anthropogenic**			
	Due to meteorological conditions	**Due to changing climatic conditions**	**Volumetric water demand for ecological flows not fully met**	**Volumetric water demand of socio-economic sectors not fully met**	**Water quality requirements of socio-economic sectors not fully met**	Accessibility is a limiting factor for socio-economic use
Temporary or incidental	**Drought**		**Water shortage**			
Mid-term or frequent	**Drought/**aridity		**Water scarcity**			
Long-term or permanent	Aridity/desertification		Desertification ([a])			

Note: This report provides an overview and assessment of temporary and mid-term drought and scarcity in Europe (the aspects indicated in bold), not including accessibility and the aridity and desertification aspects of water stress (indicated in green).

([a]) Gleick and Palaniappan (2010) also describe the peak water concept as a limiting factor in the availability of water to meet socio-economic and ecosystem demands.

Key messages

Current status: water stress in Europe is significant.

- Water stress affects 20 % of the European territory and 30 % of the European population on average every year, while droughts cause economic damage of up to EUR 9 billion annually and additional unquantified damage to ecosystems and their services.
- Southern Europe faces severe water stress problems, which occur throughout the year in many river basins, with water consumed by agriculture, public water supply and tourism being the key pressure on water resource availability. The pressures from these economic sectors reach a significant seasonal peak in summer.
- In other parts of Europe, water stress is usually not a permanent issue, as it mainly occurs occasionally and in specific hotspots, where the key pressures are water consumed by cooling processes in electricity and industrial production, public water supply and mining.
- Water use efficiency has increased in agriculture, electricity production, industry, mining, public water supply and tourism. Water consumption by these sectors was 16 % lower in 2017 (the last year for which EU-wide statistics are available) than in 1995 (baseline), while production in these sectors grew by 20 % in terms of net value added.
- The 2000 EU Water Framework Directive (WFD) provides a suitable framework for acting on the policy options to reverse water scarcity and drought, as set out in the Commission communication on water scarcity and drought, but their implementation has been slow. The 2021 EU strategy on climate change adaptation could provide a new impetus to achieve this goal.

Future prospects: water stress in Europe is expected to worsen.

- Droughts are increasing in frequency, magnitude and impact.
- Climate change is projected to cause seasonal reductions in water availability in most parts of Europe, except in north-eastern areas. The strongest impact is expected in southern and south-western Europe, with river discharge reductions in summer of up to 40 % in some basins, under a 3 °C temperature rise scenario. Large parts of western and central Europe will also be affected, albeit to a lesser degree. Changes in aquifer recharge follow roughly the same pattern.
- Improved water use efficiency could deliver a further reduction in water abstraction of 0.7 % per year over the coming years in the agricultural, industry and mining, and electricity production sectors.
- Although helpful, this will neither offset the climate change impacts on rainfall-dependent nature and on agriculture nor offset any strong local increases in water demand (see next point).
- Continued urbanisation and growth in coastal tourism will further concentrate water demand geographically. A warmer and drier climate could increase irrigation requirements by 20 %, adding to a stronger concentration of water demand in already drought-prone regions of Europe.

Solutions: potential EU-level actions to reduce water stress The opportunity offered by the WFD to manage water stress needs to be urgently realised. In particular, continued efforts will need to be made by EU Member States to develop drought management plans and coordinate or integrate them with the WFD river basin management plans.

- Drought management should be based on long-term strategies for proactive water management and should make the transition from crisis management to risk management by, for example, putting more emphasis on demand- versus supply-side measures.
- Initiatives and actions under the European Green Deal should also be used to support water stress management, including: the EU biodiversity strategy for 2030, in particular with regard to the restoration of freshwater ecosystems, restoration of river continuity, revision of water abstraction permits and implementation of ecological flows; the new EU circular economy action plan; the 2020 EU Water Reuse Regulation incentivising efficient water use through water pricing and enabling water reuse; and the 2021 EU climate change adaptation strategy incorporating climate risk into investment and policy decisions.
- Sectoral policy interventions must be coherent and coordinated with the WFD and EU water directives to ensure the effectiveness of the latter. This refers to aligning not only strategic objectives but also legal requirements as far as possible.
- The impacts of water stress are felt at local and regional scales, while its drivers act from regional to global scales. Linking these levels of analysis requires systemic thinking.
- Data collection and information flows must be further improved and tailored to the spatial and temporal scales at which water stress makes itself felt.

Executive summary

This report aims to update our knowledge of water stress (a general term that includes drought and water scarcity) in Europe to inform policymakers and interested stakeholders about the current state of play. It presents arguments for a shift from crisis management to risk management, including by putting more emphasis on demand-side measures, such as increasing water use efficiency or organising information campaigns. In order to minimise the impacts of water stress on people and ecosystems across Europe, ecosystem resilience needs to be improved, and the water use efficiency of our socio-economic systems needs to be increased. For both of these issues policies and regulations at EU level are in place, but their implementation and effectiveness need to be improved. As pointed out in *The European environment — state and outlook 2020* (SOER 2020) (EEA, 2019j), there are many indications that the environment in Europe has reached the point at which, because of the long-term overexploitation of natural resources, relatively small changes in external conditions can provoke considerable and irreversible changes in environmental quality and the supply of natural resources. These would in turn lead to permanent negative impacts on nature, the quality of life and the economy and other associated systems, which would all be difficult and very costly to reverse.

Water stress in Europe

Water stress occurs when there is not sufficient water available to meet the demands of the environment and our society and economy, in terms of quantity or quality. Water stress is a general term combining drought, quantitative scarcity, water quality and water accessibility. Drought reflects the shortage of water due to short- or long-term precipitation deficits. Droughts propagate through the hydrological cycle and, depending on their duration and intensity, may lead to such effects as low soil moisture content, decreasing groundwater levels, saltwater intrusion, deteriorating water quality and reduced river discharges. Through these effects on the hydrological cycle, droughts may lead to impacts on human well-being, socio-economic development and ecosystems.

Water stress was not perceived as a Europe-wide problem until the early 2000s. It was regarded as a problem that mostly occurs in southern Europe because of the regional climatic conditions. However, currently available information and data show that droughts and water scarcity are no longer rare or extreme events in Europe. The frequency of water stress is increasing, and the affected area is expanding towards central and western Europe, affecting an increasing number of areas important for industry and electricity production, as well as affecting more large cities and thus millions of inhabitants. Today, on average, every year water stress affects around 20 % of the European territory and 30 % of the total population (EEA, 2018b).

The drivers of water stress are usually a combination of geographically widespread factors, such as climate change impacts and the location of tourism and food production, and consumption chains, electricity production and population density. This cross-cutting nature of the water stress issue calls for coordinated action among the different policy areas.

Policy context

The EU Water Framework Directive (WFD) establishes a legal framework at the EU level aiming, inter alia, to prevent further deterioration of aquatic ecosystems and the ecosystems depending on them and to achieve sustainable water use based on the water resources available in the long term. The WFD supports integrated water management and sets out provisions to improve the efficiency of water use. Through its Articles 1, 9 and 11 the WFD creates a suitable flexible frame for action against water stress, underscoring the relation between water quantity, water quality and ecological status.

To respond to the increasing occurrence, frequency and impacts of water stress, in 2007 the EU adopted a communication on water scarcity and drought in an effort to bring more clarity to the policy priorities for addressing water stress. The communication's implementation was reviewed in several stages, and in 2012 'A blueprint to safeguard Europe's water resources' was published. Along with the policy provisions put forward in these two strategic documents, the EU Resource efficiency roadmap, the common agricultural policy (CAP) and the Seventh Environment Action Programme also announced a number of policy mechanisms aiming to protect and enhance European natural capital and water resources.

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The implementation of those policies has contributed to some positive developments, for example a decrease in total water abstraction in Europe (EEA, 2019l, 2021d; Eurostat, 2020f). Nevertheless, policies addressing water stress remain scattered, and overall progress has been slow. Building on a paradigm shift that originated in the 1980s, EU water scarcity and drought policy has begun the transition from crisis management to proactive risk management. However, this transition has been mostly conceptual, as through its implementation, the change in paradigm exposed a lack of institutional capacity in many Member States.

Today, some Member States develop and implement drought management plans complementary to the river basin management plans (RBMPs) under the EU WFD. The implementation of the RBMPs has taken place at variable speeds across the EU Member States and the various WFD thematic areas, and there are still gaps to be addressed in the next cycles of implementation. Despite the recent implementation of measures, more time is needed for all water bodies in Europe to achieve good status (EC, 2019b), while the final deadline of 2027 (where exemptions to the obligation expire) is coming near.

The WFD recognises the cross-cutting character of water as a vital resource for environmental and socio-economic systems. Similarly, the United Nations 2030 agenda for sustainable development has pointed to the need for systemic change that permeates recent EU policy, highlighting the importance of collaboration and policy integration and coherence. In practice, Sustainable Development Goal (SDG) Target 6.5 promotes integrated water management and Target 6.4 highlights the need to increase water use efficiency across all sectors and to decouple economic growth and water use. In this context, several new policy initiatives in Europe are on the eve of being implemented. The European Green Deal sets ambitious targets and objectives to protect, conserve and enhance the EU's natural capital. The new EU strategy on adaptation to climate change calls for expedited action to safeguard access to freshwater and ensure sustainable use as part of the 'faster adaptation' objective. The new circular economy action plan and the Water Reuse Regulation explicitly address water stress and water scarcity, respectively, and include provisions for improving resource efficiency in the context of managing water resources. Similarly, the EU biodiversity strategy for 2030 acknowledges the importance of natural capital to industry and agriculture and sets quantitative targets for ecosystem restoration, including restoring 25 000 km of free-flowing rivers. Furthermore it requests Member States to review water abstraction and impoundment permits and to implement ecological flows, so that they can achieve good status or potential in all water bodies by 2027. The EU sustainable finance taxonomy includes criteria on reducing the rates of water abstraction and on reducing hydromorphological pressures. The new Climate Change Law (which at the time of writing this report is being prepared for formal adoption), the sustainable finance taxonomy (EC, 2018a), the farm to fork strategy, the new CAP Pillar II and the Eighth Environment Action Programme all call for increasing resource efficiency, protecting our natural capital and improving human well-being by means of transitioning the European economy to become more sustainable by target years ranging from 2030 to 2050.

In the context of water stress, all of these policy provisions and initiatives require strong coordination and collaboration during the implementation phase across sectors and ecosystems. So far, major obstructions to more effective policy implementation are the institutional frameworks and capacity, which are not adequate to promote coordinated, cross-sectoral action and measure progress. The European Green Deal and the new EU strategy on adaptation to climate change, 'Forging a climate-resilient Europe' (EC, 2021a), represent fresh opportunities to tackle this problem, by integrating water stress and drought policy objectives into other policy areas, increasing coherence and speeding up implementation.

Renewable freshwater resources under a changing climate

Climate change is a major factor influencing the availability of renewable freshwater resources. The last few decades some of the hottest and driest years of the two last centuries have been recorded, and the annual average temperature in Europe has already increased to 1.6-1.7 °C above the pre-industrial level (EEA, 2020d). The temperature rise increases potential and actual evapotranspiration, causes more frequent extreme droughts, intensifies heavy precipitation, attenuates snowpack build-up and triggers early snow melting. These effects have led to a decrease in annual precipitation in parts of southern Europe (EEA, 2017d) and decreasing river discharges, leading to increasing water stress. In contrast, in north-eastern and northern Europe, precipitation and the intensity of heavy precipitation in winter and summer is increasing (EEA, 2019b), leading to increasing annual river discharges in those regions (EEA, 2016e). This trend is expected to continue in the coming decades (Feyen et al., 2020). A decrease in the depth of the snowpack in the Alps and Carpathian Mountains and earlier snow melt at lower altitudes in the Alps can already be observed, while recent summer droughts have struck areas reaching as far north as the Arctic circle.

Freshwater use under socio-economic change

The population of European urban centres continues to increase further, while the population in rural areas decreases. This leads to the development of more peri-urban land to meet additional needs for residences and workplaces. Moreover, tourism in Europe has reached record levels over the last decade and this has resulted in the rapid conversion of land for the development of touristic facilities and the supporting transport infrastructure. Urban sprawl accelerates in coastal areas, which are also vulnerable to future sea level rise. The expansion in impervious areas and land sealing increases the risks of urban floods and drains away water that could otherwise recharge local aquifers (EEA, 2019e, 2020a).

In 2017 almost 250 billion m^3 (250 000 million m^3) of freshwater, corresponding to 9 % of annual renewable freshwater resources, was abstracted in Europe for socio-economic purposes. After use, treated or untreated water is returned to surface water and groundwater. The average return ratio of cooling water from industrial and electricity production is around 80 % of total water abstraction, while agriculture returns around 30 %, and hydropower almost 100 %. However, returned water may cause chemical or thermal pollution of the receiving water bodies. The water that does not return to groundwater or surface water bodies after its use is considered consumed by the relevant sector (e.g. through evaporation and transpiration or integration into tissues and products). The major water consumers are agriculture (58 %), electricity production (18 %), households and services (13 %) and mining, quarrying, construction and manufacturing (11 %).

In many European river basins, water is overabstracted, leaving insufficient water for ecological processes, or returned to surface water and groundwater with significant levels of pollution. Only three EU Member States (Cyprus, Hungary and the Netherlands) have been implementing measures to protect, enhance or promote ecological flows in all river basin districts as proposed in the WFD common implementation strategy in 2016, whereas France has implemented the ecological flows in two river basin districts (EC, 2019b). In 2015, 58 % of river water bodies had not achieved good ecological status, for which water abstraction was reported as one of the main pressures in 8 % of river water bodies not achieving good ecological status. Groundwater levels have already fallen at various sites across EU Member States (EEA, 2018a). Groundwater is often seen as a buffer resource, which can be used to supply high-quality drinking water, especially when local surface waters are not suitable for exploitation or at times of water stress. Unauthorised water abstraction may be a result of incomplete application of ecological flows, their insufficient control and legal enforcement, and the application of flat tariff systems instead of volumetric tariff systems for irrigation (Buchanan et al., 2019).

Water consumption in Europe shows a trend towards decoupling from economic growth, as water use efficiency has increased in water-dependent sectors, such as agriculture, electricity production, industry, mining, public water supply and tourism. Water consumption in the above sectors was 16 % lower in 2017 than in 1995, while production in these sectors grew by 20 % in terms of net value added. Nevertheless, the issue of water stress continues to escalate. Climate change exacerbates seasonal variations in water availability. At the same time, particularly in southern Europe, in some water-dependent sectors, such as agriculture, demand is increasing in drier periods of the year, for example water demand for irrigation purposes is increasing in spring and summer, when water availability is at its lowest level. This causes increasing competition for water among economic sectors, often pushing users to shift from using surface water, leading to greater uptake from groundwater resources and ultimately exerting pressure on water bodies and the ecosystems depending on them.

The observed decreasing trend in water abstraction volumes has so far not translated into an improvement in the quantitative status of water bodies. This may be partly due to the slow process of recovery and also to climate change, which can offset volumetric gains and aggravate local pressures.

Importantly, despite progress, many challenges need further action. There is significant potential to save water across all economic sectors, but large investments are needed to unlock it. Monitoring, metering and authorisation of water abstractions and understanding the environmental interactions in river basins have progressed overall. Ecological flow requirements (e-flows) are better defined than they were, although they have still not reached a satisfactory level. Enforcement of e-flows has improved, yet there is still a long way to go to achieve full implementation of the WFD requirements and establish e-flows across all EU rivers. Leakages in the conveyance systems are still more than 25 % of the total water supply in many eastern and southern European countries (ERM, 2013). Unauthorised abstractions are persistent in some Member States. Furthermore, attention to and enforcement of water legislation is needed to avoid the rebound effects of the implementation of these water-saving measures: a situation in which efficiency gains result in less than a proportional decrease or even in an increase in net resource consumption (see Box 6.5 in Chapter 6).

While local water resources are getting more stressed or depleted, increasing urbanisation increases the local demand for water, which is often met by implementing storage and water transfer projects. Such projects have significant impacts on hydromorphology and associated freshwater habitats and species.

Promising approaches and measures

The analysis of the future gap between water availability and water demand in Chapter 5 of this report points to the increasing impact of water stress in southern Europe and in some parts of the other regions of Europe. This finding is consistent with earlier studies, such as the Joint Research Centre's Peseta IV study (Feyen et al., 2020). The increased seasonal variation in water demand for key socio-economic activities is at odds with the increased seasonal variation in water supply, and the variability caused by climate change forces Member States to explore additional measures to ensure their water supplies. Approaches focusing on valorising unconventional resources (i.e. desalination, water reuse, rainwater harvesting) are already implemented in many Member States. In this context, it is worth mentioning the new EU Water Reuse Regulation (EU, 2020b), which sets minimum quality requirements for water reuse in agricultural irrigation. The regulation has been in force since June 2020 and the rules, which will start applying in June 2023, are expected to facilitate the harmonised uptake of this practice across the EU.

The EU is dedicated to innovation as a means to tackle the water scarcity challenges identified. In fostering innovation, it gives particular focus to better monitoring of the Earth and its climate, better data management, better socio-environmental modelling, improvements in hydrological and drought forecasting, better technologies for increasing technical water efficiency, better tools for controlling water demand and better technologies for enabling and promoting alternative water sources.

A systemic analysis of water stress drivers, pressures and impacts can help researchers, water practitioners and policymakers to develop a wider and more holistic understanding of the interdependent relationships (nexus) between water, energy, land, materials and ecosystem services and of their further relationships with climate and production-consumption systems (e.g. food, energy and mobility systems). Adopting separate policy goals and management practices for each of these systems can create trade-offs, in which the benefits from using one resource may critically limit the benefits from using another resource. Integrated management responses can generate compromise solutions that deliver working results for sustainable management of both resources. Furthermore, win-win synergies can be explored to reap the benefits from the use of more than one resource: for example, water reuse can reduce the need for groundwater abstraction from overexploited aquifers, as well as the need for fertilisation because of the nutrient content of reclaimed water; the increased energy needed for reclaiming water can be offset by the reduction in energy needed for pumping groundwater and for producing and applying fertilisers, etc.

Nature-based solutions, as recently inventoried by Wild et al. (2020), need to be further explored and implemented. While the number of options dedicated to water stress appears limited, the associated approach and stakeholder involvement offer a way forward for integrative solutions to complex problems. Natural water retention measures and aquifer recharge are among the most promising options.

Need for integrated policy responses

Mainstreaming water considerations into other environmental and sectoral policies and finding synergies across them are key to enabling sustainable water management and reducing society's exposure and vulnerability to water stress. The recent WFD fitness check has highlighted that one of the key factors contributing to the effectiveness of the EU water directives in progressing towards their objectives is the (binding) cross-references to the WFD's objectives in other EU policies.

The recent adoption of the Water Reuse Regulation is a good example of integrated thinking. The new CAP programming cycle for 2021-2027 provides a fresh opportunity to integrate more ambitious environmental safeguards that acknowledge local water resource limitations and scarcity situations.

The new farm to fork strategy illustrates how the European Green Deal aims to promote a transition to more sustainable food systems by incorporating a systems approach. 'Sustainable food systems' maintain production and consumption throughout the full value chain within ecological limits, and thus they can keep the impacts of water use in agricultural food production within sustainable limits in terms of water quantity and quality. Systemic thinking to reduce Europe's vulnerability to water stress still has to permeate the policies of other economic sectors such as energy and industry, although some safeguards already exist.

Several EU policy initiatives support the use of nature-based solutions to reduce Europe's vulnerability to water stress. The EU strategy on adaptation to climate change 2021 (EC, 2021a) strongly advocates nature-based solutions as a means to improve compliance with the requirements for good ecological status and as solutions that can enhance water supply while generating co-benefits in a cost-effective way. The strategy recognises the importance of integrated solutions to tackle water stress, and it aims to expand on its predecessor's achievements on awareness-raising and mainstreaming climate adaptation concerns into EU policy, as well as shifting the focus towards rolling out and scaling up solutions to increase the resilience of communities and regions. While recent assessments indicate that the synergies between water scarcity and drought policies and climate change adaptation strategies have not been fully exploited at Member State and river basin levels (EC, 2019f), the new adaptation strategy has the potential to change this.


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1 Introduction

1.1 Setting the scene

Water is vital for the three pillars of Europe's sustainable growth: its society, its economy and its environment. All three depend on an adequate supply of water of sufficient quality at the right time and in the right location. However, in many parts of Europe, a mismatch has evolved between the demand for water and the volume of available water, resulting in water stress (Box 1.1).

This report addresses existing and future water stress conditions and risks in Europe, their potential impacts on the environment, society and economy, and the options for action that are open for exploration.

Box 1.1 Terms related to water stress

Water stress is the general term used in this report for the situation in which the amount of available water is not sufficient to meet the local demand (including environmental demand). Water stress can be caused by a volumetric shortage, by insufficient water quality, by droughts or by insufficient accessibility.

When water stress is caused by anthropogenic factors and when it has a mid-term duration (typically several months) or occurs frequently, the term 'water scarcity' is used. The term 'water shortage' is used when water stress has a relatively short duration (weeks to months) or occurs occasionally. Water scarcity and shortage are aggravated by drought. Drought is, in principle, a natural phenomenon, related to meteorological variability, but climate change adds an anthropogenic component to it. See also the glossary.

In parts of southern Europe and in densely populated areas across the EU, water stress is a permanent, year-round problem. In other parts of Europe, water stress occurs only temporarily or even only occasionally. These differences are a result of the geographical and temporal variation in meteorological conditions, which affect water availability, and of the water demand of ecosystems and society and the economy.

Droughts and water shortages have hit hitherto unexpected locations, as occurred in western and northern Europe in 2018 (see Box 1.4). Some more recent drought events in areas that are normally not perceived as prone to droughts occurred in the Arctic circle and Siberia in 2020 and 2019, the Elbe river basin in the summer of 2015 and the Black Sea area in 2007.

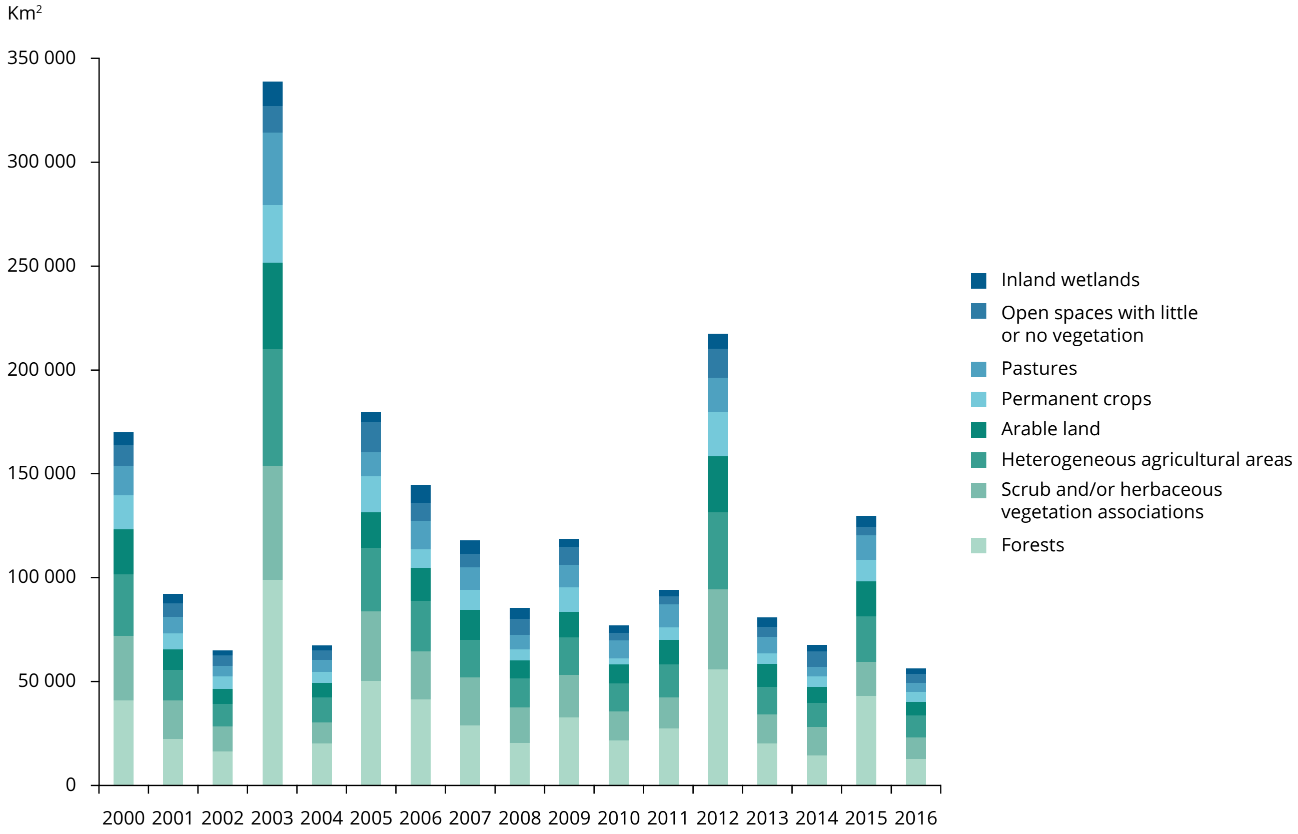
1.1.1 Impacts of droughts on habitats and species

The latest *State of nature in the EU* report (EEA, 2020h, 2020i) shows that 5.4 % of habitats and 4.6 % of species are currently affected by climate change as a pressure. Of all cases related to climate change, almost half are associated with droughts and decreases in precipitation. The highest pressures from decreases in precipitation are observed in habitats such as bogs, mires and fens. Of the animals, the most affected are the amphibians, which are very sensitive to shifts in both temperature and precipitation, and then molluscs, specific mammals and birds associated with reedbeds and reedy ponds.

As climate change is increasing temperature and changing precipitation patterns, it is expected that the risks for biodiversity will increase. The loss of existing habitats, the creation of favourable conditions for species alien to European ecosystems and the amplification of issues with invasive species are predicted to cause additional pressures for biodiversity in the future.

It is estimated that the average area of Europe affected by severe droughts is around 121 000 km^2 for the years between 2000 and 2016 (Figure 1.1). However, the annual area was highly variable, depending on the meteorological conditions that year, and ranged between 5 000 and 350 000 km^2 over the said period. The worst affected land use types included forests, scrub and/or herbaceous vegetation associations, heterogeneous agricultural areas, arable land and permanent crops. The most affected geographical areas were the Iberian Peninsula and south-western France, measured in terms of both extent of the areas under water deficit and decline in vegetation growth. In addition, a large part of central Europe and the Balkans (e.g. Bulgaria, Hungary, Romania and Slovenia) were affected by water deficits that caused a decline in vegetation growth (EEA, 2020b).

Figure 1.1 Area affected by reduced vegetation productivity due to water deficit, by land use type in Europe, 2000-2016



Note: Data are for EEA-38 plus United Kingdom.

Source: EEA (2020b).

1.2 Environmental impacts of freshwater abstraction

The main impacts of water abstraction on groundwater bodies are imbalances in the water table or lowered water tables and saline intrusion (Psomas et al., 2021). The main impacts of water abstraction on surface water bodies are hydrological or morphological changes. Both types of abstraction may cause pollution with chemicals, nutrients and organic material through return flows, either to groundwater or surface water bodies (EEA, 2018d). The impacts on groundwater and on surface water bodies may both result in negative impacts on habitats and ecosystems.

Abstraction is considered a significant pressure, affecting up to 17 % of the total groundwater body area and 10 % of the total river length in the 27 EU Member States (EU-27), Norway and the United Kingdom according to the second river basin management plans (RBMPs). These percentages are much higher (26 % and 13 %, respectively) in water-stressed areas in southern Europe (EEA, 2018d). Table 1.1 shows how different sectors contribute to significant abstraction pressures exerted on surface water and groundwater bodies in EU Member States.

As a result of the above pressures, about 9 % of the total groundwater body area in the EU-27 was found to be in poor quantitative status in the second RBMPs (EEA, 2018d), while in 2015 in 8 % of the river water bodies, water abstraction was reported as one of the main pressures causing failure to achieve good ecological status. It should be noted, however, that there are many water bodies in which quantitative and qualitative problems co-exist (e.g. due to multiple abstraction and pollution pressures over the same area) or where they are even interdependent (e.g. saline intrusion). According to the second RBMPs, 27 % of the total groundwater body area in the EU-27 was at either poor quantitative or poor chemical status, with 4 % at both poor quantitative and poor chemical status (Psomas et al., 2021).

Table 1.1 Extent of significant water abstraction pressures by sector in the second RBMPs

Driver/pressure	RBDs with affected SWBs or GWBs (%)	Member States with significantly affected SWBs (> 10 % of total)	Member States with significantly affected GWBs (> 10 % of total)
Agriculture – abstraction	42.8	Bulgaria , Cyprus, France, Netherlands, Spain	Belgium, Cyprus, France, Greece, Hungary, Italy, Malta, Spain
Public water supply – abstraction	57.2	Cyprus, France, Spain	Belgium, France, Hungary, Luxembourg, Malta, Spain
Industry – abstraction	40.1	France	Belgium, Hungary, Spain
Energy cooling – abstraction	11.2	-	Belgium

Note: GWB, groundwater body; RBD, river basin district; SWB, surface water body. Countries are listed by alphabetical order.

Source: EEA (2018d).

1.2.1 Water imbalances or lowering water tables

A recent modelling study suggests that water abstraction, supported by climate change, caused groundwater depletion in the Mediterranean and Black Sea areas, as well as in southern Germany and Ireland, between 1990 and 2015 (Gelati et al., 2020) (Map 1.1). As with any model, the results have some inherent uncertainties (e.g. because of data gaps), so additional cases of groundwater depletion could be expected in Europe. As reported in the literature, overabstraction has been a significant pressure causing the draw-down of groundwater tables in various cases (Box 1.2).

Box 1.2 Decline in groundwater levels due to overabstraction — indicative cases in Europe

Greece: Thessaly

Intensive cultivation of cotton, maize and lucerne have increased agricultural water abstractions rapidly, especially since the 1980s. Groundwater levels have been affected significantly to the south-west, where coarse-grained deposits are mixed with low-permeability clays, creating successive semi-confined and confined aquifers and aquitards. Existing buildings and public infrastructure have been damaged because of land subsidence.

Italy: Venice lagoon

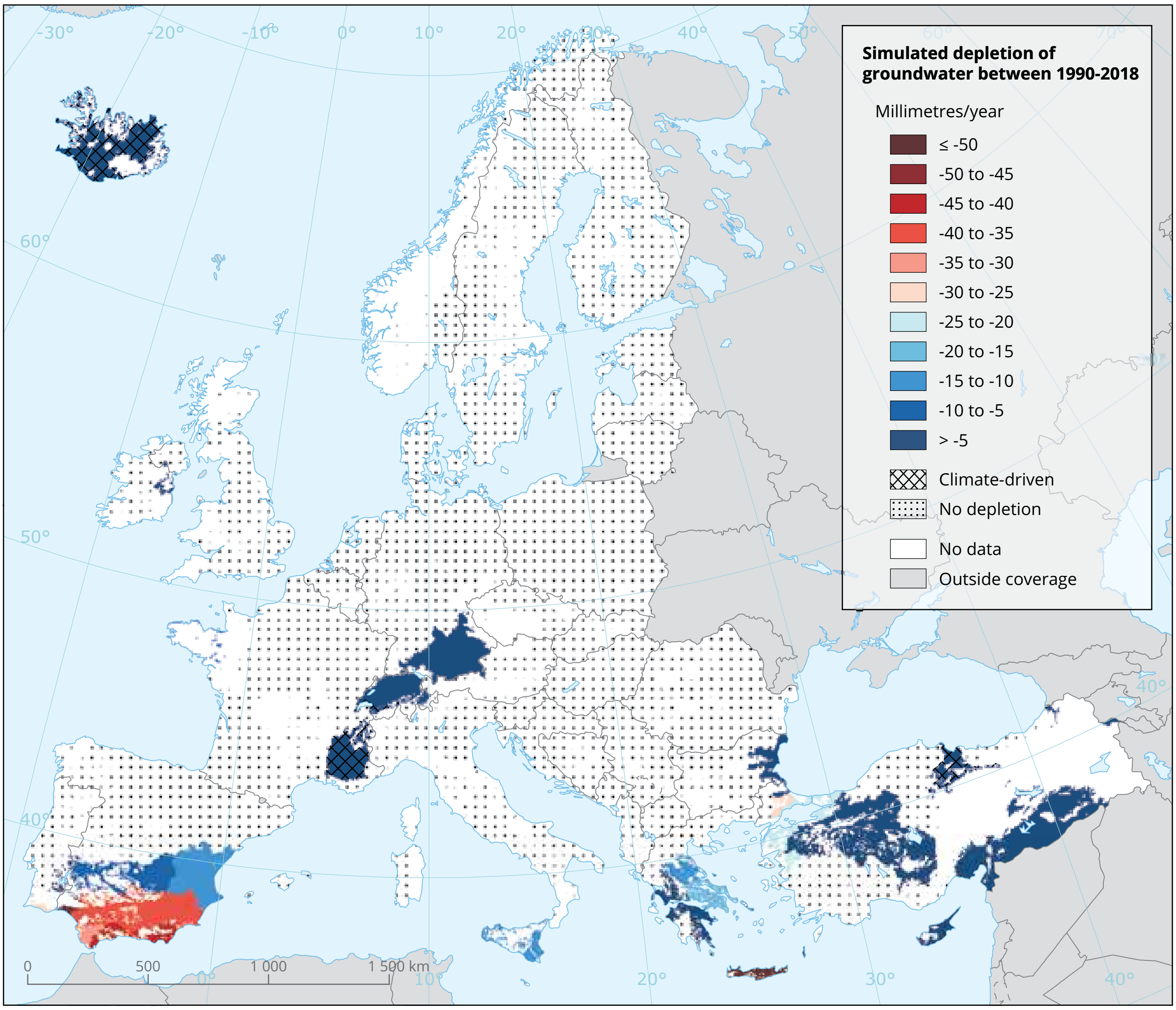
Industrial abstractions at Marghera mainly in the 1960s, caused draw-down of the groundwater table and significant land subsidence. Groundwater levels have not recovered to natural levels, despite measures adopted since the 1970s.

Netherlands: Noord-Brabant, Regge catchment

In rural areas of the Netherlands covered with drought-sensitive soils, such as Noord-Brabant and the Regge catchment, land use change has led to a reduction in groundwater recharge (e.g. soil sealing from urban expansion, more intensive use of soil water by crops). Water abstraction has caused draw-down of groundwater tables, reducing the baseflow to streams and impacting natural areas.

Sources: Muñoz-Reinoso (2001); Da Lio et al. (2013); Hendriks et al. (2015); Witte et al. (2019); Argyrakis et al. (2020).

Map 1.1 **Simulated depletion of groundwater (mm per year) between 1990 and 2018**



Reference data: ©ESRI

Note: Simulation was conducted by the European Commission Joint Research Centre using the Lisflood-EPIC model for the 1990-2018 period.

Source: Adapted from Gelati et al. (2020). Reproduced under the terms and conditions of Creative Commons CC BY 4.0 licence (https://creativecommons.org/licenses/by/4.0).

1.2.2 *Saline intrusion*

Overabstraction of groundwater in coastal aquifers can trigger salinisation of groundwater. Salinisation may also occur in inland locations, as a result of overabstraction, which causes influx and mixing of deeper salted groundwaters with clean groundwater (Psomas et al., 2021).

1.2.3 *Impacts on surface waters and dependent terrestrial ecosystems*

In the second RBMPs, 62 % of rivers, 51 % of lakes, 61 % of transitional waters and 51 % of coastal waters were not at good ecological status in 2015 (EEA, 2018b). Furthermore, 73 % of freshwater habitats were not at favourable conservation status in 2020 under Habitats Directive Article 17 reporting (EEA, 2020g). Water-dependent terrestrial ecosystems, such as wetlands, have been under serious pressure in the past decades. It is estimated that two thirds of European wetlands were lost before the 1990s, and their area has decreased further since, but the loss seems to have levelled off between 2006 and 2012 (EEA, 2020b). As mentioned above, the status of waters and ecosystems is affected by a variety of pressures. The failure of such freshwater and terrestrial ecosystems to achieve good status is mainly a result of pollution pressures. However, increased temperature and evapotranspiration, decreased recharge and overabstraction also play significant roles, either alone or in conjunction with the pollution pressures (Box 1.3).

An impression of the impact of water abstraction on the environment is provided by a European Commission Joint Research Centre study (Grizzetti et al., 2017). The study shows that, in the absence of abstraction from either groundwater or surface water, large areas in southern, western and eastern Europe could have 50-90 % fewer days of significantly low discharges in their rivers.

Box 1.3 Ecological impacts of overabstraction on wetland and riverine ecosystems in Spain

The Spanish authorities have detected cases of licensed users who are abstracting more than their allocated quota. Unauthorised water abstraction in Spain has been mainly driven by the uncontrolled expansion of irrigated agriculture, urban developments and tourism facilities (e.g. golf courses). The problem has existed for decades, leaving a legacy of overexploited aquifers across the country. The problem is also related to the existence of 'senior water rights' (i.e. old water rights granted decades ago), which have not been revised to take account of up-to-date studies on water balances and requirements. Overabstraction has affected various riverine and wetland ecosystems.

The Doñana National Park is an important coastal wetland, designated a Unesco World Heritage site, which lies at the delta of the Guadalquivir river and covers around 54 000 ha of lagoons, salt marshes, fixed and mobile dunes, scrub woodland and maquis. Overabstraction in the past has resulted in a decline in the groundwater tables in several parts of the region, the depletion of temporary ponds, a decrease in local stream flows and a reduction of groundwater recharge. In coastal areas, the groundwater-seawater equilibrium has been distorted, resulting in saline intrusion. The Doñana area is also affected by discharge of nutrients, chemicals and heavy metals originating from upstream industrial activities. The depletion of aquifers and the decrease in stream flows limits their capacity to dilute and flush out pollutants, thus increasing pollution problems such as eutrophication. Overall, the natural ecosystem faces negative impacts, which may be observed in alterations in the composition of vegetation (e.g. an increase in xeric shrubs, pine trees and juniper woodland), reductions in invertebrate communities (e.g. dragonflies), declines in populations of fish, molluscs and birds species (e.g. wintering and nesting ducks, coots) and the spread of invasive alien species to the detriment of native species. The river basin authorities have launched several proceedings over identified breaches and closed a limited number of unauthorised wells in the past. However, in 2019, the European Commission decided to refer Spain to the European Court of Justice for taking insufficient action and for alleged breaches of the Water Framework Directive and the Habitats Directive. On June 24, 2021, the Court ruled that Spain has failed to fulfil its obligations under Art. 5(1) and 11 of the WFD (EU, 2021).

Furthermore, research studies on Spanish rivers have also shown that the natural flow regime has been significantly altered in various river basins. Overabstraction has turned normally free-flowing rivers into intermittent flowing streams, and fish assemblages have been seriously affected at sites with high pressure from water abstraction. Reductions in carbon storage and breakdown of organic material and reductions in populations of shredder insects were also observed in mountain streams affected by overabstraction.

Sources: Muñoz-Reinoso (2001); WWF (2006, 2016); Benejam et al. (2010); Marcelino Botín Water Forum et al. (2010); Arroita et al. (2015); OECD (2015, 2019); De Stefano et al. (2015); Green et al. (2016); EC (2019d); Gelati et al. (2020); Unesco (2020).

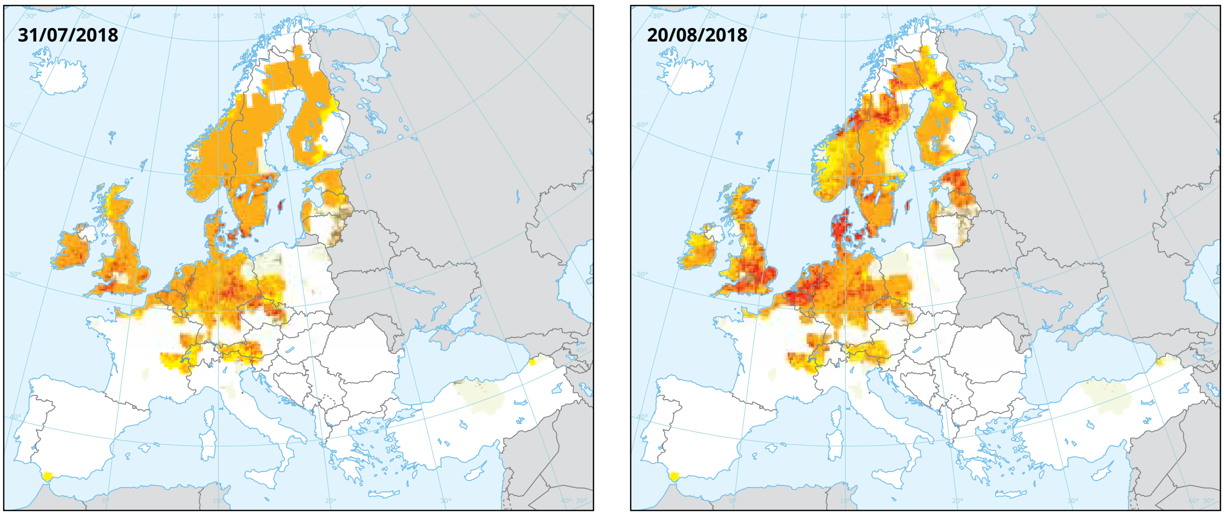
1.3 Socio-economic impacts of water stress

Water stress has negative impacts on the water-dependent economic sectors (for more detailed information, see Chapter 4). In agriculture, droughts can lead to low soil moisture content, causing losses of crop yields. If the groundwater storage is depleted, drinking water supplies may be disrupted, which can damage high-added-value sectors such as tourism and water-dependent industries. Similarly, low discharges in rivers may affect water-dependent electricity production in thermal and nuclear power plants or hydropower facilities and reduce the depth of water in free-flowing rivers, affecting inland shipping. In the third quarter of 2018, authorities were forced to stop river transport in Germany because of the severe drought that summer (see also Box 1.4). This had a serious negative impact on Germany's economic production, as it halted not only transport but also production of industrial commodities (Ellyat, 2019). In addition, there are cases where the drawdown of groundwater tables has caused damage to buildings or infrastructure because of land subsidence (see Box 1.2).

Box 1.4 The drought of 2018 in central and northern Europe

During the spring and summer of 2018, central and northern Europe experienced severe drought conditions, as a result of a combination of exceptionally warm temperatures and low precipitation (Map 1.2). Indeed, many Member States in these areas recorded one of their three hottest and driest summers ever. In contrast, southern Europe and particularly the Iberian Peninsula recorded a wetter than usual spring and summer (Eurostat, 2019b).

Map 1.2 The Combined Drought Indicator for the last 10-day period of July 2018 (left) and the second 10- day period of August 2018 (right)



Reference data: ©ESRI

The Combined Drought Indicator (CDI) for the last 10-day period of July 2018 (left) and the second 10-day period of August 2018 (right)

- Watch: rainfall deficit
- Warning: soil moisture deficit
- Alert: vegetation stress following rainfall/ soil moisture deficit
- Full recovery of vegetation to normal conditions
- Partial recovery of vegetation
- No data
- Outside coverage

0 500 1 000 1 500 km

Source: European Drought Observatory (JRC, 2020).

The 2018 drought affected farmers throughout northern Europe. The 2018 yields of cereals, potatoes, sugar beet and other crops that account for a large share of crop production in northern European countries were much lower than those in 2017. Drought also heavily affected pasture (generally not irrigated), which had detrimental effects on the livestock and diary sector.

The drought also had severe impacts on other socio-economic sectors (Harris, 2018; Toreti et al., 2019), for example higher than usual death rates among elderly people, difficulties in cooling power plants, stability issues in the Dutch dike system due to lack of freshwater, extremely low river levels, with negative impacts on the transport sector and industries dependent on waterway transport, and forest fires.

Water stress may create tensions between different water users (Box 1.5), river basin districts or even countries with respect to water management decisions (e.g. transfers, drainage), their impacts and the allocation of costs.

Economic damage from droughts is estimated to be in the order of EUR 2-9 billion annually, not including the unquantified damage to ecosystems and their services (EEA, 2020c; Maes et al., 2020).

Box 1.5 Civil associations and municipalities in Spain challenge water management decisions disproportionately affecting public water supply and urban citizens

Relocation of public water supply in the Jucar river basin

Diffuse agricultural pollution significantly affected two aquifers in the Jucar river basin designated for the supply of drinking water. The authorities decided to relocate the drinking water supply to a local surface water body and charge the costs to the nine municipalities that would be serviced. The municipalities referred the issue to the Supreme Court of Spain, which required better implementation of the Water Framework Directive polluter-pays principle. Thus, farmers were expected to bear part of the costs through the environmental costs embedded in the water tariffs.

Friction over the definition of ecological flow in downstream areas of the Tagus

The friction between environmental and economic water demands is also illustrated by the case of the Tagus River Basin Management Plan. The current plan, in force from 2015 to 2021, did not effectively take account of environmental water demand, favouring certain economic functions abstracting and consuming high volumes of water (especially irrigated agriculture). In 2016, a group of civil associations and representatives of local municipalities submitted a legal challenge to the plan. In its 2019 ruling, the Spanish Supreme Court annulled the plan's provisions on ecological flows and required the Tagus River Basin Authority to enact urgent interim measures to cover the period until the start of the next planning cycle in December 2021.

Sources: de Marcos Fernández (2016); Mlinaric and Rhodes (2018).

1.4 Extent of water stress in Europe

According to estimates from the EEA water exploitation index plus (EEA, 2018b)(Box 1.6), on average approximately 20 % of the European territory and 30 % of the European population are affected by water stress every year. Assessments in this indicator underline the fact that seasonal and permanent water stress might be exacerbated in the future. Further information on the current state and future projections of water stress in Europe is provided in Chapter 5 of this report.

Box 1.6 The water exploitation index plus (WEI+)

The WEI+ is an advanced geo-referenced implementation of the WEI developed by the EEA at river basin level and seasonal resolution (EEA, 2018b). The WEI+ is defined as the total net water use (abstractions minus returns) divided by the freshwater resources of a region, including upstream inflowing water. Constraints on water use due to insufficient water quality are not accounted for in the index. WEI+ values have a range of between 0 % and 100 %. Values below 10 % denote 'low water stress' and values between 10 % and 20 % denote 'moderate water stress'; we speak of 'water stress' when this ratio is larger than 20 %, and of 'severe water stress' if the ratio exceeds 40 %.Theoretically, if the WEI+ value exceeds 100 %, then not only are all renewable freshwater resources exploited but there is also an unsustainable exploitation of permanent water reserves (e.g. groundwater) (Feargemann, 2012).

1.5 Scope and outline of the report

The overall aim of this report is, in accordance with Article 1 of the Water Framework Directive, to address the abovementioned impacts of water stress across Europe and to promote sustainable water use based on protecting available water resources in the long term. The report addresses the trends in water availability under changes in climate, water abstractions and water use efficiency, including their impacts on the environment and on the main water-dependent economic sectors (agriculture, electricity production, manufacturing and domestic water supply). The report also explores the decoupling ([1]) of sectoral water abstraction from economic growth, future water availability and water demand, and it evaluates the potential effectiveness of current responses to water stress.

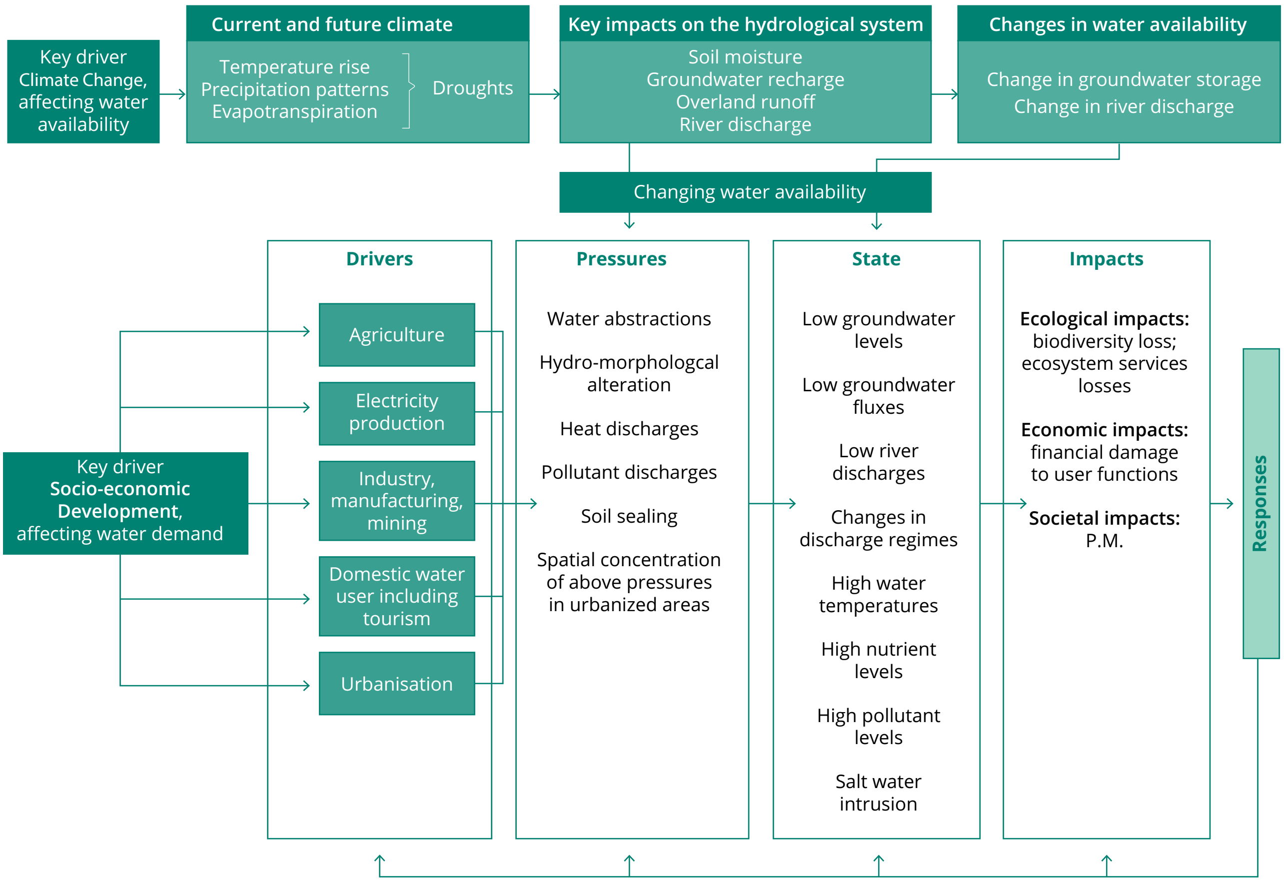
([1]) Decoupling refers to the ability to sustain economic growth while reducing the amount of resources used, such as water or fossil fuels, and stopping environmental deterioration at the same time. Decoupling may be relative (indicating decreasing resource use per unit of production value) or absolute (absolute decrease in resource use while production value increases).

The DPSIR (Drivers-Pressures-State-Impact-Responses) framework was used as the analytical framework for developing the report (Figure 1.2). Hence, this report starts with climate change and socio-economic development as key drivers of water availability and water demand. An overview of water stress-related EU policy responses is included in this report. Measures and policy responses can address any of the DPSIR steps.

This report is structured around seven chapters in line with the DPSIR framework to address various aspects of water stress issues and the impacts of multi-drivers on European water resources and EU policy responses (Figure 1.3).

Chapter 2 describes the European policy context, that is, the policies implemented for water stress management, sectoral and environmental policies with a link to water use

Figure 1.2 DPSIR schema for water stress addressed in the report



Source: Adapted by H. Wolters from EEA (2009).

or management, and cross-cutting integrative policies. It also highlights some links between the European policy landscape and recent global policy developments.

Chapter 3 presents climate change as the first of the two key drivers of water stress. The chapter addresses the meteorological parameters that have an impact on droughts and water availability and then illustrates how these are reflected in the stages of the hydrological cycle. The focus is on precipitation and evapotranspiration patterns as determinants of water availability, and on the frequency and intensity of droughts.

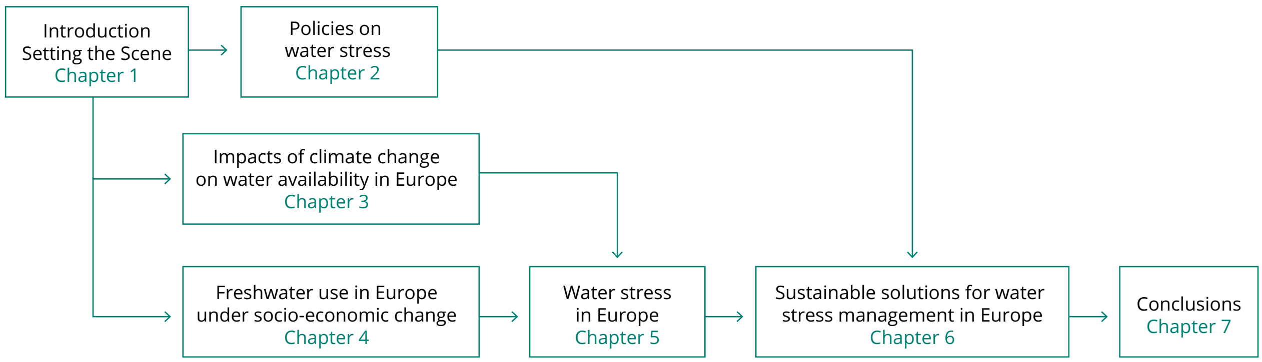
Chapter 4 starts off with the current state of water abstraction. It then highlights how water abstractions are determined by socio-economic developments, including land use changes. The chapter presents an overview of how water is abstracted and used in the major water-dependent economic sectors — energy, agriculture, households, tourism and industry — and for the environment. Socio-economic development largely determines how the economic water-dependent sectors develop, as a result of such underlying trends as population growth, technological innovations and market relations from local to global levels. The key issue in this report is how this will eventually affect the sectors' water demand.

Chapter 5 provides a consolidated overview of the findings of Chapters 3 and 4 to sketch out future trends in water stress.

Chapter 6 presents potential ways of dealing with water stress in future. These include unconventional resources, nature-based solutions, nexus approaches, innovative technologies and various policy responses. These options are introduced and their relevance for water stress management is explored. The chapter concludes with an outlook.

Chapter 7 presents the main conclusions of this report.

Figure 1.3 Structure of the report



Source: Adapted by H. Wolters from EEA (2009).

1.6 Primary stakeholders

This report is primarily relevant to EU water policymaking on water scarcity and drought. It provides insights and assessment that might also be relevant at local and national levels where water stress is a prevailing issue. Traditionally water stress concerns water users and water managers, as they are the principal stakeholders. However, the diversity of the audience is increasing. Water stress and its expected adverse economic consequences increasingly attract the attention of the finance and insurance sectors (EEA, 2020c). The World Economic Forum has listed 'extreme weather' as one of its top 5 risks with the highest likelihood of occurring since 2014 and as one of its top-5 risks with the highest impact since 2017. The urgency and magnitude of the challenge is also stated in a World Bank report (World Bank, 2016) which, among other things, indicates that, by 2050, water-related losses could result in a decline of up to 6 % of the gross domestic product (GDP) in some regions. The adverse impacts of water abstraction on the environment have driven water stress and drought issues up the list of priorities of societal organisations, such as the Right to Water citizen initiative (Right to Water, 2021), and of nature protection non-governmental organisations (NGOs), such as the WWF (World Wide Fund for Nature) and IUCN (International Union for Conservation of Nature) (Trémolet S. et al., 2019), while water scarcity risks are addressed in the annual plans of multinational companies such as Intel (Aquatech, 2019), Coca-Cola and Unilever. The water footprint assessment has played an important role in raising awareness of the implicit role of water in global economic production and trade. Several networks of private enterprises (e.g. World Business Council for Sustainable Development, Carbon Initiative, and Beverage Industry Environmental Roundtable) have taken steps to incorporate water into the scope of their corporate social responsibility initiatives, as has the European Water Stewardship scheme. All this goes to demonstrate that water stress is no longer the sole concern of water management authorities and direct water users. The 'newly involved' stakeholders can have a crucial role in the design and implementation of nature-based solutions, as illustrated by the NAIAD project on the insurance value of ecosystems (Section 6.4).

1.7 Relevance to other EEA activities

This report builds on a long chain of earlier EEA assessments and reports. A prominent predecessor is the 2009 report *Water resources across Europe — confronting water scarcity and drought* (EEA, 2009). The current report is an update of that report. Compared with the 2009 report, the current report adds recent data, an update on trends in water availability and use, and the cross-links with related sectors and disciplines, updates on policies and measures, and proposals for solutions.

Among many others, the following reports have been used as inputs in developing this report:

- *Effectiveness of urban wastewater treatment policies in selected countries: an EEA pilot study* (EEA, 2005);
- *Towards efficient use of water resources in Europe* (EEA, 2012b);
- *Water resources in Europe in the context of vulnerability* (EEA, 2012c);
- *Assessment of cost recovery through water pricing* (EEA, 2013a);
- *Public participation, contributing to better water management: experiences from eight case studies across Europe* (EEA, 2014);
- *Water-retention potential of Europe's forests: a European overview to support natural water-retention measures* (EEA, 2015);
- *Climate change adaptation and disaster risk reduction in Europe: enhancing coherence of the knowledge base, policies and practices* (EEA, 2017a);
- *Landscapes in transition: an account of 25 years of land cover change in Europe* (EEA, 2017d);
- *Water management in Europe: price and non-price approaches to water conservation* (EEA, 2017f);
- *European water: assessment of status and pressures* (EEA, 2018a);
- *Climate change adaptation in the agriculture sector in Europe* (EEA, 2019a);
- *Industrial waste water treatment: pressures on Europe's environment* (EEA, 2019c);
- *Monitoring and evaluation of national adaptation policies throughout the policy cycle* (EEA, 2020g);
- *State of nature in the EU* (EEA, 2020h);
- *Water and agriculture: towards sustainable solutions* (EEA, 2021c).

Finally, *The European environment — state and outlook 2020: knowledge for transition to a sustainable Europe* (EEA, 2019j) presents a comprehensive analysis of the above elements and offers perspectives on a systems approach.

Over recent years the EEA has put a lot of effort into collecting and organising data for the development of water accounts and indicators supporting the assessment of the state of European waters (EEA, 2019l). Furthermore, two important reports on establishing water accounts have been published by the European Topic Centre on Inland, Coastal and Marine Waters (ETC/ICM, 2016; Zal et al., 2017). This report makes considerable use of the results of those efforts, most notably the Core Set of Indictors (CSI) on water and climate change ([2]).

Along with the abovementioned reports, assessments from a number of the EEA water-, climate-, land- and biodiversity related indicators have been used extensively. Databases on the state of the environment, EEA dashboards on various topics (EEA, 2018d, 2019i) and the Eurostat database have also provided quantified assessments of the status of and pressures on Europe's water resources.

([2]) All EEA indicators can be found at: https://www.eea.europa.eu/data-and-maps/indicators/#c0=30&c12-operator=or&b_start=0

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2 Policies on water stress

Key messages

- **Globally, and in Europe, policy instruments, measures and strategies being devised to address water stress are shifting from crisis management to proactive risk management approaches.**
- **The Water Framework Directive provides a suitable, flexible regulatory framework for action against water stress, underscoring the relation between water quantity, water quality and ecological status. However, this framework is not exploited to its full potential.**
- **Despite the publication of the European Commission's communication on water scarcity and drought in 2007 and the *Blueprint to safeguard Europe's water resources* in 2012, EU policy on water stress remains scattered and the implementation of policy options and recommendations has been slow.**
- **In the second river basin management plans (RBMPs), 16 Member States reported that water abstraction is a significant pressure for their surface water or groundwater at least in some parts of their national territory. However, only eight Member States reported having drought management plans as documents accompanying all or part of their RBMPs and only three Member States had developed ecological flows in all rivers.**
- **The European Green Deal, the new circular economy action plan and especially the new EU strategy on adaptation to climate change renew previous calls for mainstreaming water stress policy objectives, and forthcoming actions under these initiatives represent fresh opportunities to increase coherence and promote implementation.**

2.1 Water stress in EU water policy

Water stands among the oldest and most advanced policy areas in the EU environmental acquis (Josefsson, 2012; Giakoumis and Voulvoulis, 2018). Since 2000, the Water Framework Directive (WFD) (EU, 2000) has been the EU's flagship legislation on water, under which the wide variety of EU regulatory instruments, strategies and policy mechanisms that have emerged and evolved over decades are coordinated. Under the WFD, the EU has set an overall aim to 'ensure access to good quality water in sufficient quantity for all Europeans, and to ensure the good status of all water bodies across Europe' (EU, 2000). Article 1 of the WFD requires the Member States to 'promote the sustainable use of water resources based on the long-term protection of available water resources' and 'ensure a balance between abstraction and recharge of groundwater, with the aim of achieving good status of groundwater bodies'. Through these requirements, the WFD sets the basis for action against water stress, and it underscores the relation between water quantity, water quality and ecological status. The fitness check of EU water legislation concluded that the WFD provides a suitable, flexible frame for the planning for and management of drought risk and the impacts of water scarcity events (EC et al., 2019).

The management of water stress across Europe has traditionally focused on supply-side measures, while drought management has been characterised by crisis management measures. Driven by shifts in the study of vulnerability and risk that originated in the 1980s (Vargas and Paneque, 2017), and underpinned by global developments such as the Yokohama strategy for a safer world (UN, 1994) and its successors, the last three decades have increasingly seen the adoption of strategies that shift the focus towards water demand management. In addition, there is increased emphasis on the need for a more proactive risk management approach against droughts, calling for a drought management approach articulated around aspects of preparedness, crisis management and resilience building (Box 2.1).

Box 2.1 Important terms in water stress management

Preparedness: monitoring of long-term water resources to evaluate the water-related risks and corresponding planning to effectively manage the anticipated water deficits, while also considering the risks from probable drought events.

Crisis management: activation of predefined emergency plans and measures to deal with critical water deficits during drought events.

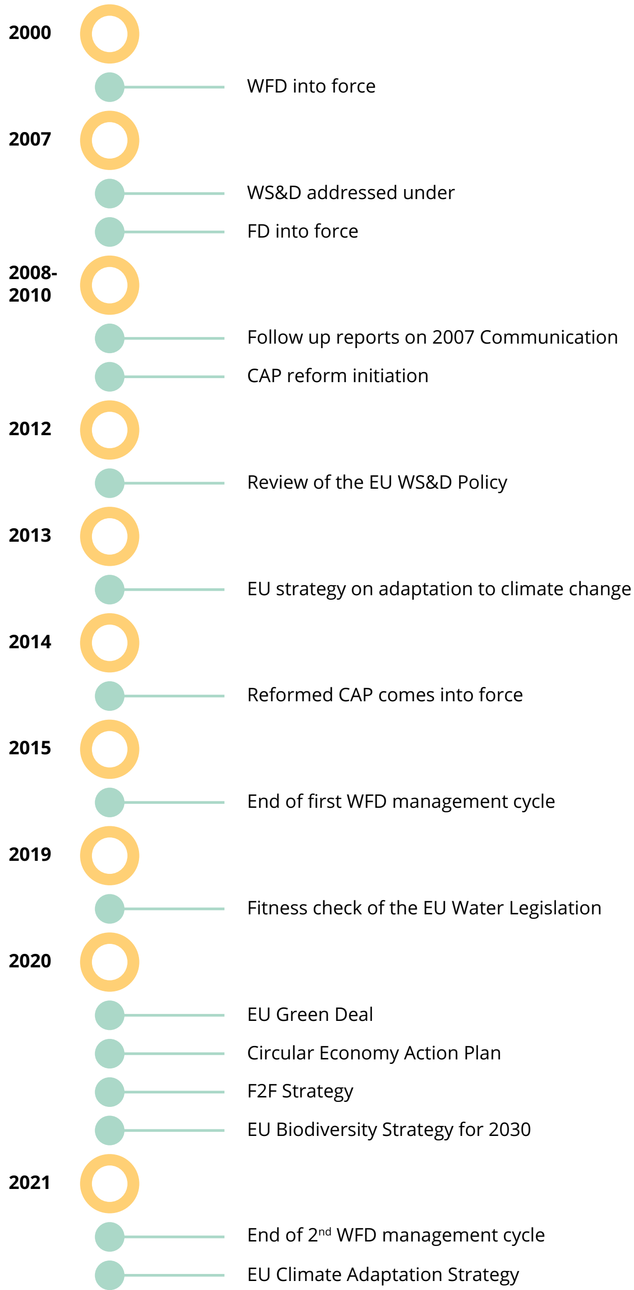
Resilience building: development of the necessary knowledge base, awareness, governance structure and technical infrastructure to support preparedness for and crisis management of drought risks (e.g. raising awareness on water security concerns; providing capacity building and training; climate-proofing of socio-economic activities and areas; employing nature-based solutions for climate change adaptation; integrating ecosystem services into finance and insurance schemes dealing with water stress).

Water stress, water scarcity and drought: the general term, included in the glossary and most widely used in this report, is water stress. However, as the titles of relevant guidance documents include the terms 'water scarcity' and 'drought', those are used in this chapter too.

Overall, EU policy on water stress has evolved around three supplementary pillars: (1) EU legislation (e.g. WFD, Groundwater Directive, Floods Directive, new Water Reuse Regulation), policy initiatives (e.g. communication on water scarcity and drought, circular economy action plan, *Roadmap to a resource efficient Europe*, EU strategy on adaptation to climate change) and sectoral policy instruments (e.g. Pillar II of the common agricultural policy (CAP) and the regional environmental policy Civil Protection Mechanism) (Figure 2.1).

The WFD itself establishes, at river basin scale, an integrated planning framework to enhance protection and improvement of the aquatic environment with the ultimate goal of achieving good environmental status in European waters. A key product of the WFD planning process is the river basin management plan (RBMP), which is accompanied by a programme of measures. The WFD recognises the cross-cutting character of water as a vital resource for environmental, social and economic systems, which puts water policy at the centre of developments in other policy areas. To tackle water stress, the WFD puts more emphasis on acting on the drivers underpinning water demand (i.e. reducing demand from economic sectors consuming water) than on increasing water supply. The WFD encourages abstraction control through permits, water demand management and efficient water use.

Figure 2.1 Timeline showing major policy developments related to water stress since the adoption of the WFD



Note: F2F, Farm to Fork; FD, Floods Directive; WS&D, Water Scarcity and Droughts.

However, supply-oriented infrastructure, including reservoirs or diversions (inter-basin transfers), have also been planned in recent years by many Member States (e.g. Austria, Bulgaria, Croatia, France, Greece, Italy, Poland, Romania, Slovenia, Spain) in response to their concerns on water and energy security or to shift their local water supply to alternative sources, because of the depletion and degradation of local groundwater (Buchanan et al., 2019).

In 2007, the European Commission published its communication on water scarcity and drought (EC, 2007a), which outlines seven concrete policy options to address water scarcity and drought at European, national and regional levels:

- putting the right price tag on water;
- allocating water and water-related funding more efficiently;
- improving drought risk management;
- considering additional water supply infrastructure;
- fostering water-efficient technologies and practices;
- fostering a water-saving culture in Europe;
- improving knowledge and data collection.

The communication calls for a 'water efficient and water saving economy' that integrates 'water issues into all sectoral policies'. There is an explicit recognition that economic development, in the form of, for example, new urban areas, industrial production capacities or irrigation perimeters, must take into account the availability of local water resources to avoid exacerbating water stress and the risk of damaging droughts. The implementation of the policy options promoted by the communication was assessed in three annual follow-up reports and a policy review (EC, 2008, 2010, 2011b).

Three additional policy documents addressing water stress and droughts explicitly have since been published:

- The *Blueprint to safeguard Europe's water* (EC, 2012) re-emphasised the need to take action against water stress. It integrates a particular focus on the need to increase resource use efficiency and decouple growth from resource use, drawing on the 2011 *Roadmap to a resource efficient Europe* (EC, 2011a) and recently re-emphasised in the new circular economy action plan (EC, 2020b) under the European Green Deal (EC, 2019e).

- The EU strategy on adaptation to climate change (EC, 2013) served to establish reference points and define new aims to increase climate resilience and disaster preparedness. This was closely linked to efforts to improve drought risk management under the 2007 communication and preparation of drought management plans (DMPs) by Member States (EC, 2007a).

- In 2021, the European Commission adopted a new EU strategy on climate change adaptation (EC, 2021a). This new policy explicitly seeks to accelerate the development and roll-out of solutions to safeguard the availability of freshwater. It recognises the need for action to ensure the availability and sustainable use of freshwater resources and calls for protecting water quality in the face of climate change to guarantee a stable and secure supply of drinking water. The strategy was conceived in the belief that climate change impacts will affect all economic sectors and all social groups, and so policy mainstreaming and systemic change are prominently featured. It resonates with the 2007 communication on water scarcity and drought in that it emphasises the need for climate-informed and future-proofed investment and policy decisions, for improved collection of and access to climate-related risk and loss data, for fostering efficient water use in the domestic, agricultural and industrial realms, for promoting drought management planning, and for setting water prices that adequately reflect the value of the resource.

Undertakings at the EU level to support water stress management have resulted in achievements in the form of research, policy options and technical guidance (Hervás-Gámez and Delgado-Ramos, 2019). However, the EU policy approach towards water quantity is generally less well developed than it is for water quality (Stein et al., 2016; Eslamian and Eslamian, 2017), and the pace of change in this specific policy area has been slow.

Developing comprehensive and incentive regulatory frameworks and incentive pricing mechanisms is as important for facilitating the uptake of new technologies as developing the technical solutions themselves (Buchanan et al., 2019). Recently, general considerations on water stress have been integrated into the European Green Deal, the biodiversity strategy for 2030, the farm to fork strategy, the 2030 climate and energy framework, the new circular economy action plan and the 2050 long-term strategy. Elements of water security and insurance are also embedded in the EU's sustainable finance taxonomy. For instance, as outlined in environmental objective 3 of the taxonomy on the 'sustainable use and protection of water and marine resources', investment in economic activities that make a substantial contribution to reducing the rates of water abstraction or reducing hydromorphological pressures without significantly hindering the achievement of the taxonomy's five other environmental objectives will classify as sustainable. Technical screening criteria to determine when a contribution can be considered substantial will be adopted at the end of 2021 and applied from 2023 onwards. Similarly, the new EU strategy on adaptation to climate change makes explicit reference to the issues of water availability and sustainable use. Thus, a proportion of the 100 demonstrators of adaptation solutions that are considered in the mission proposal *A climate resilient Europe* ([3]) will be partly or fully oriented towards increasing resilience to water impacts. The challenge will continue to be transposing the principles and provisions of the new policy initiatives and making them operational, as well as scaling up the solutions demonstrated.

2.1.1 Implementation challenges

To date, the management of water stress remains largely a national policy, but it operates within a multi-level governance scheme in which different administrative levels play distinct roles. In keeping with the subsidiarity principle, the WFD and EU water scarcity and droughts policy provide a framework for integrating and building on Member States' knowledge of local conditions while avoiding short-term regional or local interests putting the future needs of the wider community at risk. This effectively means that the EU complements the regulation and management responsibilities of local and regional authorities (EU Committee of the Regions, 2011). Nonetheless, there could be cases in which the responsible public administration fails to develop a long-term strategy looking beyond the 6-year management cycles of the WFD and building effectively on the RBMPs (Buchanan et al., 2019).

On the one hand, authorities and stakeholders in many Member States have scaled up collaboration in planning and management, leading to greater policy integration of water stress issues at local and regional levels. This triggered action from some Member States, and the latest DMPs were accepted in 2018. The compliance assessment of the second RBMPs (EC, 2019b) showed that 15 Member States and the United Kingdom reported water abstraction as a significant pressure for their surface water or groundwater at least in some parts of their national territory ([4]) . However, only seven Member States and the United Kingdom reported having DMPs as accompanying documents to all or part of their RBMPs ([5]) . Furthermore, the content of these plans and the depth of the analysis differ greatly among Member States, despite the existence of a relevant technical report on the development of DMPs (EC, 2007b). Cyprus and Spain are two countries with very detailed and comprehensive DMPs accompanying their RBMPs. Some elements of these plans are regarded as novel and promising (Hervás-Gámez and Delgado-Ramos, 2019).

The assessment of the second RBMPs also showed that EU Member States with significant pressures from abstraction in their territory may have gaps in their knowledge of the exact volume of water abstracted at river basin level either because of unauthorised abstractions or lack of metering devices or because of the exemption of 'small' abstractions from reporting (EC, 2019b).

On the other hand, it should be noted that progress in implementation has been slow since the publication of the *Blueprint to safeguard European waters* back in 2012. The transition from crisis to risk management approaches has been mostly a conceptual one, as during its implementation this change in paradigm has exposed a lack of institutional capacity across many Member States (Tsakiris, 2015). Furthermore, to be truly effective, the risk management approach has to be adopted by all sectors that have a direct or indirect influence on water, for example through decisions on land use (EU Committee of the Regions, 2011). It will be important to renew efforts on this, especially in areas with recurrent drought issues, as the impacts of temporary drought events can last much longer than the initial phenomenon and their socio-economic damage can be considerable. The European Green Deal and the forthcoming actions under the new EU strategy on adaptation to climate change are opportunities to do so.

Between the first and second WFD planning cycle, water pricing was applied more widely by EU Member States, and new pricing schemes were introduced in various sectors (e.g. drinking water and sanitation, agriculture, industry). However, although incentive pricing is an explicit requirement of the WFD to ensure compliance with its principles and objectives, the current pricing mechanisms do not always provide adequate incentives for efficient water use and sustainable water management (Buchanan et al., 2019).

One of the findings of the fitness check of the WFD was that implementation should be increased and budget for it should be secured in the Member States. Often, the key reason for delays in the implementation of measures tackling water stress is a lack of secure budgets. Implementation relies largely on the public budget, and the capacity of EU funds is not always fully exploited (Buchanan et al., 2019). The coordination of the EU CAP and the rural development plans is a good example here, as highlighted by EEIG Alliance Environnement (EC, 2020f).

([3]) The mission proposal aims to 'support 200 communities to develop solutions for transformative adaptation, and scale up 100 deep demonstrations of climate-resilience' (EC, 2020a).

([4]) Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, France, Germany, Greece, Hungary, Italy, Malta, Portugal, Slovakia, Spain. Countries are listed by alphabetical order.

([5]) Cyprus, Czechia, Greece, Italy, Netherlands, Slovakia, Spain.

Finally, the lack of robust governance of water stress at EU level has left ample space for discrepancies between Member States in their interpretation of it, and drought policy has important limitations regarding compliance (Stein et al., 2016). For example, most Member States apply exemptions from registration or permitting for water abstractions considered to be 'small' ([6]) in volume. However, the accumulation of all of these small abstractions over a large area could result in a significant pressure (e.g. on local groundwater bodies), which is disregarded. Similarly, in some areas, there are issues with the overallocation of water rights that were issued before the adoption of the WFD. Although the WFD has provided significant motivation for local authorities to review pre-existing water rights and to revise them according to the overexploitation problems identified, Member States usually have difficulty in intervening in case of permits that were granted a long time ago and what are known as 'senior water rights'. As a result, most Member States have become stricter when issuing newer water permits (Buchanan et al., 2019; EC, 2020f).

Combined, these barriers slow down progress in achieving the WFD's objectives and limit the ambitious implementation of EU water scarcity and drought policy. There is thus a continued need to address issues such as policy integration, coherence and compliance (EC, 2015d, 2020f).

2.2 Sectoral policy responses and their links to water stress

Beyond the dedicated water policies that have been the main focus of this chapter so far, a wide range of sectoral and environmental strategies, instruments and measures are in place that directly or indirectly address the impacts of water stress and drought. These include policies in the fields of agriculture, energy, industry, transport, biodiversity, nature protection and climate change.

The European Green Deal has largely managed to encapsulate global developments advocating systemic change, and its ongoing action plan intends to enable (deep) sustainable transitions in Europe. The strategy recognises the need to 'restore the natural functions of ground and surface water' and tackle the 'excessive consumption of natural resources'. It sets out a number of industry reforms aligned to foster the transition towards circularity and towards a greener and resource-efficient economy. At a macro-level, the Green Deal aims to increase sustainable finance and channel public and private investment into sustainable activities and projects. The use of cross-cutting instruments such as the EU sustainable finance taxonomy is highlighted in the Green Deal, as it aims to establish financing standards to increase the efficient use and protection of — among other things — water resources across the European economy.

Agriculture is the sector with the highest water consumption and was one of the worst hit in the recent drought events of 2018 and 2019. Impacts on the sector include loss of yields, increased costs of water supply and irrigation, and heightened potential for tensions, disputes and even conflict between competing users. The sector's flagship policy, the CAP, is undergoing a reform process that includes readjusting its focus to incorporate better water management into farm practices. Under the Rural Development Regulation, also known as Pillar II of the CAP, a set of measures, including training and farm modernisation, to promote water efficiency are concrete elements widening the scope of agricultural practice to increase environmental protection and improvement.

In the **energy sector**, common impacts include reduced energy production in thermal plants due to low river discharges (and reduced access to cooling water), decreased electricity production in hydropower plants due to low reservoir levels, and increased electricity prices. The Commission's reiterated commitment to achieve climate neutrality and fully decarbonise power generation by 2050, with 80 % of the EU's power generated from renewable sources, creates expectations of future changes in the sector's water demand. Links to water stress in the Renewable Energy Directive (EU, 2009a) and the EU's energy union strategy (EC, 2015a) are indirect and mainly stem from integrated climate and energy planning and monitoring of greenhouse gas emissions. The recent EU strategy for energy system integration 2020 (EC, 2020d) includes consideration of the water footprint of EU energy production and the potential for sustainable production of bioenergy from wastewater.

The **industrial sector** includes manufacturing operations and mining and quarrying, which are in many cases activities with a high water demand. Impacts of imbalances in water availability include restrictions on production plants and even plant shutdowns in highly water-dependent operations. Policy responses in this sector have focused primarily on resource efficiency and circularity approaches and include the *Roadmap to a resource efficient Europe* (EC, 2011a) and the 2015 circular

([6]) Perceptions and definitions of 'small' abstraction differ among Member States, e.g. in France: 1 000 m³/year, and in the Netherlands (indicative, varies by water board) 100 m3/h (registration is obligatory but no permit required).

economy action plan (EC, 2015b), which was recently updated (EC, 2020b) under the European Green Deal (EC, 2019e). Furthermore, the Industrial Emissions Directive (EU, 2010) is under review, and a proposal for its revision is expected in late 2021. It is anticipated that this revision will address resource efficiency, including water efficiency. The new industrial strategy for Europe (EC, 2020c) that was published in March 2020 does not include any clear references to water quantity issues. The strategy's review in 2021 is also expected to address the aspect of water efficiency in industry.

Lastly, the **transport sector** can also be significantly affected by water stress events. The 2018 drought caused restrictions on inland navigation in central Europe and disrupted supply chains throughout entire river basins.

These are just some examples of the main sectoral impacts and measures that give us insight into the importance of concerted and coordinated action beyond sectoral silos.

2.3 Water stress in European climate change, nature and biodiversity policy

Worldwide, there is growing awareness of the need for policy responses that address the impacts of climate change on water (Quevauviller and Gemmer, 2015). In Europe, climate change and population growth are shifting conditions, affecting a wider geographical spread (see Chapter 3). Member States such as Sweden and Germany suffered large economic losses stemming from droughts in 2018 and 2019, and increased variability in weather patterns is making the existing hotspots (e.g. southern Europe) worse off. This is drawing renewed attention to water availability issues at the EU level, once more calling for updates on water scarcity and drought policy and action.

Regarding the consideration of climate change in the second RBMPs, significant progress has been achieved compared with the first cycle. Most Member States used the CIS guidance document (EC, 2009), and climate change was integrated in a series of actions related to the preparation of the RBMPs. However, there are still large gaps to address before climate change can be considered fully integrated. In addition, eight Member States reported the planning of specific measures to address climate change adaptation. Various Member States have also reported multipurpose measures, which could be relevant in the context of climate change adaptation, although this is not explicitly stated (Buchanan et al., 2019; EC, 2019c).

The 2013 EU climate change adaptation strategy aimed to build capacity and increase resilience to extreme weather events, including droughts. It promoted progress in raising awareness, developing national adaptation policy and exploring adaptation solutions that incorporate natural elements in them, such as green infrastructure and nature-based solutions. The new adaptation strategy from 2021 aims to shift the focus towards action on climate change and to accelerate the roll-out of physical solutions, such as creating more green spaces. It adopts a systemic perspective to both the impacts of and possible solutions to water stress. It appeals directly to the WFD and DMPs, advocating nature-based solutions as means to improve compliance with requirements for good ecological status and potential and as solutions that can 'boost the supply of clean, fresh water' while generating co-benefits in a cost-effective way. These commonalities between EU adaptation policy, the EU strategy on green infrastructure and the biodiversity strategy for 2030 represent another interface between policy areas in which water plays a central role. Here, progress has been made on the study of natural water retention measures that enable the achievement of multiple objectives such as increasing drought resilience and water security, reducing habitat fragmentation, decreasing the emission of greenhouse gases, and providing spaces for recreation. Nevertheless, the primary objectives behind the construction of natural water retention measures so far have been flood risk management, nutrient buffering and wastewater treatment, hydromorphological restoration and biodiversity protection (Buchanan et al., 2019). To date, water quantity and climate change adaptation objectives seem to be less influential in motivating the application of natural water retention measures. This will change following the shift in focus of the new adaptation strategy and the proposed demonstration and scaling up of solutions for transformative adaptation under the mission on adaptation of the Horizon Europe research programme.

2.4 Policy developments at the global level

To tackle water stress, the international community has recognised the need for an integrated approach to water, energy, food and ecosystems (Carmona-Moreno et al., 2019). The approval of the UN 2030 agenda for sustainable development (UN, 2015b) invigorated the discussion on systemic change that has permeated recent EU policy, highlighting the importance of collaboration and policy integration and coherence. The nature of the Sustainable Development Goals (SDGs) is cross-cutting and calls for joint implementation. As for their coverage of water stress issues, Target 6.4 highlights the need to increase water use efficiency across all sectors and decouple economic growth from water use, and Target 6.5 promotes integrated water management. Key sectors include agriculture, energy, industry and public water supply. This makes the WEFE (water, energy, food, ecosystem) nexus approach suitable for the pursuit of the SDGs. WEFE nexus assessments and projects are gaining traction around the world, and the underlying principles of the approach can also be identified in the most recent EU policy developments. The collective experience gathered by these projects could become instrumental in resolving the known issues regarding the differentiation between concepts (e.g. water abstraction and water use), the inclusion of ecological flows in the development and reporting of the indicator group on SDG 6, and the review of water allocation and impoundment permits as requested by the EU biodiversity strategy for 2030.

From a climate resilience perspective, the previously mentioned paradigm shift on vulnerability and risk is largely reflected today in the UN Sendai Framework for Disaster Risk Reduction. Since its publication in 2015, the global framework has brought about the transition away from crisis management towards risk planning that had already been under way in European countries such as Spain since the 1990s. It has also been effective in creating a framework for international coordination on the management of hydrometeorological risks such as droughts. The Sendai Framework will remain in force until 2030, which, in the context of the current climate crisis, raises citizens' awareness but also emboldens Member States to implement measures to increase water supply. It will also be an important lever for maintaining the emphasis on addressing unsustainable water management and exploitation practices. A similar boost is expected from the sixth assessment report of the Intergovernmental Panel on Climate Change (IPCC), which is due in 2022.

3
Impacts of climate change on water availability in Europe

Key messages

- Climate change is expected to aggravate the existing pressures on freshwater resources in Europe, the most so in southern Europe, which already faces severe water stress, but also in parts of western and central Europe.
- Northern and north-eastern Europe and mountainous areas all across Europe will be affected by reduced snow cover and early snow melting.
- Climate change will increase seasonal weather extremes, such as droughts and floods, and will trigger more frequent incidences of high flows during the wet season and low flows during the dry season of the year.
- More frequent and intense droughts are already striking extended areas across southern, central and limited parts of northern Europe. Because of climate change such extremes are expected to worsen and expand further in northern Europe in the future.

3.1 Key meteorological impacts of climate change

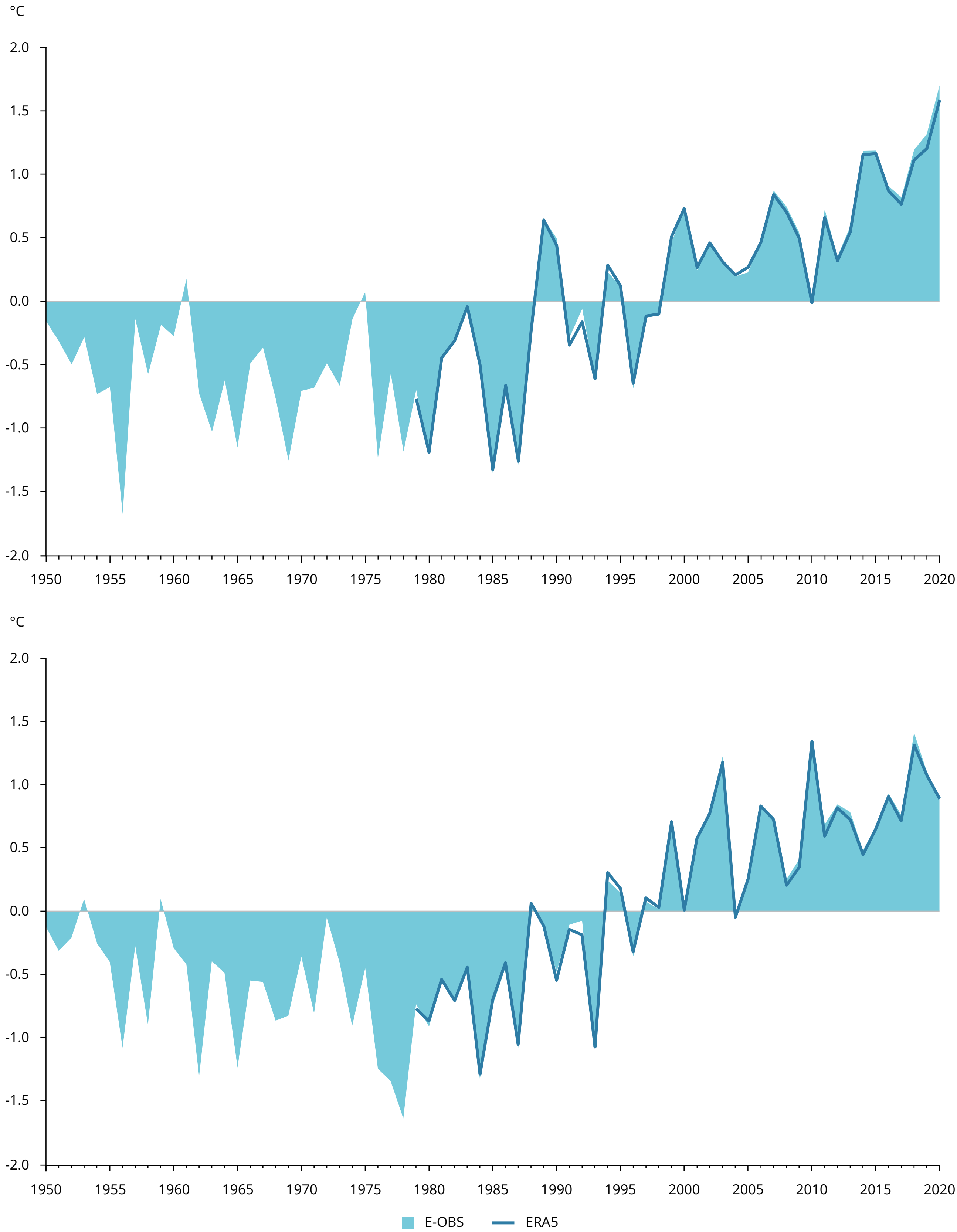
3.1.1 Temperature

Past trends in temperature

The mean average annual global near-surface temperature has been increasing since the mid-19th century. Compared with pre-industrial levels (1850-1900), the global temperature has increased by almost 1 °C. This increase has accelerated since the 1970s; it is estimated that the temperature increases by 0.1 °C every 5-6 years. All signatories to the UN Framework Convention on Climate Change (UNFCCC) (UN, 1992) committed in the Paris Agreement (2015) to limiting global temperature increase to well below 2 °C above pre-industrial levels by 2050. They agreed and to pursuing efforts to limit the increase to 1.5 °C (UN, 2015a). The goal is to prevent serious environmental, economic and societal impacts of climate change. The warming observed so far already amounts to half of the maximum 2 °C increase that would be compatible with goals of the Paris Agreement (EEA, 2020d).

In Europe, the period 2009-2020 was the warmest ever recorded, with a mean annual land surface air temperature of 1.6-1.7 °C higher than pre-industrial levels. Since 2000, Europe has been struck by a sequence of extreme heatwaves (2003, 2006, 2007, 2010, 2014, 2015, 2017, 2018, 2019 and 2020) (ESOTC, 2020), and it has recorded 11 of the 12 warmest years on record (Figure 3.1). The warmest year ever recorded in Europe was 2019, followed by 2014, 2015 and 2018 (ESOTC, 2020). Almost the whole European territory is getting warmer; exceptions cover only a few small areas. The largest annual temperature increases are observed in central and eastern Europe. Warming is observed across all seasons, with changes being more pronounced in autumn (ESOTC, 2020). The number of significantly warm days doubled between 1960 and 2018 (EEA, 2020d). Water temperatures have also increased in European rivers and lakes. In major European rivers such as the Danube, Rhine and Meuse, water temperatures have increased by 1-3 °C over the last century.

Figure 3.1 **Historical trends in annual (top) and summer (bottom) land surface air temperature anomalies across Europe between 1950 and 2020 (compared with the annual average for the 1981-2010 baseline period)**



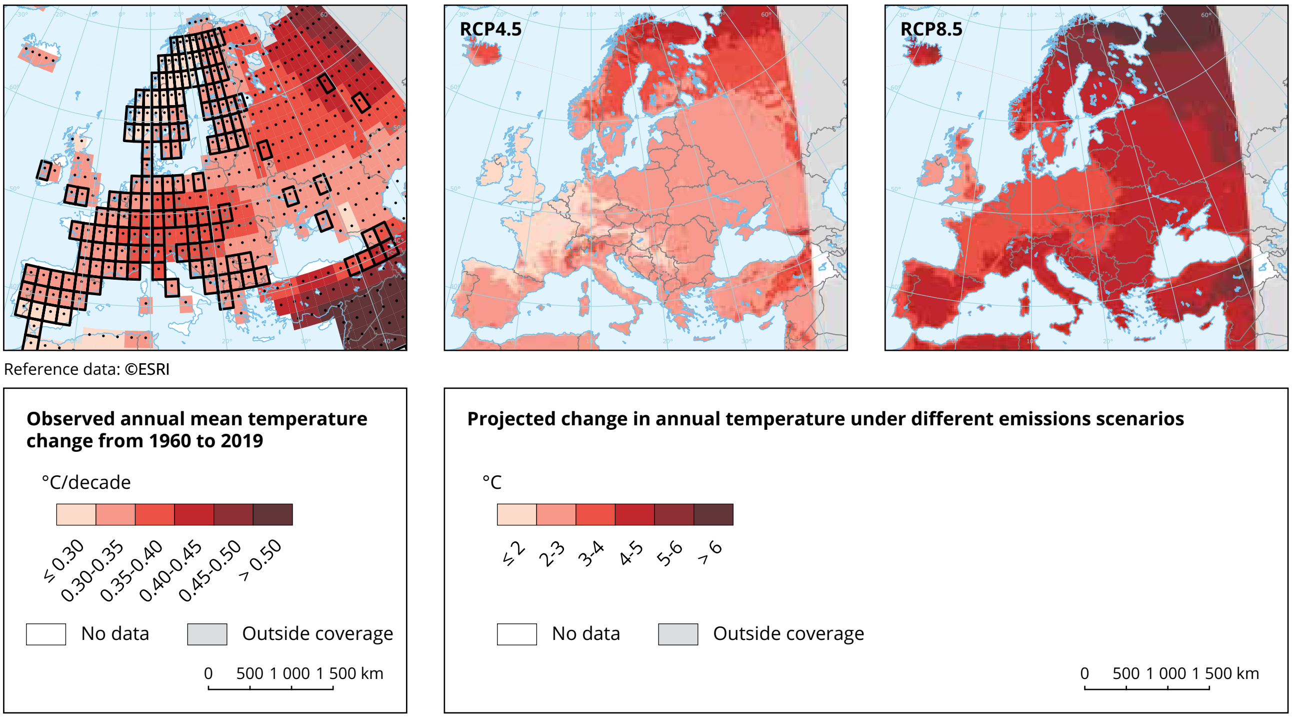
Source: ESOTC (2020).

Future projections for temperature

Climate change projections comparing the historical period 1971-2000 with the future period 2071-2100 (under high-emission Representative Concentration Pathway, or RCP, scenario 8.5), suggest that the climate could become warmer by 2.5-5.5 °C, which is above the agreed UNFCCC threshold of 2 °C for the whole planet (Map 3.1). Extreme heatwaves are expected to occur much more frequently in the second half of the 21st century (e.g. once every 2 years) (Russo et al., 2015). In summers, the strongest warming is projected to occur in the Iberian Peninsula and other parts of southern Europe. In winter, warming will affect the most north-eastern parts of Europe and Scandinavia (EEA, 2020d).

Projections show that water in the oceans, rivers and lakes will also continue to warm in the future (EEA, 2016g, 2020d).

Map 3.1 Observed annual mean temperature change from 1960 to 2019 (left panel) and projected change under different emissions scenarios (right panels) in Europe



Note: RCP, representative concentration pathway. Left panel: boxes outlined in black indicate areas with at least three stations, so are more likely to be representative; areas with significant long-term trends are indicated by black dots. Right panel: projected changes in near-surface air temperature by the period 2071-2100, compared with 1971-2000 for RCP4.5 and 8.5 emissions scenarios; simulations are based on the multi-model ensemble average of simulations of the EURO-CORDEX initiative.

Source: EEA (2020d).

3.1.2 Precipitation

Past trends in precipitation

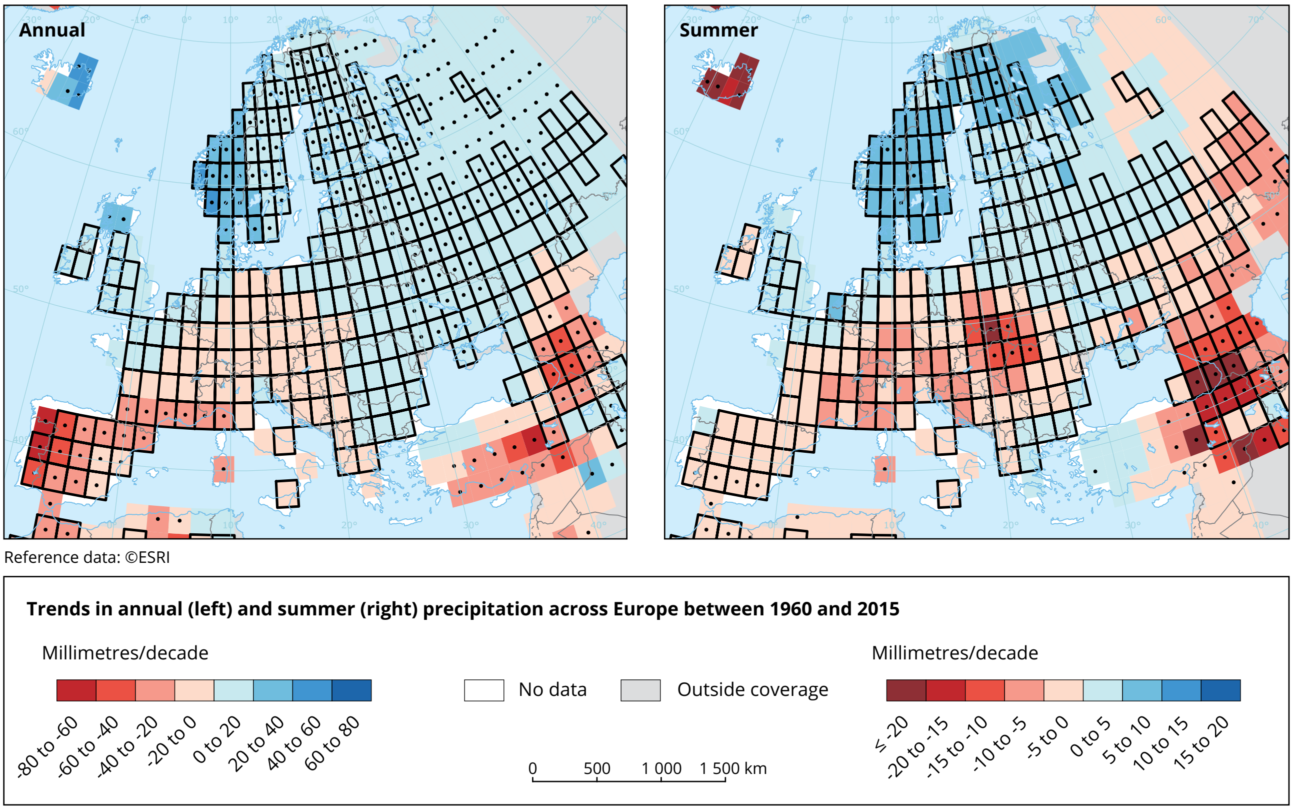
For the period 1960-2015 (EEA, 2017d), in parts of northern Europe, annual precipitation increased by up to 7 mm and summer precipitation by up to 1.8 mm. By contrast, in southern Europe, annual precipitation decreased by up to 9 mm and summer precipitation by up to 2 mm. In the mid-latitudes of Europe, precipitation shows no significant changes on an annual scale, but significant decreases can be observed in the summer season in parts of central and eastern Europe. This applies especially to certain part of the Danube river basin district, shared by Poland, Slovakia, Hungary and Romania (Map 3.2).

The precipitation patterns within the year have changed significantly. Between 1960 and 2018, heavy precipitation in winter and summer generally became more frequent and intense across Europe, especially in northern and north-eastern areas. A decrease in heavy precipitation can be observed in the Iberian Peninsula and southern France in winter and summer and on the eastern coast of the Adriatic in summer (EEA, 2019b).

Future projections for precipitation

Climate change projections (under high-emission RCP scenario 8.5), comparing the historical period 1971-2000 with the future period 2071-2100, suggest that mean annual precipitation will decrease by 10-30 % in many parts of southern Europe and by more than 30 % in the south-eastern and south-western Mediterranean (EEA, 2017d; Feyen et al., 2020). Furthermore, a stronger decrease is expected in the summer season, as summer precipitation is expected to decrease by 20-40 % in an extended area that covers southern and western Europe, the Balkans and the Black Sea. In contrast, an annual increase of 10-30 % is expected in many parts of central, eastern and northern Europe. Especially in the Baltic and Scandinavian countries, significant increases of up to 30 % are also expected in the summer season (Map 3.3).

Map 3.2 Trends in annual (left) and summer (right) precipitation across Europe for the period 1960-2015

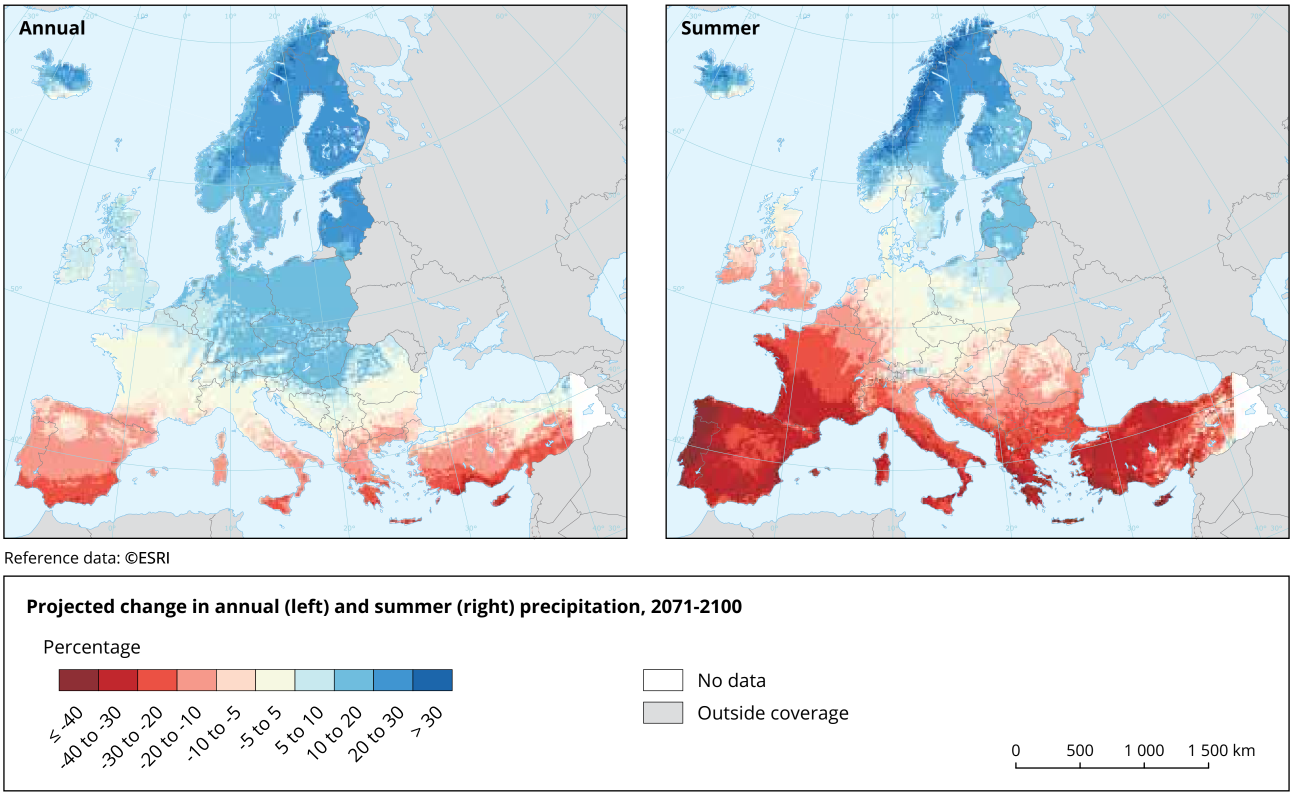


Reference data: ©ESRI

Note: Grid boxes outlined in solid black contain at least three stations and so are likely to be more representative of the grid box. A black dot indicates that the long-term trend is significant at the 5 % level. The classes for annual and summer precipitation differ (by a factor of 4) because annual precipitation covers 12 months, whereas summer precipitation covers only 3 months.

Source: EEA (2017d).

Map 3.3 **Projected change in annual (left) and summer (right) precipitation across Europe for the period 2071-2100 (versus 1971-2000 average)**



Source: EEA (2017d).

Heavy precipitation is expected to become more frequent and intense in future almost everywhere in Europe in winter, with significant increases of up to 35 % in Scandinavia, north-eastern and eastern Europe due to more frequent extreme extratropical cyclones. Heavy precipitation in summer will remain similar or slightly increase in most parts of Europe. The exceptions are many coastal areas of southern European countries, as well as the Pyrenees and part of the Alps, where significant decreases are expected. The projected decrease in cyclone frequency in the Mediterranean contributes in part to the phenomena described above (EEA, 2019b).

3.1.3 Glaciers and snow

Snow accumulates over the colder period of the year and melts slowly in spring. Melted snow and glaciers discharge into groundwater, streams and rivers with a lag time of many months after the initial snowfall. The snow cover thus significantly affects the timing of hydrological processes in river basins, generally in central and northern Europe and in mountain areas across the continent.

Past trends in snow cover

The extent of the snow cover has decreased significantly in the northern hemisphere as a whole in the past 90 years, with the greatest part of this decline occurring since the 1980s. Overall, it is estimated that the extent of the snow cover in Europe (EEA member and cooperating countries, the EEA-38, and the UK) decreased by 13 % for the average March and April and by 76 % for the average June between 1980 and 2015. The equivalent mass of snow in melted water also decreased in Europe (EEA 38 and the UK) over the same period by around 30 %, which is above the average observed reduction in the northern hemisphere, around 7 % (EEA, 2016f).

In recent decades, early snow melt has also been observed in the Alps, which are considered the 'water tower' of Europe (Box 3.1). Large European rivers, such as the Danube, the Rhine and the Po, spring from the Alps. Thus, their flow regimes are affected by the changing patterns of snow fall and accumulations and melting of glaciers.

Future projections for snow cover

Future climate projections (under high-emission RCP scenario 8.5) indicate that the duration of the snow season in the northern hemisphere could decline further up to 40 days, the March/April snow cover could be reduced by up to 25 %, and the snow mass could decrease by up to 30 % (EEA, 2016f).

3.1.4 Evapotranspiration

Past trends in evapotranspiration

Evapotranspiration is closely related to the type of land cover and climate conditions (e.g. temperature, wind, humidity, solar radiation) over a specified area. The analysis of the underlying the ENSEMBLES daily gridded observational dataset used for the European water accounts (Zal et al., 2017; EEA, 2018b, 2019l) shows that evapotranspiration increased across all regions of Europe for the period 1990-2017. Proportionately, the most significant increases were observed in northern, eastern and western Europe (between 9 % and 27%), whereas the increase was lower (4 %) in already water-stressed southern Europe. These trends show that transpiration from vegetation and evaporation from soil and water surfaces in Europe has increased significantly in recent decades. The increase in evapotranspiration is mainly attributed to the increase in the transpiration from vegetation, which can be further linked with the expansion of agricultural land since the 1980s and the observed increase in the land temperature across Europe (Zhang et al., 2016).

Future projections for evapotranspiration

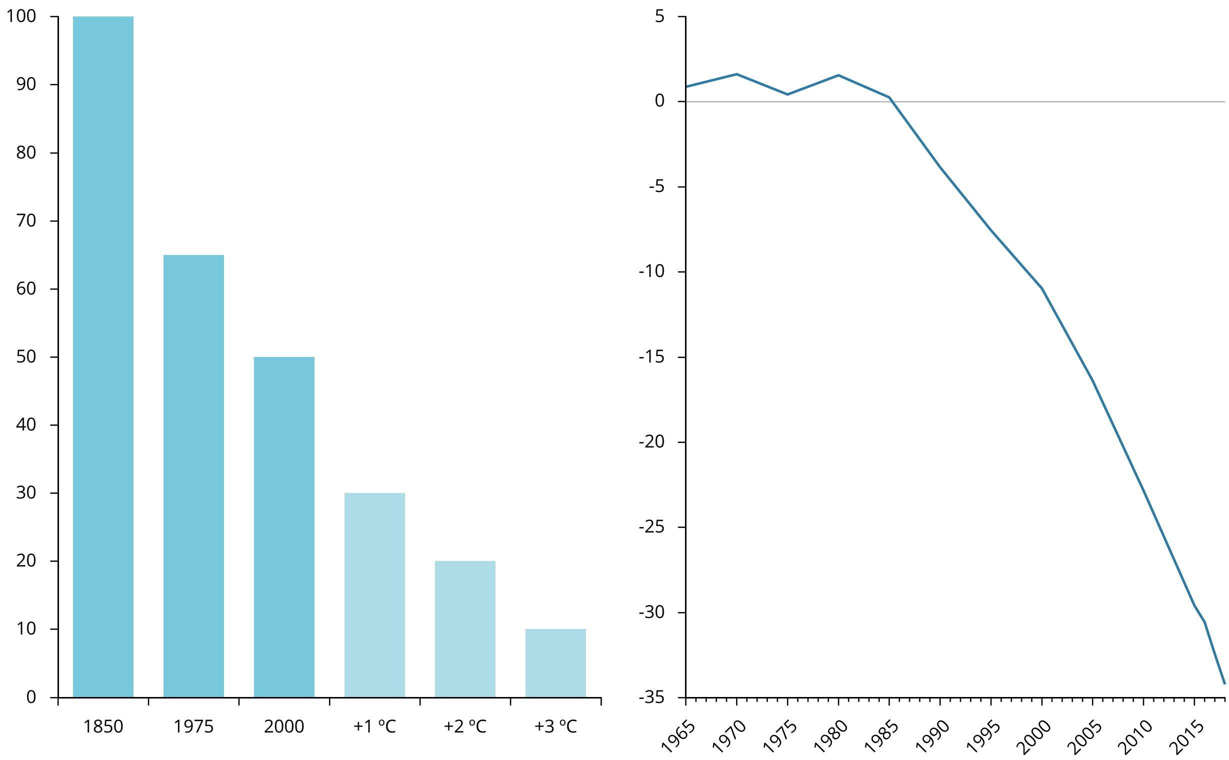
Driven by the projected increase in temperature, evapotranspiration in Europe will increase further in the future (Map 3.4). However, the potential increase could be partly offset by reduced transpiration from vegetation due to higher atmospheric concentrations of CO_2 (EEA, 2016b). Increased evapotranspiration is expected across most of Europe and across all seasons. The largest increases could be expected especially in winter and autumn. Compared with spring and summer, water availability is higher in autumn and winter, so the increase in temperature could cause more water to evaporate from open water surfaces and transpire from vegetation. Furthermore, a small decrease in evapotranspiration could be expected in central-northern Europe in spring.

Box 3.1 Glaciers and snow cover have been shrinking in the Alps since the 19th century

The Alpine region, which covers approximately 190 700 km², extends over eight European countries (Austria, France, Germany, Italy, Liechtenstein, Monaco, Slovenia, Switzerland), hosting more than 14 million people. The average temperature in the Alpine area has risen by almost 2 °C since the 19th century, which is twice as fast as the average rate of temperature rise in the northern hemisphere. Furthermore, future climate change projections show that the average temperature will increase further by 1-2 °C in most parts of the region by 2050, which may have significant impacts.

The extent of the glacier surface in the Alps now is less than 50 % of what it was in the mid-19th century, and it is projected to decrease further to 30 % or even 10 % if the temperature increases by another 1 °C and 3 °C respectively (Figure 3.2, left). Furthermore, Swiss scientists and authorities have observed that the cumulative mass of eight Alpine glaciers shows a decreasing trend which has been accelerated in recent decades (Figure 3.2, right). This is related to the increase in the temperature, which causes larger and earlier melting within the year. And it is also related to the change in the precipitation patterns, which results in an increase in the share of the precipitation falling as rain rather than snow. In the last 50 years, the snowpack in Switzerland has shown decreasing trends across all elevation zones from below 1 000 m to over 2 500 m.

Figure 3.2 Remaining glacier surface in the Alps (left); annual cumulative glacier mass balance in Switzerland (right)



Source: Permanent Secretariat of the Alpine Convention (2017), based on the underlying data from Zemp, M., Haeberli, W., Hoelze, M. and Paul, F., (2006), Alpine glaciers to disappear within decades?, Geophys.Res.Lett., 33, L13504, doi:10.1029/2006GL0263319

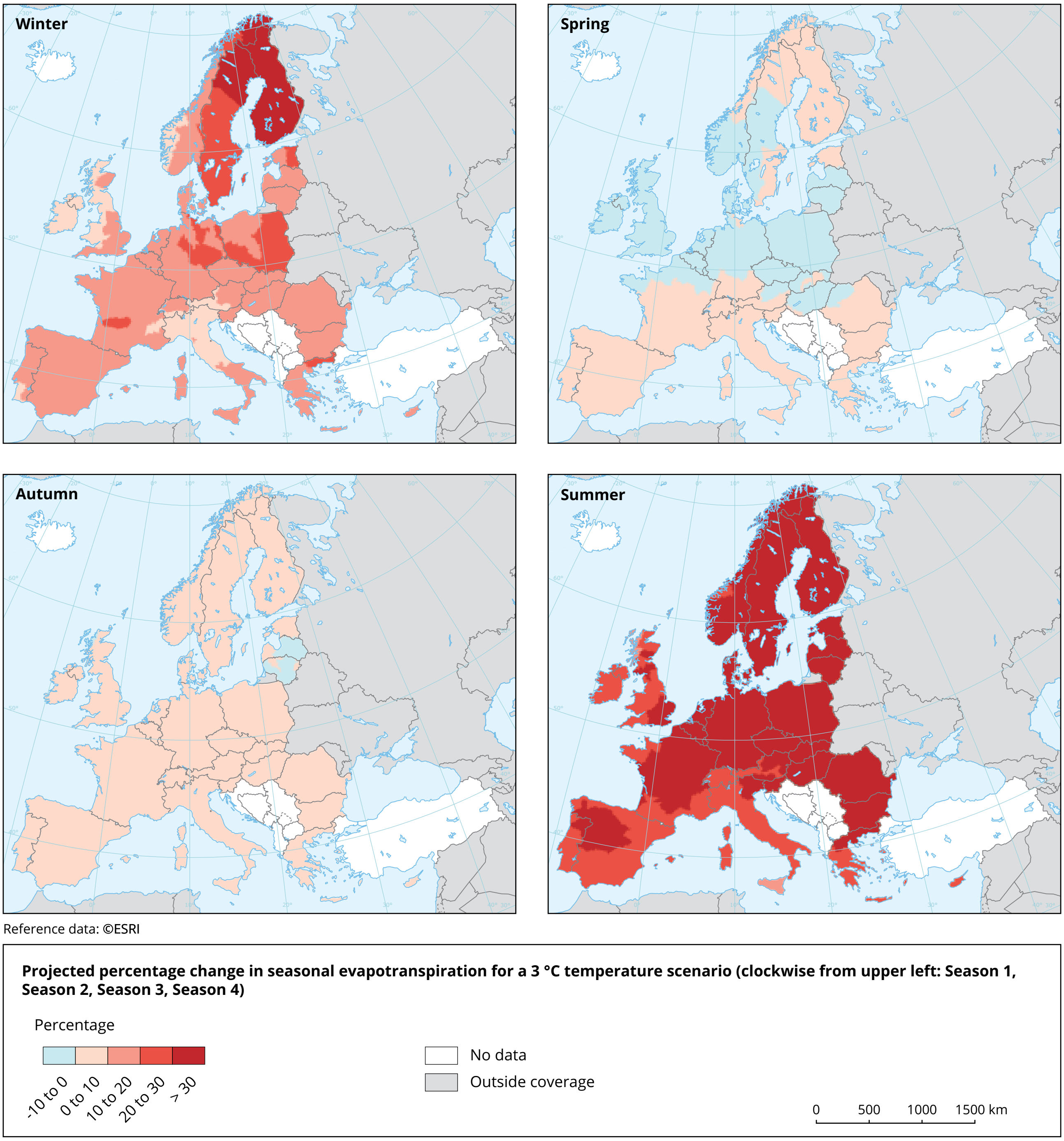
Source: FOEN (2020b).

The flow patterns of the rivers are affected in various ways. For example, higher rainfall in winters causes higher winter discharges, increasing the risk of floods. Furthermore, the lower extent and mass of glaciers and accumulated snow decrease the storage of equivalent water, which could melt and recharge rivers, especially during the spring months. Higher temperatures are also causing higher evapotranspiration. Thus, summer discharges tend to become lower on average. As drought events are also occurring more frequently, especially in the southern and south-eastern Alps, it is expected that climate change will further decrease the observed low river discharges annually. River flow observations in the Swiss part of the Rhône (Porte-du-Scex) since the start of the 20th century show an amplification of seasonal patterns with increased discharges in winter and decreased discharges in summer.

The Alpine landscape is home to a very diverse ecosystem, where 30 000 animal species and 13 000 plant species can be found. As the climate becomes warmer, those species that flourish in colder conditions need to migrate. Therefore, shrinking glaciers and snow cover limit the extent of the habitats suitable for traditional alpine species. It is projected that 30-50 % of the alpine plant species will lose over 80 % of their suitable habitats, resulting in knock-on effects upon the animal species too.

Sources: Permanent Secretariat of the Alpine Convention (2017); Elmi et al. (2018); FOEN (2020a, 2020b, 2020c, 2020d).

Map 3.4 **Projected percentage change in seasonal evapotranspiration for a 3 °C temperature scenario (clockwise from upper left: Season 1, Season 2, Season 3, Season 4)**



Note: Results provided at Ecrins sub-basin level (EEA, 2012a). Seasons are defined in calendar year (S1; J, F, M – S2; A, M, J – S3; J, A, S – S4; O, N, D).

Source: Underlying data obtained from the JRC Peseta IV report (Feyen et al., 2020).

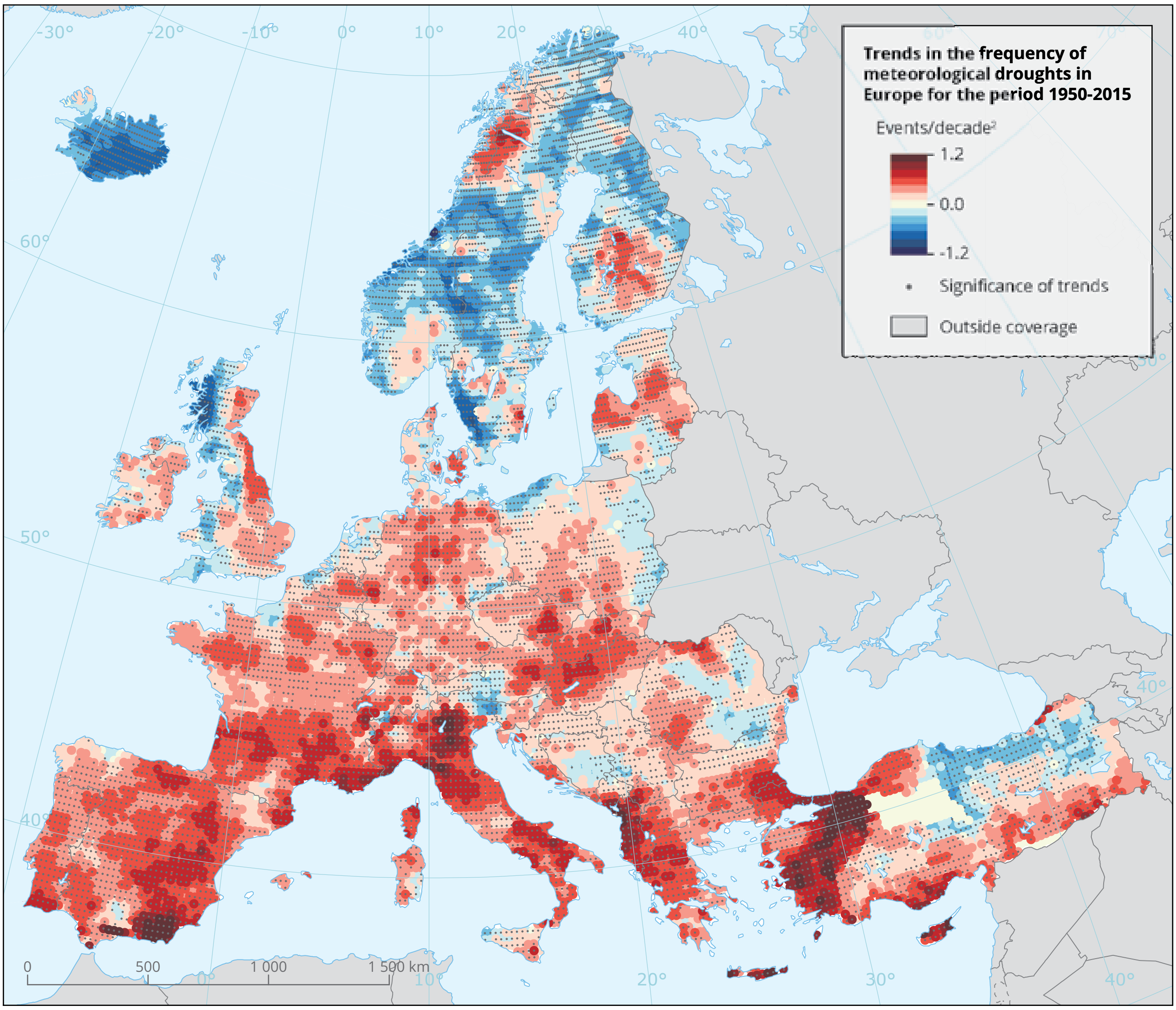
3.1.5 Droughts

Past trends in droughts

In southern Europe and in most parts of central Europe droughts have become more frequent, with up to 1.3 additional droughts per decade over the period 1950-2015 (Map 3.5).

Furthermore, droughts have intensified roughly over the same areas, as the minimum discharges during the driest month of the year have decreased by between 5 % and 20 %. In contrast, droughts have become less frequent and less intense in certain areas of Scandinavia and north-eastern Europe (EEA, 2019g) (notwithstanding the extreme drought event of 2018 in that region; see Box 1.4).

Map 3.5 Trends in the frequency of meteorologica droughts in Europe for the period 1950-2015



Reference data: ©ESRI

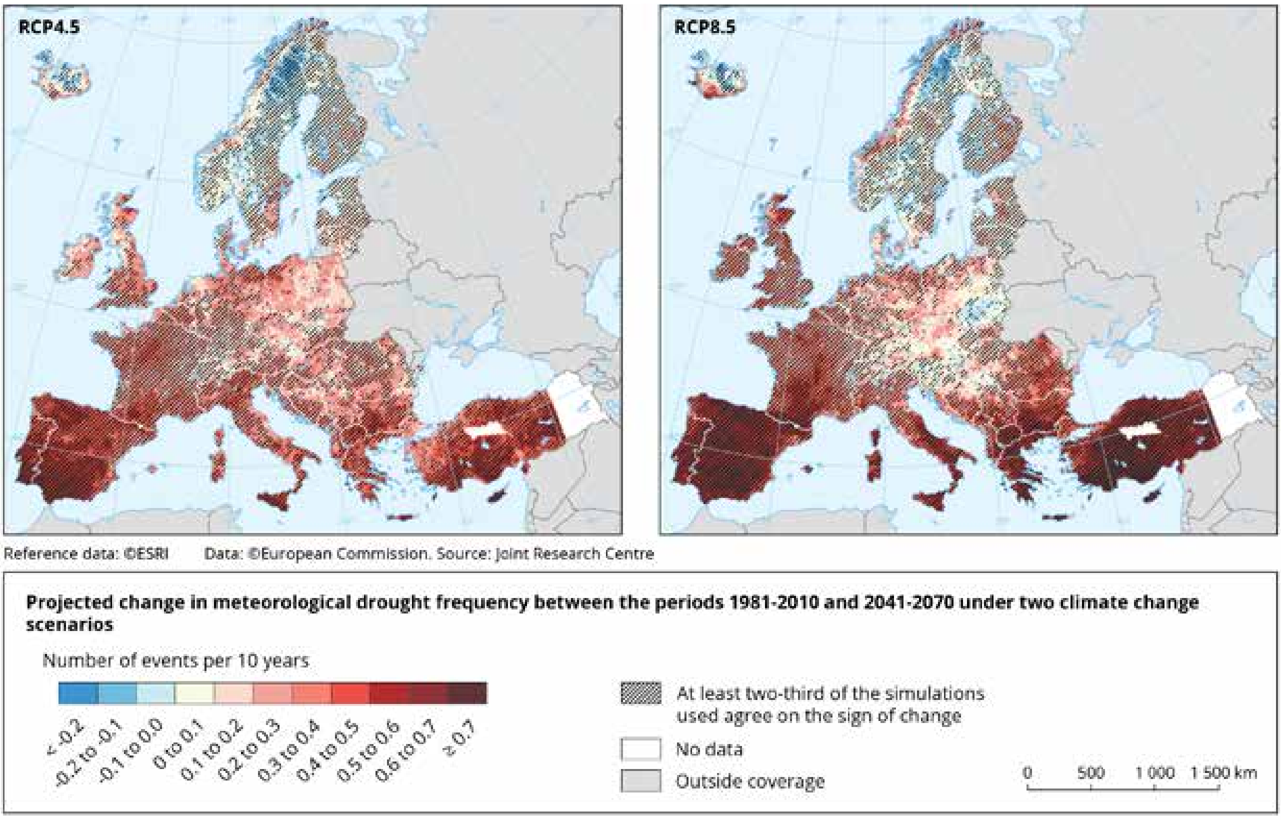
Note: In the map, the concept of drought is regarded as observed trend in the frequency of meteorological droughts and observed trend in run-off during the driest month (EEA, 2019g). Hatching indicates the areas in which the trends are statistically significant at the 95 % level.

Source: EEA (2019g).

Future projections for droughts

Climate change projections (under high-emission RCP scenario 8.5), comparing the historical period 1981-2010 with the future period 2041-2070, suggest that the frequency of meteorological droughts will increase in most parts of Europe, with the exception of several areas in central-eastern and north-eastern Europe (Map 3.6). The projections show mixed results for northern Europe and suggest that most areas there will experience less intense and frequent droughts, especially in RCP scenario 4.5. RCP scenario 8.5 (3 °C scenario) up to 2100 may reverse this picture in certain areas. Southern Europe is projected to be the hotspot for more frequent and intense droughts in future. On a seasonal basis, intense droughts will be more likely than at present in summer, and then in spring and autumn, whereas intense droughts will become less likely in winter (EEA, 2019g).

Map 3.6 Projected change in meteorological drought frequency between the periods 1981-2010 and 2041-2070 under two climate change scenarios



Note: In the map, the concept of drought is regarded as observed trend in the frequency of meteorological droughts (EEA, 2019g). The lines represent the areas in which at least two thirds of the simulations used agree on the sign of the change.

Source: EEA (2019g).

3.2 Impacts of climate change on the hydrological cycle

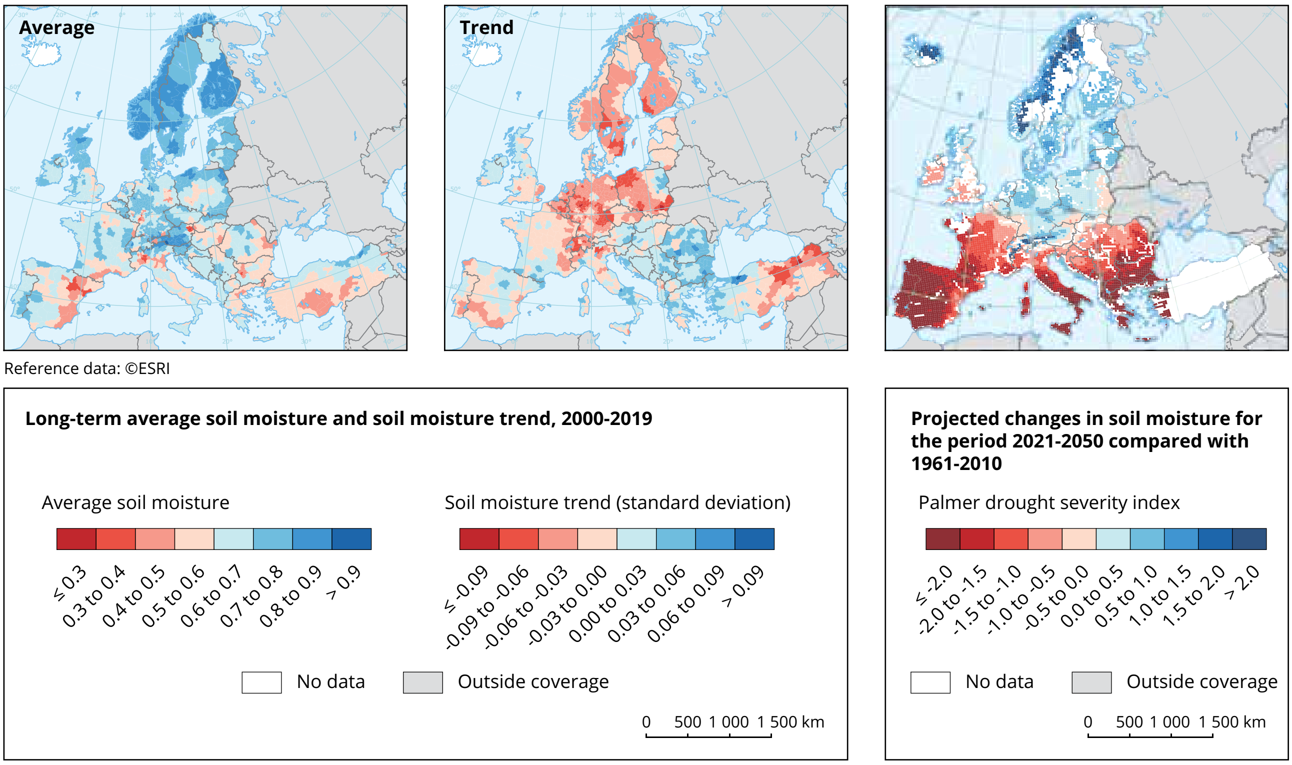
3.2.1 Soil moisture content

Past trends in soil moisture content

The average annual soil moisture content shows a downwards trend between 1979 and 2019, with this trend being more pronounced after 1990 and the last decade being the worst of the last 40 years (Map 3.7).

Over the three years 2018-2020, the average soil moisture in most parts of Europe was below the average for the period 1961-2010, with significantly low soil moisture being observed in central Europe during summer and in south eastern Europe during autumn (Figure 3.3) (ECMWF, 2020).

Map 3.7 Long-term average soil moisture and soil moisture trend (2000-2019) and projected changes in soil moisture for the period 2021-2050 compared with 1961-2010

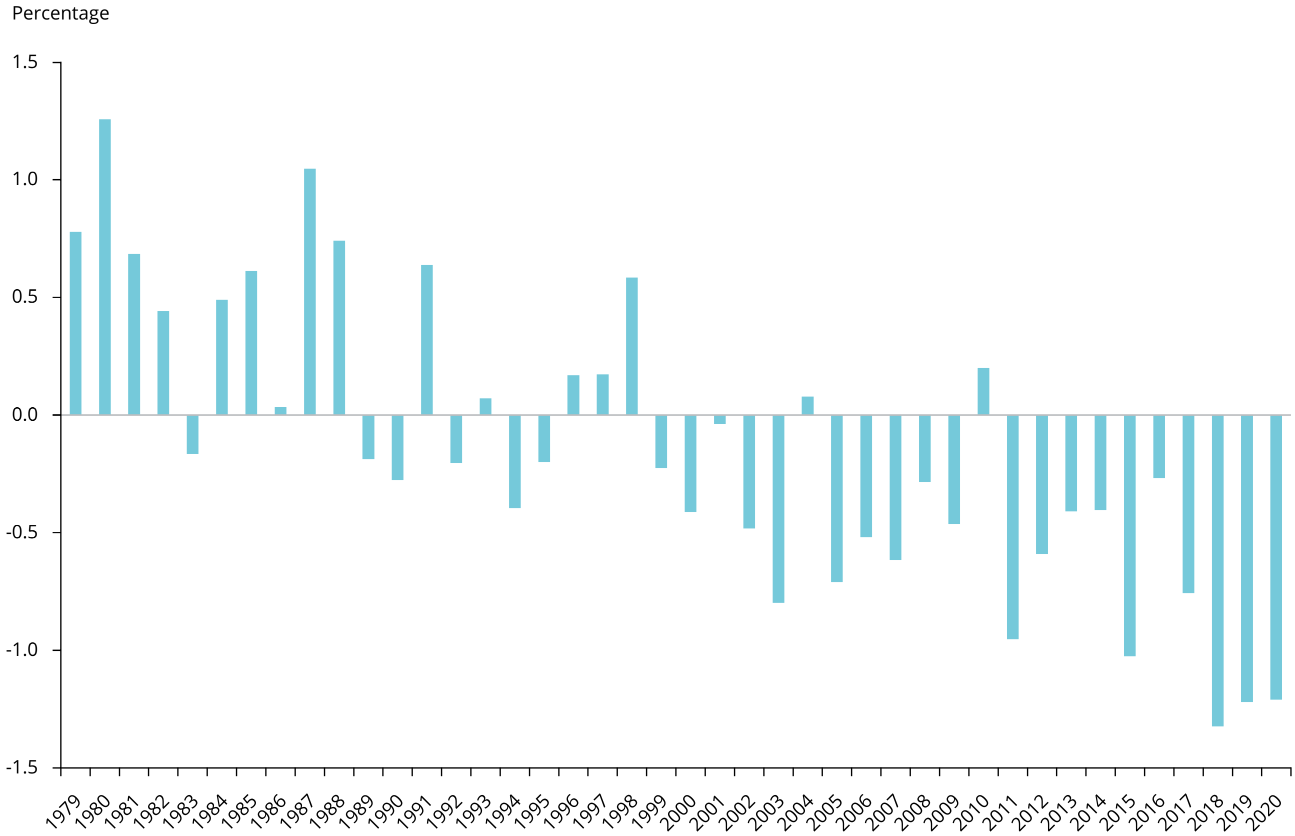


Note: The maps show the long-term average soil moisture contents (left) and the trends in soil moisture values (right), aggregated by NUTS3 regions. Soil moisture is equal to 0 when the soil is severely dry (wilting point) and equal to 1 when the soil moisture is above the field capacity. Low long-term average soil moisture values indicate areas where during the 2000-2019 period the soil moisture deficit was the biggest problem. Trends are expressed in standard deviation from the long-term average. Negative trends indicate that soil moisture values show a decreasing tendency during the 2000-2019 period. Areas with lower soil moisture content together with decreasing tendency in the soil moisture are in risk of losing their land functions of supplying ecosystem services.

The Palmer drought severity index spans -10 (dry) to +10 (wet).

Source: EEA (2017e).

Figure 3.3 Annual soil moisture anomalies in Europe between 1979 and 2020



Source: ESOTC (2020).

Future projections for soil moisture content

Future projections of the soil moisture content, comparing the periods 2021-2050 with 1981-2010, indicate a decrease of the soil moisture content in certain areas of southern Europe (e.g. the Iberian Peninsula), especially during summer, and an increase in central-eastern and north-eastern Europe (EEA, 2017e, 2019a).

3.2.2 Groundwater

Past trends in groundwater recharge

According to a recent modelling study (Gelati et al., 2020), the climate has contributed to a certain degree to the depletion observed in many European aquifers between 1990 and 2018, mainly in southern Europe. However, the role of climate change is mostly supplementary, compared with the role of water management practices. Overabstraction of groundwater by agriculture and other water-dependent sectors was found to be the key pressure leading to aquifer depletion in the above cases. Climate change was identified as a more prominent factor for groundwater depletion in the case of the Rhône river basin, as well as in Iceland.

The higher storage capacity of aquifers, and their lower vulnerability to evaporation and better protection from pollution, are key features that distinguish them from surface waters. In principle, groundwater flows more quickly through porous aquifers made up of loosely consolidated sands, silts and gravels, highly productive fissured aquifers and karstic formations, and significantly fractured aquifers. Therefore, when recharge decreases, the risk of rapid groundwater depletion is also higher for these types of aquifers. However, the risk of depletion is also affected by factors such as the size of the aquifers, local topography and hydrogeology. For instance, a shallow unconfined aquifer of little thickness within a river flood plain is more likely to be rapidly affected by decreases in the average river discharge than a deep, confined and thick aquifer that is fed from highly productive karstic systems (Psomas et al., 2021).

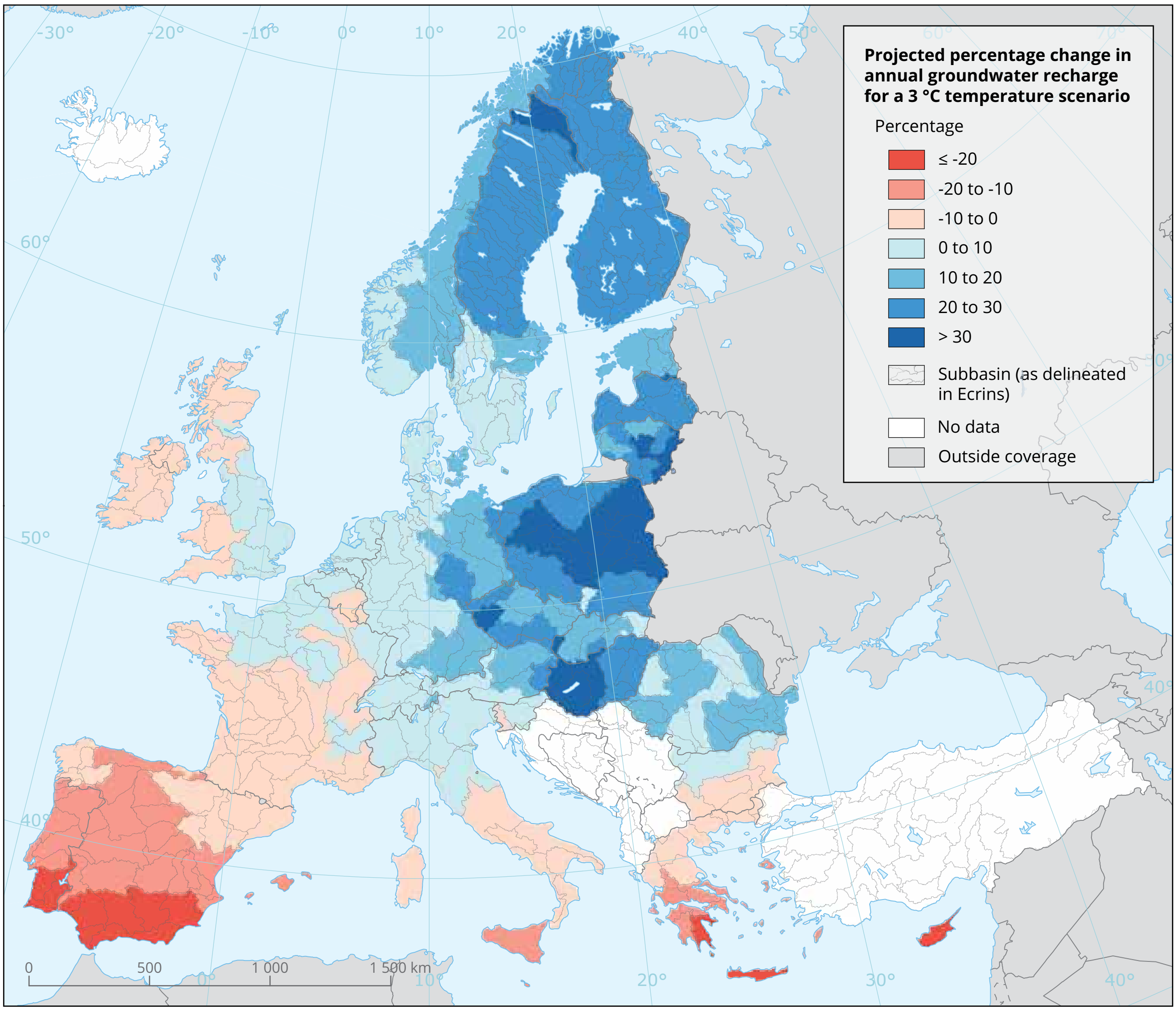
Future projections for groundwater recharge

In those areas where climate change is projected to cause lower precipitation and increased temperatures and evapotranspiration (see previous sections), it is expected that groundwater recharge will generally decrease (Box 3.2). Therefore, decreases in groundwater recharge are expected in southern and western Europe, whereas increases are expected in parts of central, eastern and north-eastern Europe (Map 3.8) (Feyen et al., 2020).

Earlier snow melting is expected to cause a shift in groundwater recharge with melted snow from spring to winter. Thus, the peak time of baseflow to surface waters could also occur earlier. Hence, low summer flows that are particularly sustained by baseflow could be seriously affected (Kløve et al., 2014).

Furthermore, climate change is expected to cause a rise in the average sea level and increase storm surges. Coastal aquifers, especially those that are being exploited intensively, may be significantly affected by the intrusion of water from the sea into groundwater. Salinisation can make the groundwater unsuitable for use and affect dependent ecosystems.

Map 3.8 Projected percentage change in annual groundwater recharge for a 3 °C temperature scenario



Reference data: ©ESRI

Note: Results provided at Ecrins sub-basin level (EEA, 2012a).

Source: Underlying data obtained from the JRC Peseta IV report (Feyen et al., 2020).

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Box 3.2 Climate change will lower groundwater levels in the Loire and south-western France

The Explore 2070 project has developed and assessed strategies to adapt to climate change impacts on hydrological systems and coastal environments in mainland and overseas France up to 2070, based on various climatic, demographic and socio-economic scenarios. Rises in temperature (and consequently evapotranspiration) combined with decreasing rainfall will lead to a decrease in effective precipitation in the future. The application of seven climate models using the median greenhouse gas emission scenario (A1B, fourth Intergovernmental Panel on Climate Change report) enabled an estimate of the change in natural recharge rates. With predicted recharge variations of +10 % to -30 % in the optimistic scenarios, and -20 % to -55 % in the pessimistic scenarios, a decline of similar proportions in groundwater levels would be expected, and therefore groundwater resources are likely to decline significantly overall in France by 2070. Two areas that are likely to be severely affected are the Loire basin, with a 25-30 % recharge decline across half of the basin area, and the south-west of France, with a 30-50 % decline in recharge. All of the scenarios also show a decline in average river flow by 2065, which varies from a 10-40 % reduction in the northern half of the country to a 30-50 % reduction in the southern half, with local extremes of up to 70 %. Despite this relative decline in river flow, some models show that very high surface water levels are nevertheless possible during the winter in some catchments (e.g. the Somme and Rhine rivers), confirming the likelihood of lengthy periods of flooding.

Furthermore, water balance studies have shown that many catchments and aquifers present high structural water deficits, affecting ecological flows, leading to the imposition of abstraction caps on water users, in particular for agricultural irrigation. In addition, more than 50 % of French departments were forced to issue restrictions on water use — for watering gardens, filling swimming pools, washing vehicles, etc. — in 2003, 2005, 2006 and 2011. The recurrence of these episodes of water stress has made it necessary to reinforce the security of the supply of drinking water services.

Sources: Delgoulet (2014); Maréchal and Rouillard (2020).

3.2.3 River discharges

Past trends in river discharges

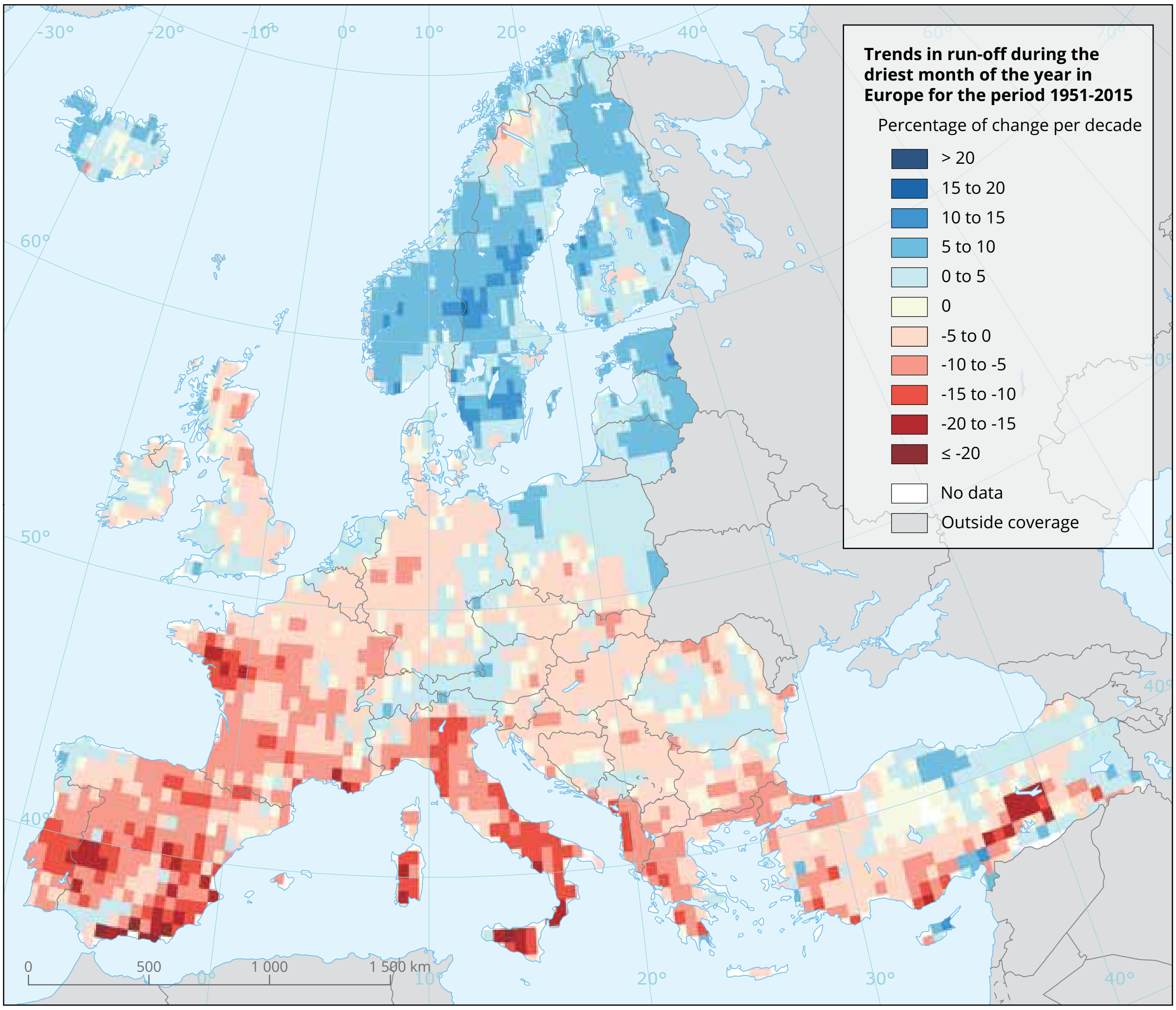
In southern and western Europe and parts of eastern Europe, the summer discharges in the years 1951-2015 show a decreasing trend. The trend is most pronounced in areas of Spain, Portugal, Italy, Greece, Turkey and France (Map 3.9) (EEA, 2016e).

After a decade of very warm and dry years, 2019 was also a particularly dry year. As a result, the river discharges across Europe fell to below average for almost two thirds of the year (i.e. during spring, and throughout July to October) (C3S, 2019). The most extreme low river discharges were observed in central Europe. However, in November and December a rapid turnaround to high river discharges occurred in western Europe, causing a large number of flood events (ECMWF, 2020).

Future projections for river discharges

Climate change is shifting the seasonal patterns of river discharges across Europe and increasing the occurrence of seasonal extremes (Figure 3.4). Future summer discharges are projected to further decrease in southern Europe and parts of western and northern Europe, whereas an increase is expected in parts of eastern and north-eastern Europe during all seasons (Map 3.10) (Feyen et al., 2020). In addition, spring and summer peak discharges will generally occur earlier in the season as a result of proportionally more rainfall instead of snowfall during winter and earlier melting of the snow cover and glaciers (EEA, 2016e).

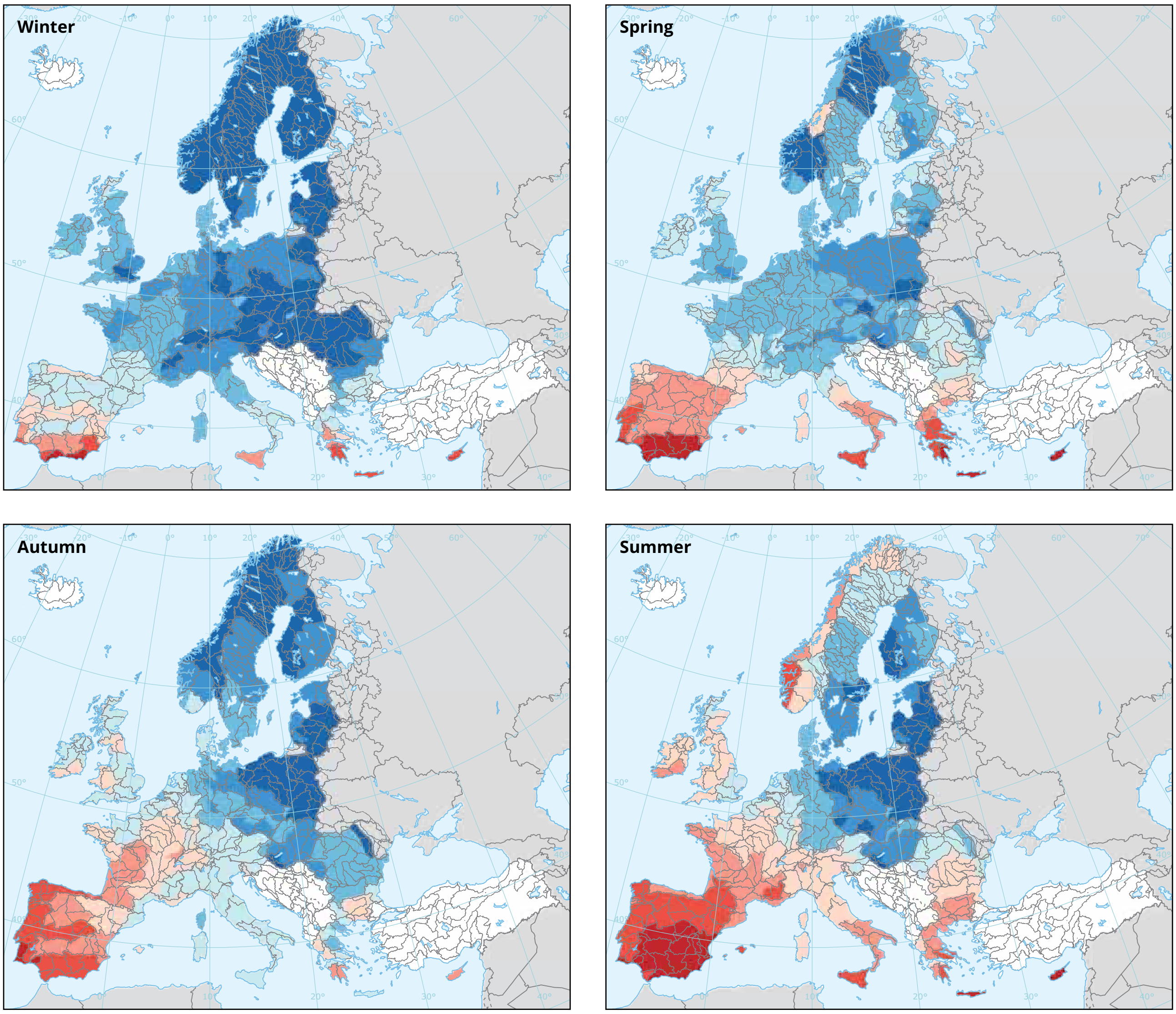
Map 3.9 Trends in run-off during the driest month of the year in Europe for the period 1951-2015



Reference data: ©ESRI

Source: EEA (2020j).

Map 3.10 Projected percentage seasonal change in river discharge (clockwise from upper left: Season 1, Season 2, Season 3, Season 4) for a 3 °C temperature scenario



Reference data: ©ESRI

Projected percentage seasonal change in river discharge (clockwise from upper left: Season 1, Season 2, Season 3, Season 4) for a 3 °C temperature scenario

Percentage

≤ -30
-30 to -20
-20 to -10
-10 to 0
0 to 10
10 to 20
20 to 30
> 30

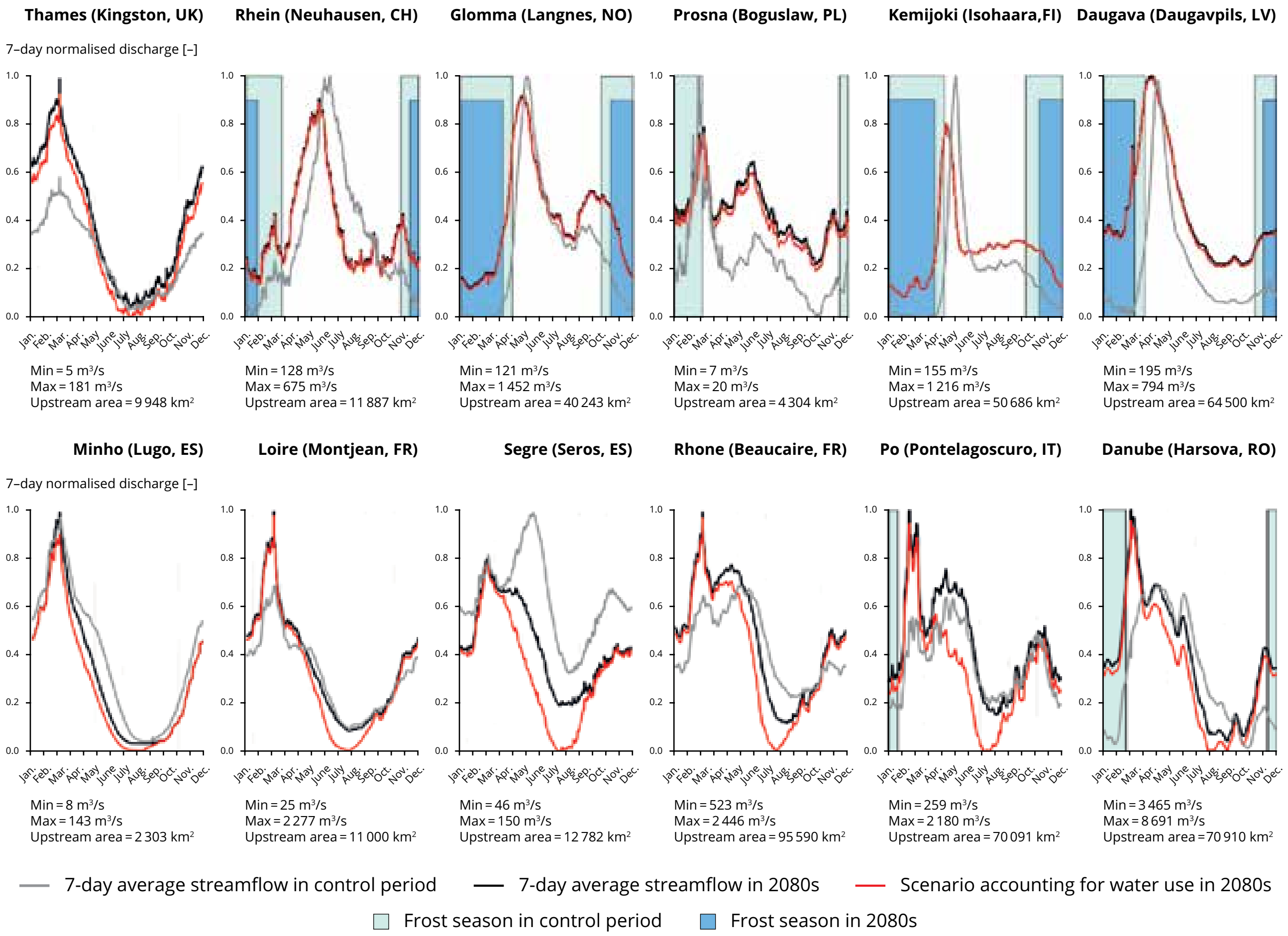
No data
Outside coverage

0 500 1000 1500 km

Note: Results provided at Ecrins sub-basin level (EEA, 2012a). Seasons are defined in calendar year (S1; J, F, M – S2; A, M, J – S3; J, A, S – S4; O, N, D).

Source: Underlying data obtained from the JRC Peseta IV report (Feyen et al., 2020).

Figure 3.4 Projected change in seasonal streamflow for 12 European rivers



Source: EEA (2016e).

4 Freshwater use in Europe under socio-economic change

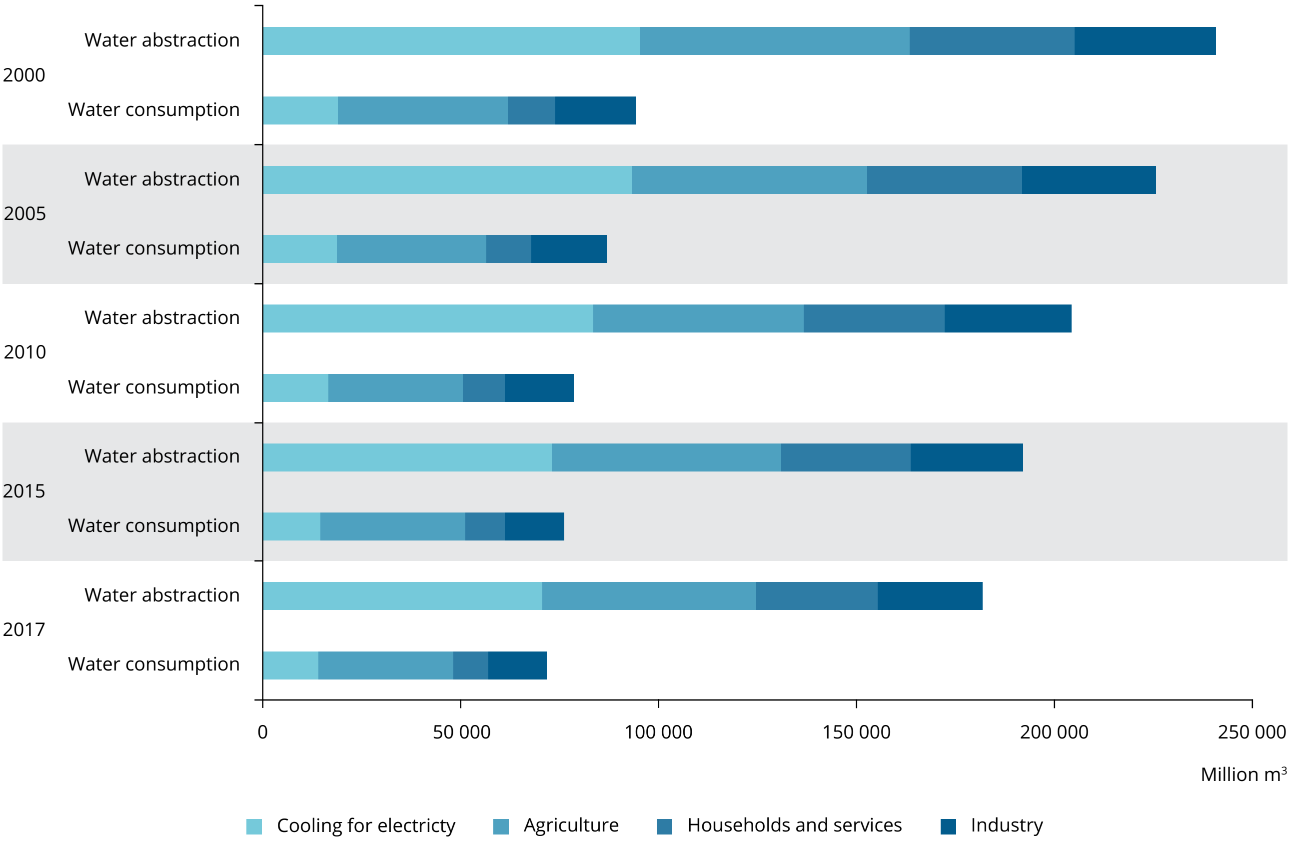
Key messages

- Potential gross domestic product (GDP) is projected to increase by 1.3 % per year in the period 2016-2070 in the EU-27 and the UK. This growth will not be reflected linearly in water demand because of increasing water use efficiency, absolute decoupling and a shift towards renewable energy sources.
- The population in Europe (EU-27 and the UK) is projected to increase slowly until around 2030 and then decrease gradually towards 2100. Further urbanisation and an associated increase in water demand and soil sealing is expected, most strongly in existing major urban centres.
- Agriculture remains the major water consumer in Europe, because of high water consumption in irrigated agriculture in the south, but the sector shows signs of decoupling water consumption from growth in southern, western and northern Europe.
- The installation of renewable energy generation schemes has contributed to significant reductions in water consumption in the energy sector, because they have replaced combustion plants, which require water for cooling. Western Europe shows significant trends towards decoupling water consumption from growth in the energy sector.
- Water consumption in the industrial sector is decreasing, while the value of industrial production continues to grow in western, northern and eastern Europe, suggesting a trend towards absolute decoupling.
- The public water supply sector has achieved significant water savings overall in Europe. However, the volume of public water supply increased in southern countries, and tourism has posed significant local pressures, especially in the Mediterranean.
- A comprehensive update of a 2007 study on potential water savings in the EU's economic sectors (Dworak et al., 2007) is urgently needed to estimate the remaining potential and help identify realistic goals for saving water.

4.1 Freshwater use in Europe

Almost 250 000 million m^3 of water were abstracted in Europe (EEA member and cooperating countries (EEA-38) and the UK) in 2017 to serve the needs of the various sectors of the European economy. This corresponds to nearly 9 % of the annual renewable freshwater resources in Europe. After its abstraction, water is transported, treated, distributed, used in production processes, partly evaporated and transpired, and partly integrated into products. Intermediate losses, unused water and waste water finally find their way back into surface water and groundwater as returns. In 2017, around 40 % of the total abstraction was consumed and 60 % was returned before or after use to the surface water and groundwater. Such returned water may have its physical or chemical properties altered (e.g. higher temperature, pollutants). The percentage of abstracted water that is returned differs greatly among sectors. In the agricultural sector it is 30-40 %. The returns of cooling water from the industrial and energy sector can be up to 80 %, while hydropower returns almost 100 % (EEA, 2018b) (Figure 4.1).

Figure 4.1 Trends in water abstraction and water consumption (million m3) in Europe (EEA-38 and the UK) between 2000 and 2017



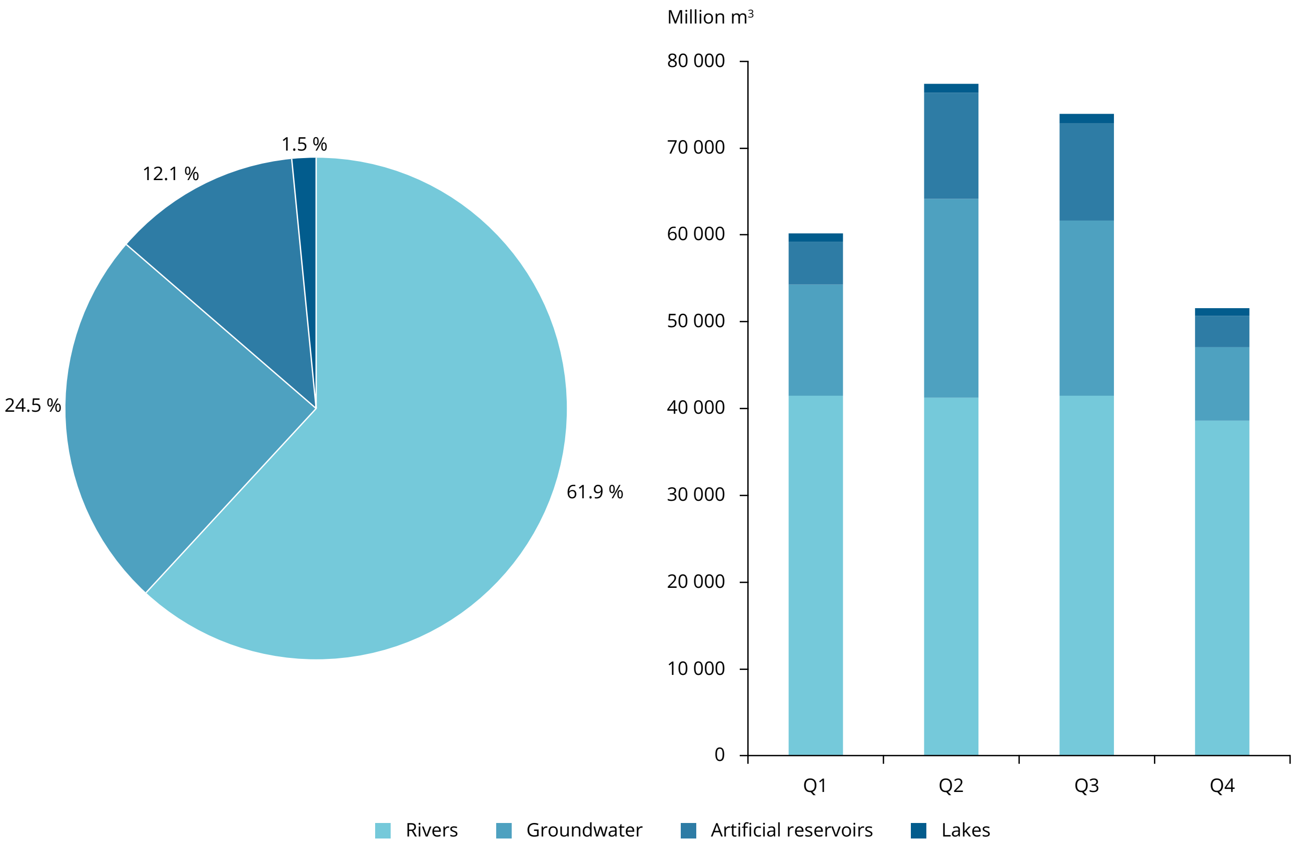
Sources: EEA (2019l, 2021d); Eurostat (2020f).

4.1.1 Freshwater abstraction by source of water

On average, rivers supply 62 % and groundwater 25 % of total water abstraction in Europe (Figure 4.2). Groundwater is mainly used for drinking water and agriculture. Around 12 % of the total volume of abstracted water is taken from artificial reservoirs and 1 % from natural lakes.

The pressure on surface and groundwater resources is higher in spring and summer because of abstractions by agriculture and public water supply. In autumn and winter, the highest pressure, especially on rivers, is from abstraction for cooling water for the energy and manufacturing sectors (EEA, 2018b).

Figure 4.2 **Annual (left) and seasonal (right) freshwater abstraction by source of freshwater in Europe (EEA-38 and the UK), 2017**



Note: The pie chart shows the annual data for the year 2017 for water abstraction by source at the European level. The quarterly values have been used to show the development of seasonal water abstraction by source.

Q1: January, February and March

Q2: April, May and June

Q3: July, August and September

Q4: October, November and December

Data coverage: EEA member countries: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom.

Cooperating countries: Albania, Bosnia and Herzegovina, Montenegro, North Macedonia, Serbia, Kosovo (under United Nations Security Council Resolution 1244/99).

Source: EEA (2018b).

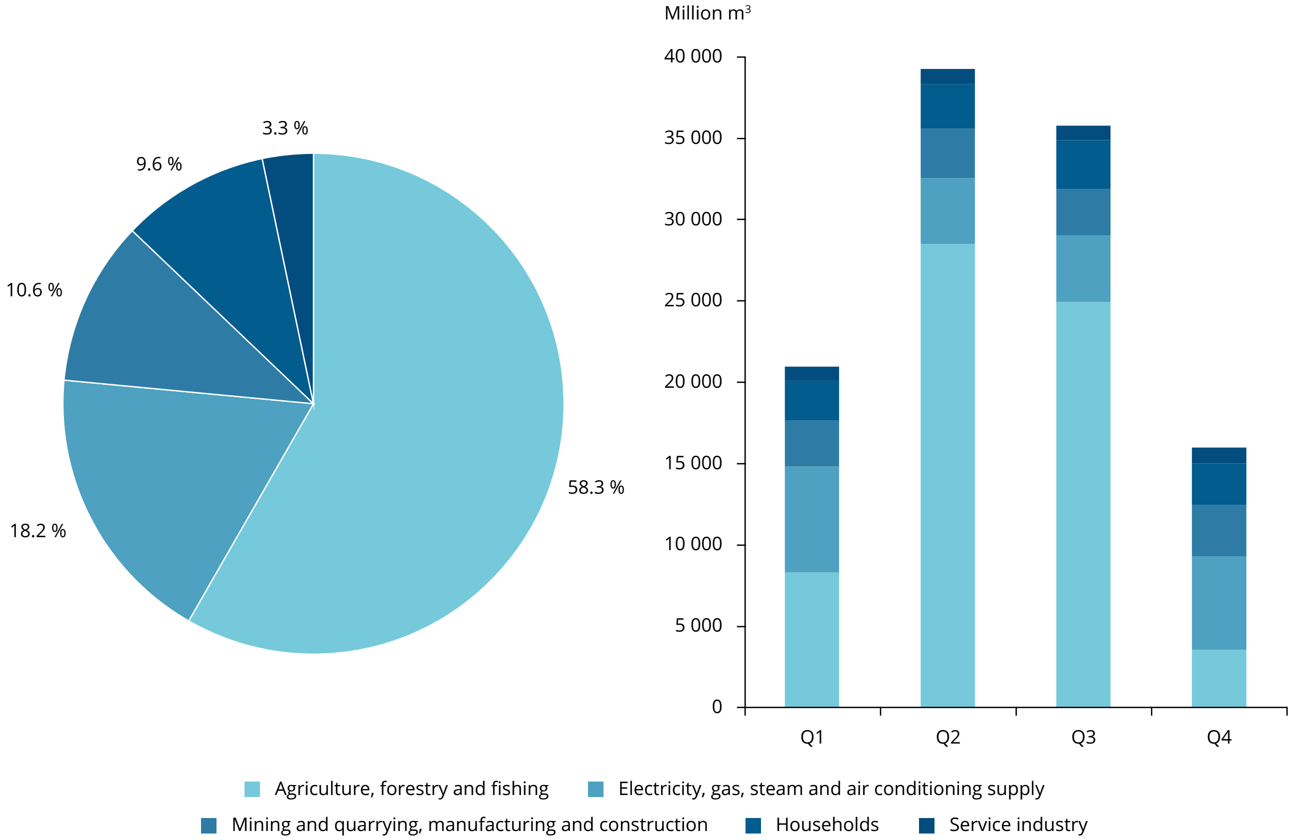
4.1.2 Freshwater consumption by socio-economic sector

In 2017, the sectoral breakdown of water consumption was agriculture (58 %), cooling water for electricity production (18 %), mining, quarrying, construction and manufacturing industries (11 %), households (10 %) and services (3 %) (EEA, 2018b).

However, there are significant regional differences in the breakdown of water consumption. In western, eastern and northern Europe, the major consumers are industry and electricity production (2017: 67 %). In southern Europe, the major consumer is agriculture (2017: 80 %).

Furthermore, water consumption has significant seasonal differences. The total water consumption almost doubles during spring and summer compared with autumn and winter, because of the high demand from agriculture during the dry part of the year (Figure 4.3) (EEA, 2018b).

Figure 4.3 Freshwater consumption by sector in Europe (EEA-38 and the UK), 2017



Note: For the pie chart, the data series for water abstraction by sector at the European level are calculated annually for 2017. The quarterly values have been used to show the development of seasonal water use by sector in Europe. Economic sectors were identified according to NACE classes.

Q1: January, February and March

Q2: April, May and June

Q3: July, August and September

Q4: October, November and December

Data coverage

EEA Member countries: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom.

Cooperating countries: Albania, Bosnia and Herzegovina, North Macedonia, Montenegro, Serbia, Kosovo (under United Nations Security Council Resolution 1244/99).

Source: EEA (2018b).

4.2 Socio-economic drivers affecting freshwater demand in Europe

4.2.1 Economic growth

Economic development drives the demand for water from industry, services and associated electricity production, albeit not in a linear manner. The potential gross domestic product (GDP) is projected to increase by 1.3 % per year in the period 2016-2070 in the 27 EU Member States (EU-27) and the UK (EC, 2018c). This growth will not be reflected linearly in water demand because of increasing water use efficiency and decoupling from growth (see Figures 4.9, 4.11 and 4.12) and a shift towards renewable energy sources. Furthermore, there is an EU-wide trend towards an increasing share of the GDP being covered by the services sector (EC, 2015c), a sector that is less water demanding than others.

4.2.2 Population change

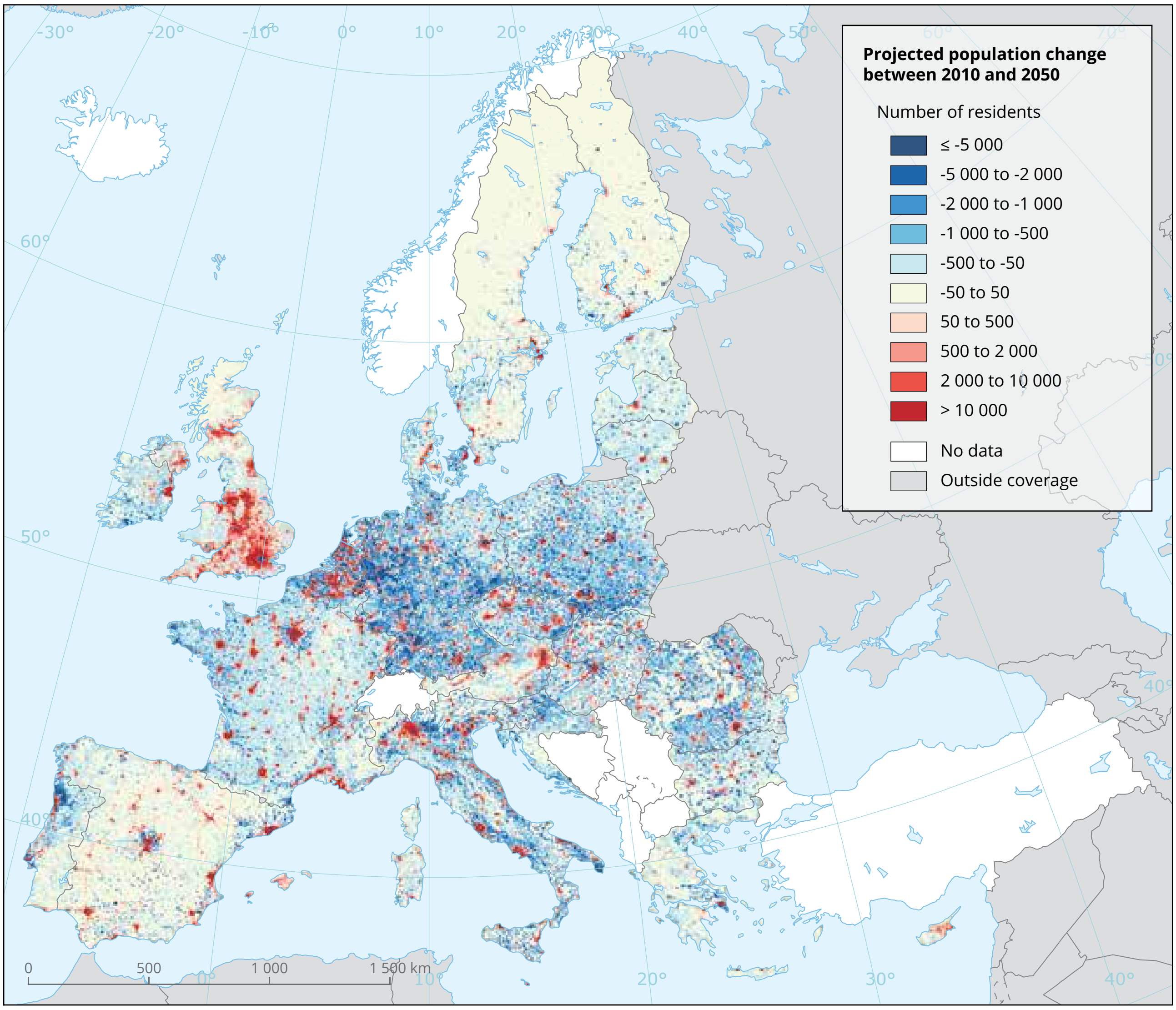
Between 1990 and 2017, the European population (EEA-38 and the UK) increased by 11 %. The highest increase was in southern Europe (+17 %), followed by northern (+13 %) and western Europe (+11 %). In eastern Europe the population decreased by 6 %, as a result of migration to other countries (Eurostat, 2020c). Roughly 200 million people migrated from one place in Europe (EEA-38 and the UK) to another between 2000 and 2019 (Eurostat, 2020d). Over the last 70 years, the urban population in Europe has increased from around 55 % to around 70 % of the total population. Urban areas are attracting young people, who come to cities to study and work, whereas older people tend to move into the periphery of urban centres and into peri-urban areas (EEA, 2017c). Currently, the areas with highest urban populations in Europe at NUTS 3 (Nomenclature of Territorial Units for Statistics 3) level are Istanbul (Box 4.1), Madrid, Rome, Berlin, Lisbon, Nord-Pas-de-Calais and Stockholm (Box 4.2) (Eurostat, 2020d).

Future outlook

Assuming that fertility rates, life expectancy and migration rates remain constant, then the population in Europe (EU-27 and the UK) is projected to increase slowly until around 2030 and then decrease gradually towards 2100. The population in Europe is also ageing, as the share of people over 65 years old is projected to increase significantly over the same period (EEA, 2016d).

The urban population has been projected to reach 80 % of the total population around 2050, according to a scenario simulation (Kompil et al., 2015). The major urban centres of western and central Europe are projected to experience the highest increases in their population (Map 4.1).

Map 4.1 Projected population change between 2010 and 2050



Reference data: ©ESRI

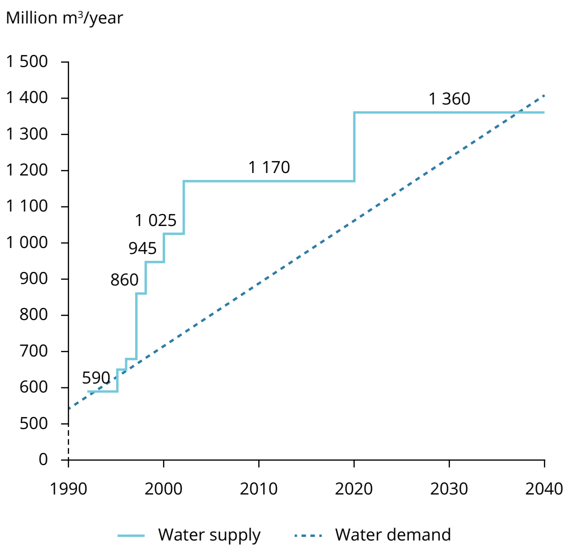
Source: Kompil et al. (2015).

Box 4.1 Population growth and climate change causing water demand to offset increases in water supply in Istanbul

Istanbul is the largest urban agglomeration of the EEA member and cooperating countries, and it is classified as a megacity (i.e. a city with a population over 10 million people). Istanbul has a population of more than 15 million inhabitants, and its total population increased by 36 % over the last decade (1.7 % annual average growth).

Although not a 'naturally dry' area, water scarcity is a local issue because of the concentrated population and its increase over time. Despite enormous efforts to increase the water supply, projected future urbanisation and population growth, together with climate change, will further increase water demand (Figure 4.4).

Figure 4.4 Water supply and demand in Istanbul, 1990-204



Source: Altinbilek (2006).

Sources: Altinbilek (2006); van Leeuwen and Sjerps (2016).

Box 4.2 Population growth as a prominent driver of urban sprawl and regionally high water consumption in Stockholm

The metropolitan region of Stockholm saw a 30 % population increase between 2000 and 2019 (+1.4 % per year on average), with an increase of over 500 000 inhabitants during the last 20 years. In the same period, 400 km^2 of artificial surfaces was added. In addition to this population growth and urban sprawl, Stockholm also has higher (albeit not yet alarming) freshwater consumption as a share of renewable freshwater resources in summer than other Scandinavian areas (i.e. frequently exceeding 10 %).

Sources: EEA (2018b, 2019d); Eurostat (2020d).

4.2.3 Patterns of freshwater use

People use water to meet basic needs, such as drinking, cleaning, washing and personal hygiene, as well as to support specific consumption patterns, such as dietary/lifestyle patterns and recreation purposes.

As a result of human mobility (e.g. tourism, work migration), the use of water in one place is not necessarily by people living permanently in that place. Similarly, because of trade, the use of water in the production of commodities does not necessarily occur where the commodities are consumed. In a globalised environment the linkages between local water, food and material demand, local water use and local water stress can be very complex. Therefore, the water stress problems observed in a given region in Europe can be caused by indirect water consumption elsewhere. Similarly, the water stress problems in areas of other continents can be related to consumption patterns in Europe.

Changes in food consumption patterns in Europe

The average water footprint ([7]) of food consumption (dietary patterns) in the EU is estimated at 5 730 litres/capita per day (Vanham et al., 2013).

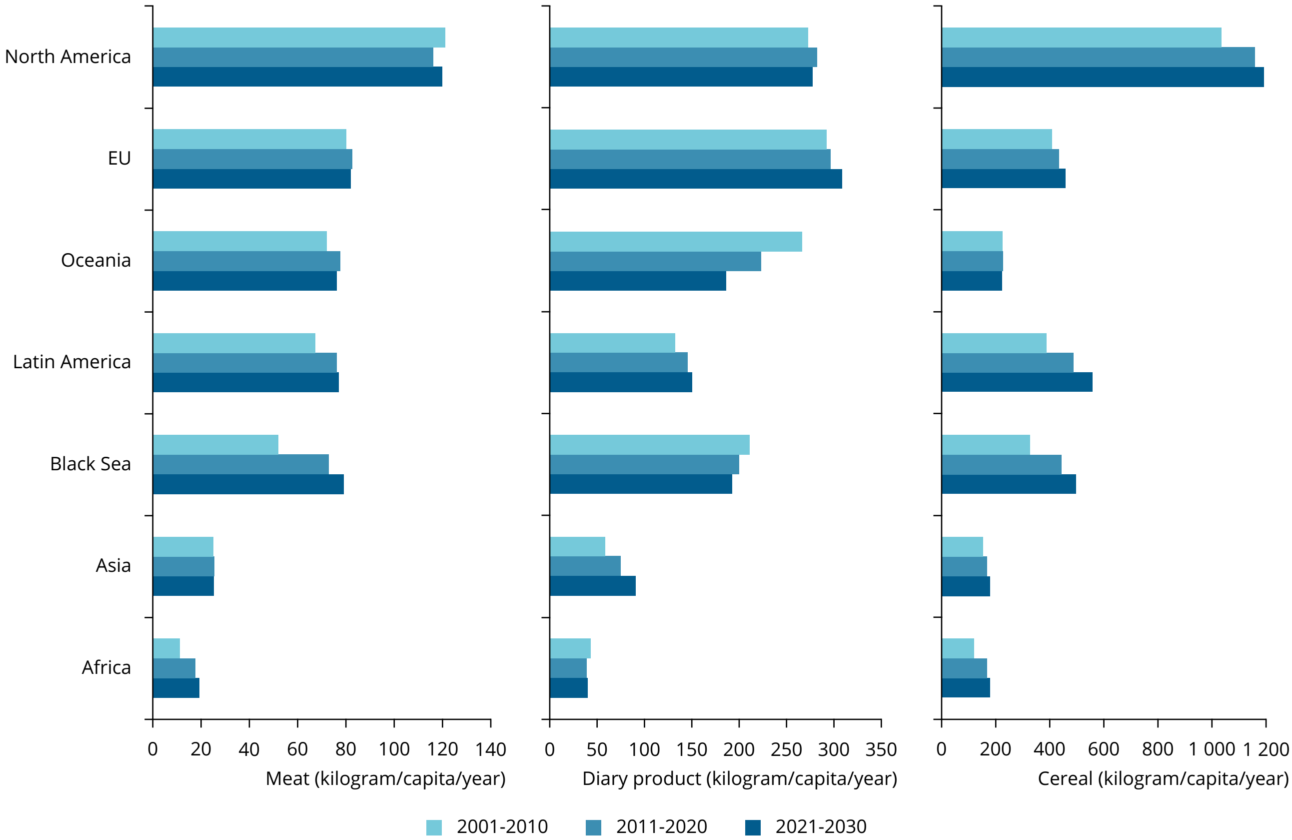
Overall, the average consumption of meat, dairy and cereal products per person is increasing in the EU (Figure 4.5), while Europe is one of the top consumers of these products in the world (EC, 2019f). Meat and dairy products require proportionately more water than most crops for their production (Mekonnen and Hoekstra, 2012, 2011), which means that the average diet of European citizens is becoming more water intensive.

Furthermore, not all food produced actually reaches consumers' plates. Food waste throughout the whole food chain is a major concern, as it is also linked to a considerable waste of water, soil and energy resources, which are used to produce the wasted food. Currently, the average food waste in the EU amounts to 173 kg/capita per year, with 30 % occurring during production and processing and 70 % occurring in food retail, food services or households (Stenmarck et al., 2016).

A European Commission outlook study suggests that the consumption of cereals and dairy products will increase until 2030, whereas meat consumption is likely to stabilise or reduce, partly because of a projected shift towards a more plant-based diet for the average European citizen (EC, 2019f).

([7]) The water footprint measures the amount of water used to produce each good or services. It can be measured for a single process, for a product or for an organisation or company (Water Footprint Network, 2021).

Figure 4.5 **Changes in per capita consumption of food commodities in the EU compared with the rest of the world**



Note: Figures do not include butter. The Black Sea includes Russia, Ukraine and Kazakhstan. Latin America includes South America and Mexico.

Source: EC (2019f).

4.2.4 Land use change

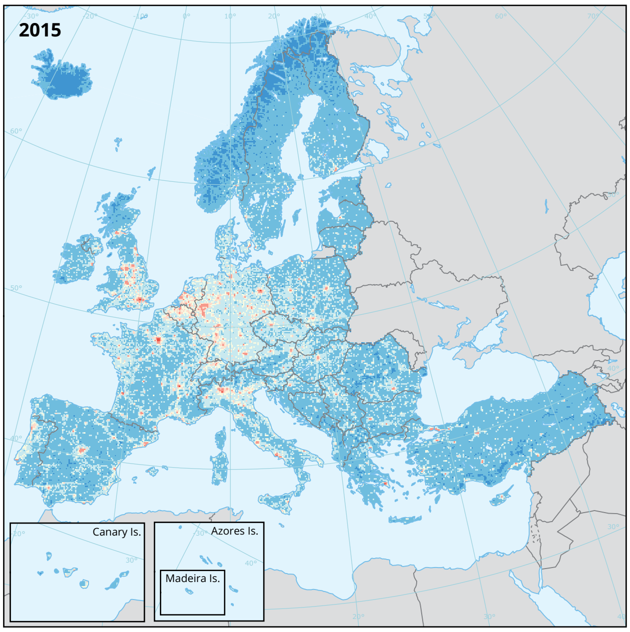
Area of urban land and soil sealing

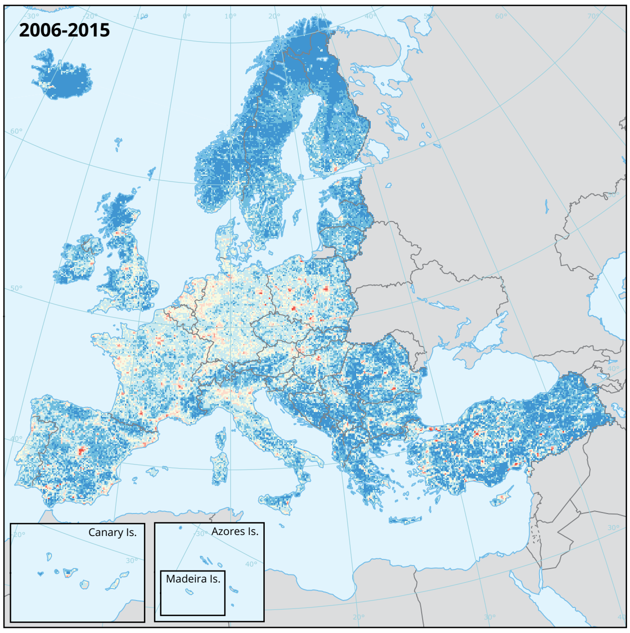
Extended soil sealing causes serious environmental impacts. These include reduced infiltration and groundwater recharge, drinking water quality problems in underlying groundwater bodies due to the accumulation of urban pollutants, and faster rainfall run-off leading to more frequent and intense flooding. As a result of surface sealing, the soil can no longer perform many of its ecological functions in and above the ground. Urban sprawl and expansion of the transport infrastructure also cause fragmentation of landscapes and disturbance of ecosystems (EEA, 2019e, 2019f, 2020e).

The significance of urban areas for the European economy is increasing. Urban areas produced 50 % more GDP than other areas in the EU between 2000 and 2013, while employment grew by 7 % in urban areas and decreased slightly in other areas (EEA, 2017c). The increase in the European urban population has led to the development of more urban and peri-urban land and concentrated the demand for public water supply. In 2017, artificial land cover, which includes residential, industrial and commercial land and the transport infrastructure connecting areas, exceeded 4 % of the total land cover (EEA, 2019d). The Netherlands, Belgium, France, Germany, the United Kingdom and Italy (particularly the Po river basin) are significant hotspots of urbanised and artificial land, while recent trends in urbanisation (2006-2015) show high rates of land conversion in France, Spain, eastern Europe and Turkey. Between 2000 and 2018, 78 % of the land converted to artificial uses in the EU-27 and the UK was arable land and permanent crops, pastures and heterogeneous agricultural areas, and grasslands.

In addition, urban sprawl has accelerated in coastal areas. However, the development of land and infrastructure in coastal areas is vulnerable to climate change, for example the projected rise in the average sea level will increase the risks of coastal inundation and flooding from storm surges. Around 40 % of European citizens currently live in coastal areas, and a large share of European tourism is concentrated in the coastal areas and islands of Europe. In recent decades, there has been rapid land conversion for residential, touristic and recreational facilities and for the supporting transport infrastructure (e.g. highways, ports and harbours) (Map 4.2) (EEA, 2013b).

Map 4.2 **Density of impervious cover across Europe in 2015 (left) and average annual change in soil sealing between 2006 and 2015 (right)**





Reference data: ©ESRI

Density of impervious cover across Europe in 2015 (left) and average annual change in soil sealing between 2006-2015 (right)

Percentage: 0; 0-1; 1-5; 5-10; 10-20; 20-50; > 50

Outside coverage

0 500 1 000 1 500 km

Percentage: < 0; 0; 0-0.001; 0.001-0.01; 0.01-0.04; 0.04-0.1; 0.1-0.2; > 0.2

Source: EEA (2020f).

Source: EEA (2020a).

Area of agricultural land under irrigation

The area of agricultural land has expanded and its use intensified between 1990 and 2006; this has occurred partly at the expense of high nature value farmland, pastures and marginal land. The period since 2006 has seen a reversal in the overall trend, and the total area of agricultural land in Europe has started to decline (EEA, 2017c), although the decline has not been substantial. Furthermore, significant conversions to agricultural land have been observed in some EU Member States (e.g. Czechia, Germany, Hungary, Ireland and the Baltic countries).

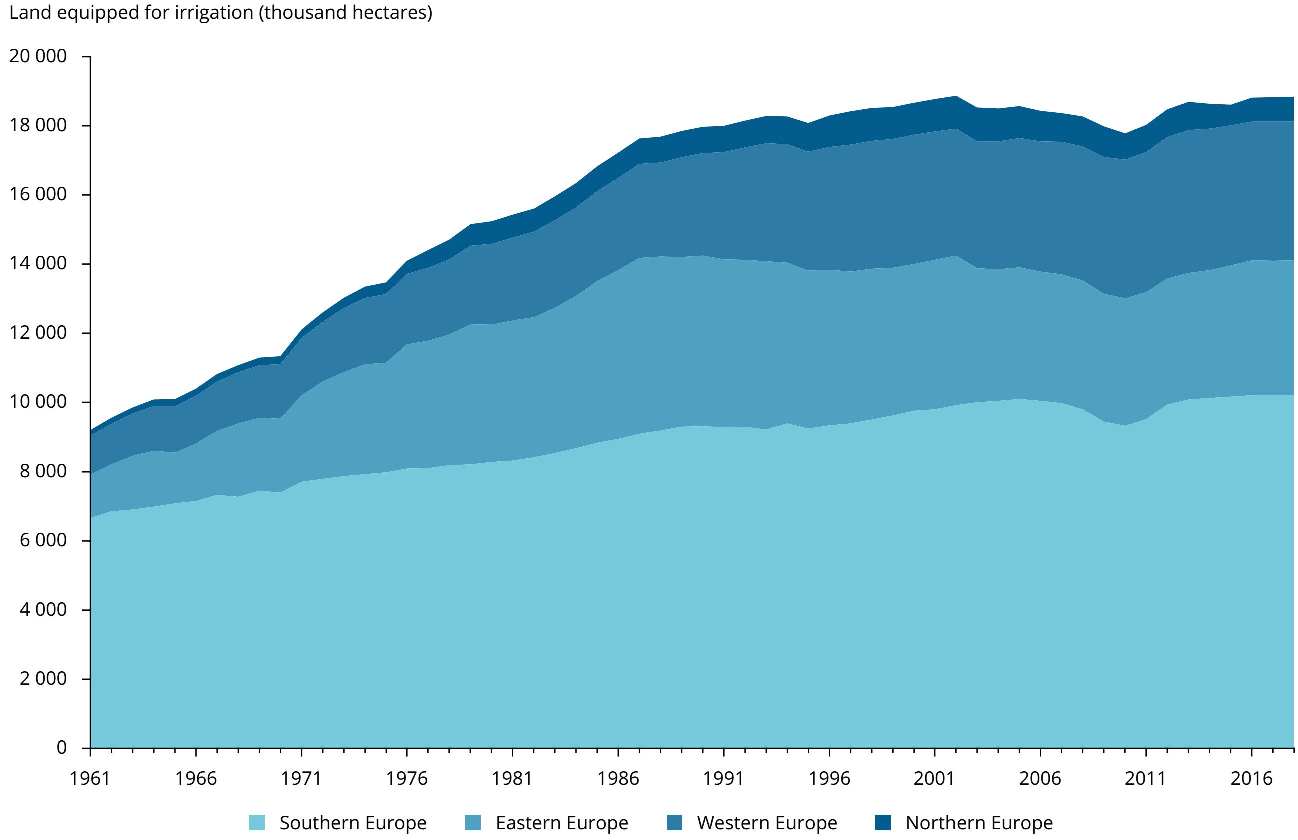
Around 60 % of all irrigated areas in Europe are in southern Europe, where 85 % of total irrigation abstraction takes place. This legacy is still putting a lot of pressure on regional water resources, despite recent trends that show a reduction in the water intensity of crop production of 11 % between 2005 and 2016 (EEA, 2019k). Figure 4.6 shows the increase in irrigable area in the four European regions since 1961.

As a result of climate change, the increased occurrences of droughts will increase irrigated areas in the future and intensify the pressure on local water resources, even in areas which are currently perceived as less threatened. Furthermore, there is a high likelihood that agricultural activities in central and northern Europe will expand (EEA, 2016a, 2016c) (see Section 4.3).

Area of forested land and wetlands

In several Member States, including Finland, Hungary, Ireland, Poland, Portugal and the Baltic countries, there has been significant conversion to forested land and woodland, resulting in an overall increase in the area of forests in the EU-27 and the UK (EEA, 2017c). Furthermore, the area of water bodies and wetlands showed a small increasing trend between 2006 and 2012, which could reflect the implementation of policies related to nature protection, water retention, renaturalisation and environmental restoration (EEA, 2017c).

Figure 4.6 Irrigable area in the EU-27 and the UK since 1961



Note: The figure presents estimates from the Food and Agriculture Organization of the United Nations (FAO), which differ from data reported through Eurostat. For instance, according to Eurostat, the total irrigable area in the EU (EU-27 and the UK) in 2016 was 15.5 million hectares (Eurostat, 2019c). This compares with 18.5 million hectares according to FAO estimates. Such discrepancies highlight the need for better monitoring and reporting of agricultural irrigation data.

Source: Faostat (2021).

Future outlook

The Seventh Framework Programme (FP7) Volante project ([8]), 'Visions of land use transitions in Europe', concluded with a series of projections of land use change in Europe. The key outcomes are that various drivers are expected to cause more urbanisation, land uptake, land degradation, soil pollution and loss of ecosystems.

Furthermore, some areas of agricultural land will be abandoned, while other areas will be recultivated, including new areas of land previously considered marginal, where energy crops could be grown. Projections suggest that the total area of land occupied by crops will remain similar until 2040. Cultivation of crops is expected to become more intensive and sophisticated (e.g. precision farming) in the areas where farming prevails (EEA, 2017c).

([8]) https://cordis.europa.eu/project/id/265104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4.3 Water use by agriculture

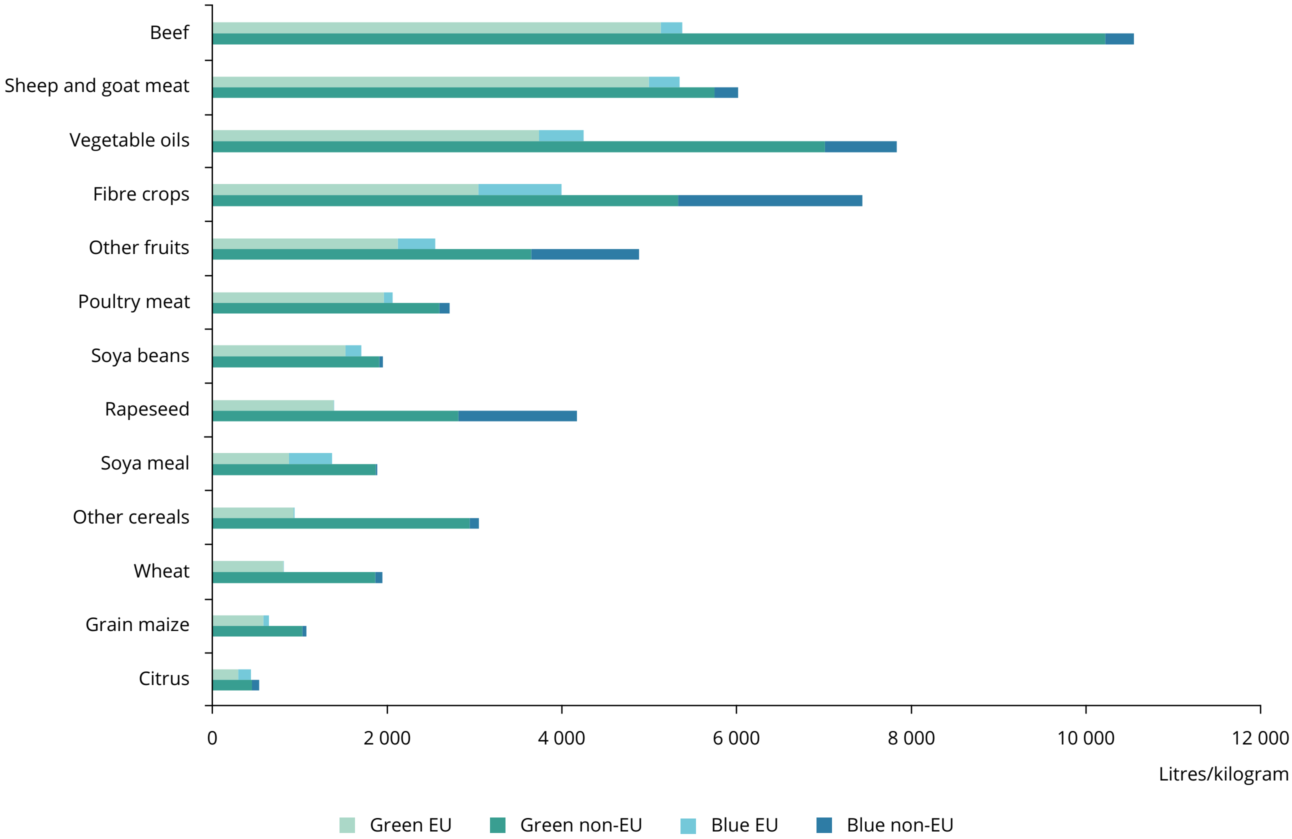
Water is an essential resource for agriculture. In areas with more temperate climates, agriculture is mostly rain fed, but irrigation is also applied to regulate seasonal water deficits and ensure satisfactory quality and yields of products. Soil conditions can be a critical factor in this case. For example, in Denmark irrigation is mainly needed for farming on sandy soils with low water retention capacity, whereas nearly no irrigation takes place in other parts of the country with clay soils ([9]). In drier climates, however, rain can provide only part of the crop's water requirements. Thus, additional water needs to be provided to enable crop production. Water is also needed for raising animals to meet their direct needs for consumption and the requirements for growing their food and cleaning livestock facilities. Aquaculture and forestry are also dependent on water availability, although they are not directly dependent on water abstraction.

Water abstraction in Europe for agriculture is very unevenly distributed: almost 90 % occurs in southern Europe and only 10 % in the other parts of the continent. The area of arable land in Europe is around 113 million ha, and nearly 19 million ha is equipped for irrigation (irrigable area). Depending on the climatic conditions, the actually irrigated area is approximately 8-9 % of the total arable land. The shares of irrigated land are much higher in southern Europe, ranging from 28 % in Malta to 13 % in Spain and Portugal. Agriculture accounts for 40-60 % of total water consumption in Europe, most of it used for irrigation. Water consumption by agriculture shows the highest fluctuation throughout the year, as the demand for irrigation water rises sharply during spring and summer, especially in southern Europe. In southern Member States, agricultural water abstraction accounts for approximately 80 % of total water abstraction (EEA, 2018b, 2019k).

The water footprint of different crop and meat products differs considerably (Figure 4.7). The highest water footprint is observed for vegetable oils, fibre crops and fruits among crop products and for beef and sheep and goat meat among meat products. Crop and meat products that are produced in Europe are estimated to have a lower water footprint than similar products imported into Europe from foreign countries, because of the different climatic conditions, water management practices and environmental policy frameworks.

([9]) Information provided by the Danish representative (Ingelise Møller Balling) during consultation about the report with the Eionet group.

Figure 4.7 Water footprints of crop and meat commodities in the EU and in non-EU countries exporting to the EU (litres/kg of product)



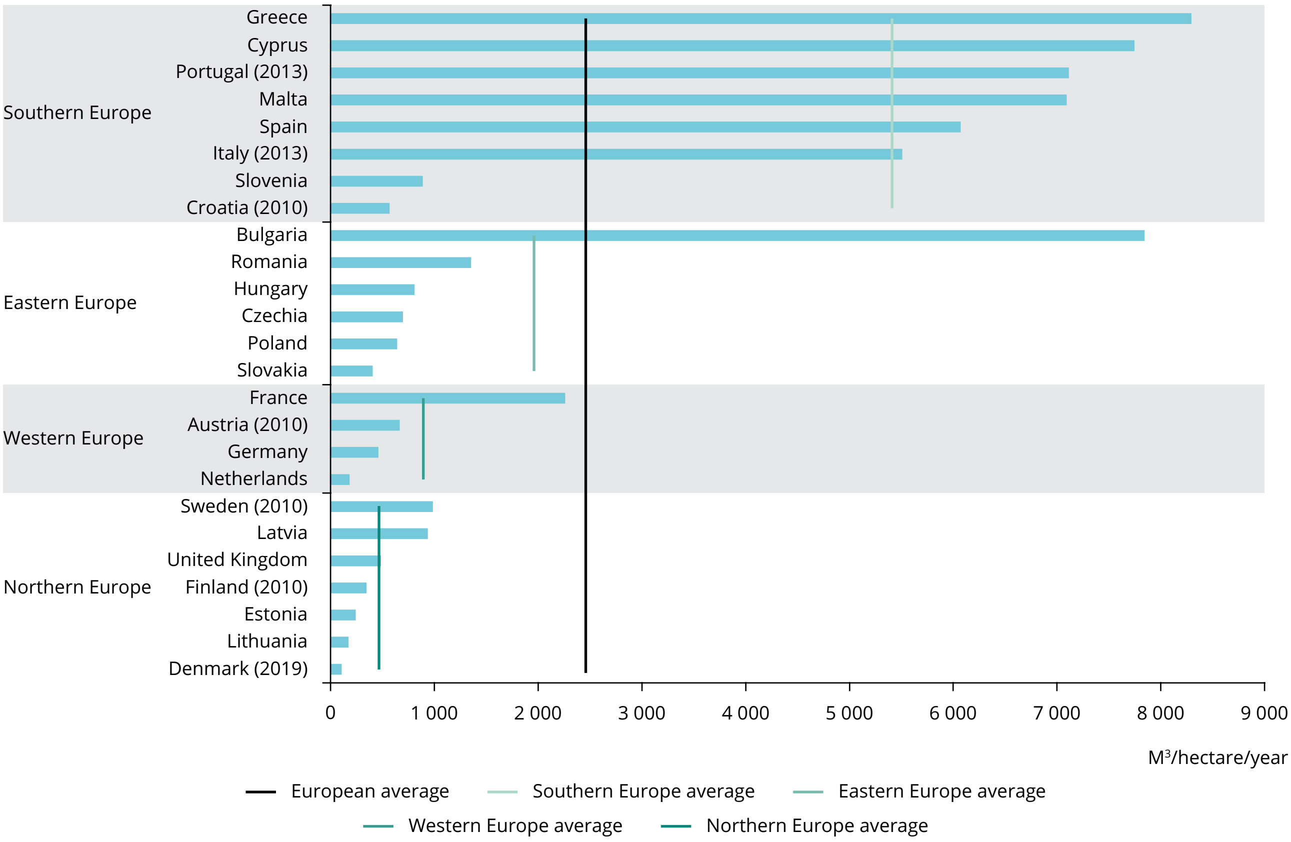
Note: Green EU and Green non-EU is water from precipitation that is stored in the root zone of the soil and evaporated, transpired or incorporated by plants; in crop and meat production inside and outside the EU, respectively.

Blue EU and Blue non-EU is water that has been sourced from surface or groundwater resources and is either evaporated, incorporated into a product or taken from one body of water and returned to another, or returned at a different time; in crop and meat production inside and outside the EU, respectively.

Source: EC (2019f).

In general, the cropping patterns in southern Europe include many crops with high water requirements (e.g. cotton, lucerne, maize, fruit trees, vegetables) (Eurostat, 2019a; EEA, 2019k), which are cultivated there for various reasons, including favourable climatic and soil conditions, long-standing tradition and know-how (e.g. special equipment and trained professionals) and current levels of revenues (especially from fairly commercial/tradeable crops). Because of the low water availability and semi-arid conditions in many parts of southern Europe, the water demand of these crops is largely provided by irrigation. The irrigation abstraction per hectare exceeds 5 000 m^3 in most southern European countries, as well as in Bulgaria. Values higher than 1 000 m^3 are also observed in countries such as Romania and France (Figure 4.8).

Figure 4.8 Irrigation abstraction per hectare of irrigated arable land in Europe, 2016



Note: Country grouping is adapted from UN Geo schema M49 (UNSD, 1999).

Source: EEA (2019k, 2019l); Statistics Denmark (2021).

During the 1990s and 2000s the World Trade Organization undertook significant reforms, which liberalised global trade. Stimulated global trade within a globalised economy has provided new opportunities and new markets for European agricultural products. However, after the 2003 common agricultural policy (CAP) reform, and more recently of the 2013 CAP reform, has resulted in a decoupling of direct payments from agricultural production and raised sustainable water management as a key objective of rural development policy. This has contributed to a slowdown or reversal in the expansion of irrigated areas, as well as the modernisation of irrigation infrastructures to achieve more efficient water use, for instance in France (Rouillard, 2020).

Between 2002 and 2017 the irrigated area shrunk by 6 %, although the total utilised agricultural area expanded by 4 % in Europe. Nevertheless, in already water-stressed southern Europe, both agricultural land and irrigated area increased (+12 %) over the same period (EEA, 2018b).

A study of the climate change impacts shows that crop water requirements and crop water deficits increased in many areas of southern and eastern Europe between 1995 and 2015. Furthermore, the growing season is becoming longer, especially in northern and eastern Europe (EEA, 2016a, 2016c).

During the period 2010-2017, the total water consumption by agriculture in Europe (EEA-38 and the UK) decreased. However, in southern Europe water consumption increased in many countries, including Italy and Turkey, which are large consumers of water for agriculture (Figure 4.9).

Figure 4.9 Trends in water consumption by agriculture in Europe (EEA-38 and the UK), 2010-2017

Agriculture							
Eastern Europe		**Northern Europe**		**Southern Europe**		**Western Europe**	
Bulgaria	↓	Denmark	↓	Albania	↓	Austria	↓
Czechia	↓	Estonia	↓	Bosnia and Herzegovina	N/A	Belgium	↓
Hungary	↑	Finland	↓	Croatia	↑	France	↑
Poland	↓	Iceland	N/A	Cyprus	↓	Germany	↓
Romania	↑	Ireland	N/A	Greece	↑	Liechtenstein	N/A
Slovakia	↓	Latvia	↑	Italy	↑	Luxembourg	N/A
		Lithuania	↓	Kosovo*	↑	Netherlands	↓
		Norway	↓	Malta	↑	Switzerland	↓
		Sweden	↓	Montenegro	N/A		
		United Kingdom	↓	North Macedonia	↓		
				Portugal	↓		
				Serbia	↑		
				Slovenia	↑		
				Spain	↓		
				Turkey	↑		

Increase in water consumption ↑ Decrease in water consumption ↓ N/A - Not applicable

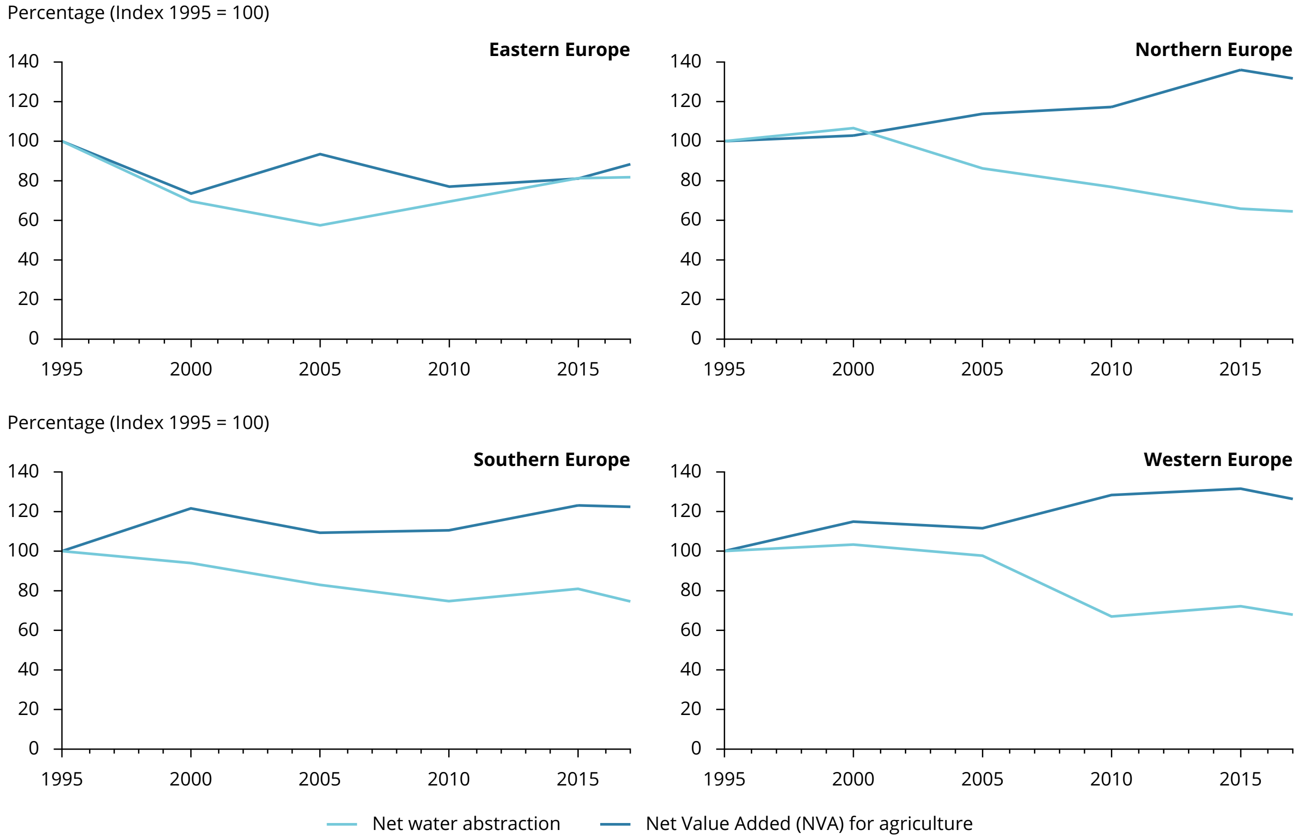
Notes: Country grouping adapted from UN Geo schema M49 (UNSD, 1999). According to the European dataset on water abstraction for agriculture there is small increase in France, particularly for the period 2010-2017, whereas France indicated no significant change in annual water abstraction for agriculture (for the same period).

Sources: Data derived from EEA (2019l, 2021d); Eurostat (2020f).

Agriculture contributes around 2 % of the gross value added of the European economy and directly provides 4 % of total employment, without counting indirect jobs in upstream and downstream activities. The EU is the global leader of agri-food exports, which reached EUR 138 billion in 2018 (EC, 2019a). Imports of agricultural products are also important to the EU.

Comparing the total water consumption in the agricultural sector with its net value added (NVA) shows that trends towards absolute decoupling of economic growth from water consumption are already visible in northern, western and southern European countries (Figure 4.10).

Figure 4.10 Comparison of regional trends in water consumption and economic growth in the agricultural sector in Europe (EEA-38 and the UK), 1995-2017



Notes: Light blue line indicates water consumed by agriculture (indexed 1995 = 100); dark blue line indicates net value added (NVA) by agriculture (indexed 1995 = 100).

Country grouping is adapted from UN Geo schema M49 (UNSD, 1999). Eastern Europe: Bulgaria, Czechia, Hungary, Poland, Romania, Slovakia. Northern Europe: Denmark, Estonia, Finland, Ireland, Lithuania, Latvia, Norway, Sweden, United Kingdom. Southern Europe: Cyprus, Greece, Italy, Malta, Portugal, Slovenia, Spain. Western Europe: Austria, Belgium, Germany, France, Luxembourg, Netherlands.

Sources: EEA (2019l, 2021d); Eurostat (2020a, 2020f).

4.3.1 Future outlook

A European Commission outlook study (EC, 2019f), based on agro-economic modelling and consultation with stakeholders, international institutions and experts, suggests that the area of agricultural land in the EU is expected to decrease slightly by 2030 with the current agricultural and trade policies. This is in line with the findings of the recent FP7 Volante project, which also concluded that a limited reduction in the size of the agricultural area is the most likely scenario by 2030. The area of cereals, fodder and pasture is expected to decrease, whereas oilseeds, pulses and other crop areas are expected to increase. The study also indicates that the production of milk and beef could decrease in the EU.

Projections show that the warming climate could cause the growing season to become longer in most European regions. As a result, crops growing in warmer conditions could be cultivated in northern latitudes, and crop cultivation in certain areas of southern Europe (e.g. Spain), could shift into the winter season (EEA, 2016a, 2016c). Moreover, warmer climatic conditions earlier in spring and later in autumn may enable crop cultivation for longer periods of time and possibly multiple harvests. As a result, climate change could increase crop water deficits, and irrigation water requirements could increase by more than 20 % in southern Europe (Konzmann et al., 2013). An overall increase is projected across all of Europe (EEA, 2016b). Regarding future crop yields, the projections show high variability depending on location, crop type, climate and management conditions. Overall, an increase in productivity is expected in northern Europe and a decrease in southern Europe, although this is not uniform across all crop types (EEA, 2016h).

The potential water saving from individual technical measures for irrigated agriculture differs considerably, and it relies upon site-specific conditions (e.g. soils, crop types) and the technology applied. An indication of potential water savings is provided in Table 4.2. It has been estimated that the potential water savings in irrigated agriculture could exceed 40 % of the total abstraction if combinations of the above measures were applied (Dworak et al., 2007).

As part of the Blue2 project, several scenarios were developed for potential water-saving measures for irrigated areas in southern European countries (Benitez Sanz et al., 2018). The main outcomes were that up to 5 % of the annual renewable freshwater resources in each river basin could be saved, if all planned irrigation efficiency measures from the river basin management plans (RBMPs) were implemented. In comparison, 10 % of the annual renewable freshwater resources could be saved if all feasible technical measures were implemented, regardless of their total cost (e.g. upgrading conveyance systems to reduce leakage, seepage and evapotranspiration losses; applying the most efficient irrigation technology on a case-by-case basis). Although these gains are considerable, taking into account the significant levels of water stress in many southern river basins (often exceeding 30 % of the annual renewable freshwater resources), they are not sufficient on their own to reverse water scarcity conditions. In addition, to capitalise on the aforementioned potential water savings, which can be achieved by improving irrigation systems and equipment, both investments and supporting actions are required (e.g. adjusting end users' management practices).

Table 4.2 Potential water savings from applying indicative technical measures in the agricultural sector

Measure	Potential water saving (%)
Upgrading conveyance infrastructure (e.g. closed pipes replacing open trenches)	10-25
Changing to use irrigation methods with higher application efficiency (e.g. drip micro-irrigation replacing furrow irrigation)	15-60
Changing irrigation practices (e.g. rescheduling irrigation, mulching)	30
Crop restructuring (e.g. drought-resistant crops replacing water-demanding and drought-sensitive crops)	50
Irrigating with reclaimed water	10

Source: Dworak et al. (2007).

4.4 Water use by electricity production

The energy sector comprises several activities, such as electricity production, primary energy production and oil refineries. Electricity production, which includes mainly combustion plants and nuclear stations, hydropower, wind turbines and solar panel installations, represents more than 90 % of the total freshwater abstraction by the energy sector in the EU-27 and the UK. Water abstracted for electricity production is consumed to varying degrees (see sub-sections below and Figure 4.10), and the rest is discharged to surface waters. In general, water consumption for electricity production is much lower than that for other sectors (e.g. irrigated agriculture). Although the total freshwater abstracted for primary energy production (e.g. oil and gas extraction, coal mining, and biomass production), as well as for oil refineries, is very low compared with that abstracted for electricity production (less than 10 %), we should be cautious about coming to rapid conclusions. For each of these activities, the water consumption per unit of energy generated is far from negligible (see Figure 4.11) (Jin et al., 2019; Magagna et al., 2019; Hidalgo Gonzalez et al., 2020).

© Ali Ihsan Gokcen – Coruh river, Artvin-Turkey

From this point onwards, this section focuses on activities for electricity production, which represents the largest share of freshwater abstraction in the energy sector.

Combustion plants and nuclear stations abstract water to cool the hot steam that is created by burning fuel and is used to rotate turbines. Electricity generated from combustion plants covers around 60 % of the total electricity consumed in Europe. The discharge of cooling water to the receiving water bodies causes thermal pollution, resulting in the risk of fish populations suffering from hypoxia. Cooling water for electricity production was responsible for nearly 18 % of total water consumption in Europe in 2017. The use of cooling water is relatively high in western and eastern Europe. France and Germany have the highest consumption of cooling water; together they make up 45 % of Europe's total consumption (EEA, 2018b).

Hydropower plants using freshwater are usually installed in running water ('run-of-river installations') or at river dams ('dam installations'). Hydropower plants provide approximately 12 % of the total energy production (average 2015-2019) ([10]). As river or reservoir water flows through the hydropower installation, a series of turbines rotate and generate electricity. Virtually all of the water used in hydropower plants is directly returned to the water bodies. Therefore, the amount of water consumed by hydropower plants during their operation is considered negligible. However, this actually depends on the site and the configuration of the technology, and there is no overall estimate for its range (IEA and OECD, 2010). Throughout the life cycle of a dam installation, part of the reservoir water evaporates. Thus, hydropower installations are partly accountable for the consumption of reservoir water through evaporation.

Hydropower installations can have significant hydromorphological impacts, as they impede the natural water and nutrient cycles, and they create obstacles for the transport of freshwater biodiversity, sediments and substances.

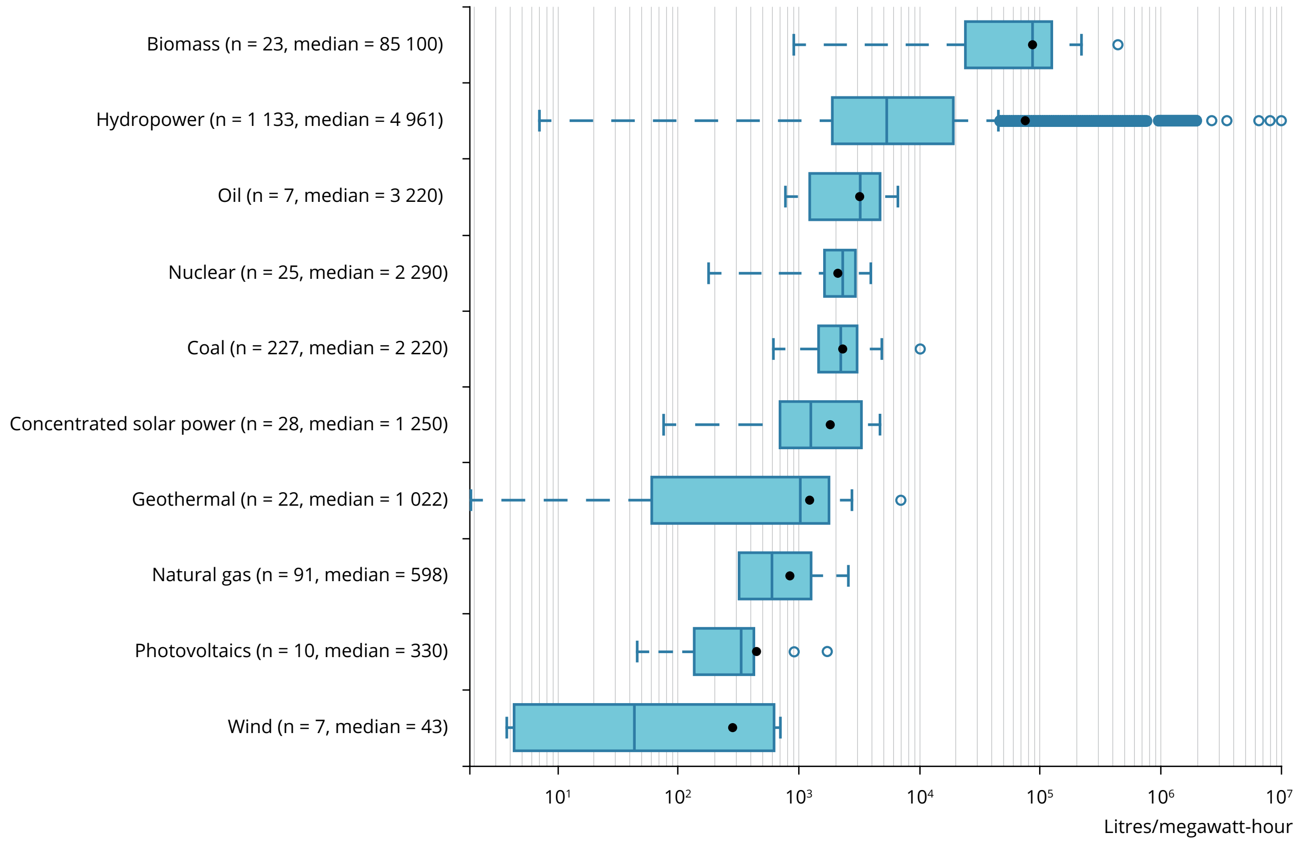
The generation of hydropower from large and small dams increased substantially during the last century, but that growth has slowed in recent decades, because the most productive locations are already occupied and because environmental permitting in Europe has become more comprehensive, following the adoption of the Water Framework Directive (WFD) (permitting procedure under Art. 4.7). However, hydropower installations have multiplied in areas such as the Western Balkans. More than half of the electricity produced in Albania, Austria, Croatia, Iceland, Luxembourg and Montenegro comes from hydropower (EEA, 2018b). In the second RBMPs, 5 337 surface water bodies (out of a total of 146 510) were reported to experience significant hydromorphological pressures from dams for hydropower (EEA, 2018d).

([10]) https://ec.europa.eu/energy/sites/default/files/energy_statistical_countrydatasheets.xlsx (accessed 26 May 2021).

Electricity from renewable energy sources is largely generated by wind turbines and solar panels. These technologies have a much lower water consumption throughout their life cycle than conventional forms of energy (Figure 4.11).

Figure 4.12 presents recent trends in the water consumed by electricity production per country (grouped in regions) for the period 2010-2017. It shows that water consumption is decreasing in the majority of countries. This is for a number of reasons: upgrades of existing power plants, whereby aged equipment is replaced with new and more efficient installations; in some cases, relocation of power plants near coasts, where seawater is used for cooling; and increases in the shares of the least water-intensive renewable energy sources (EC, 2015c).

Figure 4.11 Water consumption per unit of energy generated during the life cycle of different types of energy sources



Notes: Water consumption is shown on a log scale. Circles represent the outliers, while the dots represent the average for each power type.

CSP, concentrated solar power; mdn, median value of water consumed; PV, (solar) photovoltaic.

Source: Jin et al. (2019). Reproduced under the terms and conditions of Creative Commons CC BY 4.0 licence (https://creativecommons.org/licenses/by/4.0).

Figure 4.12 Trends in water consumption by electricity production in Europe (EEA-38 and the UK), 2010-2017

Electricity, gas, steam and air conditioning supply							
Eastern Europe		**Northern Europe**		**Southern Europe**		**Western Europe**	
Bulgaria	↑	Denmark	↓	Albania	↑	Austria	↓
Czechia	↓	Estonia	↑	Bosnia and Herzegovina	↑	Belgium	↓
Hungary	↓	Finland	↓	Croatia	↓	France	↓
Poland	↓	Iceland	↑	Cyprus	↓	Germany	↓
Romania	↓	Ireland	↑	Greece	↑	Liechtenstein	N/A
Slovakia	↑	Latvia	↑	Italy	↓	Luxembourg	↓
		Lithuania	↓	Kosovo*	↑	Netherlands	↓
		Norway	N/A	Malta	↓	Switzerland	↓
		Sweden	↓	Montenegro	↑		
		United Kingdom	↑	North Macedonia	↓		
				Portugal	↓		
				Serbia	↑		
				Slovenia	↑		
				Spain	↓		
				Turkey	↓		

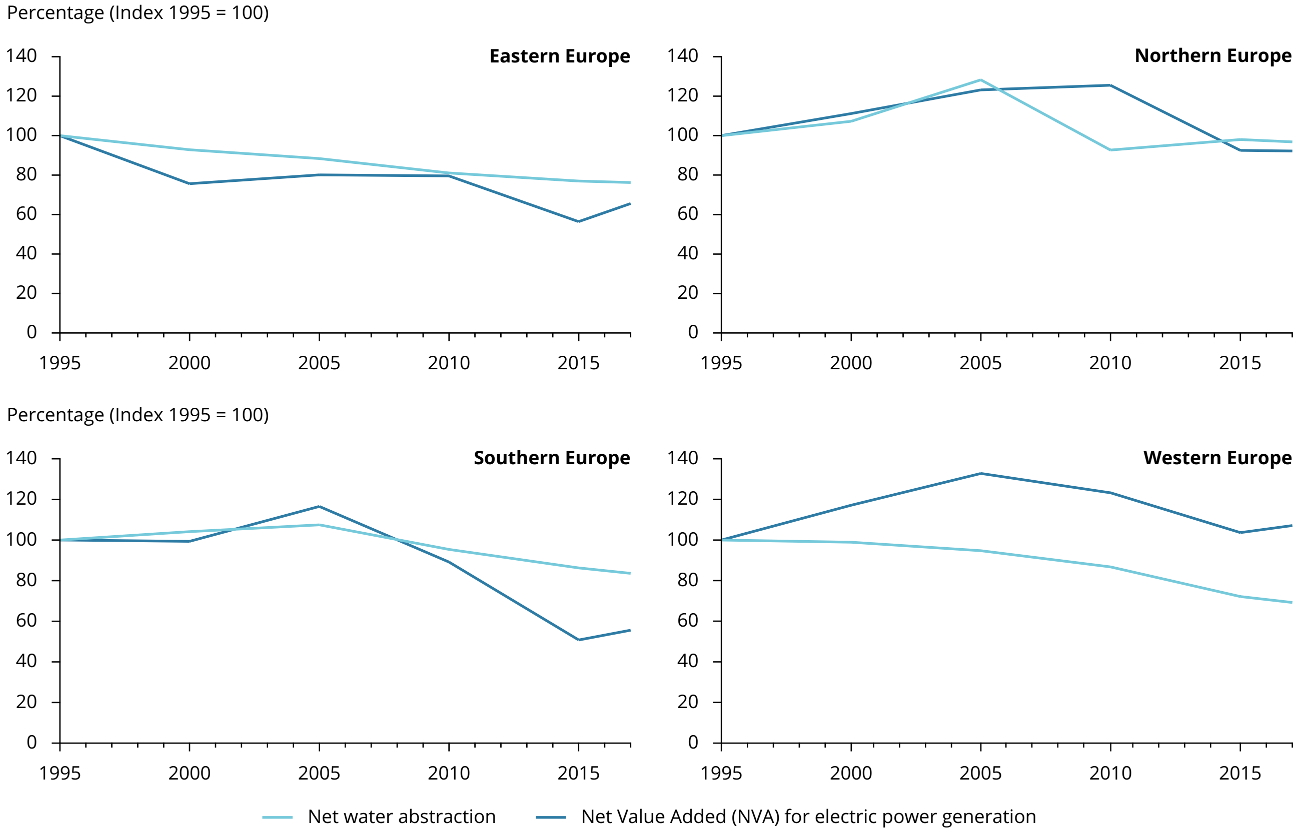
Increase in water consumption ↑ Decrease in water consumption ↓ N/A - Not applicable

Notes: Country grouping is adapted from UN Geo schema M49 (UNSD, 1999).

Sources: Derived from EEA (2019l, 2021d); Eurostat (2020f).

Comparing the total water consumed by electricity production with the NVA generated in the economy from that sector shows that trends towards absolute decoupling of economic growth from water consumption are already visible in western European countries (Figure 4.13). In the other regions, decoupling is not occurring or not clearly visible. What is positive is that water consumption for electricity production is decreasing in all regions.

Figure 4.13 Comparison of regional trends in water consumption and economic growth in the electricity production sub-sector in Europe, 1995-2017



Notes: Light blue line indicates water consumed by electricity production (indexed 1995 = 100); dark blue line indicates net value added (NVA) by electricity production excluding renewables (indexed 1995 = 100)

Country grouping is adapted from UN Geo schema M49 (UNSD, 1999). Eastern Europe: Bulgaria, Czechia, Hungary, Poland, Romania, Slovakia. Northern Europe: Denmark, Estonia, Finland, Ireland, Iceland, Lithuania, Latvia, Norway, Sweden, United Kingdom. Southern Europe: Cyprus, Greece, Italy, Portugal, Slovenia, Spain. Western Europe: Austria, Belgium, Germany, France, Luxembourg, Netherlands.

Sources: EEA (2019l, 2021d); Eurostat (2020a, 2020f).

4.4.1 Future outlook

The EU reference scenario for energy, transport and greenhouse gas emissions up to 2050 (EC, 2015c), as updated by the more recent European Council (EUCO) scenario series (EC, 2021d), reflects the EU's long-term strategy to decarbonise its economy, including the production and consumption of energy. An updated EU reference scenario is also expected by the end of 2021.

Electricity production, in particular, will be characterised by the rapid expansion of renewable energy sources in the future and the replacement of coal and petroleum with natural gas in combustion plants. New investments are expected to focus on new, more efficient, installations, as well as on upgrades and retrofitting of obsolete power installations. In addition, the construction of combined heat and power systems is expected to result in higher efficiency in the use of input fuels for electricity production.

Furthermore, the retrofitting of outdated installations of solar panels and wind turbines with new-generation technology on the same sites is considered a feasible, economic solution, which has much lower environmental impacts than brand new installations.

Freshwater abstraction for electricity production in the EU-27 and the UK could decrease by roughly 25 % and freshwater consumption by 10 % up to 2050 (Hidalgo Gonzalez et al., 2020) by replacing combustion plants with wind turbines. Nevertheless, it should be noted that such estimations include a degree of uncertainty, because of the diversity in the data reported on water consumption per unit of energy generated and the inherent nature of scenario development. Furthermore, the estimations may obscure local patterns, such as regions locked in to specific technologies for electricity production; thus, we need robust political steer and investment to achieve a faster transition to cleaner electricity production.

4.5 Water use by industry and mining

Manufacturing industry and mining are two different sectors that both require water, mainly for processing activities.

Manufacturing industry includes a variety of sub-sectors, including food and beverages, textiles, chemicals, pulp and paper, and iron and steel. The above sub-sectors need water for cooling purposes, processing activities, washing and cleaning of facilities and equipment, and for integration into products. The returned cooling water can cause problems with thermal pollution and hypoxia. Furthermore, industrial discharges can be highly contaminated and then require appropriate treatment before discharge. In the case of washing and cleaning, water consumption is considered low to negligible, but discharged water may need treatment because of its nutrient and organic contents (EEA, 2018b).

Mining and quarrying include a diversity of activities, such as mineral extraction (e.g. coal, ores, petroleum, gas) and preparatory actions for the supply of materials to markets (e.g. crushing, grinding, cleaning, drying, sorting, concentrating ores, liquefaction of natural gas, agglomeration of solid fuels). Groundwater is pumped out to drain mining and quarrying sites, which, among other impacts, can affect groundwater flow regimes (Box 4.3). When mining activities cease, the dewatering operations are gradually phased out, resulting in a rebound to normal groundwater levels. As groundwater flows through the fractured rocks, acidification may take place. Acid drainage, pooling in underground galleys or flowing out from surface openings can degrade the quality of local surface water and groundwater. Furthermore, water is abstracted and used for processing activities, such as rock crushing and dust control. The retention ponds for residual mine slurries and the leachate from precipitation falling on unprotected heaps of mine waste can be additional sources of pollution if poorly managed. In 2017, the share of water abstracted for mining was the highest in western (40 %) and southern (22 %) Europe ((EEA, 2018b; Tayebi-Khorami et al., 2019).

Water consumption by manufacturing industry and mining and quarrying is generally decreasing with the exception of many Western Balkan and eastern European countries (Figure 4.14). This trend can be attributed to the modernisation of production processes, technological improvements, more efficient methods, and water recycling and reuse. Furthermore, water consumption by the industrial and mining sector has also declined, because of the de-industrialisation of specific regions in Europe since industrial production has been partly transferred abroad. At the same time, the overall production of the sector increased by 9 % between 2010 and 2017 (EEA, 2018b; Eurostat, 2020e).

Box 4.3 Czech and German concerns over cross-border drainage impacts from Polish coal-mining activities

In March 2021, the Czech authorities filed an injunction, arguing that open-cast lignite mining activities in the Polish city of Turów were draining aquifers near the common border of the two countries, thus causing significant problems with the supply of water to Czech citizens. Similar concerns had been expressed earlier by the neighbouring German city of Zittau, and several non-governmental organisations had sent a joint letter of complaint to the European Commission. The European Court of Justice issued a temporary judgment in May 2021, saying that the Polish authorities had granted a renewed licence for the Turów mining activities without first evaluating the environmental impacts and engaging in dialogue with the stakeholder. It also ordered that all operations cease until a final judgment is given.

Source: AP (2021).

Figure 4.14 Development of water consumption by industry and mining in Europe (EEA-38 and the UK), 2010-2017

Mining, quarrying, manufacturing and construction			
Eastern Europe	**Northern Europe**	**Southern Europe**	**Western Europe**
Bulgaria ↑	Denmark ↓	Albania ↑	Austria ↑
Czechia ↓	Estonia ↓	Bosnia and Herzegovina ↑	Belgium ↓
Hungary ↑	Finland ↑	Croatia ↑	France ↓
Poland ↑	Iceland ↓	Cyprus ↓	Germany ↓
Romania ↑	Ireland ↑	Greece ↑	Liechtenstein N/A
Slovakia ↓	Latvia ↑	Italy ↓	Luxembourg ↑
	Lithuania ↓	Kosovo* ↑	Netherlands ↓
	Norway N/A	Malta ↑	Switzerland ↑
	Sweden ↓	Montenegro ↑	
	United Kingdom ↓	North Macedonia ↓	
		Portugal ↓	
		Serbia ↑	
		Slovenia ↓	
		Spain ↓	
		Turkey ↑	

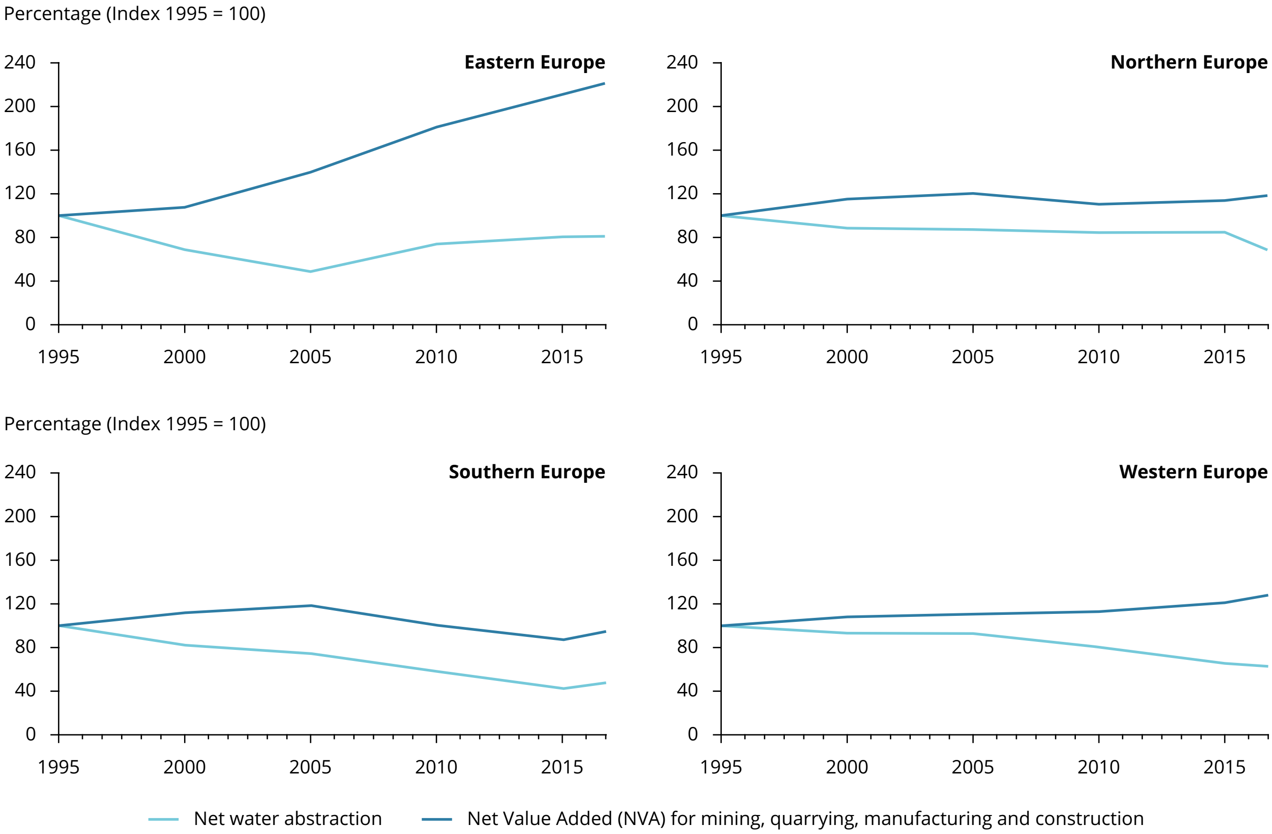
Increase in water consumption ↑ Decrease in water consumption ↓ N/A - Not applicable

Notes: Country grouping is adapted from UN Geo schema M49 (UNSD, 1999).

Sources: EEA (2019l, 2021d); Eurostat (2020f).

Comparing the total water consumed in the industrial sector with the NVA generated in the economy from that sector shows that trends towards absolute decoupling of economic growth from water consumption are already visible in all countries, although the pace of decoupling differs between the regions (Figure 4.15).

Figure 4.15 Comparison of regional trends in water consumption and economic growth in the industrial sector in Europe (EEA-38 and the UK), 1995-2017



Notes: Light blue line indicates water consumed by the industrial sector (indexed 1995 = 100); dark blue line indicates net value added (indexed 1995 = 100).

Country grouping is adapted from UN Geo schema M49 (UNSD, 1999). Eastern Europe: Bulgaria, Czechia, Hungary, Poland, Romania, Slovakia. Northern Europe: Denmark, Estonia, Finland, Ireland, Lithuania, Latvia, Norway, Sweden, United Kingdom. Southern Europe: Cyprus, Greece, Italy, Portugal, Slovenia, Spain. Western Europe: Austria, Belgium, Germany, France, Luxembourg, Netherlands.

Sources: EEA (2019l, 2021d); Eurostat (2020a, 2020f).

Bernhard et al. (2021b) estimate that the average increase in the efficiency of water use in the industrial sector between 2000 and 2015 is 2.2 % per year. This is roughly in agreement with Figure 4.12. Dworak et al. (2007) estimate that the potential water savings in the industrial sector are between 15 % and 90 %, with 43 % as average.

4.5.1 Future outlook

The difficulty in getting more reliable estimates of water use and potential savings in this sector can be linked to the difficulty of obtaining such information from enterprises, because of the diversity of the sub-sectors and technologies involved and because such data are considered strategic information (TNO et al., 2014; Benitez Sanz et al., 2018).

Creating a partial inventory of three categories of cleaning equipment in industry (Benito et al., 2009) showed that the most and the least water-efficient techniques could differ by a factor of 6. This may offer room for improvement, but actual potential savings are extremely case specific.

4.6 Public water supply

Public water supply includes providing water to meet the demands for drinking, washing, cleaning, sanitation, cooking, home gardening, etc., in residential and business premises. It also includes water for tourism and, sometimes, for the industrial or agricultural sector. The public water supply industry consists of utilities that abstract water from surface water and groundwater, treat it to remove hazardous substances and pathogens, and supply the treated water to end users.

In 2017, households accounted for over 60 % of the total public water supply in Europe. In 2017, around 50 % of public water supply was accounted for by southern Europe, which is associated with the impact of tourism in this region (EEA, 2018b).

Public water supply often faces water quality issues in the water source, such as salinisation in coastal areas, as well as problems with nitrates, sulphates, heavy metals, pesticides, pharmaceuticals, and other contaminants. The WFD requires that all Member States establish safeguarded zones to protect drinking water. In addition, the (revised) Drinking Water Directive of 16 December 2020 regulates the quality of water intended for human consumption, including the accompanying quality standards for the water supplied, to ensure that the risks to human health are mitigated (EU, 2020a).

In 2017, the average water consumption of households in Europe was estimated at 147 litres/day per person ([11]). The daily minimum required to meet basic human needs is estimated at 50 litres/day per person (Gleick, 1996), so the European average is comfortably above that threshold. Nevertheless, the average water supply to European households varies substantially on a national level, for example from 115 litres/day per person in Belgium to 265 litres/day per person in Spain. Bernhard et al. (2021a) collected household water use data for the period 2000-2013 at NUTS 3 level. Aggregated to four categories of regions, based on climate and income, they find water use varying between 112 and 159 litres/day per person, with the lowest values in cool and/or low-income areas, and the highest in warm and/or high-income areas.

Water leakage is a major concern, because it puts extra pressure on water resources without any benefit to the users, as well as wasting energy and resources for pumping and treating the wasted water. Thus, leaks result in financial losses for water suppliers and they may affect the affordability of water services as a result of higher bills. In major European cities, such as Athens, Istanbul, Madrid or Paris, drinking water may come from very distant sources, which sometimes lie 100-200 km from the city (EEA, 2018c). The length, the operation and the maintenance of the pipes affects the level of leakages. According to EurEau ([12]) estimates (EurEau, 2017), the average leakage rate of the drinking water distribution networks across Europe is approximately 23 % of all water distributed. A review of case studies across Europe (ERM, 2013) indicated that the losses from drinking water distribution networks range between 10 % and 72 % of the abstracted volumes. The revised Drinking Water Directive requires EU Member States to assess the level of infrastructural leakages and the potential for improvement, applying to at least water suppliers supplying more than 10 000 m^3 per day or serving more than 50 000 people. The Commission has been delegated to define a threshold for water leakages, and countries exceeding that threshold will be required to present an action plan to address the issue (EU, 2020a).

Thanks to a combination of increased pricing, water-saving technologies and measures, and awareness campaigns, Europe saw significant reductions in the public water supply demand for households between 1990 and 2017 (-16 %), despite a parallel increase in the European population. However, southern Europe did not follow this trend, as public water supply for households increased by 10 % over the same period (EEA, 2018b).

4.6.1 Future outlook

Dworak et al. (2007) estimated that a reduction in domestic water use of 50 % or even more was feasible. Benito et al. (2009) estimated the potential water savings in households at 32 %, by using more water-efficient household appliances, and at 20 %, by using more water-efficient toilets and showers alone.

Increasing population and changes in household types (i.e. more single households, which on average consume more water per capita) are expected to increase the demand for public water supply.

The role of household income is ambiguous. On the one hand, higher incomes have traditionally led to the adoption of better living standards and has been considered a factor in increasing water use per individual. On the other hand, nowadays, higher household incomes can result in more rapid access to novel and more water- and energy-efficient household appliances, better maintenance and timely replacement. Thus, income could also be a factor contributing to lower water use in households.

4.7 Water use by tourism and recreation

Tourism and recreation is a special sub-sector, which is supplied with water from the public water supply. It includes various types of water use, such as water for hotel and accommodation services, food and restaurant services, spas, saunas and swimming pools, golf courses, parks and urban green spaces, and outdoor sports and leisure activities in natural landscapes. Water quality can be an important concern for this sub-sector because the water supplied needs to meet different types of criteria, for example fit for human consumption

([11]) Calculated as the ratio of the total volume of household water consumed and the total population in the EEA-38 and the UK.
([12]) EurEau is the European Federation of National Associations of Water Services (https://www.eureau.org).

and skin contact, suitable for bathing, as well as aesthetic criteria ('landscape beauty). For example, eutrophication or embankments showing because of low flows and drawdown can contribute to a negative experience for visitors (EEA, 2018b).

As the tourism industry has grown over the decades, millions of people in Europe and abroad are taking a holiday away from home and visiting popular destinations. It has been estimated that this mobility accounts for around 9 % of the annual water consumption of the accommodation and food service sector in Europe (EEA, 2018b). The most important tourist attractions in Europe are large cities, such as Brussels, London, Paris and Rome, and the coastal areas and islands of the Mediterranean, the Baltic, the North Sea or the North-east Atlantic. Currently, Europe attracts 50 % of global international tourist arrivals, with nearly 20 % of them arriving in the Mediterranean (UNWTO, 2017). Tourism in Europe has reached record levels over the last decade. It should be noted that tourism activities in the Mediterranean peak during the summer season, at a similar time to the peak in agricultural activities. This results in high levels of seasonal water stress. It is estimated that the number of tourists who visit the Mediterranean areas annually is 16 times higher than the permanent population of these areas, while tourists' average daily water use is two to three times higher than the locals' daily water use (Iglesias et al., 2007). In the last decade, the number of nights spent by tourists in Europe increased by 30 % in southern Europe, whereas there was no significant change in other parts of Europe (Eurostat, 2020b). Over the same period, water abstraction for tourism almost doubled. The local and national economies of many southern European countries (e.g. Cyprus, Greece, Malta, Spain, Turkey) are largely dependent on tourism.

4.7.1 Future outlook

Future developments in tourism will rely on health considerations related to external shocks such as COVID-19 and changes in the working and business environments. The technical water-saving measures that can be implemented in the tourism sector are similar to those for households. However, estimating the potential water savings for tourism remains difficult, as little information is available and the future development of this sector is not clear.

It has been estimated that the potential to save water in hotels, bed and breakfast facilities and camping sites is in the range of 30 % to 50 %. Furthermore, there are cases of individual measures, such as technical interventions and awareness campaigns, which could result in significant gains of up to 30 %. The water-saving potential is even higher (up to 80 %) in outdoor water uses, such as irrigation of green spaces and golf courses, as well as in restaurants and cafes (Dworak et al., 2007).

5
Water stress in Europe

Key messages

- **The average amount of water available per capita in Europe is 4 560 m³/year, with large geographical variation: from 120 m³ per year in Malta to 70 000 m3 per year in Norway. Between 1990 and 2017, the amount of water available per inhabitant decreased in southern, western and northern Europe. An increase was observed in eastern Europe. These changes were largely driven by trends in population rather than climate change.**
- **Water stress affects approximately 20 % of the European territory and 30 % of the European population on average every year.**
- **In some parts of the EU, which in many cases are already water stressed, water consumption is increasing while water availability is decreasing. In other parts, increasing efficiency of water use will help to keep pace with the impacts of climate change.**
- **In all of the EU, climate variability is expected to increase, while urbanisation concentrates demand for water in urban areas. The expected outcome is that in southern Europe water stress problems will become more pressing than they already are, while in an increasing area of the EU water stress will be experienced irregularly but with increasing frequency and impact.**

Building on and combining the results of Chapter 3 (which explains how water availability is affected by climate change) and Chapter 4 (which highlights the current situation and future trends in water consumption), this chapter presents a brief sketch of current and future water stress in Europe.

5.1 Per capita freshwater availability in Europe

The availability of freshwater per inhabitant in Europe ([13]) amounts to 4 560 m³ per year (averaged over the period 1990-2017). However, this availability is highly variable and unevenly distributed in both space and time (Figure 5.1). For example, in 2017, renewable freshwater resources available per inhabitant ranged between 120 m³ per year in Malta to 70 000 m³ per year in Norway. At smaller spatial scales, for example when comparing a highly urbanised area with its surrounding rural region, even more variation occurs.

The spatial and temporal variation in available freshwater resources is affected by numerous factors, such as global and regional climate circulation, hydrometeorology and local weather patterns, topography, land cover and use, and hydrogeology. Thus, low water availability can be a local issue that is not compensated for by high water availability in another part of the same country or region. Similarly, low water availability can be a temporary issue that is not compensated for by high water availability in another month or season of the year (e.g. a dry summer followed by a wet winter). National and regional aggregates of freshwater availability should therefore be treated with caution, as they may obscure the local or seasonal realities encountered by European citizens.

Freshwater availability alone is not an indication of high or low water stress, as the concept of water stress compares the water consumed by all socio-economic activities with the renewable freshwater resources over a specified area and period. Thus, the spatial distribution of population and socio-economic activities and the timing of their demand for water must also be factored in to identify a lack of capacity to meet local and temporal needs for water.

([13]) Calculated as the ratio of the total volume of renewable freshwater resources and the total population in the EEA member and cooperating countries (EEA-38) and the UK.

Figure 5.1 **Trends in water availability per inhabitant (m^3/capita), 2000-2017**

Country	2000	2010	2017
Austria	11 298	9 477	8 444
Switzerland	7 728	6 113	4 902
Romania	4 500	8 159	4 956
Spain	4 146	2 308	2 042
France	3 933	3 286	2 430
Germany	2 438	2 323	1 629
Italy	2 120	3 060	1 320

Sources: EEA (2019l, 2021d); Eurostat (2020f).

Between 1990 and 2017, the amount of freshwater available per inhabitant decreased in southern, western and northern Europe. An increase was observed in eastern Europe. These changes were largely driven by trends in population rather than climate change. For example, in western Europe, annual renewable freshwater resources increased by 4 %, while the regional population increased by 11 %. In eastern Europe there was an increase in available renewable freshwater resources, but there was also a reduction (-6 %) in the regional population (EEA, 2018b).

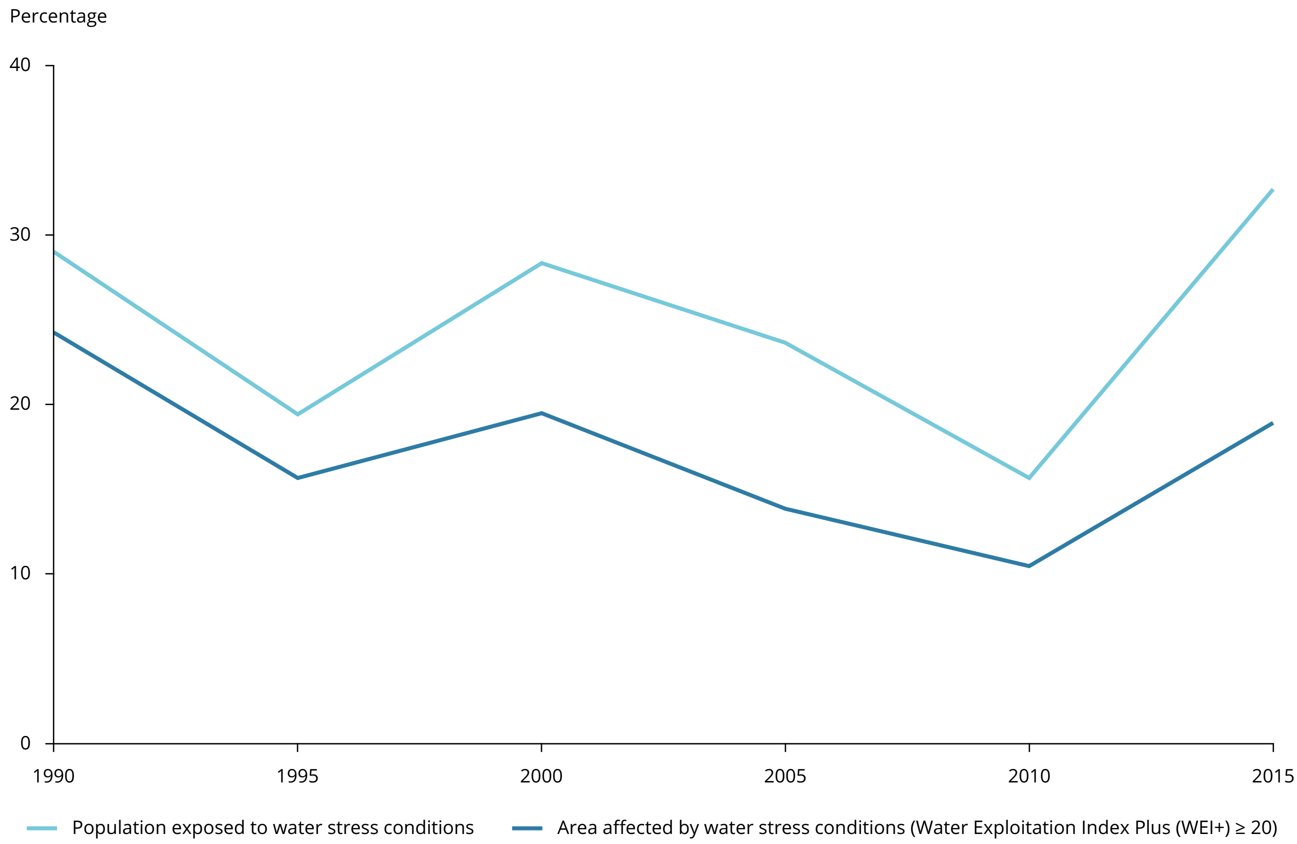
Freshwater availability is expected to decrease further in some parts of the continent, such as the Iberian Peninsula, due to decreasing precipitation and increasing temperature and evapotranspiration (EEA, 2016f, 2017d, 2019g). The situation will be aggravated by random drought events, which are becoming more frequent and intense in the context of climate change (EEA 2019g). In other parts of the continent, such as northern Europe, freshwater availability is expected to increase. This is due to projected increases in precipitation, including heavy precipitation that creates problems with excess water (e.g. floods). However, even these areas are projected to face higher temperatures and evapotranspiration, less snow, and more frequent and intense droughts than at present (see Chapter 3).

5.2 Current water stress in Europe

5.2.1 Annual water stress in Europe

Water stress affects approximately 20 % of the European territory and 30 % of the European population on average every year, based on the EEA's spatial analysis in indicator CSI 018 (water exploitation index plus, WEI+) (Figure 5.2; see also Box 1.6) (EEA, 2019g). The cost of economic damage from droughts is in the order of EUR 2-9 billion annually, not including the unquantified damage to ecosystems and their services (EEA, 2020c; Maes et al., 2020).

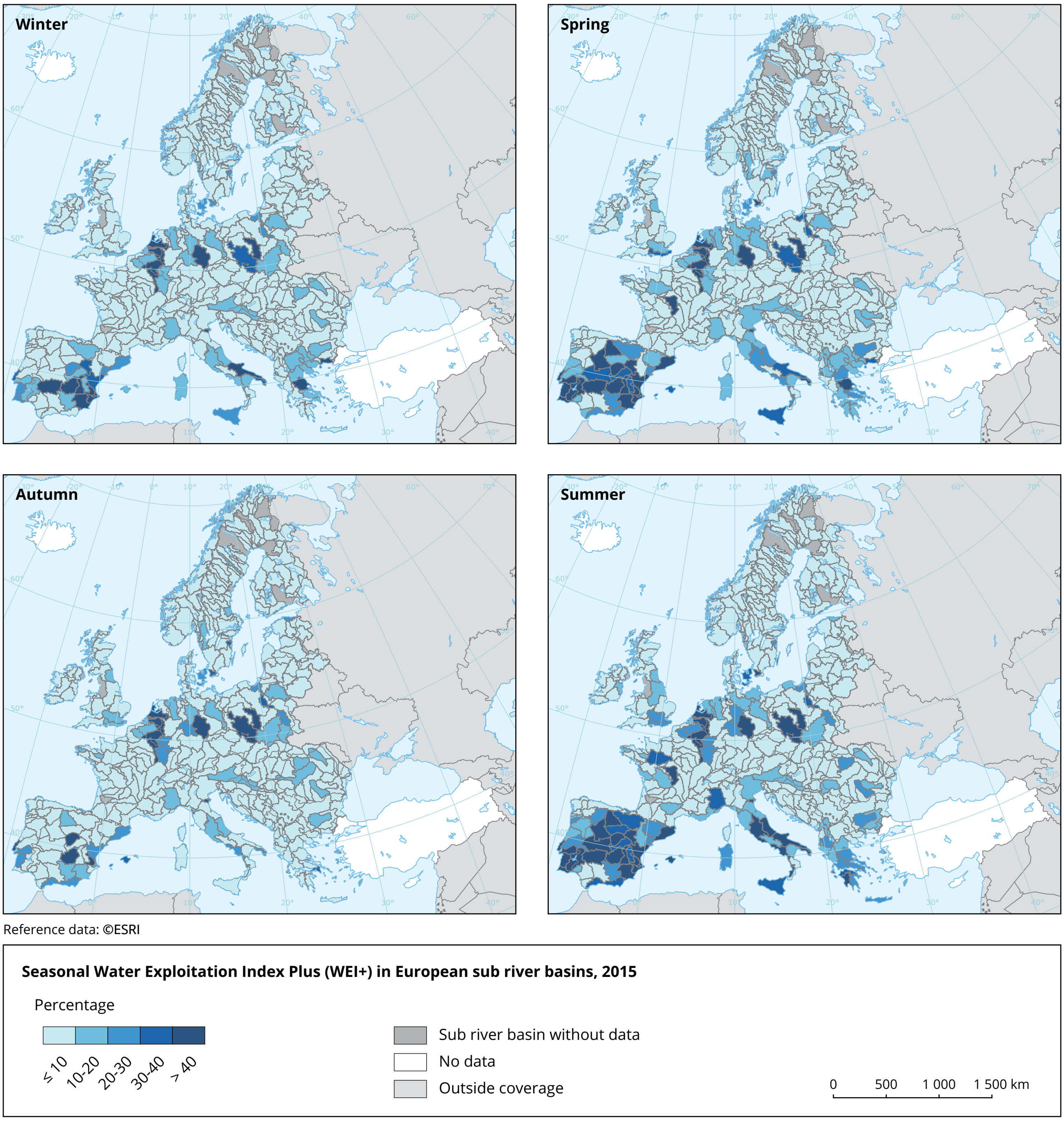
Figure 5.2 **Population and area exposed to water stress conditions in Europe in summer, 1990-2015**



Note: Estimation based on a WEI+ of 20 % and over.

Source EEA (2018b).

Map 5.1 **Seasonal water exploitation index plus (WEI+) in European sub river basins, 2015**



Note: Assessments of the sustainability of water abstraction at the European level remain limited by data availability and the approach to the interpretation of water returns. This may lead to large differences in the European WEI compared with national data sets. An example of this occurs in the south-western sub-basin of France along the Atlantic coast, an important maize production area. There the national estimate of WEI is around 50 % because it assumes no water returns from agriculture, whereas the European estimate, which is based on a 31 % returns ratio from agriculture, is below 10 %.

Source: EEA (2019h).

Southern Europe is the worst affected region (Map 5.1), with approximately 30 % of its population living in areas with permanent water stress and up to 70 % of its population living in areas with seasonal water stress during summer. On the one hand, this is a result of naturally occurring low water availability and aridity, which are part of the local climate. On the other hand, the water consumed by economic activities such as agriculture, public water supply, tourism and electricity production is relatively high compared with the local renewable freshwater resources.

Water stress increases between April and September, when water demand for agriculture, drinking water supply, and tourism or recreation reaches a seasonal peak. Severe water stress problems are usually observed in areas with intensive agriculture, which have a high share of irrigated land and receive large applications of irrigation water, fertilisers and pesticides. In this context, agriculture causes water stress because it depletes natural water sources (e.g. rivers dry up, groundwater levels decrease critically) or pollutes local freshwaters (e.g. high concentrations of pollutants exceeding legal requirements for water quality). Agriculture-driven pollution can make water resources unsuitable for other purposes downstream (e.g. drinking water), unless significant costs are incurred for their treatment. Severe water stress problems are also observed in coastal areas, because of high concentrations of human activities, including tourism. In such areas, local freshwater availability is usually low compared with the water supply required. In addition, the local water sources are vulnerable to saline intrusion. Therefore, pollution and poor water quality can also be a reason for local water stress issues in various parts of Europe.

Water stress issues also increasingly occur in parts of western, eastern and northern Europe. Compared with the average regional conditions, water stress levels are generally high in the wider area of Copenhagen (Denmark), London (United Kingdom) and Stockholm (Sweden) and in the river basins of the Loire (France), Meuse (France-Netherlands-Belgium), Oder (Germany-Poland) and Weser (Germany), as well as in several sub-basins of Bulgaria, Hungary and Romania. This is usually a result of urbanisation, rising living standards and locally significant demand for public water supply and cooling water used in the industry and energy sectors.

Between 1990 and 2017 the abstracted volume of water in the 27 EU Member States (EU-27) and the UK declined by 9 % and in the EEA member and cooperating countries (EEA-38) and the UK by 17 % (EEA, 2018b). Furthermore, between the first and second cycles of the implementation of the Water Framework Directive (2010 vs 2016), the area of groundwater bodies affected by overabstraction decreased by around 7 % (EEA, 2018d). These overall trends are encouraging, because they show a tendency towards reduced pressures from water abstraction in Europe. However, it should not be overlooked that water stress is a local and seasonal issue. Thus, overall reductions are not always informative about the actual severity of the problem at finer spatial and time scales. Similarly, water stress in rain-fed agriculture and in rain-dependent natural areas is not or barely mitigated by reduced water abstraction.

5.3 Future projections of water stress in Europe

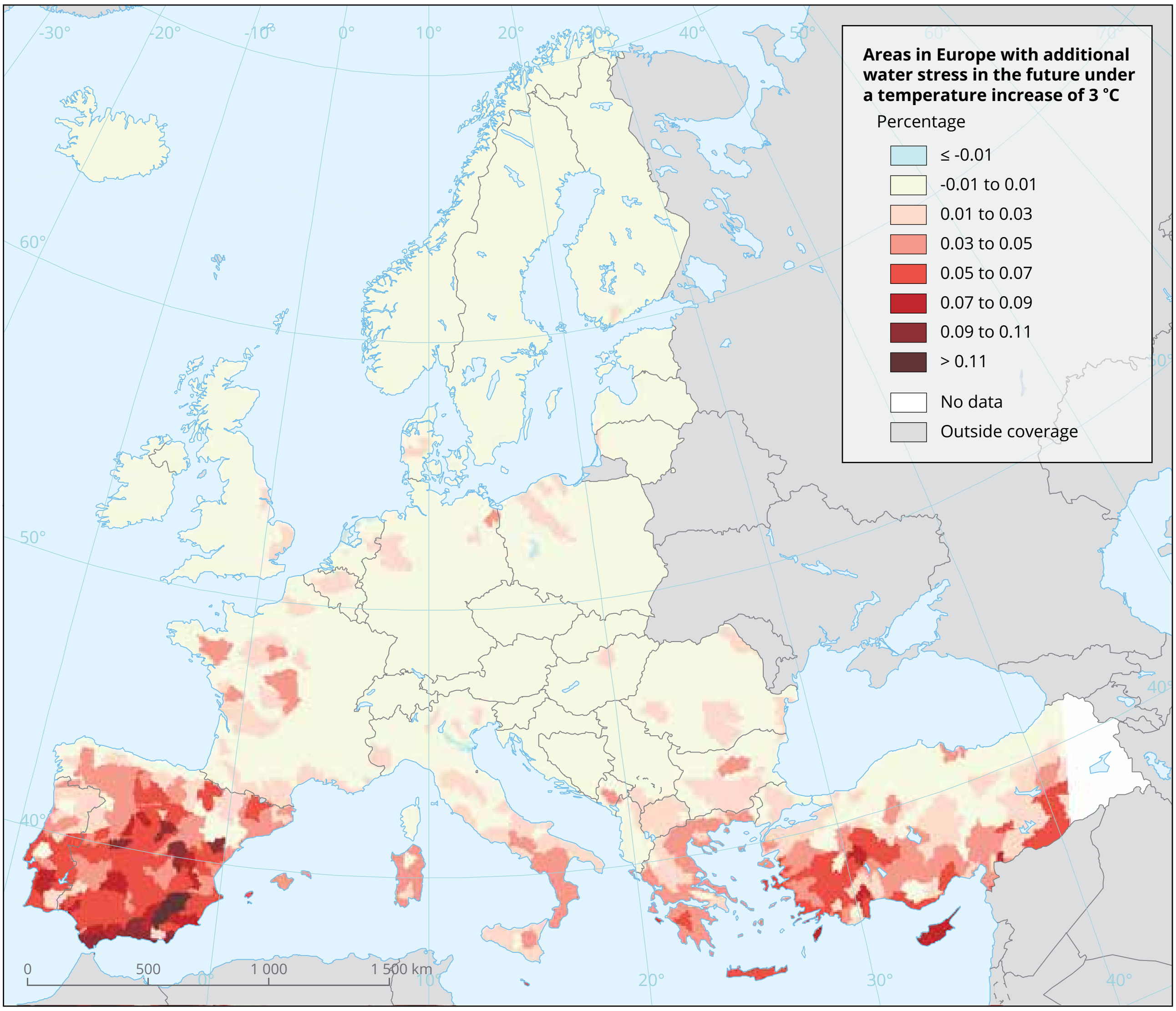
Water stress in Europe is expected to worsen in the future, as a result of climate change and socio-economic development. In the Peseta IV project the European Commission Joint Research Centre modelled two different emission scenarios, resulting in three global temperature increases, with 3 °C as the highest, compared with pre-industrial levels (Bisselink et al., 2020) (Map 5.2). For an increase in global temperature of 3 °C, conditions of significant water stress will be extended and intensified in southern Europe, as well as in other parts of Europe, including areas in Belgium, Bulgaria, France, Germany, Poland and Romania. Moreover, the duration of seasonal water stress is projected to increase by up to a month, with the highest increase expected in the Iberian Peninsula and other parts of the Mediterranean. In these calculations it was assumed that economic sectors' use of water increases as a ratio of growth in gross domestic product (GDP), so increasing efficiency of water use was not included.

Combining the findings of Chapters 3 and 4, the following estimate of the difference between water demand and water availability emerges, and how it will develop over the coming decades.

5.3.1 Potential impacts of climate change on water availability in future

As a result of climate change, the average availability of water in surface water and groundwater bodies is expected to increase in north-eastern Europe and decrease in southern and south-western Europe, while mixed patterns are expected in the central parts of Europe. Under the 3 °C temperature increase scenario (Representative Concentration Pathway (RCP) scenario 8.5), the mean summer discharge in Spain and other parts is estimated to become 20-40 % lower than it is now. In parts of the other Mediterranean countries the impact is less pronounced, but with reductions in the order of 10-20 % still very significant (Bisselink et al., 2020)**.** Aquifer recharge follows roughly the same pattern.

Map 5.2 Areas in Europe with additional water stress in future under a temperature increase of 3 °C



Reference data: ©ESRI

Source: Peseta IV project (Bisselink et al., 2020).

5.4 The impact of water use efficiency

According to the available data (Figures 4.10, 4.13 and 4.15), economic growth shows an overall trend towards absolute decoupling from water consumption in Europe. Water use efficiency has increased in agriculture, electricity production, industry, mining and public water supply. Water consumption in these sectors was 16 % lower in 2017 than in 1995 (an average decrease of 0.7 % per year), while production grew by 20 % (0.8 % per year on average) in terms of net value added (NVA).

The estimates of potential improvements in water use efficiency outlined in Chapter 4 are in the order of 2 % per year, somewhat higher than what has been reported in the past. With an overall GDP growth rate of 1.3 % per year (EC, 2015c) and assuming that GDP growth is at the same level as NVA growth, the net decrease in water demand can be estimated at 0.7 % per year ([14]).

([14]) Some words of caution are in order here: (1) The data collected on water consumption do not cover all Member States and are partly based on proxies. (2) General estimates at the whole EU level do not represent the local impact of water stress. For example, in Sections 4.3 and 4.6 it was pointed out that the increase in the irrigated area and in per capita household water use is highest in southern Europe, which is already the most water stressed region in Europe. (3) These estimates are therefore only indications of future trends in water stress.

That said, there are clear signs that water is being used more efficiently in the European economy. This will allow for better accommodation of environmental water demands (which have not yet been assessed at EU level) and for climate change impacts.

Comparing the potential water savings with expected changes in water availability and water demand shows that, in some parts of Europe, the current pace of water saving in the economy is sufficient to compensate for the decrease in water availability as a result of climate change. Environmental water demands have not been accounted for in this comparison. The water uses that directly depend on precipitation, such as rain-fed agriculture and terrestrial nature, do not benefit from these water savings. The impacts of increasing climate variability and the spatial concentration of water demand in households and industry, too, are not mitigated by increased efficiency of water use.

6
Sustainable solutions for water stress management in Europe

Key messages

- Progress in establishing ecological flows, and subsequently revising water permits, is slow.
- Sustainable water management needs to rely more on water demand management, supply from alternative water resources, and circular and nature-based solutions. Improvements in efficiency should be transparently documented to promote cross-fertilisation and transfer of technology and knowledge.
- In areas where the problems cannot be solved in a sustainable way at a local or regional scale by current measures to manage water demand, systemic changes are called for .
- Given the significance of abstraction pressures on European water resources, sectoral policy interventions must not only work in synergy with water policies but also actively support them.
- A key factor contributing to the effectiveness of water directives are the (binding) cross-references to the objectives of the Water Framework Directive (WFD) in other EU policies. However, although the WFD has been in force for 20 years, few integrated governance frameworks have been implemented.
- Only eight Member States reported drought management plans as accompanying documents to all or part of their second river basin management plans.
- Nature-based solutions can contribute to drought risk management through their integrative and stakeholder-driven approach and can thus provide a link to nexus approaches and systemic change.
- Major technological innovations that will contribute to improved drought risk management are expected in the field of Earth observation, mobile data collection and data integration.

6.1 Principal strategies for managing water stress

Strategies to combat water stress are similar for most economic sectors, if considered at a sufficiently abstract level, and they can be divided broadly into four categories (Box 6.1). The water hierarchy (EC, 2007a) promotes the measures to be investigated consecutively from top to bottom.

Box 6.1 Principal strategies for managing water stress

- Reduce water demand
  - Reduce losses in the supply system
  - Reduce losses during use
    - Raise awareness
    - Introduce economic measures
  - Apply more water-efficient technologies
  - Select products for their low water demand
- Store water temporarily during water-abundant times
  - In surface reservoirs
  - In the soil and in aquifers, natural water retention measures and nature-based solutions
- Accept shortage and focus on dealing with its consequences
  - Prioritise water allocation
  - Introduce insurance schemes
- Increase water availability or water supply
  - Reuse wastewater
  - Desalinate brackish or salt water
  - Divert water from water-abundant to water-stressed locations (only if no other options remain)

However, current practices show that the majority of measures are more sector-, time- and region-specific than strategies. Shifting sectoral water management towards a more sustainable paradigm entails a series of challenges, because of the trade-offs between making a sector less water intensive and keeping up its production levels. The broad challenge, similar for all types of water use, is to link water resources, resource efficiency and ecosystem conditions (thus addressing the need for ecosystem-based management) in an integrated water resource management approach or a nexus approach. As a general rule, practise more sustainable water management and put more reliance on water demand management, supply from alternative water resources, and circular and nature-based solutions (NbS).

EU Member States are planning and implementing a wide variety of measures to tackle different aspects of water stress as part of their national programmes related to the implementation of the Water Framework Directive (WFD). The measures can be categorised as follows (Buchanan et al., 2019):

- establishing water balances and water accounts;
- establishing ecological flows (e-flows);
- permitting, registration and control of water abstraction;
- establishing pricing mechanisms promoting cost recovery and sustainable water management;
- diversifying water sources, including using unconventional water resources and water reuse;
- establishing water-saving and water use efficiency schemes;
- augmenting the water supply, including through new storage areas and diversions, land use planning and natural water retention measures.

Taking into account overall policy provisions under the European Green Deal and its supplementary initiatives, such as the circular economy, new climate change adaptation strategy, farm to fork strategy, zero pollution action plan and biodiversity strategy for 2030, various sustainable options for water stress management should be explored at various spatial and temporal scales. Some of the key measures are addressed below as examples offering further inspiration.

6.2 Establishing ecological flows

A flow regime that is based on environmental requirements is a prerequisite for achieving good ecological status in rivers (EC, 2016). Establishing ecologically based flow regimes (Box 6.2) is therefore an important measure in the river basin management plans (RBMPs) (EC, 2019b). In most Member States, work on defining and implementing ecological flows was still ongoing in the second cycle (EC, 2019b). In the second RBMPs, ecological flows were reported to have been derived and implemented for all relevant water bodies in only three Member States. In the majority of Member States, ecological flows have been derived and implemented for only a subset of all water bodies, either in all or in part of their river basin districts (RBDs) (Table 6.1).

Table 6.1 Derivation and implementation of ecological flows in the second RBMPs

Derivation and implementation of ecological flows		Member States
Ecological flows **derived**	in **all** water bodies	*All RBDs*: CY, EE, ES, HU, NL *Some RBDs:* FR (4 RBDs), IT (2 RBDs)
	in **some** water bodies (work is still ongoing)	*All RBDs*: AT, CZ, DK, RO, SE, SI *In some RBDs*: BE (1 RBD), BG (1 RBD), DE (7 RBDs), FI (7 mainland RBDs), FR (10 RBDs), PL (8 RBDs), PT (9 RBDs), UK (England, Northern Ireland, Scotland, Wales)
Ecological flows **implemented**	in **all** water bodies	*All RBDs*: CY, HU, NL *Some RBDs*: FR (2 RBDs)
	in **some** water bodies (work is still ongoing)	*All RBDs*: AT, CZ, EE, ES, RO, SE, SI *Some RBDs*: BG (1 RBD), DE (7 RBDs), FR (2 RBDs), IT (2 RBDs), PL (8 RBDs), PT (8 RBDs), UK (England, Scotland, Wales)
Ecological flows derived **but not implemented** but there are plans to do so in third cycle		*All RBDs*: DK *Some RBDs*: BE (1 RBD), FI (7 mainland RBDs), UK (Northern Ireland)
Ecological flows **not derived** but there are plans to do so in third cycle		All RBDs: HR, LU, LV, MT, SK, *Some RBDs*: BE (7 RBDs), BG (3 RBDs), IT (5 RBDs), PL (1 RBD), PT (1 RBD)
Ecological flows **not derived** and no plans to do so in third cycle		DE (3 RBDs), FI (1 RBD), IT (1 RBD), PL (1 RBD)

Note: For some of the RBDs where there is no intention to derive ecological flows, this is because no river water bodies are reported.

Source: EC (2019b).

Box 6.2 Indicators for defining sustainability in water use

Setting a global threshold in identifying sustainable use of water resources is a scientific challenge. For the time being, overall, three different indicators are widely implemented to define whether water use is sustainable or not. These indicators are:

- *Ecological flows indicating critical stages and discharges.* In principle, the methods for defining ecological flows can be classified into four major categories: (1) hydrological methods; (2) hydraulic rating; (3) habitat simulation models; and (4) holistic methodologies (Zeiringer et al., 2018). An inventory by Ramos et al. (2018) reveals that, in most cases where ecological flows have been derived, they were mainly based on hydrological methods. This means that a static or dynamic fraction of the mean annual flow is defined as ecological flow without making an explicit link to ecological variables. In addition, most respondents do not differentiate ecological flows between dry and normal years. In terms of critical stages and discharges of rivers and artificial canals, ecological flows are defined as minimum flow requirements using hydrological and hydroecological methods (EC, 2016).

- *Critical levels of water stress,* e.g. water exploitation index plus (WEI+) (Raskin and Gleick, 1997). The indicator takes 20 % of water abstraction from water availability in the environment as an indication of water stress. In addition, the *Roadmap to a resource efficient Europe* (EC, 2011a) set this threshold of 20 % as a key goal. The spatial analysis of WEI+ shows that water consumption exceeds the 20 % threshold in many river basins, especially in southern Europe. Under the UN Sustainable Development Goal Indicator 6.4.2, the Food and Agriculture Organization of the United Nations has set the threshold for defining unsustainable management at 25 %.

- *Critical levels of droughts*. Applying a set of available drought indicators, e.g. standard precipitation index, SPI ([15])).

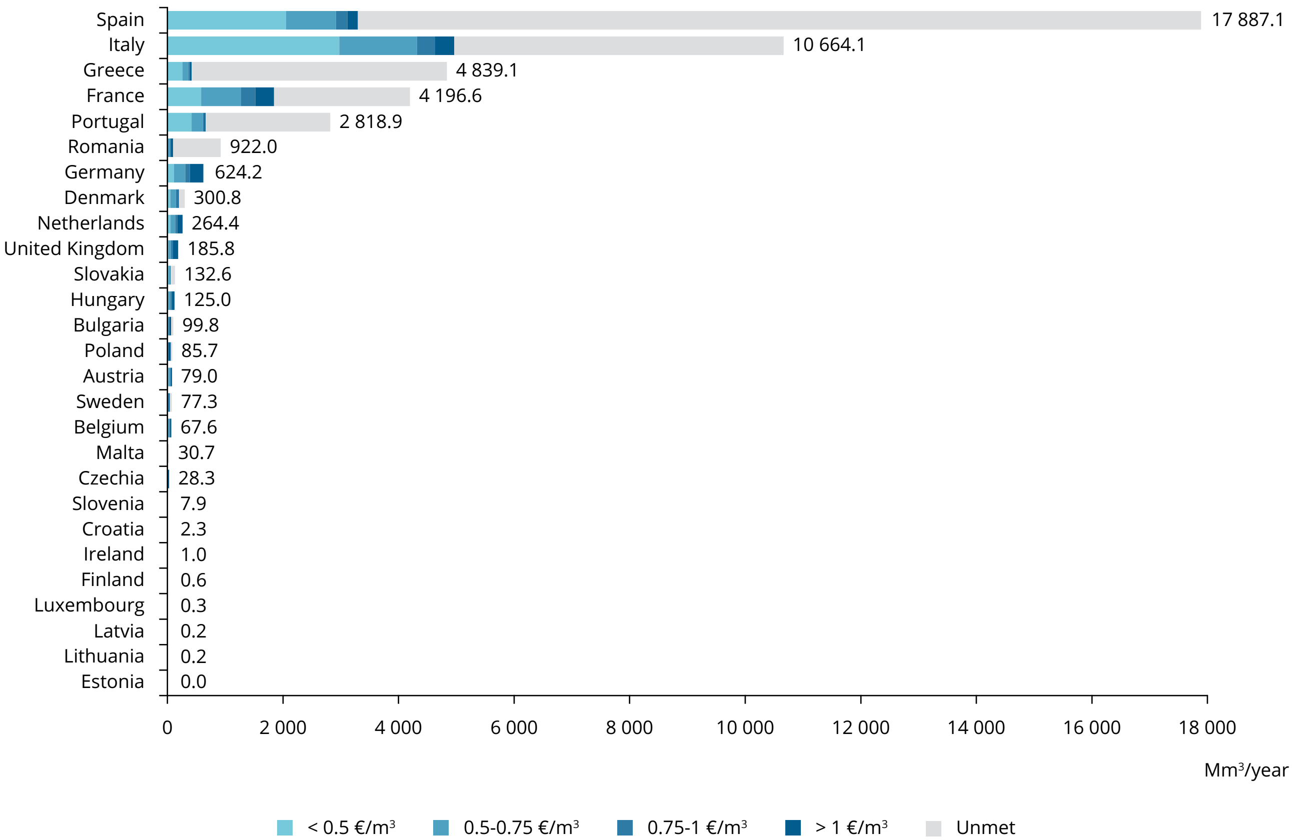
([15]) The SPI is used for detecting and characterising meteorological drought (https://edo.jrc.ec.europa.eu/documents/factsheets/factsheet_spi.pdf).

6.3 Unconventional water supply measures

6.3.1 Water reuse

The new Water Reuse Regulation (EU, 2020b) entered into force in 2020. Its new rules and minimum water quality requirements, designed to stimulate and facilitate safe water reuse in the EU, will apply from 26 June 2023. Currently, water reuse represents a very low share of total water use in Europe, and it is mainly practised in southern Europe (e.g. Cyprus, Malta, Spain) (Figure 6.1). Most reuse schemes aim to generate alternative water supplies for irrigated agriculture or to manage aquifer recharge to mitigate saline intrusion in coastal areas (Buchanan et al., 2019). In principle, the total volumes of water that can be reused for irrigation are significant, and they may help reduce water stress by up to around 10 % in regions where irrigation is an important activity (Bouraoui et al., 2017). The treatment and energy costs for water reuse are low compared with the costs of the infrastructure required to transport reclaimed water from urban waste water treatment plants to irrigated areas. As these costs are highly variable, the economic attractiveness of reclaimed water for farmers may differ significantly (Figure 6.1). However, there are examples (e.g. Cyprus) of applying an incentive pricing policy to further promote water reuse (Bouraoui et al., 2017).

Figure 6.1 Water reuse potential per EU Member State (Mm³ per year) for different levels of production cost



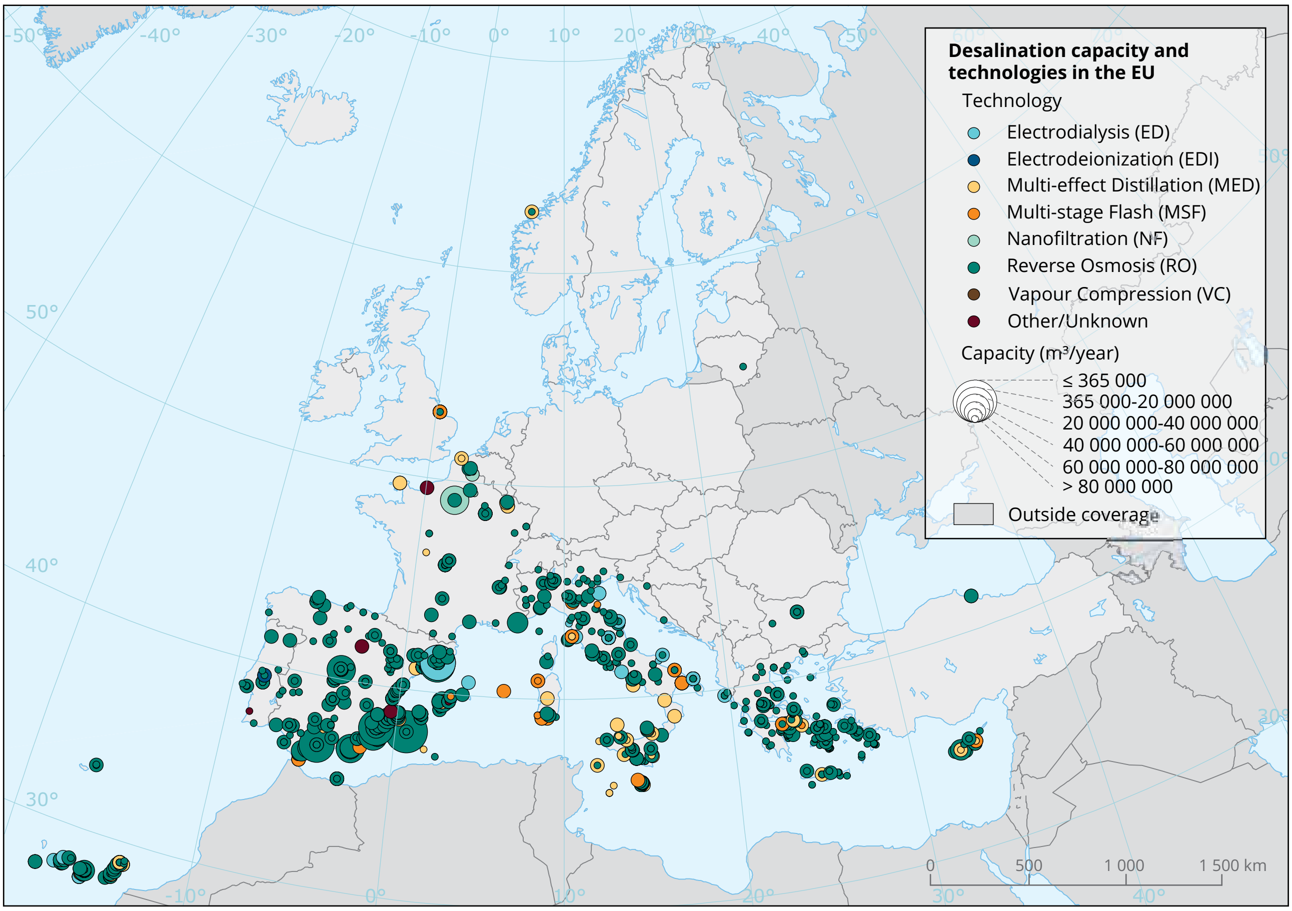
Note: Amounts of reclaimed water that can be potentially deployed at different total costs for 26 EU Member States (Cyprus not included due to missing irrigation estimates) and the United Kingdom. 'Unmet' indicates that irrigation demand estimated for the country in excess of potential supply of reclaimed water.

Source: Bouraoui et al. (2017).

6.3.2 Desalination

Desalination has been mainly applied for drinking water purposes (Figure 6.2). Currently, the highest share of the installed desalination capacity in Europe lies in the Mediterranean (Map 6.1). Under serious water stress conditions, desalination is becoming a more affordable and reliable option than other solutions for water supply (Hidalgo Gonzalez et al., 2020). The costs have decreased significantly over recent decades,, and for reverse osmosis of seawater in the Mediterranean they could be around EUR 0.65/m³ (World Bank, 2019). For brackish waters the costs could be lower. However, the environmental impacts of desalination must be assessed carefully, because desalination is associated with significant environmental problems such as brine disposal, energy use and CO_2 emissions.

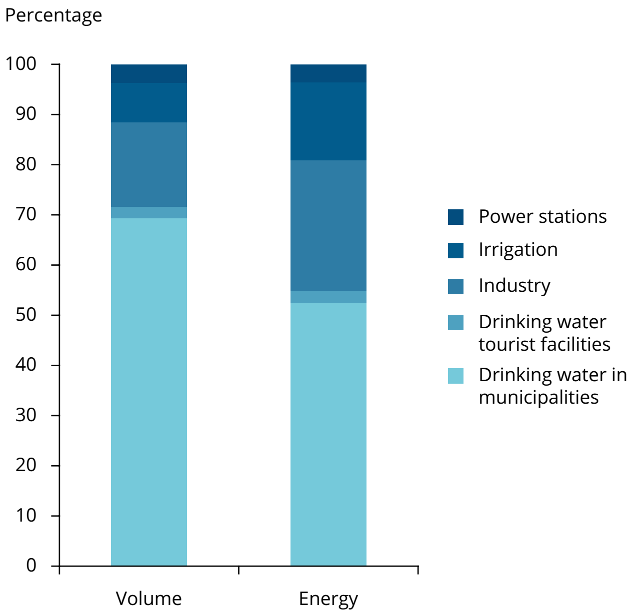
Map 6.1 Desalination capacity and technologies in the EU



Reference data: ©ESRI

Source: Magagna et al. (2019).

Figure 6.2 Volume supplied and energy used during desalination of water for various end users



Source: Magagna et al. (2019).

6.4 Nature-based solutions and ecosystem services

The 2012 *Blueprint to safeguard Europe's water resources* (EC, 2012) mentioned wetland restoration, floodplain restoration and groundwater recharge as promising nature-based multifunctional storage and regulation elements. Until now, there have only been a few well-documented cases of NbS that have been specifically designed to address the issues of water stress. The 2020 overview of the state of the art in EU-funded projects does not change this conclusion, even if drought management can also benefit from several NbS (EC, 2020i): there is a wide range of **small-scale on-farm measures** that increase the infiltration of rainfall into the soil and/or the storage of groundwater.

NbS can be cost-effective for achieving the Sustainable Development Goals and for climate adaptation in cities (IPBES, 2019). As an example, the Horizon 2020 Naturvation project ([16]) assesses what NbS can achieve in cities, examines how innovation is taking place, and works with communities and stakeholders to develop the knowledge and tools required to realise the potential of NbS for meeting urban sustainability goals.

The Horizon 2020-funded NAIAD project ([17]), which aims to demonstrate upscaling the implementation of NbS, emphasises the insurance value of such measures as a way of making convincing business cases. The insurance sector is a natural partner for this approach, both as an insurance provider and as an institutional investor. The project highlights the roles of the funding, financing and procurement phases of NbS implementation projects. The proposed approach relies on collaborative modelling approaches, because only collaboratively built consensus can include the diversity of affected and benefiting stakeholders and have confidence in bringing all relevant benefits together in a complete business case (Altamirano et al., 2020). One of the project's case studies deals with water stress, albeit in qualitative terms only: the Medina del Campo aquifer in central Spain. The Rotterdam case study in the same project proposes measures to improve both flood and drought management in an urban area.

Current challenges in implementing NbS include the necessary upscaling of measures: challenges in financing, in quantifying the benefits and in securing the acceptance of the benefits. Furthermore, there are knowledge gaps in understanding and securing social equity in the impacts of climate change.

6.4.1 Natural water retention measures

Since the early 1900s, dams have been constructed at a rapid rate across European rivers, advocated by the need to supply drinking and agricultural water and produce hydropower. Almost 30 000 surface water bodies in the 27 EU Member States (EU-27), Norway and the UK (i.e. 20 % of the total) were found to be significantly affected by barriers in the second RBMPs, with one third of them designated as heavily modified. The current number of barriers could exceed one million (EEA, 2021a, 2021b). Since 2000, the WFD provisions have provided a stricter framework for the justification and construction of dams. Nevertheless, despite their overall alignment with the above policy lines, several EU Member States (e.g. France, Greece) have reported their intention to further construct supply-oriented measures, such as reservoirs or diversions (inter-basin transfers), because they consider (whether justified or not) that these measures could contribute to various goals, including water and energy security, adaptation to climate change, achievement of ecological flows in water-stressed aquatic ecosystems and protection of overexploited groundwater bodies from further deterioration (Buchanan et al., 2019).

The RBMPs of the various EU Member States have not fully exploited the potential of natural water retention measures ([18]). The links between urban planning and water management have

([16]) https://naturvation.eu/home
([17]) http://naiad2020.eu
([18]) Find further information on the catalogue of natural water retention measures at www.nwrm.eu

rarely been highlighted. National policies related to territorial planning and economic development plans could promote these approaches more in the future (Buchanan et al., 2019) (see Section 6.2). The recent adoption of the EU biodiversity strategy for 2030, which explicitly states the importance of restoring freshwater ecosystems and river continuity, sets out the ambitious goal of restoring 25 000 km of free-flowing rivers by 2030.

6.4.2 Managed aquifer recharge

Managed aquifer recharge (MAR) is one of the options to improve aquifer conditions and raise groundwater levels, provided that it is done in compliance with the WFD and Groundwater Directive (EU, 2006). For instance, particular attention should be given to the quality of the water used in the process (to avoid pollutants entering the groundwater body and not compromise environmental objectives). MAR is the intentional recharge of water to suitable aquifers for subsequent recovery or to realise environmental benefits; the managed process should ensure adequate protection of human health and the environment. MAR can also reduce the occurrence and degree of flooding. Various methods are used to recharge aquifers, including bank infiltration, infiltration in boreholes and wells, in-channel interception and run-off harvesting. Some of these methods are more nature based than others, for example infiltration from wells may be considered a less natural approach. MAR is already widely practised across the world. The most common incentives are to increase the buffering capacity to withstand seasonal droughts, to manage saline intrusion and to create a strategic reserve for emergency situations. The benefits may extend to the ecology of the area and in specific cases to protecting wooden pilings or managing land subsidence.

6.4.3 Applying ecosystem services in water stress management

Looking at water stress from an ecosystem services perspective puts a strong focus on combinations of economic benefits for water-using sectors and of environmental and social values. This broadened scope is required to solve the problems caused by more traditional practices. As IPBES states (IPBES, 2019): 'Economic incentives have generally favoured expanding economic activity, and often environmental harm, over conservation or restoration. Incorporating the consideration of the multiple values of ecosystem functions and of nature's contributions to people into economic incentives has, in the economy, been shown to permit better ecological, economic and social outcomes.'

There are two ecosystem services that come to the fore in the context of water stress management: (1) provision of water; and (2) temporary storage of water in aquifers, rivers and lakes during the wet season for use in dry spells. In addition, water bodies have an attenuating effect on temperature fluctuations during heatwaves, especially in urban areas (i.e. acting as a regulating service, connected to climate regulation as a prominent ecosystem service) (Maes et al., 2020).

Temporary water storage in aquifers and lakes helps to maintain, in parallel, the base flow in rivers during dry spells, thus providing the necessary conditions for water-dependent ecosystems. Unsustainable water abstraction and land use changes causing rapid discharge of water during rainfall events, and a decrease in surface water storage and groundwater recharge, have led to a decrease in both ecosystem services (see Section 3.3). This decrease is in some cases exacerbated by water quality problems, such as eutrophication and algal blooms in surface waters that become stagnant, saltwater intrusion in coastal areas, or reaching arsenic-contaminated water in overexploited aquifers.

The benefits of restoring ecosystem services to their natural level extend well beyond the interests of the economic sectors and stakeholders that have caused the deterioration. The case for an ecosystem services approach can thus only be made if the affected stakeholders are known and involved in the assessment. Over recent years much research has aimed at mapping ecosystem services and quantifying their economic impacts for a wide range of water-dependent sectors. Examples that deal specifically with water stress, however, are scarce. The recent exercise, mapping an assessment of ecosystems and their services (MAES) (Maes et al., 2020) does not include ecosystem services specifically connected to water stress, but it illustrates how the degradation of ecosystems hampers their provisioning services (which also relate to water, both in quantity and quality). It thus provides a framework for future analysis of water stress.

The examples in Box 6.3 provide an overview of the state of play with regard to applying the ecosystem services concept to water stress problems. Many initiatives are already evolving and good progress is being made in Europe. Knowledge gaps to be bridged include connecting ecological status to drought or stress indicators and putting a value on the appreciation of environmental quality.

Box 6.3 Examples of analytical frameworks on ecosystem services assessment

The Knowledge Innovation Project on an integrated system for natural capital and ecosystem services accounting (KIP INCA) is preparing, at the time of writing this report, several outputs: accounts on ecosystem extent and ecosystem condition; accounts on ecosystem services; and a valuation of natural capital and ecosystem services. Water abstraction is one of the provisioning services that is analysed in the project (EC, 2020g). A question to be answered is 'What is the value of ecosystems in reducing or preventing water stress?' (by analogy with the value of ecosystems in flood control, which was estimated at EUR 16 billion for the EU-27 and the UK in 2012 (Petersen, 2019)).

The Blue2 project mapped the size and impacts of four environmental pressures and assessed a selection of related measures. One of the pressures considered is water abstraction. To compare and appreciate the different model outcomes for the measures considered, a step-wise approach was developed, based on estimations of the value of ecosystem services by willingness-to-pay (WTP) approaches (Schasfoort et al., 2018). Some data are available in the literature on the WTP for an improvement or deterioration of ecological status. Apart from the uncertainties and discussions of WTP approaches, a methodological difficulty that remains to be solved is connecting a step up or down in ecological status to one of the available drought indicators (e.g. water exploitation index plus or Q10 flow indicator).

On a similar note, the Dessin project on demonstrating how ecosystem services can enable innovation in the water sector aimed to establish the link between Water Framework Directive water body environmental status and ecosystem condition (in the Drivers-Pressures-State-Impact-Responses framework). The focus on beneficiaries allows clearer identification of co-benefits and the incorporation of economic values, both relevant for the integrated management of water resources (Anzaldua et al., 2018).

6.5 Towards managing the water-energy-food-ecosystems nexus

Societies around the world have always been aware that water, energy, land and food resources are interdependent, while they also interact with natural ecosystems. Policy and research have addressed this idea already since the late 1940s and 1960s (Wichelns, 2017). The International Conference on Water and the Environment in Dublin and the UN Conference on Environment and Development in Rio de Janeiro, which were held in 1992, contributed to the development of the principles that characterise the integrated water resources management (IWRM) paradigm. The Global Water Partnership initiative summed up IWRM in the following definition in 2000 (Global Water Partnership, 2000): 'A process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.'

Therefore, the IWRM paradigm specifically addresses three pillars, namely environmental sustainability, economic efficiency and social justice, which are also used to describe our understanding of sustainable management. Furthermore, it makes specific reference to 'water, land and related resources' and to the need to protect and conserve 'vital ecosystems'.

Nevertheless, research and policy have often developed in 'working silos' over recent decades, as a result of scientific specialisation and administrational mandate. This has resulted in separate and often conflicting sectoral goals, strategies and policies, as well as fragmented actions overall (Leck et al., 2015). Furthermore, while research has also addressed the interactions between different resources, the relevant studies have mostly focused on the interactions between water and another resource (e.g. water-energy or water-food), thus missing a more holistic and systemic perspective (Endo et al., 2017).

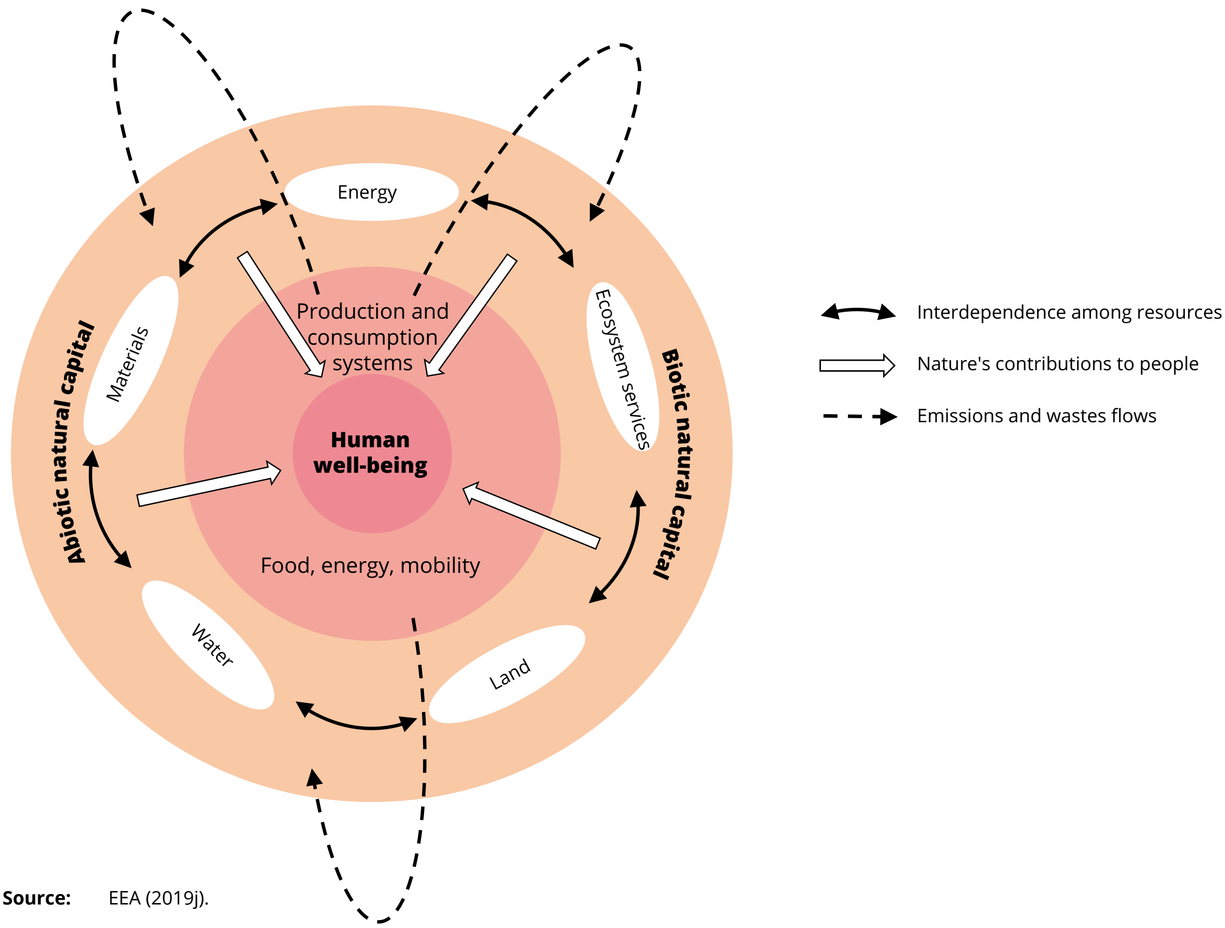
The water-energy-land-food nexus is a holistic conceptual framework, which underlines the need for integrated and systemic thinking and for cross-sectoral and multi-scale actions for the protection and management of resource systems. While it carries the legacy of the IWRM paradigm, it also considers the experiences gained from its implementation, and it modifies and expands it. The EEA has recently advocated the use of the water-energy-land-materials-ecosystem services nexus ('resource nexus') for systemic analysis of production-consumption systems (see Box 6.4).

Box 6.4 Development of the nexus concept

The nexus concept was first introduced in 2011, when the World Economic Forum published a report on the water-food-energy-climate nexus (Waughray, 2011) and the German Federal Government organised the Bonn 2011 International Conference with the theme 'The water, energy and food security nexus — solutions for the green economy' (Martin-Nagle et al., 2012). The links to biodiversity, ecosystems and their services were also highlighted in subsequent research publications (Karabulut et al., 2016). Thus, the core of the nexus is often expanded to include further considerations, such as interactions with climate and ecosystems, and to address not only resources themselves but also the management objectives for the resources (e.g. water, energy and food security concerns). The nexus concept has also been studied in the context of transboundary river basin management in the Mekong river (Keskinen et al., 2015) and the Upper Blue Nile (Allam and Eltahir, 2019).The overall concept of the nexus formed the underlying basis for the establishment of the Sustainable Development Goals by the United Nations in 2015. These global goals highlight the need for systemic approaches to meeting their targets, including those goals related to resource management (Weitz et al., 2014).

In 2019, the EEA advocated the 'resource nexus' concept as one of the main approaches to systemic analysis of synergies and trade-offs to achieve a sustainable transition of the European economy (EEA, 2019j). In this case, water, land, energy and ecosystems services, as well as materials, are considered interdependent resources, which are exploited by the food system and other production-consumption systems (e.g. energy system, mobility system). Production-consumption systems contribute to human well-being, relying on the intake of resources from the environment and affecting the environment through emissions and waste (Figure 6.3).

Figure 6.3 Proposed set-up for understanding the water-energy-land-materials-ecosystem services nexus and its interactions with production-consumption systems



Source: EEA (2019j).

While the discussion on nexuses has been widely theoretical or related to assessment studies, putting nexuses into practice in real-life applications has been limited in Europe and worldwide (Bizikova et al., 2013; Leck et al., 2015). The recently formed Nexus Cluster is developing a list of relevant projects around the globe, including research projects funded by the EU (e.g. Sim4Nexus): https://www.nexuscluster.eu/Projects.aspx

A systemic analysis of water stress drivers, pressures and impacts can help researchers, water practitioners and policymakers to develop a wider and more holistic understanding of the interdependent relationships between water, energy, food, ecosystem services, and their further relationships with climate. Adopting separate policy goals and management practices for each of these systems can create trade-offs, whereby the benefits from using one resource may critically limit the benefits from using another resource (e.g. expansion of farmed land for food production causing overexploitation and pollution of groundwater, thus limiting the availability of groundwater of sufficient quality for drinking, etc.). Integrated management responses can find compromise solutions that deliver working results for sustainable management of both resources. Furthermore, win-win synergies can be explored for reaping the benefits from the use of more than one resource: for example, water reuse can reduce the need for groundwater abstraction from overexploited aquifers, as well as the need for fertilisation because of the nutrient content of reclaimed water, and the increased needs for energy to generate reclaimed water can be offset by the reduced energy needed for pumping groundwater and for producing and applying fertilisers (Ringler et al., 2013; Psomas et al., 2018).

6.6 Need for policy responses that promote systemic change

Mainstreaming water management considerations into other environmental and sectoral policies and finding synergies across them are key to enabling sustainable water management and reducing society's exposure and vulnerability to water stress. The recent WFD fitness check highlighted that one of the factors contributing to the effectiveness of water directives in progressing towards their objectives are the (binding) cross-references to the WFD's objectives in other EU policies (EC et al., 2019). However, despite the WFD being in force for 20 years, few integrated governance frameworks have been implemented (EC et al., 2019). Until recently, sectoral policies at EU level even contributed to increasing pressures on water resources, for instance by promoting agricultural development, industrial growth or the development of hydropower without sufficient environmental safeguards (Rouillard et al., 2018; Carvalho et al., 2019; Kampa et al., 2020).

Under the Sixth and Seventh Environment Action Programmes (2002-2012 and 2014-2020, respectively), greater attention was given to aligning sectoral policy objectives with environmental targets. To tackle threats from water stress, the focus has been on promoting efficient use of water in economic activities. The 2011 *Roadmap to a resource efficient Europe*, the 2020 communication on a new circular economy, and many of the initiatives under the European Innovation Partnership on Water, as well as those funded through the Horizon 2020 research programme, include technological innovations for increasing water efficiency in production systems, as well as for waste minimisation and recycling strategies. This effectively opened a channel for the more active involvement of the industrial sector in EU environmental research and innovation activities and strengthened corporate social responsibility and extended producer responsibility schemes. The proposal for the Eighth Environment Action Programme (8th EAP) (EC, 2020h), published in 2020, endorses the environmental goals of the European Green Deal and is meant to support the implementation and enforcement of its environmental and climate policies, in part through the roll-out of a new monitoring framework. This is relevant to EU water policy in general, as monitoring, implementation and enforcement are aspects in which shortcomings have been recurrent. Among its priority objectives, the proposed 8th EAP includes decoupling economic growth from resource use and enhancing natural capital (including water resources and freshwater ecosystems).

As shown in Chapter 4, manufacturing is the sector in which decoupling is the most prominent, and this is reflected in all EU regions. To ensure the continuity of this trend and its replication in other economic activities, it is crucial to learn from these developments. Specifically, in the case of the industrial sector, sharing data on investments in water-saving technologies would be fundamental from both the water and the resource efficiency policy perspectives. Improvements in efficiency stemming from implementations at the company level should be more transparently documented to promote technology/knowledge transfer and cross-fertilisation. This requires a reporting architecture that centralises the knowledge while protecting the strategic interests of private enterprises. Any progress made here could open up pathways to increase transparency in other sectors such as agriculture, mining and quarrying and establish a benchmark for concrete, integrated action to achieve systemic change.

6.6.1 Water-dependent ecosystems

When developing their RBMPs under the WFD, authorities must pay particular attention to wetlands, which are often protected under the Birds Directive (EU, 2009b) and Habitats Directive (EU, 1992). These two directives have commonly been used to reinforce the case for reducing abstraction pressures in surface water and groundwater, leading to the degradation of wetlands and groundwater-dependent ecosystems.

Although the abstraction pressure on renewable freshwater resources has started to decline over recent decades (see Chapter 4), substantial improvements are not yet seen in the quantitative status of groundwater bodies. There are two potential reasons for this. Firstly, groundwater flow and flush-out of pollutants is a slow and complex process in certain types of aquifers, so there can be a long lag time between reducing abstraction and significant recovery of groundwater levels. Secondly, climate change and socio-economic development (e.g. population growth, land use change) may aggravate existing water balance deficits, thus overriding the gains from recently implemented measures (Psomas et al., 2021).

Several EU initiatives more or less indirectly support the use of NbS to enhance Europe's vulnerability to water stress and risk of droughts. The multifunctional role of forests in regulating water flows in rural and urban catchments and in increasing resilience to climate change is recognised by the new EU forest strategy (EC, 2021b). Wetlands and forests for instance form an important part of the EU strategy on green infrastructure, which aims to build a coherent and resilient network of ecological corridors across Europe. The recent biodiversity strategy for 2030 sets out to legally protect a minimum of 30 % of the EU's land area and to promote widespread restoration. The strategy emphasises in particular the importance of restoring ecological flows in rivers, notably through a review of abstraction permits. Furthermore, the still elusive, yet achievable co-benefits of green infrastructure and NbS pursued in the policies mentioned represent a focus for economic activities such as tourism, recreation, sustainable agriculture and urban water services. This is especially relevant as an opportunity to address water abstraction, resulting in multiple pressures on freshwater ecosystems.

6.6.2 Circular economy and water reuse

One example of this integrated thinking, from a circular economy perspective, is the adoption of the Water Reuse Regulation (EU, 2020b), previously introduced in Section 6.3.1. This new regulation will enable the scaling up of small experimental projects and local initiatives and will widen the scope of water reuse applications in Europe. Here, the notion of 'getting the economics right', included in the circular economy action plan, is a shared principle for water policy, and it will be fundamental for the successful implementation of the new Water Reuse Regulation. An important consideration is that, where water is scarce, the benefit of reuse is to alleviate pressures on surface water and groundwater bodies stemming from agricultural abstraction and from pollution from waste water discharges. However, to effectively reduce abstraction pressure, reuse must act as a substitute for existing abstraction and not as an additional source of water for irrigation (Drewes et al., 2017).

6.6.3 Water pricing, cost recovery and sustainable finance

As mentioned in Chapter 2, gaps remain in setting pricing strategies that effectively lead to the efficient use of water. The recent evaluation of the second RBMPs found that a number of Member States have upgraded their water pricing policies, notably by fulfilling the ex-ante conditionality for water under the Common Provisions Regulation for the European Structural and Investment Funds for the period 2014-2020. Furthermore, increased funding and investments are still necessary to meet the objectives of the WFD (EC, 2019b). Here, the wider exploitation of EU funds, including the EUR 1 trillion of sustainable investments over the next decade pledged through the Green Deal investment plan, should finally happen. They should also be used to leverage private investment employing the EU taxonomy for sustainable finance (contributing to achieving the third environmental objective of the taxonomy: 'Sustainable use and protection of water and marine resources') and the new policy tools that will emerge from the renewed sustainable finance strategy. This complementary source of much-needed funding could be used to promote more ambitious planning and implement measures that help correct imbalances in cost bearing, effectively levelling the playing field for different water users (including the environment). However, any future investments must take account of past experiences.

6.6.4 Water and agriculture

The common agricultural policy (CAP) programming period for 2014-2020 aimed to incentivise sustainable management of water in agriculture by linking CAP payments to compliance with the national legislation that implements the WFD. To receive payments, farmers had to comply with good agricultural and environmental conditions (GAEC), one of which was a requirement to comply with authorisation procedures for water abstraction (i.e. GAEC 2). In addition, the European Agricultural Fund for Rural Development (EAFRD) recognised efficient water use as a key strategic objective for European agriculture, and support was available through rural development plans for sustainable investment in conserving water, improving irrigation infrastructures and enabling farmers to improve irrigation techniques. Given the high cost of switching to more efficient water use, rural development plans have been pivotal in supporting investments in improving the efficiency of the use of irrigation water in agriculture. In 2018, more than 5 % of irrigated land in the EU-27 was under management contracts to improve water use efficiency (EC, 2021b).

Article 46 of the EAFRD 2014-2020 required that investments in new and existing irrigation systems comply with specific water-saving requirements, with view to limiting the potential to increase water stress and avoid the rebound effect (see Box 6.5). Some countries, such as Croatia, went beyond these minimum requirements and required water savings of at least 25 % to be eligible to receive support for modernising of irrigation equipment and improving the efficiency of water use.

Box 6.5 Managing the rebound effect and the Jevons paradox in water stress situations

Increasing the efficiency of production is one of the main goals of European policies, with the overall goal being to decouple economic growth from resource use. However, improvements in the efficiency of resource use do not always translate into net savings, because producers and consumers adapt their behaviour (Paul et al., 2019). The rebound effect refers to the situation in which efficiency gains do not result in a reduction in resource use. In some cases, the same chain of events even results in higher net resource consumption; this is known as the Jevons paradox.

The rebound effect can occur when efficiency improvements affect consumers' positive perception of the final product, leading to less restraint in its consumption or in the consumption of other products. It can also occur when efficiency improvements affect economic performance by reducing production costs. This may lead to increased production, reduction in product prices, or cost saving being used to expand production elsewhere. Psychosocial and economic rebound effects lead to increased demand (Paul et al., 2019). The rebound effect is well documented on the consumption of a number of resources, such as energy use.

In water management, there is substantial evidence for the rebound effect in irrigation water use, where the adoption of more water-efficient devices is not necessarily accompanied by a reduction in water abstraction (Ward and Pulido-Velazquez, 2008; Dumont et al., 2013; Gómez and Pérez-Blanco, 2014; Berbel et al., 2015, 2018). In some cases, the saved water can be redirected to other beneficial economic uses, for instance higher value but more water-consuming crops or an expansion in the area of irrigated land. As a result, this may lead to a reduction in field water losses, reduced infiltration and percolation, and reduced groundwater recharge and return flows to surface water bodies.

In other cases, such as in the Mancha Oriental in Spain, increasing efficiency has been accompanied with a reduction in total water consumption, despite an increase in the irrigated area (JCRMO, 2019). In this case, the modernisation of irrigation infrastructure occurred in conjunction with greater controls over water use by the organisation in charge of monitoring and controlling its use. Thus, the net effect of adopting more efficient irrigation systems on agricultural abstraction pressure depends on several factors, including technological, agronomic and climatic conditions (e.g. influencing irrigated crop evapotranspiration) and the actions implemented in addition of the incremental gains in efficiency.

The new CAP programming cycle for 2021-2027 provides fresh opportunity to integrate more ambitious environmental objectives that acknowledge local water resource limitations and scarcity situations. In particular, the new 'eco-schemes' aim to support farmers who observe agricultural practices that are beneficial to the environment and climate. New indicators are included in the Commission's proposal to assess the CAP's contribution to the objective of fostering sustainable development and efficient management of natural resources such as water. For instance, the water exploitation index Plus (WEI+) is included as a new impact indicator on water resources. It can contribute to improving the measurement of how the objectives related to the conservation of water resources are met in the long term and for future policy design.

Given the significance of agricultural abstraction pressures on European water bodies, additional efforts are necessary to better integrate the objectives of the different policies, and it is essential that future agricultural policy interventions not only work in synergy with water policies but also actively support them. Potential additional requirements under CAP conditionalities could be minimum efficiency standards for the irrigation infrastructure associated with a water permit.

In the funding available under rural development plans (2014-2020), the water-saving targets were not accompanied by a requirement to adjust water permits and ensure water savings from increased efficiency that benefited the water balances of linked surface water and groundwater bodies. Overall, investments in water efficiency programmes should be accompanied by a careful consideration of water balances at farm, aquifer and basin level, including consideration of surface-groundwater exchanges (EC, 2015d). Clear limits on resource use should accompany efficiency targets and should be established at hydrologically relevant spatial scales. Policies promoting more efficient use of natural resources should also include a realistic assessment of the possible savings and the impact of the policy on the producer and consumer impact.

Furthermore, some rural development plans in the period 2014-2020 integrated measures for adopting climate adaptation and the need to build resilience into farming systems through appropriate crop diversification (e.g. in Greece) and adopting drought-resistant crops (in Romania) (Berglund et al., 2017). In view of climate change impacts, the next CAP programming period should ensure that countries support the adoption of crops or varieties/hybrids with a reduced requirement for water and more resistance to droughts and the adoption of appropriate soil management practices, following the principles of agroecology and organic farming, to increase farm resilience while preserving water resources. Although CAP support for agroecological practices and organic farming has increased in the recent reforms, more support will be needed to reduce agricultural pressures on the environment and foster a large-scale transition towards more sustainable and resilient farming systems.

It will also be important to overcome the known limitations in terms of the institutional and technical capacities for monitoring and enforcement. The requirements for implementing the WFD have motivated water authorities to push water suppliers to improve data collection, organisation and reporting. For example, water utilities and irrigation cooperatives have accelerated the installation of water meters or improved their maintenance and repair (Buchanan et al., 2019). However, opportunities remain. For instance, the data and statistics reported frequently lack the necessary accuracy, because of the issue of overabstraction (including incidents of unauthorised and unregistered abstraction). The challenge is most serious in the agricultural sector and particularly in southern Europe (Buchanan et al., 2019).

Digitalisation has already become common in all sectors, but the exploration and validation of its potential applications differs by sector (e.g. energy is a frontrunner, water follows slowly). In the context of the updated EU digital strategy, this should be seen as an opportunity to use the experience of sectors that are well ahead to leapfrog towards meaningful and effective exploitation of digital solutions. For implementing water policy, digital applications could facilitate data collection and information sharing while reducing the administrative burden associated with reporting. Digitalising water is also seen as an enabler of circular economy models (e.g. turning waste water treatment plants into 'blue resource centres' ([19])) and could have potential to increase participation and mutual learning to identify new and innovative ways of overcoming the societal challenges of our era.

The slow transition towards sustainable water use in agriculture is linked to the costs and complexities not only of modifying farm systems but also of reforming whole production and consumption systems (EC, 2020j). Transforming agricultural systems to tackle water scarcity issues and to become more resilient to droughts requires a transition in supply chains and consumer demand to give the right market signals to farmers (EEA, 2017b). The new farm to fork strategy illustrates how the European Green Deal aims to support such integrated and systemic thinking and promote more sustainable food systems. Emphasis is given not only to providing the right incentives to producers but also to leveraging sustainable investments from food system stakeholders (such as cooperatives and supermarkets), reducing waste throughout the food chain, and moving consumption patterns towards sustainable diets to reduce the total demand for natural resources, including water (EEA, 2021c).

6.6.5 Renewable energy systems

Such systemic thinking to reduce Europe's vulnerability to water stress still has to permeate policies in other economic sectors, although some safeguards already exist. For instance, the 2030 climate target plan and the EU strategy for energy system integration are major EU policy areas that drive substantial levels of investment, notably towards renewable energy.

([19]) For more information see: https://cordis.europa.eu/project/id/690323

Achieving a carbon-neutral Europe by 2050, without increasing the pressure on freshwater resources, requires shifting the focus onto the systemic challenges characterising this transition. Low-carbon technologies should be considered not only from the perspective of expected gains in CO_2 emissions but also from the perspective of their water requirements (Magagna et al., 2019) (Box 6.6), because some renewable sources of energy can increase water scarcity and vulnerability to droughts, for instance the large-scale adoption of biofuels or hydropower affecting the hydrology and hydromorphological dynamics of surface water bodies (Vanham et al., 2019). Directive 2009/28/EC (EU, 2009a) on the promotion of the use of energy from renewable resources recognises this when it calls for using sustainability criteria when cultivating crops for biofuels. In such cases, Member States will need to ensure that energy policies do not encourage the expansion of irrigation for the production of bioenergy where basins and aquifers are already overexploited. Currently, no Member States have such a safeguard in place. With the renewed and expanded commitments on climate neutrality and 80 % of electricity to be produced from renewable sources by 2050, this becomes increasingly relevant. The classification system for 'green' and 'sustainable' economic activities under the sustainable finance taxonomy should provide an additional layer of protection.

Box 6.6 Further deployment of current hydrogen solutions for electricity storage could increase total water consumption

According to the European Commission's hydrogen strategy for a climate-neutral Europe (EC, 2020e), increased production of hydrogen could account for up to 16-20 % of total EU energy production. Hydrogen could be used to store surplus production of electricity, and then convert it back to hydrogen gas, which could be used in combustion engines generating kinetic power and water. It could be applied in various sectors, but mostly in transport and industry. However, further deployment of current hydrogen solutions could increase water consumption in the energy sector by more than 30 %.

Sources: Magagna et al. (2019); Hidalgo Gonzalez et al. (2020); Moya et al. (2020).

6.6.6 Forging a climate-resilient Europe: the new EU strategy on adaptation to climate change

The EU climate change adaptation strategy from 2021 aims to realise the 2050 vision of a climate-resilient Union, by making adaptation smarter, more systemic and swifter and by stepping up international action. It recognises that adaptation policy has a systemic nature, and it calls for adaptation action to be implemented 'in an integrated manner with other European Green Deal initiatives' (EC, 2021a). It aims to build on and expand the achievements of the 2013 strategy regarding the mainstreaming of adaptation into EU policies and the incorporation of climate risk into decision-making (EC, 2021). This represents an opportunity to build on the synergies between water stress policies and climate adaptation strategies, which according to recent assessments are not fully exploited at Member State and river basin levels (Buchanan et al., 2019). Furthermore, Member States not yet facing water stress are not taking sufficient action to address future threats as a result of climate change (Buchanan et al., 2019). As climate change progresses, the intersection between adaptation measures, water and agriculture will gain relevance. On the basis of the expected changes in growing seasons and suitable crops across different European regions, economic integration and coordinated economic planning will be crucial to ensure the resilience of the EU economy. The collection of climate-related data, the enhancement of their usability, and the transfer of knowledge and technology will also be fundamental, and digitalisation could play a facilitating role in all of these. Here, once more, the lessons learned from the energy sector in setting up the Just Transition Mechanism could prove useful in keeping up with the pace of environmental change.

6.7 The role of EU innovation policy in reducing water stress

Over the last two decades, the European Commission has laid the foundations for EU innovation policy and taken action to generate the necessary conditions for innovation to flourish in the region (European Parliament, 2020). Financially underpinned by the Horizon 2020 programme, the innovation union policy initiative set out to secure Europe's global competitiveness (EC, 2015e). The refreshed goals for EU research and innovation policy, the three 'O's — open innovation, open science, open to the world — further reinforced this vision (EC, 2021c). Over time, these policies have supported numerous research, development, innovation and demonstration projects on climate change adaptation, environmental protection and resource efficiency. They have also enabled the creation and operation of various initiatives and partnerships that foster innovation in Europe, including in the area of water and the environment: European innovation partnerships (EIPs) (e.g. EIP-Water, EIP-Agriculture); joint efforts by the European Institute of Innovation and Technology's innovation hubs (e.g. the project Water Scarcity in South); joint programming initiatives (e.g. JPI Water, JPI Climate, JPI FACCE (Agriculture, Food Security and Climate Change), JPI Oceans); joint technology initiatives and European technology platforms (e.g. WaterEurope, formerly WssTP). Furthermore, European research organisations on water have teamed up to create thematic fora (e.g. EurAqua).

Securing Europe's leadership in scientific excellence and innovation as a way to stimulate its economy, boost climate action and promote sustainable development continues to be a priority for the European Commission, as set out in the reflection paper *Towards a sustainable Europe by 2030*

(EC, 2019g) and manifested in the European Green Deal (EC, 2019e). As regards water stress and climate resilience, the new EU strategy on climate change adaptation and the mission on adaptation, which informs the new Horizon Europe programme, depend heavily on innovation to generate region-specific portfolios of solutions to be demonstrated in a large number of European communities and regions (EC, 2020a). A good proportion of such solutions could be developed by small and medium-sized enterprises capable of exploiting the capacity generated by Copernicus —the EU's Earth observation programme — and other sources, which would thereby seize a share of the value of the data economy envisaged in the updated EU digital strategy (EC, 2020i).

In the field of water, European research and innovation is currently focusing on a wide range of topics (see Annex 1 for selected EU projects related to water stress management). The aspects most relevant to the topics of water quantity and water stress are:

- better monitoring of the Earth and its climate and of water uses (e.g. satellite technology, remote sensing, unstaffed aerial vehicles, citizen observatories and information crowdsourcing, digitalisation of the water sector);
- better data management and analysis (e.g. internet of things, big data science, machine learning, geographical information systems, advanced information and communication technologies, integrated data visualisation and decision support platforms);
- better socio-environmental modelling and forecasting (e.g. near-real-time modelling and forecasting of natural phenomena including hydrological and drought forecasting, agent-based modelling of coupled socio-environmental systems, elicitation of social attitudes through serious gaming);
- better technologies for increasing technical water efficiency (e.g. leakage detection and control in water networks, precision agriculture technologies, industrial symbiosis);
- better tools for raising awareness and controlling water use (e.g. mobile applications promoting awareness of and behavioural change towards water use, schemes on water footprinting of processes and products) (Box 6.7);
- better technologies for enabling and promoting water supply from alternative water sources (e.g. more energy-efficient desalination and water reuse with minimal environmental risks, real-time monitoring of water quality parameters for safe water reuse, cost-efficient and safe water recovery from effluent from processing industries);
- better technologies for managed aquifer recharge.

Box 6.7 Berlin uses augmented reality to foster citizen engagement in urban groundwater management

Since 2000, Germany has registered 9 of its 10 warmest years on record. This is considered an unusual accumulation of record years of high temperatures (Helmholtz-Klima-Initiative, 2020). In 2019, the neighbouring states of Berlin and Brandenburg were ranked the two warmest German Länder (Berlin.de, 2020). Furthermore, according to scenarios informing its climate adaptation programme, the city of Berlin expects to have a Mediterranean climate by the year 2100, similar to that of present-day Toulouse (Reusswig et al., 2016). In this context, the prospects of decreased precipitation and variations in seasonality are bringing water resource challenges onto the German capital's agenda and, with this, a need for increased citizen awareness of the origin and management of their water resources.

Managed aquifer recharge, using the natural aquifer for treatment and storage, is the main process Berlin uses for drinking water production.

Since 2019, the Digital Water City project (Digital Water City, 2021) is set to (1) raise public awareness of Berlin's water resources; (2) increase acceptance of policies promoting the sustainable use of urban water, and (3) foster public involvement in urban water management. To do so, the project is developing an augmented reality mobile application ([20]) providing its users with an immersive view into a 'hidden part' of the water cycle. The app uses modelling of the city's geology and hydrology to enable visualisation of groundwater resources. By making groundwater visible, the project partners intend to build citizens' trust in natural treatment techniques and promote the consumption of tap water over bottled alternatives. Incorporating the app into guided waterworks tours, public events and school initiatives, and installing quick response (QR) codes at drinking water dispensers and well sites, the initiative aims to reach 20 000 citizens every year. The app is developed by a local small enterprise in collaboration with the city's water utility.

Source: Digital Water City (2021)

([20]) For more information, please visit: https://www.digital-water.city/solution/augmented-reality-ar-mobile-application-for-groundwater-visualization

6.8 Cooperation in international river basins

In international river basins, cooperation is usually sealed with formal international agreements, and frequently with the establishment of an international coordinating body. In such river basins, the EU Member States are required to prepare national RBMPs, covering their own territory but also coordinated with the RBMPs of any other territories sharing the river basin. Alternatively, they may develop single international RBMPs, in which they should also involve non-EU countries that share a river basin with them. These are used less frequently, though. In Europe, there are nine cases of international river basins with active international agreements, established international coordinating bodies and international RBMPs in place: Danube, Elbe, Ems, Meuse, Odra, Rhine, Sava, Scheldt and Teno/Tana (see Box 6.8 and 6.9). In other international river basins, a single international RBMP or an international coordinating body may be missing. However, cases where no international agreement has been signed are rare (EC, 2019c).

A review (EC, 2019c) of the above cases reveals that water stress is not highlighted as a significant issue requiring international cooperation in most of them. Thus, the issues of overabstraction, water scarcity and droughts do not receive sufficient attention. The focus of international cooperation is commonly on water quality issues, hydromorphology or flooding.

Consideration of climate change and cooperation on climate change adaptation (CCA) at international level has also strengthened in Europe over the last decade (Ramieri et al., 2018). The EU climate adaptation strategy, launched in 2013, included references to cross-border issues. Furthermore, the evaluation conducted by the European Commission in 2018 showed that the strategy promoted several cross-border actions on climate risks between Member States (EC, 2018b). Transnational strategies or action plans on CCA have been developed in many regions ([21]), including the Mediterranean, the Danube, the Alps and the Baltic. Existing international conventions (e.g. OSPAR Convention on the protection of the North-East Atlantic, Barcelona Convention on the protection of the coastal region of the Mediterranean) have also catalysed the transnational dialogue and cooperation on CCA issues. Moreover, web-based adaptation platforms, knowledge centres and networks have been set up, and transnational CCA-related projects are being implemented. However, CCA-related projects are more focused on knowledge creation and dissemination, awareness-raising, capacity-building, networking and cross-country exchange, and less focused on actual implementation of joint measures. Interreg programmes have provided significant support to transnational cooperation on CCA (Figure 6.4) (Ramieri et al., 2018). The new EU strategy on adaptation to climate change calls for more ambitious and more proactive EU-level action on climate adaptation, both domestically and internationally (EC, 2021a).

Box 6.8 Examples of international cooperation in water stress management

Danube: the International Commission for the Protection of the Danube River strategy on adaptation to climate change, developed in 2012 and updated in 2018, providing guidance on the definition of adaptation measures, such as restoring water retention areas and addressing water scarcity and drought risks.

Elbe: climate change outlooks considered in the economic analysis of water use in the long term.

Ems: assessment of future climate change impacts; climate-proofing of measures considering their sensitivity to climate change impacts under different scenarios.

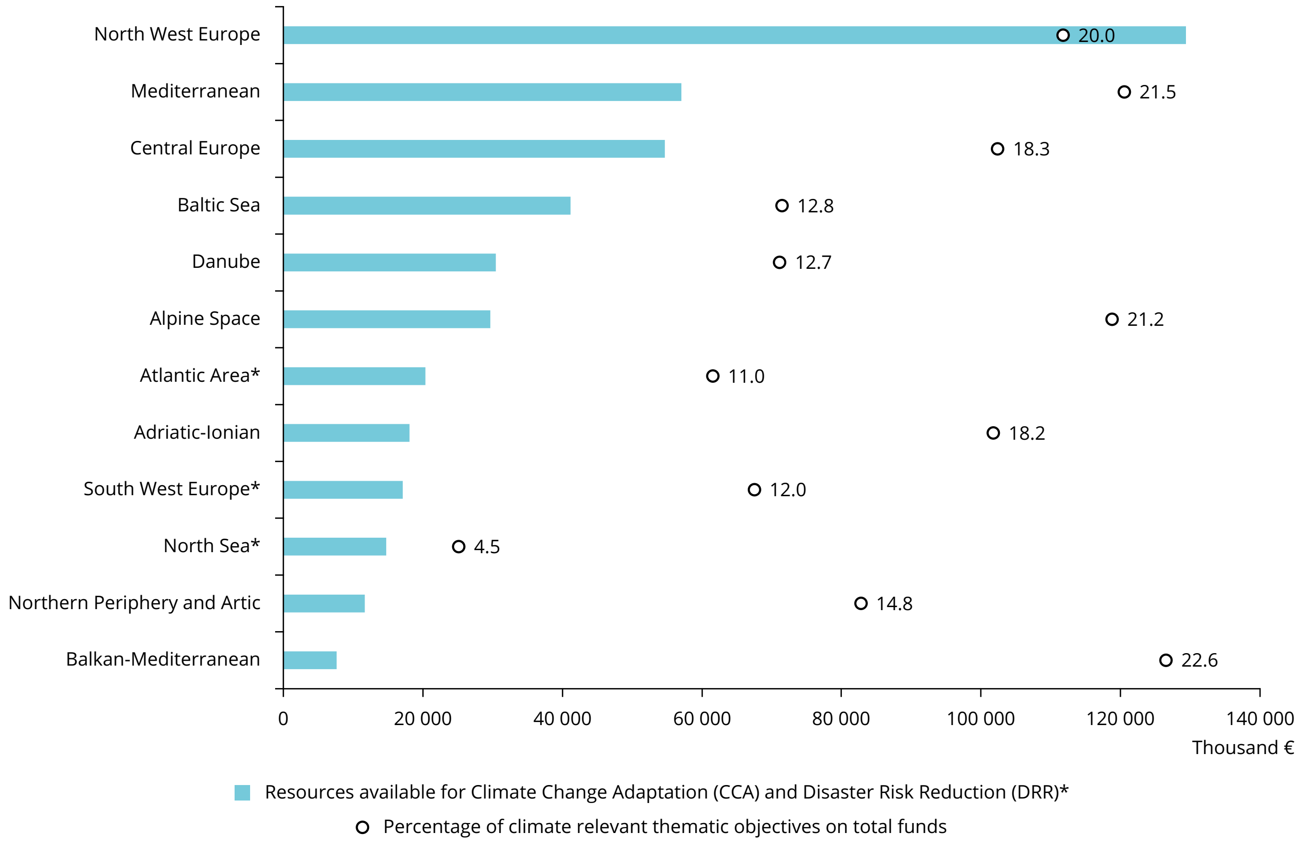
Meuse: joint status assessment of transboundary groundwater bodies; ongoing work on a joint report on water scarcity that will support the development of an updated framework for managing low-flow events (for the current framework see Box 6.1); ongoing work programme to increase information exchange on national and international activities related to climate change assessment and adaptation.

Rhine: International Commission for the Protection of the Rhine strategy for adapting to climate change, developed in 2015, considering climate change impacts, the discharge regime of the river, prolonged periods of low flow and frequency of flood events under different scenarios; definition of the basic principles of selecting adaptation measures.

Scheldt: initial exploratory climate memorandum signed, including droughts aspects, such as a discussion on possible restrictions on water abstraction.

([21]) North Sea, Northern Periphery and Arctic, Baltic Sea, Danube, Alpine Space and Mediterranean.

Figure 6.4 Available funds for Interreg V B 2014-2020 programmes related to climate change adaptation (CCA) and disaster risk reduction (DRR) in vaious regions of Europe



Source: Ramieri et al. (2018).

6.9 Prospects for solutions

The search for solutions to the increasing impacts of water stress can take roughly four directions, each with its preferred applications:

1. Continue and intensify the development of technologies for measures to address sectoral water demand and for saving water in households, agriculture, industry and electricity production. This is considered a no-regret option. In the longer term it will become necessary in most parts of the EU, and in the short term it offers environmental gains.

2. Intensify the development of nexus approaches, capitalising on synergies between economic sectors, including NbS.

3. Continue and intensify the pursuit of additional means of water supply in areas with coastal tourism, high-value agricultural and horticultural areas near coasts, and urbanised areas. In this context, inter-basin water transfers are considered a last resort because of their serious environmental impacts. The use of this measure should be restricted to cases of genuine necessity and, where possible, combined with NbS.

4. Continued systemic change aimed at addressing the root causes of overexploitation of natural resources, as part of a much broader transformation than of water management alone, following one of IPBES's conclusions (IPBES, 2019): 'Goals for conserving and sustainably using nature and achieving sustainability cannot be met by current trajectories, and goals for 2030 and beyond may only be achieved through transformative changes.'

The most likely outcome seems to be a mixture of site- and case-specific combinations of the first three approaches, while the fourth option offers an alternative pathway — maybe to be explored first in areas where current practices can no longer be continued. Whichever approach is chosen, it will be fully dependent on and must therefore be interconnected with economic and legal measures and measures to increase public awareness. What counts is the (public's) awareness that continuing current practices is no longer possible in hotspots, and that there are areas that are likely to become additional hotspots in the coming decades.

One benefit of the gradual nature of the progress of water stress problems is that it leaves some time to develop new practices and exchange lessons learned across the EU. Implementing measures to address water demand will buy some more time — provided lock-ins are avoided. Long-term planning may include methods such as adaptive planning and pathways that view short-term measures through a long-term perspective, to take a long-term view and to avoid additional lock-ins as much as possible.

Box 6.9 Dealing with low flows during droughts in the Meuse river basin

The Meuse International River Basin District (iRBD) covers parts of the territories of France, Luxembourg, Belgium (Wallonia, Flanders), Germany and the Netherlands. The iRBD covers an area of almost 35 000 km², with close to 9 million inhabitants. The length of the river is 905 km.

Urbanisation, industrialisation, agriculture and navigation affect the status of the waters of the iRBD Meuse. The Meuse is the source of drinking water for almost 7 million people. Navigation is of particular interest in the area, both in Belgium (Flanders) and in the Netherlands. Over the past two centuries an intricate network of shipping canals has been developed that depends entirely on the Meuse for its water supply.

The estimated water exploitation index plus (WEI+) of the Meuse is about 30 % on average. This makes the iRBD stand out as one of the more water stressed in western Europe (see Map 5.1).

In 1995, after long negotiations, the issue of the distribution of available water during low-flow periods resulted in the Meuse discharge convention between Belgium (Flanders) and the Netherlands. The guiding principle of the Meuse discharge convention is to secure equal rights to use water for economic purposes for both countries and to accept joint responsibility for the stretch of the Meuse that marks the international border. In this stretch, low discharges can be harmful to the valuable ecology.

Simultaneously, in 1995, France, Belgium (Wallonia, Brussels Capital Region, Flanders) and the Netherlands reached agreement on a wider, multilateral convention on the protection of the Meuse. This convention was succeeded in 2002 by the International Meuse Commission (IMC) upon the signature of the Meuse Convention (Treaty of Ghent, which now includes Germany and Luxembourg). The purpose of the convention is to achieve sustainable and integrated water management of the Meuse iRBD.

The Meuse discharge convention stipulates that both Belgium (Flanders) and the Netherlands take measures to limit their water use during times of water shortage. In the Netherlands this mainly involves pumping back water to the upstream stretches at the ship locks. The passage of ships through locks is also performed in a 'water-economical' manner, using water-saving devices. If this is not sufficient, the water allowances of other water-using sectors are cut back, according to the order described in the national priority sequence. Flanders limits its water use by installing pumps at the ship locks. A considerable part of the water intended for Flanders is used for these ship locks. When one of the parties at some point finds it difficult to meet the conditions of the treaty, it is jointly considered whether that party may temporarily use more water. The associated costs are settled afterwards (Bastings et al., 2011).

Lessons learned from the Meuse Convention (Mostert, 1999; Bastings et al., 2011);

- Conventions are a matter of mutual trust. In the Meuse it took a long time to overcome historical disputes between Belgium and the Netherlands and build such trust.
- Linking different issues can result in a package deal that is attractive to all parties. In the case of the Meuse, breakthroughs were reached after linking water quantity in the Meuse with seaport accessibility in the Scheldt.
- To arrive at an attractive package deal, a cross-sectoral approach is often instrumental.

The 2018 drought again demonstrated the vulnerability of the Meuse basin to water shortages. The Dutch evaluation of the 2018 drought includes specific actions to reinforce dialogue with Germany and France on drought and low flows (Ministerie van Infrastructuur en Waterstaat, 2019).

7 Conclusions

Water stress can be caused by natural phenomena (drought events), by phenomena arising from human activities (unsustainable water abstraction, deterioration of water quality, lack of access to water) or by a combination (climate change). Climate change is manifesting itself with increasing impact. It is expected to cause a major increase in the occurrence of water stress, affecting an increasing area of the EU and an increasing percentage of its inhabitants annually. Water stress caused by overabstraction is persistent, but this report presents clear evidence that the efforts made to reduce it are having an effect.

Water stress caused by overabstraction is often a local and temporary phenomenon, predominantly occurring in urban areas, irrigated agricultural areas and tourist hotspots in the summer months. Such areas tend to have high economic value and considerable vulnerability to water stress. The impacts of overabstraction in such areas can be aggravated by droughts. The impacts are aggravated even more by the continuing trend towards concentrating the population and economic activities in urban areas.

Evidence is growing that water is being used in the EU with increasing efficiency. The economic sectors that depend most on water availability are agriculture, electricity production, industry and drinking water supply. Comparing the water consumption and net value added of agriculture, electricity production and industry clearly indicates a trend towards increasing efficiency of water use, albeit not always consistently in the time span for which data are available (1995-2017) or among the four regions of Europe (eastern, northern, western and southern).

Care must be taken that this gain does not only reinforce economic growth (and associated water demands) but instead benefits the environment. One way of securing this is by incorporating ecological flows in river basin management plans and drought management plans. The analysis of sectoral water use and outlooks in this report signals that ecological flows have not yet been well defined in most of the river basin management plans.

The agricultural, electricity production and industry sectors may have potential for further water savings in the order of 20-40 %; an updated assessment of this potential is needed. Where demand management alone is not sufficient, alternative water supply methods, such as waste water reuse and desalination, may offer perspectives at the local scale. This report has not addressed the costs and benefits of these measures.

Policy responses at EU level that address or touch on water stress form an intricate network. The Water Framework Directive is at the centre of this network. Distinct progress is being made in its implementation, while additional efforts are needed in monitoring, modelling and licensing of abstractions. Intertwined are sectoral policies and emerging integrated initiatives. Our analysis suggests that 'anchoring' water management objectives in sectoral policies is a prerequisite for successful water stress management. The European Green Deal and the new EU strategy on adaptation to climate change have great potential to leverage policy integration and increase Europe's climate preparedness and resilience.

To demonstrate the impacts of past and future water stress events, the evidence needs to be available and presented at sufficient temporal and geographical detail. This level of detail is not always present in the data currently reported by the Member States to the European Commission and the EEA.

Insufficient quality or coverage of data is a persistent and recurrent issue in water management in general, and also in water stress management. Emerging technological innovations offer promising perspectives for detailed (in both time and space) observations of such issues as snow cover, soil moisture, actual evapotranspiration and unauthorised abstraction. For data collection that depends on the cooperation of stakeholders (e.g. in the industry) collaboration must be intensified and the lessons learned expanded to other sectors.

In the parts of Europe where water stress problems need urgent action, the challenge is to avoid continued lock-in to technical solutions, such as water transfers, and instead start off with an analysis that includes the root causes of the problem, using nexus approaches and systemic analysis. Ecosystem approaches and nature-based solutions are measures readily associated with such approaches.

Abbreviations

8th EAP	Eighth Environment Action Programme
CAP	Common agricultural policy
CCA	Climate change adaptation
CIS	Common implementation strategy
CSI	Core Set of Indicators (EEA's indicators system)
DMP	Drought management plan
EEA	European Environment Agency
EEA-38 and the UK	The 32 member countries and six cooperating countries of the EEA and the United Kingdom
EIP	European innovation partnership
E-OBS	Daily gridded observational data set under the Ensembles project
ETC/ICM	European Topic Centre on Inland, Coastal and Marine Waters
EU	European Union
EU-27	The 27 Member States of the European Union
EU-27 and the UK	The 27 Member States of the European Union and the United Kingdom
FP7	Framework Programme 7 (funding programme)
H2020	Horizon 2020 (funding programme)
Interreg EU	Instrument supporting cooperation across borders through project funding
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
JPI	Joint Programming Initiative
JRC	Joint Research Centre
MAES	Mapping and assessment of ecosystems and their services
NbS	Nature-based solutions
NGO	Nongovernmental organisation
NUTS	Nomenclature of Territorial Units for Statistics (Eurostat's geocode standard)
NVA	Net value added
Peseta	Projection of economic impacts of climate change in sectors of the European Union based on bottom-up analysis
RBD	River basin district
RBMP	River basin management plan
RCP	Representative Concentration Pathway
RDP	Rural development programme
SDG	Sustainable Development Goal
SPI	Standardised precipitation index
UN	United Nations
WEFE nexus	Water, energy, food, ecosystem nexus
WEI	Water exploitation index
WEI+	Water exploitation index plus
WFD	Water Framework Directive
WG	Working Group
WISE	Water Information System for Europe

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Annex 1
Recent EU innovation projects for water stress management

Table A1.1 Selection of recent EU projects dealing with water quantity challenges and/or digitalisation in the water sector

Research project	Vision and key objectives
Globaqua Managing the effects of multiple stressors on aquatic ecosystems under water scarcity (FP7, 2014-2019)	Globaqua explored the impacts of different combinations of pressures acting at the same time (e.g. organic and inorganic pollution, water abstraction, land use change) under water scarcity conditions, emphasising the potentially unknown synergies that might take place and amplify the degradation of the chemical and ecological status of freshwaters. Furthermore, the project studied and evaluated the potential implications for associated ecosystem services following a participatory approach. The project also explored the potential to improve river basin management through the integration of ecosystems services in freshwater policies and management.
EartH2Observe Global Earth observation for integrated water resource assessment (FP7, 2014-2017)	EartH2Observe aimed to integrate available global Earth observations via satellites and in situ data from ground stations with global hydrological and land surface models to perform a re-analysis and generate a comprehensive and consistent data set for global water resources. The project reconstructed time series of sufficient length (several decades) for key components of the water cycle, such as precipitation, evapotranspiration, soil moisture, groundwater and others. Therefore, it improved our knowledge of water budgets, especially in regions with gaps in their monitoring coverage. A key product of the project was the Water Cycle Integrator data portal, which provides all data sets online. The usefulness of the project outputs was demonstrated in selected case studies with the participation of local stakeholders.
DestinE Destination Earth (European Commission, 2021-2030)	The ambition of the Destination Earth initiative is to create digital replicas of different subsystems of the Earth (e.g. weather and climate, global ocean circulation and biogeochemistry of the oceans, freshwater, food) and integrate them into a unique 'digital twin' of the Earth. This digital twin will contain high-precision information on the status and operation of the physical world, including environmental and socio-economic activities, and it will be capable of simulating different scenarios for sustainable development. Therefore, it could improve policymaking and decision-making in the EU. The core feature of the project will be a federated cloud-based modelling and simulation platform, which will provide access to advanced computing infrastructure, artificial intelligence applications and analytics, sophisticated software and data sets. It will be funded as part of the European Commission's programme for Digital Europe, while certain aspects will also be supported by Horizon Europe and the EU space programme. Although the initial end users are public authorities, the initiative will also provide opportunities for exploitation of the results by scientific and industrial users in the future.
Hydrousa Demonstration of water loops with innovative regenerative business models for the Mediterranean region (H2020, 2018-2022)	Hydrousa focuses on the development of a circular business model for the Mediterranean and other water-scarce regions across Europe and worldwide, by establishing decentralised regenerative solutions for water/waste water treatment and management that close the local water loops, improve agricultural production and benefit local value chains. The project devises and demonstrates innovative solutions with low-energy footprints for different types of water (i.e. rainwater, groundwater, waste water, saline water and vapour). Proposed solutions adopt traditional handcraft and ancient technologies and combine them with modern nature-based and nature-inspired approaches, as well as with information and communication technology systems and automation.

iWAYS Innovative water recovery solutions through recycling of heat, materials and water across multiple sectors (H2020, 2020-2024)	iWAYS focuses on the recovery of energy, material and water from industries with gaseous and waste water emissions by applying non-disruptive approaches that combine exhaust condensation, water treatment and waste valorisation. The novel approaches will be tested in industries related to ceramics, chemicals and steel, which are considered water and energy intensive. The project targets recovering 30 % of water and heat from humid chimney plumes and cutting down freshwater use by 30-64 %. In addition, it aims to recover valuable acids or particulates from flue gases, which also protects the environment from harmful emissions.
Aqua3S Enhancing standardisation strategies to integrate innovative technologies for safety and security in existing water networks (H2020, 2019-2022)	Aqua3S aims to combine standardisation of existing sensor technologies with state-of-the-art technologies to detect water safety and security risks for water networks, including the use of unstaffed aerial vehicles, satellite images and citizen observations through social media crowdsourcing. The key project output will be an integrated platform that serves as an early warning and decision support system. The platform will assist water utilities in mitigating risks, handling crisis events and alerting the public and the authorities on evolving issues with their water networks, thus reducing the potential for water shortages and improving response times in the event of crises.
Digital Water.City Leading urban water management to its digital future (H2020, 2019-2022)	Digital Water.City investigates a range of digital solutions that could be applied in urban and peri-urban environments to help the water authorities tackle modern water challenges and increase citizens' awareness and participation in water protection and management. The project demonstrates case studies from five major cities in Europe (i.e. Berlin, Copenhagen, Milan, Paris and Sofia). Inter alia, it develops digital solutions for increasing the volume of safe water reuse, promoting precision farming, raising awareness of groundwater risks, and facilitating integrated monitoring and management of groundwater resources. A variety of methods and technologies is being combined and tested, including artificial intelligence, machine learning, unmanned aerial vehicles, real-time sensors, modelling, augmented reality, mobile technology and cloud computing. The project also addresses the issues of interoperability, cybersecurity and governance regarding digital infrastructure.
Fiware4Water Fiware for the next generation of internet services for the water sector (H2020, 2019-2022)	Fiware4Water builds upon the Fiware platform, which is an open-source smart solution incorporating modules that enable the connection of the internet of things, context information management, big data services and cloud services and facilitates smart city initiatives and the next generation of internet initiative. The project aims to support the adoption of the Fiware platform by end users of the water sector (e.g. cities, water utilities, water authorities, citizens and consumers) and solution providers (e.g. private utilities, small and medium-sized enterprises, developers), because of its capacity to enable interoperability, standardisation, cross-domain cooperation and data exchange. The project demonstrates four European case studies of digital water solutions for optimised selection of water sources and routing of water, increased water saving and safety in water networks, real-time monitoring and awareness of household consumption, and optimisation of waste water treatment operation.
Naiades A holistic water ecosystem for digitisation of the urban water sector (2019-2022)	Naiades focuses on real-time monitoring of water use in residential, commercial and public buildings and the exploitation of big data analytics in three dimensions (i.e. spatial, temporal and nodal). A mobile application has been developed to support consumers' awareness of and behavioural change towards their personal water use through a stepwise commitment to more sustainable water use goals. The project also measures the safety and reliability of water supply after examining equipment failures and maintenance schemes, in order to understand and improve water asset management strategies by water utilities. Furthermore, the project collects information on water quality and applies machine learning techniques to predict potential quality problems before they arise, thus increasing the confidence of consumers regarding the quality of their tap water.

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