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List of Abbreviations

CAP – Common Agricultural Policy
CF – Cohesion Fund
CIS – Common Implementation Strategy
CORDEX – Coordinated Regional Climate Downscaling Experiment
CS – Climate Service
C3S – Copernicus Climate Change Service
DMP – Drought Management Plan
EEA – European Environmental Agency
ESA – European Space Agency
EC – European Commission
ERDF – European Regional Development Fund
EU – European Union
FD – EU Floods Directive
FP – Framework Programme
FRM – Flood Risk Map
FRMP – Flood Risk Management Plan
GIS – Geographic Information System
IFRMP – International flood risk management plan
Interreg – European territorial cooperation
IPCC – Intergovernmental Panel on Climate Change
iRBMP – International River Basin Management Plan
JPI – Joint Programming Initiative Healthy and Productive Seas and Oceans
JRC – Joint Research Centre
ISO – International Organization for Standardization
KTM – Key Type of Measure
LIFE – L'instrument financier pour l'environment
MS – Member States
NFRD – Non-Financial Reporting Directive
PESETA – Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis
PoMs – Programmes of Measures
RBD – River Basin District
RBMP – River Basin Management Plan
RBO – River basin organisation
SDG – Sustainable Development Goal
UK – United Kingdom of Great Britain and Northern Ireland
UNECE – United Nations Economic Commission for Europe
WFD – Water Framework Directive

Introduction and background

Climate change impacts primarily manifest in changes to the water cycle. Changing seasonal and regional rainfall patterns impact water availability, droughts and heavy rainfall events cause increasing damages, water stress and rising water temperatures deteriorate the quality of an ever-growing number of aquifers, rivers, lakes, wetlands, coastal waters and oceans. Increasing water scarcity, droughts and reduced water quality have serious consequences, not only for drinking water supply and the health of water-related ecosystems and the services they provide to humans, but also for other sectors such as agriculture and forestry, energy production or inland waterways. Moreover, more frequent and more intensive flooding and storm surges threaten settlements, cities, and infrastructure, especially in coastal areas and along rivers. Adaptation to these water-related climate impacts is a core challenge for various sectors in the EU that depend on water resources or face water-related risks.

This dependency on water, in turn, makes sustainable water management, including the preservation of healthy ecosystems, a critical tool for overall climate resilience of economic sectors and society at large. Sustainable water management is crucial to ensure the capacity of both natural and human systems, to deal with future extreme events, adapt to changing conditions and transforming in situations of crises (Falkenmark, Wang-Erlandsson, Rockström 2019). Climate-resilient water management requires managing water resources in an integrated way, balancing the needs for ecosystems and humans, while taking into account future climate change – not only in the immediate water-sector activities of storage, supply and sanitation, but in other sectors that affect or depend on the availability and quality of water resources. Successful implementation, therefore, requires coordinated action between these sectors and across all political-administrative levels, from local, national to transboundary. This way, it can also leverage synergies with policy objectives in climate mitigation, biodiversity conservation, and other sustainability areas. Nature-based solutions and ecosystem-based approaches to adaptation can deliver benefits towards any of these objectives.

The failure to integrate climate-resilient water management will result in billions of euro in damages, as the agricultural sector or inland waterways transport already witnessed in the wake of the drought in 2018 and 2019. The costs of not adapting to climate change could amount to at least 175 € billion in annual welfare loss in the EU under a 3°C global warming scenario (Feyen et al. 2020). In a similar vein, poorly designed adaptation strategies in one sector can have negative impacts on other sectors, often referred to as maladaptation. Typical examples of maladaptation include energy-intensive adaptation measures, such as desalination to adapt to water scarcity, which further accelerate global warming, or the construction of large dams to increase storage capacity in order to deal with increased climate variability, which leads to detrimental downstream effects for biodiversity and communities that depend on riverine ecosystems.

Moreover, the EU and its Member States (MS) will be affected by climate change impacts outside Europe through international trade, supply chains, migration, and more. Increasing and abrupt occurrences of climate change impacts, such as heatwaves, sea level rise, water stress and hydrological extremes are likely to disrupt water, food and production systems in the future all over the world. This may destabilise societies, threaten peace and security, and force people to migrate – especially in fragile countries. If these developments take place outside the EU, this could directly impact European countries, which makes it a concern for all MS and the EU in many fields, including security policy and external relations (Rüttinger et al. 2015).

Intensifying climate impacts combined with increasing human pressure on water resources will likely show the limits of current adaptation practices, calling for more transformational approaches. Some economic sectors, ecosystems, and entire populations or regions in Europe will be exposed to significant water-related risks. These risks might overwhelm the resilience of even the most robust systems. Under such circumstances, incremental adaptation strategies, including increasing flood protection measures and water use efficiency, are becoming inadequate. Transformational adaptation will be necessary. This includes systemic change in current water management practices and across water-dependent sectors, including fundamental changes in current land-use or urban planning, and will require adjustment in how water is valued by all users.

European institutions have played a key role in establishing the framework conditions that enable relevant actors in the Member States to accelerate efforts to enhance water and climate resilience. The EU achieved the first milestone to this end with the publication of the White Paper "Adapting to climate change: Towards a European framework for action" in 2009. The EU Adaptation Strategy followed in 2013, forming the strategic framework for Europe's climate change adaptation policy. Since then, the EU Adaptation Strategy has prompted the mainstreaming of adaptation into various policy areas, knowledge generation and exchange, and supported national adaptation strategies. Based on an evaluation of the strategy over the past years, the European Commission is currently preparing a new EU Adaptation Strategy, to be published in early 2021. While a Blueprint for the new Strategy outlines various provisions to be considered, it will be critical to stress the fundamental role of water as the most affected medium, with far-reaching impacts for various water-dependent sectors.

Several water-related policies at EU-level directly or indirectly address issues of adaptation to water-related climate impacts in the MS, such as the Water Framework Directive (WFD) or the Floods Directive (FD). In 2019, the European Commission conducted a "fitness check" of the most important water-related EU Directives including the two directives mentioned above. It concludes that climate change impacts are increasingly considered in river basin and flood risk management plans, yet with large differences between basins (EC 2019). Other policies, such as the new Biodiversity Strategy, promote resilience of water-dependent ecosystems in a holistic way. Other sectoral policies, such as the Common Agricultural Policy (CAP), also have a significant impact on Europe's waters: For example, through the type of farming it promotes, aspects of the CAP may contribute to over-abstraction of water, soil degradation, water pollution, increased flooding, and biodiversity loss, thereby undermining water-related ecosystems and their services for climate resilience (such as water retention). Adaptation objectives, however, especially those supporting climate-resilient water management, appear to play only a minor role in the new CAP. Similarly, the Cohesion Policy and the Trans-European Transport Network (TEN-T) policy may have impacts on Europe's waters through the types of infrastructure (incl. waterways) they fund and promote. While climate and disaster proofing are built into the appraisal of major projects for cohesion policy support, there is a need to better track if expenditure under the CAP, Cohesion Policy, and TEN-T deliver real adaptation benefits. The new EU Taxonomy Regulation offers opportunities to track adaptation benefits of private sector investment.

There is a need for expanding efforts of mainstreaming water-related climate adaptation into EU policies in order to reduce negative impacts from conflicting sectoral policies and to tap into synergies, e.g. with the new biodiversity strategy. This requires exploiting upcoming windows of opportunity arising either from planned revisions or extensions of key policy instruments highly relevant for water-related climate change adaptation. In particular, the further development of the EU adaptation strategy offers opportunities to integrate lessons learned and the experiences of different actors in the process of implementing initial adaptation measures.

Germany's EU Council Presidency in the second half of 2020 provides a special opportunity to have an impact on these policy processes. To this end, the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) is hosting the conference *"Climate change and the European water dimension - Enhancing resilience"*. The conference brings together stakeholders from all EU MS and EU institutions and administrations, non-governmental organisations, research and relevant economic sectors. With this initiative, the Federal Government continues its engagement on the topic, which successfully started with a conference on water and climate change during the previous Council Presidency in 2007.

As a basis for discussion during the conference, this background paper provides an overview of:

a. observed and expected future climate change impacts on water bodies and effects for different water-dependent sectors in different regions of the EU;

b. policy approaches and strategies for climate change adaptation at the EU, MS and transboundary level;

c. required action and possible entry points for EU activities to enhance adaptation efforts in the EU MS and transboundary basins.

It does so for four different thematic clusters, each featuring several sub-topics. The paper is based on a literature review, interviews and discussions with the steering committee for the conference. The background paper provides the basis for a policy paper that will provide tangible recommendations on EU initiatives to respond to the challenges and entry points identified.

Climate change impacts on water resources and extremes in Europe

Climate change impacts today

Climate change most significantly manifests itself through the altering and disrupting of the water cycle (IPCC 2014). According to different observational records, global average near-surface temperature in the period 2009-2018, was 0.91°C to 0.96°C, i.e. warmer than the pre-industrial average, making it the warmest decade on record. Over continental Europe, the average annual temperature in the same period was even 1.6°C to 1.7°C warmer (Figure 1). The European Environmental Agency (EEA) has summarized the expected impacts on Europe (Figure 2). One of the major concerns is the increase in number and intensity of hydro-meteorological extremes, such as heat-waves, storms, floods and droughts. Some of the impacts are already detectable, while observations show that annual precipitation totals generally increased in western and northern Europe, many regions in central and southern Europe observed decreasing annual sums (Figure 1).

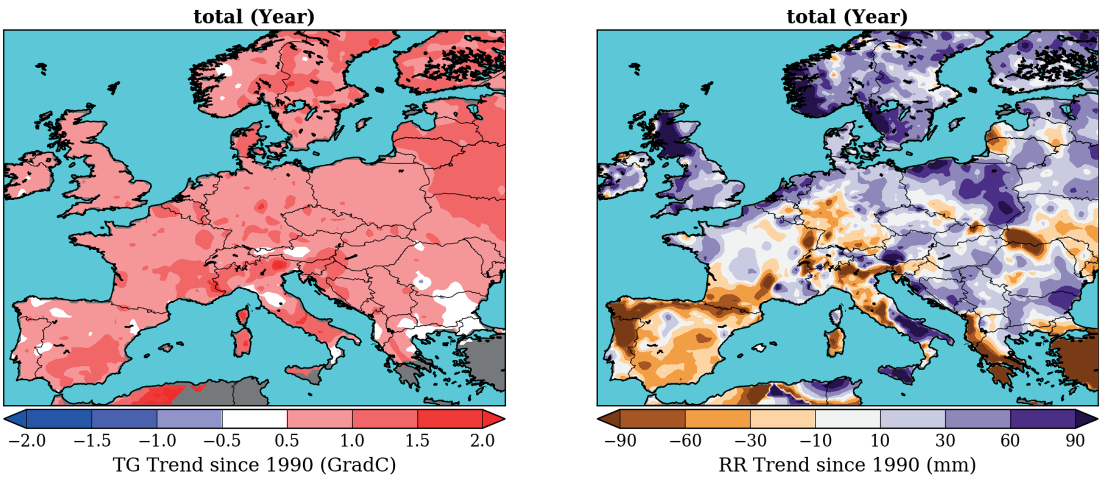


Figure 1: European maps of the cumulative anomalies from 1961-2018 related to 1961-1990 of (a) annual mean temperature and (b) annual precipitation (European gridded observation dataset (E-OBS), Hoffmann et al. 2020, changed).

Climate change impacts in Europe's regions

Climate change is projected to impact the availability of water in Europe, putting additional pressure on southern regions already facing water stress. Other parts of Europe are expected to face more frequent flooding events, while low-lying regions are at risk from storm surges and sea level rise.

Mediterranean region

Large increase in heat extremes
Decrease in precipitation and river flow
Increasing risk of droughts
Increasing risk of biodiversity loss
Increasing risk of forest fires
Increased competition between different water users
Increasing water demand for agriculture
Decrease in crop yields
Increasing risks for livestock production
Increase in mortality from heat waves
Expansion of habitats for southern disease vectors
Decreasing potential for energy production
Increase in energy demand for cooling
Decrease in summer tourism and potential increase in other seasons
Increase in multiple climatic hazards
Most economic sectors negatively affected
High vulnerability to spillover effects of climate change from outside Europe

Boreal region

Increase in heavy precipitation events
Decrease in snow, lake and river ice cover
Increase in precipitation and river flows
Increasing potential for forest growth and increasing risk of forest pests
Increasing damage risk from winter storms
Increase in crop yields
Decrease in energy demand for heating
Increase in hydropower potential
Increase in summer tourism

Continental region

Increase in heat extremes
Decrease in summer precipitation
Increasing risk of river floods
Increasing risk of forest fires
Decrease in economic value of forests
Increase in energy demand for cooling

Atlantic region

Increase in heavy precipitation events
Increase in river flow
Increasing risk of river and coastal flooding
Increasing damage risk from winter storms
Decrease in energy demand for heating
Increase in multiple climatic hazards

Coastal zones and regional seas

Sea level rise
Increase in sea surface temperatures
Increase in ocean acidity
Northward migration of marine species
Risks and some opportunities for fisheries
Changes in phytoplankton communities
Increasing number of marine dead zones
Increasing risk of water-borne diseases

Arctic region

Temperature rise much larger than global average
Decrease in Arctic sea ice coverage
Decrease in Greenland ice sheet
Decrease in permafrost areas
Increasing risk of biodiversity loss
Some new opportunities for the exploitation of natural resources and for sea transportation
Risks to the livelihoods of indigenous peoples

Mountain regions

Temperature rise larger than European average
Decrease in glacier extent and volume
Upward shift of plant and animal species
High risk of species extinctions
Increasing risk of forest pests
Increasing risk from rock falls and landslides
Changes in hydropower potential
Decrease in ski tourism

Figure 2: Expected climate change impact in Europe (Source: EEA Report No 1/2017)

Another observation with far reaching consequences is that soil moisture decreased over the last four decades, especially in summer, and also in regions where annual precipitation sums generally increase, because higher temperature stimulates evapotranspiration. This is of vital importance for vegetation in general and therefore also for food production, since as a result, the growing season starts earlier in spring and so does the water demand of the vegetation (Figure 3). Different publications have recently highlighted that the earlier start of the vegetation season – and the associated, earlier uptake of water – can amplify droughts in summer (Lian et al. 2019, Bastos et al. 2020).

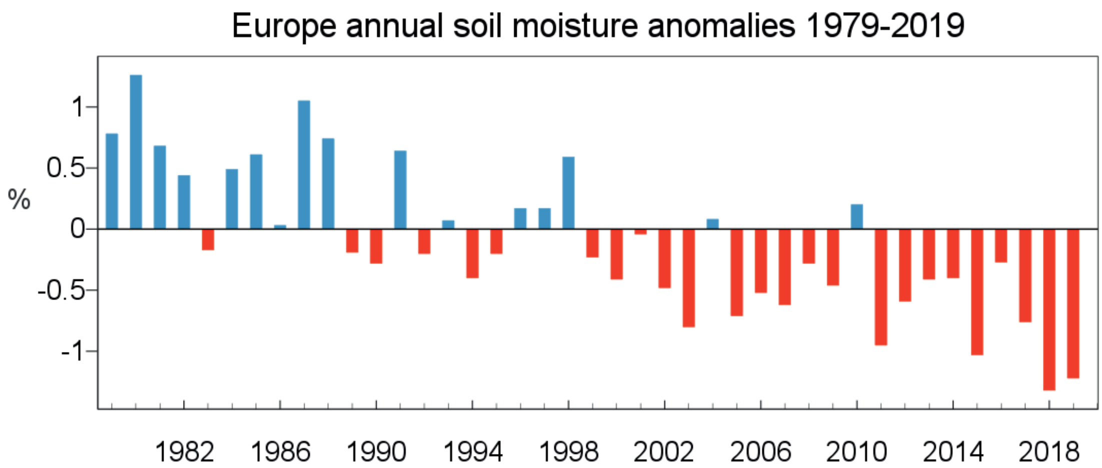


Figure 3: Annual European soil moisture anomalies from 1979 to 2019, relative to the annual average for the 1981-2010 reference period. The soil moisture represents the volumetric moisture content of the top 7 cm of soil. Source: ERA5. Credit: Copernicus Climate Change Service (C3S)/ECMWF[1].

Observations suggest also that weather patterns become more persistent (Man et al. 2018). In 2018, for example, three longer lasting meteorological events showed persistent weather conditions over several months resulting in summer heatwaves and droughts in central and northern Europe, while the Mediterranean was hit by several catastrophic flood events.

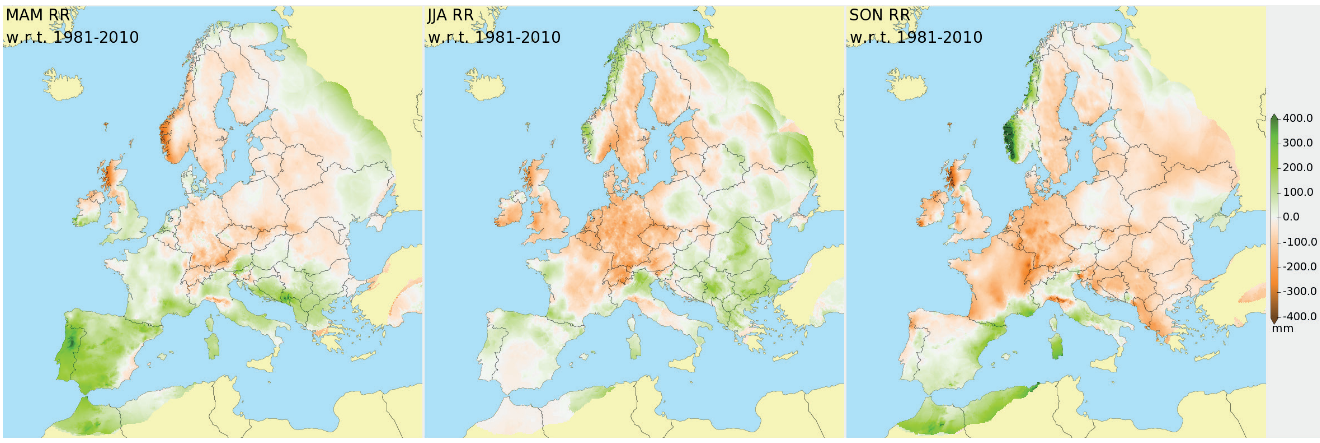


Figure 4: Total precipitation anomalies (mm) for spring, summer and autumn 2018 relative to the respective seasonal average for the period 1981-2010. Data source: E-OBS. Credit: Copernicus Climate Change Service (C3S)/KNMI[2].

[1] https://climate.copernicus.eu/ESOTC/2019/european-wet-and-dry-conditions

[2] https://climate.copernicus.eu/dry-and-warm-spring-and-summer

The persistent weather was caused by a blocking weather pattern over Europe that was present in June, with a remarkably high surface pressure over the British Isles and the North Sea, which continued later into July over north-eastern Europe (Scandinavia and northern Russia). As a result, the north of Europe experienced a very dry year and the south a wet one (see Figure 4). In parts of central and northern Europe, seasonal precipitation totals were less than 80% of normal levels for spring, summer and autumn. The south of Europe, instead, saw several heavy rainfall events throughout the year, causing devastating flood events. Recent work suggests an increase in the occurrence of favourable conditions for blocking weather pattern and associated extreme weather, possibly linked to amplified Arctic warming (Man et al. 2018).

The same hydro-climatic processes impacting on soil moisture also affect groundwater resources. Groundwater is an important source of drinking water for European countries, with around 75% of EU inhabitants depending on groundwater for their water supply. Groundwater resources and tables in Europe have been increasingly affected by various negative influences over the last few decades. In most parts of Europe, groundwater recharge happens mainly in winter when water demand of vegetation is low. Due to climate change, vegetation periods grow and periods without vegetation cover shrink (Lian et al. 2020). As a consequence, groundwater recharge decreases in regions where this trend is not compensated by a strong increase in (winter) precipitation. An additional overexploitation of groundwater resources, for example in parts of Spain, Portugal and southern Italy, led to strong declines in groundwater levels (Custudio et al. 2016). Another negative effect of climate change is global sea level rise, with saltwater intruding into coastal aquifers. Groundwater resources of coastal and small island aquifers are probably the most vulnerable towards saltwater intrusion (Rasmussen et al. 2011).

Because of the larger water holding capacity of a warmer atmosphere, there are also concerns that climate change leads to an increase in number and intensity of flood events. The concerns are reinforced by evidence of increasing economic losses associated with flooding in many parts of the world, including Europe. In a recent study, Blöschl et al. 2019 demonstrate that there are regional patterns of both increases and decreases in observed river flood discharges in the past five decades in Europe, which are interpreted as manifestations of a changing climate. However, their study investigated mainly larger river floods and did not account for the effects of heavy precipitation events leading to flash floods. There are, indeed, strong indications that the intensity and number of heavy precipitation events is on the rise, often resulting in local but disastrous flash floods (Lehmann et al. 2015). Compound events have the potential to reinforce flood events. For example, a drought leading to very dry and partly impermeable soils followed by heavy rainfall can cause extreme flood conditions. Very wet soils followed by heavy storm events can cause higher storm damage in forests.

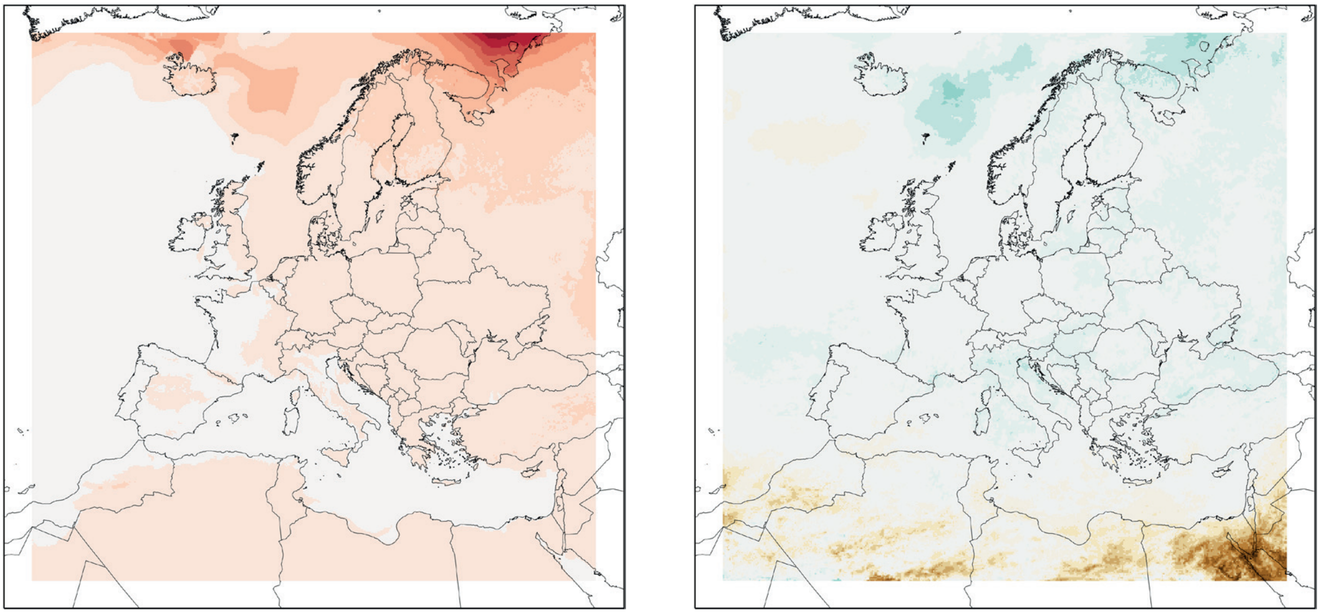
Discussed here are mainly European-scale results, while EU regulations (e.g. the EU Water Framework Directive and the EU Flood Directive) explicitly call for water management at the river-basin scale. Recent reports on national level and in transboundary river basins discuss climate change impacts in more detail. Adaptation strategies were developed and updated accordingly – for example, the climate change adaptation strategy of the International Commission for the Protection of the Danube River (ICPDR 2019). ICPDR and the International Commission for the Protection for the Rhine have conducted studies on climate change scenarios, forecasts for the water discharge regime, and water temperature development (ICPDR 2018, ICPR 2014).

Global sea level rise has accelerated since the 1960s to around 3.3 mm/year over the period 1993-2018 (IPCC 2019). As a result, global mean sea level in 2018 was 20 cm higher than at the beginning of the 20th century. All coastal regions in Europe have experienced an increase in absolute sea level, but with significant regional variation: it is lower around the northern Baltic Sea and the northern Atlantic coast due to the land rise caused by the post-glacial rebound. The observed increase in extreme high coastal water levels is mostly due to an increase in mean sea levels rather than increase in storm activity (Weisser et al. 2014).

What will the future bring? Climate change projections

While Figure 1 summarizes the main projected climate change impacts in Europe, their strength and regional manifestation is very dependent on the extent of further global temperature increase.

a. RCP2.6



b. RCP8.5

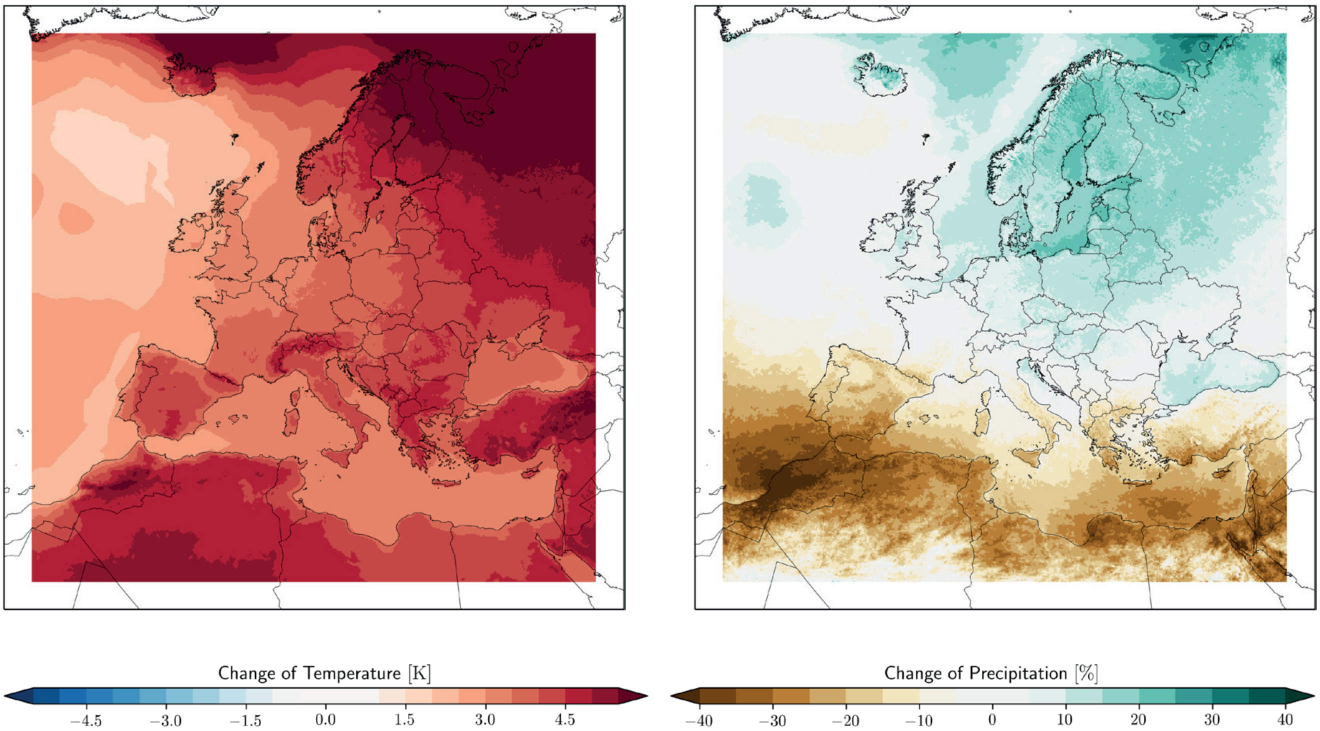


Figure 5: Changes in temperature (left) and precipitation (right) until end of the century (2071-2100 vs. 1971-2000) for RCP2.6 (top, 11 regional model simulations) and RCP8.5 (25 regional model simulations) (Coordinated Regional Climate Downscaling Experiment (CORDEX), data processed at PIK).

Climate models project further increases in global average temperature over the 21st century (for the period 2081–2100 relative to 1986–2005) of between 0.3°C and 1.7°C for the lowest emissions scenario (Representative Concentration Pathway RCP 2.6) and between 2.6°C and 4.8°C for the highest emissions scenario (RCP8.5) (IPCC 2014). Annual average land temperature over Europe is projected to increase even more: by the end of this century (2071–2100 relative to 1971–2000) in the range of 1.0°C to 2.5°C under RCP2.6, and 2.5°C to 5.5°C under RCP8.5 (Figure 5). The strongest warming is expected across north-eastern Europe and Scandinavia in winter and southern Europe in summer. Extreme heatwaves as strong as the ones in 2019 or even stronger are projected to occur as often as every two years in the second half of the 21st century under a high emissions scenario (RCP8.5). In southern Europe, they are projected to be particularly strong. Also, longer and stronger droughts are projected (EEA 2017).

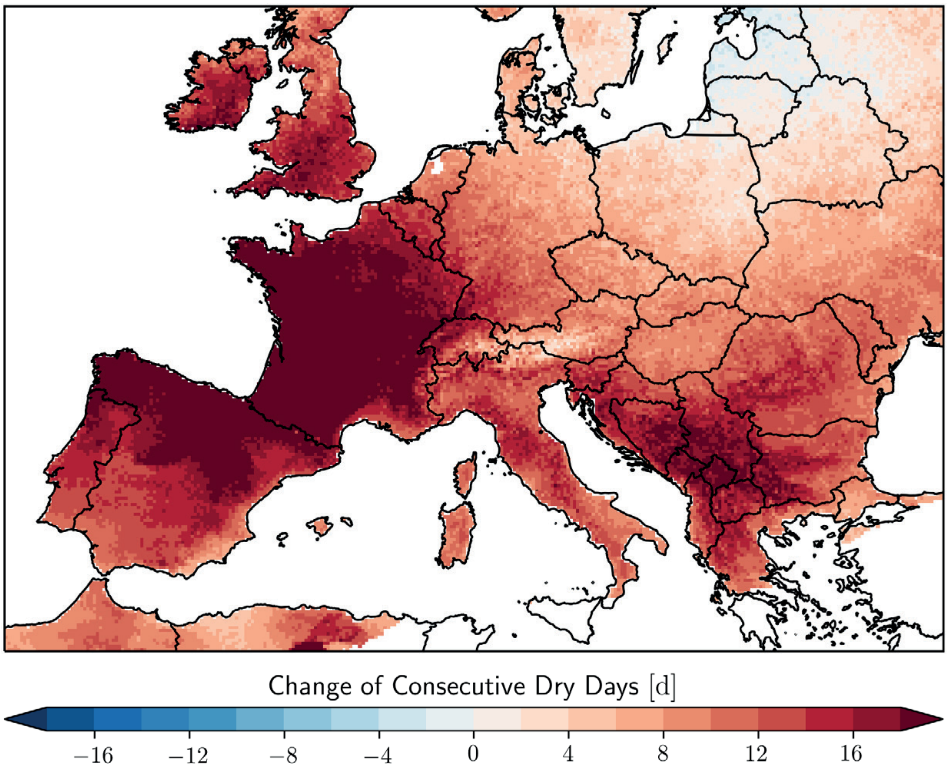


Figure 6: Change in days with consecutive persistent dryness (precipitation below 1.0 mm over at least 5 days) under RCP8.5 climate conditions (2071-2100 vs. 1971-2000) for the month April to August (Coordinated Regional Climate Downscaling Experiment (CORDEX) data processed at PIK).

Figure 6 illustrates the increase in the number of days with persistent dryness until the end of this century under RCP8.5 scenario conditions. It is remarkable that there is an increase in all European regions, likely leading to more droughts, with the strongest trend in parts of south-western and south-eastern Europe.

In a technical report for the European Commission, Bisselink et al. (2018) quantify the impacts of a changing climate, land use, and water usage on Europe's water resources. The report focusses on a 2°C warming scenario and on a high warming scenario (RCP8.5). The results of the model show a strong north-south pattern across Europe for water availability. Overall, Southern European countries are projected to face decreasing water availability, while central and Northern European countries show an increase in annual water availability. The seasonal analysis shows differences between summer and winter stream flows, especially in France, Belgium and the UK with wetter winters and drier summers, thereby increasing water availability in winter, and decreased water availability over the summer months. Generally, the report shows that current pressures on water availability are exacerbated in southern and some central-eastern European countries, especially in summer (see Figure 7).

An increase of flood intensity and number under climate change conditions in larger parts of Europe is reported in different studies (Dankers and Feyen 2009, Dankers et al. 2014, Hattermann et al. 2018). Projected are generally increases in northern and western and decreases in eastern and southern Europe. However, these studies also concentrate on larger river floods, while changes in pluvial floods are much more difficult to detect because of the very complex physics of thunderstorm generation.

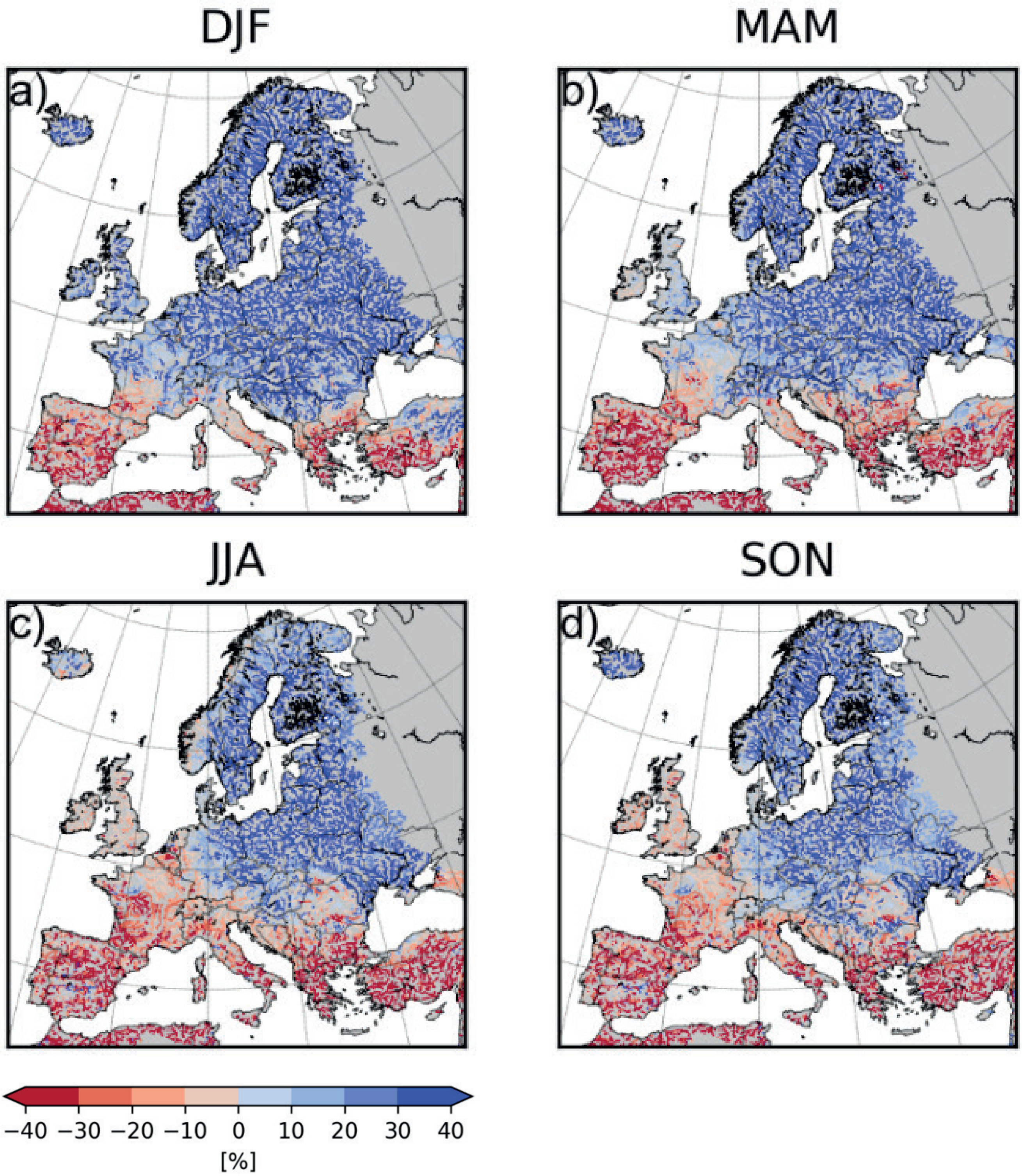


Figure 7: Impact of the RCP8.5-2070-2099 climate change on median seasonal streamflow (50th percentile), as compared to the 1981-2010 control climate (Bisselink et al. 2018).

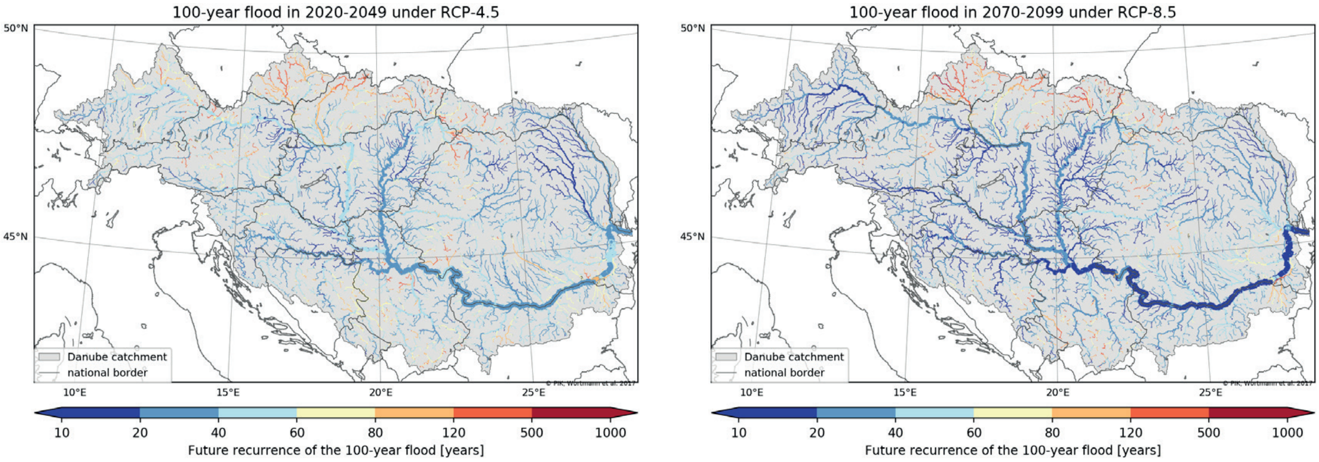


Figure 8: Left - Recurrence of the present 100-year flood magnitude in the near future (2020–2049) and under moderate scenario conditions (RCP4.5) and right for the far future (2070-2099) and under high end scenario conditions (RCP8.5) compared to climate conditions in 1971-2000 (out of the 4 EURO-CORDEX model runs). Changes in ensemble median values are shown. The former 100-year flood occurs more frequently in blue-shaded streams and less frequently in red-shaded streams (from Hattermann et al. 2018, changed).

Trends in flood occurrence in the Danube basin have been presented and discussed in Hattermann et al. 2018. Figure 8 gives the future recurrence of a former 100-year flood modelled by the hydrological model SWIM, driven by an Ensemble of CORDEX runs. The results show that even under moderate climate change conditions and in the near future, strong increases in magnitude and number of flood events can be expected in the main stream of the Danube and most tributaries. Until the end of the century and under high end climate conditions, a former 100-year flood would occur 10 times more often in larger parts of the basin.

The projected global mean sea level rise over the 21st century will most likely further accelerate with a range of increase of 0.29-0.59 m until 2100 for a low-emissions scenario and 0.61-1.10 m for a high-emissions scenario (IPCC 2019). However, several recent studies and assessments have suggested an upper boundary for 21^{st} century global mean sea level rise in the range of 1.5-2.5 m (Hansen et al. 2016, Mengel et al. 2018). As a result, also extreme high coastal waters are projected to increase, and some recent studies show that along the northern European coastline this could be also the result of more intense storm surges (Rasmussen et al. 2018). Without adaptation, related damages would show a strong increase (Prahl et al. 2018).

Uncertainties in climate impact projections

One major challenge in assessing the hydrologic effects of climate change remains the estimation of uncertainties associated along the impact model chain. This includes different sources of uncertainty, such as global climate models, emission scenarios, downscaling methods, hydrologic models and water sector models (Hattermann et al. 2018). In general, global climate models contribute most of the uncertainty associated with projections of climate change impacts for the water sector, followed by scenarios on greenhouse gas emissions and hydrological models. However, uncertainty contributions may change under different hydro-climatological conditions with respect to both spatial and temporal patterns. Improving the data basis is discussed and suggested as a possible measure to increase the robustness of hydrological impact assessments.

Cluster 1: “Too much water” – river floods, heavy rain events, and sea-level rise

While changes in temperature and rainfall imply that many places will have too little water, others will suffer from having too much water. Because warmer air holds more water, intense precipitation events are likely to occur more often. A warming climate also causes the melting of snow and glaciers that source rivers. Especially during spring snowmelt, rivers can swell rapidly and overtop or burst their banks, threatening adjacent human settlements through flood events. Heavy rain events are especially problematic in urban areas with many concealed surfaces and dense populations. In these settings, surface water runoff accumulates rapidly and easily causes flash floods that are highly damaging. Too much water will also be a growing risk in coastal areas, not only in the form of extreme events like coastal flooding, but also through a slow-onset sea-level rise caused by the melting of ice on land.

River floods

Flooding is a natural phenomenon in rivers and a critical element of their flow regimes, sustaining ecosystems and their services. Extreme flood events, however, pose significant risks to European societies, not only in terms of damage to infrastructure or loss of agricultural lands, etc., but also by endangering human lives. Extreme floods affect many sectors, including all modes of inland transport, energy production, agriculture, industry, and housing. The high sediment loading in floodwaters and subsequent siltation in riverine habitats and floodplains, as well as the high hydraulic pressure, can be catastrophic to riverine ecosystems. Moreover, river floods cause pollution and deteriorate water quality, e.g. as they prompt sewer overflows or damage fuel tanks and industrial infrastructure. The PESETA IV study concludes that river flooding is the costliest natural disaster in Europe, estimating that at present 170,000 people every year are exposed to river flooding in the EU and UK, with damages of €7.8 billion/year.

Climate change has affected the frequency and intensity of floods in Europe. However, changes in flood patterns will manifest differently across the continent. For example, the magnitude of floods is predicted to increase in some northern countries, a trend that can already be witnessed from Scotland to the Alps. In the Mediterranean region and Eastern European countries with a continental climate, river floods are expected to decrease. This is because lower rainfall combined with higher evapotranspiration will reduce run-off and consequently river discharge. Without any additional adaptation measures and assuming 1.5°C of global warming, the PESETA IV study expects damage from river floods in the EU and UK to be three times higher by 2100 than currently, reaching €24 billion per year, and nearly 250,000 people to be exposed to flooding annually.

However, many of predictions of future flood impacts are still subject to considerable uncertainty, which is why their results need to be treated with caution (Blöschl et al. 2019). Remaining uncertainties particularly relate to the frequency and intensity of future extreme flood events, but also to socio-economic developments such as urbanisation. In fact, one major cause of long-term increases in economic losses from weather- and climate-related disasters has been the increasing exposure of people and economic assets (IPCC 2014). Uncertainties regarding future flood hazards and impacts call for flood risk management that offers robust and flexible solutions that are effective over a large range of potential future conditions.

Non-structural measures, such as the adaptation of land use regulation, flood-adapted planning, early warning or insurance systems, are often effective across different future scenarios. In recent years, debate and research in this regard have especially focused on the role of nature-based solutions, and to what extent they can replace or be combined with conventional grey infrastructure like dykes and dams. While dykes are effective in averting floods locally, they tend to relocate flood risks downstream – a typical example of maladaptation. Instead, maintaining or restoring floodplains upstream of vulnerable areas flattens the flood wave, thereby reducing the overall risk and the need to build or increase dykes and other grey infrastructure. Such nature based-solutions can have multiple co-benefits, including for biodiversity, water storage and purification, but also for climate mitigation if they contribute to maintaining wetlands or forests and their carbon sinks. One example of multiple-use flood protection measures are regulated polders, which can be used for extensive green-land farming. As a last resort, the provision of planning measures to evacuate flood-prone areas during extreme events can be a suitable coping strategy to manage remaining risks.

Adaptation strategies and measures at the EU, Member State and transboundary level

In recent decades, and in particular since the disastrous floods in the Elbe and Danube basins in 2002, there has been increasing debate and research in Europe on how to deal with floods. Measures to improve flood risk management (including prevention, protection, preparedness, and recovery) have been taken up at the EU and MS levels, as well as in cross-border regions and transboundary basins.

The 2007 EU Floods Directive (FD) provides the legal framework for managing flood risks in Europe's river basins. The implementation process of the FD is accompanied by the Common Implementation Strategy (CIS) and its dedicated Working Group on Floods (CIS WG-F), which meets twice annually to exchange information about the implementation of the FD and to work jointly on relevant topics. The European Flood Awareness System (EFAS) is the European operational centre for monitoring and forecasting floods across Europe, providing e.g. probabilistic, medium-range flood forecasts, flash flood indicators or impact predictions to the relevant national and regional authorities. The JRC's Risk Data Hub, an online GIS platform for exchanging and sharing geospatial data, compiles available information on exposure, loss and damage from river floods in Europe. The EEA has done considerable research on the restoration of green infrastructure such as floodplains that support flood risk management. EU-funded research under the 6th and 7th framework programmes has informed the development and implementation of the FD. In recent years, the Horizon 2020 programme has supported research on improved forecasting of hydrological extreme events under climate change as well as activities to demonstrate the benefits of nature-based solutions for flood risk management. The EU also supports the implementation of flood risk management measures through project funding e.g. within the LIFE programme, the INTERREG programme supporting i.e. transboundary cooperation in flood risk management and at a local level through the climate adaptation pillar of the EU Covenant of Mayors.

EU MS have taken a range of diverse approaches in flood risk management and in applying the requirements of the FD. Some of them have developed large, integrated flood risk management programmes and national strategies that seek to reach objectives of flood risk management, water security and adaptation jointly. Examples include the Dutch Delta Programme or the French National Flood Risk Management Strategy, adopted jointly by the French ministers of the Environment, Interior, Agriculture, and Housing. Germany also launched a large flood protection programme in 2015, which focuses on measures beyond the municipal and federal state level and prioritises action that provides synergies with nature conservation. In transboundary basins, the FD requires riparian countries to coordinate their Flood Risk Management Plans (FRMP). Such international Flood Risk Management Plans FRMP (iFRMP) have been developed in the Danube, Rhine, Scheldt, Meuse, Odra, and Elbe basins, among others.

The FD underlines that climate change leads to greater "likelihood and adverse impacts of flood events" (preamble, recital 2), calling on MS to address climate change through developing Preliminary Flood Risk Assessments (PFRAs) and in the second cycle of the FRMPs (Article 14[4]). With regard to the consideration of climate change in the implementation of the FD, the EC implementation report (EC 2019) outlines the following picture:

- 17 MS, out of 23 that were included in the assessment, considered climate change in their PFRA
- A high proportion of MS considered at least some aspects of climate change in their FRMPs. The FRMPs of 10 MS provided strong evidence that climate impacts were considered; those for 14 MS provided some evidence (out of FRMPs assessed in 26 MS)
- In the international FRMPs, the level of detail provided regarding climate change varies for the different international River Basin Districts (iRBDs). While there has been a clear effort to consider climate change in some of the iRBDs, in others the iFRMP states that it will only be considered in the future. In general, consideration of climate change is more developed in those basins where an international institutional body has been established.

Looking at the types of measures included in the FRMPs, it can be concluded that, in general, there has been a shift towards more robust and flexible solutions: several countries have implemented flood protection measures that relocate dykes and levees further inland instead of constructing new or reinforcing existing flood defence infrastructure; almost all MS included measures on spatial planning and land use in their FRMPs (for example those that control new developments in floodplains and integrate flood risks into spatial plans); and an increased number of FRMPs contain nature-based solutions for flood risk management, including re-naturalisation of rivers and riverbeds, restoration of the geomorphology of rivers, and afforestation of areas along rivers, coastlines and dams. However, while there has been significant progress, the implementation report concludes that MS should seek to identify further opportunities to use nature-based solutions for flood risk management.

Required action and possible entry points for EU activities to enhance adaptation efforts in the EU Member States

Increase consideration of climate change in flood risk management planning. The 2019 implementation report on the FD concludes that, in order to better integrate climate change into flood risk management, MS should (1) address uncertainties related to climate change and floods through enhanced research on climate scenarios and the impacts of climate change on future floods, (2) derive pertinent measures 'making appropriate use of EU modelling tools such as those available through the Copernicus Climate Change Service, and (3) coordinate the FRMPs with national climate change strategies and their adaptation measures.

Acknowledge the limits of incremental adaptation in flood risk management and better coordinate flood risk management with spatial planning. As mentioned above, in some parts of Europe, the frequency of severe flooding is expected to increase significantly. In large parts of the Danube basin, for example, 100-year floods could occur 10 times more often. Stark climate change effects like this will likely render inadequate incremental adaptation measures to mitigate floods such as building additional or increasing existing dams. Instead, a more systemic change will be needed, such as changing land-use and settlement patterns in order to expand the area and restore floodplains. This requires an integrated approach and better coordination with spatial planning in order to prevent that the necessary room will simply be occupied by competing uses (EEA 2016). Another transformational approach would be changing the way settlements are built, e.g. towards floating structures or housing on stilts.

Dealing with uncertainty about the manifestation of climate impacts. Despite further expected advances in climate research and modelling, uncertainties in forecasts of climate impacts will remain and therefore require new approaches to deal with them. Making use of probabilistic approaches can help quantify uncertainties to integrate them into decision-making. Another way to deal with uncertainties is by applying an adaptive management approach, which allows for adapting solutions to changing conditions based on a continuous iterative process of review, learning from new information and adapting the strategy accordingly. The cyclical implementation process of the FD provides a starting point for an adaptive approach. One good practice example of adaptive management is the application of so-called adaptation pathways in the Adaptive Delta Management concept of the Dutch Delta Programme. Adaptive management also requires adaptive governance structures that allow for learning and increased coordination.

Considering long-term effects on resilience in cost-benefit analysis. The FD implementation report concludes that MS should consider a more systematic analysis of the costs and benefits in the selection and prioritisation of measures in order to promote cost-effective paths for efficient flood risk management. A thorough consideration of the costs and benefits is critical to directing scarce funding to the most beneficial flood risk management measures. Most cost-benefit analysis methodologies, however, discount the future and therefore do not appropriately account for long-term benefits in terms of resilience. While this also refers to the long term costs of measures, nature-based solutions often are more resilient and cost-effective in the longer term – and therefore misrepresented by cost-benefit analyses discounting the future. Moreover, assessing the full range of potential co-benefits, not only those that can be monetised, is important to support coordination with adaptation efforts in other sectors, as it can demonstrate how land use change, e.g. to restore floodplains or to increase water retention in the catchment, can increase overall resilience also of the agricultural or forestry sector.

Heavy rain events

When disproportionately large amounts of rain fall within a short period of time, this is referred to as heavy rain events, torrential rain or extreme precipitation. Heavy rain events often take place during hot summer days and can lead to rapidly rising rivers, flash floods, soil erosion or landslides. All of these impacts can threaten human life, infrastructure and natural ecosystems.

Definitions for heavy rain events vary and existing data on resulting damages is insufficient. While the German Weather Services refers to heavy rain events when more than 10 mm occur in 60 minutes or 1.7 mm in 10 minutes, the definitions vary across Europe. Nevertheless, there is consensus that in recent decades the occurrence of such events has increased in Europe. Comparing observations of days with heavy rain in Europe between 1951 to 1980 and 1981 to 2013 shows that the number of such days has increased by about 45 per cent (Fischer and Knutti 2016). Europe-wide data on damages caused by heavy rain is not available. However, in Germany, for example, heavy rain events led to 6.7 billion Euros worth of damages related to residential buildings alone between 2002 and 2017 (GDV 2019). Damages most often related to flooded basements and ground floors, washed away cars and roads. Similarly to river floods, damages become more severe when equipment or buildings affected hold chemicals or other pollutants that contaminate the water and soil.

Modelling exercises strongly suggest that the probability of more frequent heavy rain events in Europe will increase with a changing climate, especially towards the end of the 21st century (while extended dry spells will also become more likely, Rajczak et al. 2013). For the winter months, heavy daily precipitation is projected to increase all over Europe, especially in the north and east, by up to 35 percent in the 21st century (EEA 2019). As for the summer months, modelling studies forecast increases for most of Europe, except for the Iberian Peninsula and southern parts of France and Italy (EEA 2019).

Past trends in damages caused by heavy rain and future projections make apparent that more actions need to be taken to mitigate future impacts of such events – but this is by no means trivial: For river floods for example, hazards zones with different return periods can be defined based on statistical data, landscape profiles, etc. Heavy rainfall events and resulting floods, however, can occur everywhere and thereby also affect areas and people who do not have any prior experience with floods. This makes preparation challenging – lacking solid data for the magnitude of the risk poses difficulties for mobilising funding as well as for building political will for mitigation measures. Another important challenge – and again a difference compared to river floods – relates to forecasting: While warnings for river floods can be made many hours or even days before the event occurs, the warning times for heavy rainfall events are significantly shorter and associated with much greater uncertainties (Kind et al. 2019: 38).

Many conventional approaches – flood retention basins, for example – can only offer very limited relief to heavy rain events; they involve such vast amounts of water that it renders them insufficient. Large-scale measures like larger sewerage systems might help more, but the costs are usually magnitudes higher than the expected benefits. Furthermore, such a step would be neglecting a contrary development: In many European countries, dry spells are projected to become more frequent, which poses entirely different problems for sewerage systems e.g. bacteria, fermentation gas etc.

There is no EU-wide policy guidance for heavy rain events. While the EU Floods Directive (FD) does not exclude any type of flooding, it does not provide guidance to systematically integrate the risk of heavy rainfall in its implementation. There are also barriers to integrating related risks systematically in the implementation of the WFD as heavy rainfall events and the resulting flooding occur independently of the river network. Consequently, the river basin as the preferable unit of consideration by the WFD is unsuitable; rather, a smaller and more fine-grained scale is necessary to assess and prevent risks from heavy rainfall (Kind et al.2019). Nevertheless, heavy rain events in cities are a relevant issue to the WFD and also the Urban Wastewater Treatment Directive (currently under review), as they regularly cause combined sewer overflows and pollution. Guidance and knowledge exchange may therefore be addressed by these directives as well as the FD.

Adaptation strategies and measures at EU, Member State and transboundary level

As the challenge of heavy rain events is an inherently local one, many EU initiatives that tackle the issue focus on action in urban areas. The EU supports urban and local climate adaptation primarily through the EU Covenant of Mayors, providing capacity-building directly to cities, and supporting the development of local adaptation strategies and action plans. The Climate-ADAPT platform also provides MS and local authorities with case studies for actions to reduce the impacts of floods. In addition to these initiatives, a number of Interreg- and LIFE-funded projects support municipalities in dealing with heavy rain events: The project “RAINMAN”, for example, worked with municipalities in six Central European countries and helped map heavy rain hazards and develop suitable risk mitigation strategies. The project “LIFE LOCAL ADAPT” supported smaller municipalities with coaching and knowledge transfer on this topic. On the research side, there are efforts to improve methods for measuring the economic costs of extreme weather events such as heavy rain (H2020 project COACHH), refining forecasting and early warning systems (H2020 project ANYWHERE) and of course research efforts on climate models that project changes in precipitation, e.g. CORDEX.

Looking beyond actions funded by the EU, a variety of activities by insurance, specialist companies, national and local governments can be observed. In recent years, insurance companies have become more involved in raising awareness of the risk posed by heavy rain events and promoting structural risk mitigation measures for buildings (and insurance products). Specialist companies are developing new technical solutions to address the problem, e.g. semi-permeable surfaces that allow rainwater to seep into the ground below or improved retractable flood barriers. Many actions on national level in the MS focus on raising awareness and on funding research and selected pilot activities in municipalities. At the sub-national level, actions tend to be more specific and concerted: The state of North Rhine-Westphalia, for example, published a dedicated heavy rain strategy in 2016, is providing funding for rain hazard maps, and has introduced a legal requirement to consider the impacts of climate change for any actions on wastewater disposal. The state of Baden-Württemberg provides funding to municipalities for developing heavy rain action plans, while also supplying them with high-resolution spatial data for risk assessments. This information makes it much easier for local decision-makers to have hazard maps prepared and makes the maps themselves more comparable. At the city-level, measures range from well-publicised flagship actions like multifunctional water plazas (Rotterdam) or water playgrounds (Hamburg) that retain rainwater to very small and simple actions like raising the curb in a curved street to direct a possible water flow towards a forest and away from residential buildings.

Required action and possible entry points for EU activities to enhance adaptation efforts in the EU Member States

Supporting the development of a unified definition or threshold for heavy rain events. The current variety of definitions for heavy rain events across Europe makes it difficult to monitor developments in this realm. Creating consensus for a common definition would improve the foundation of all monitoring and research activities on this topic in Europe.

Defining minimum standards for rain hazard maps. The variety of maps has greatly increased in recent years. They are a useful and popular tool for addressing the topic. However, decision-makers at the local level would benefit from guidance on what type of map to develop, or on what minimum standards they should take into account. As there is currently no EU wide policy process addressing heavy rain events, a suitable framework for developing joint standards needs to be found. It could, for example, be taken up by the WFD/FD CIS process or the European Committee for Standardization (CEN).

Steering the development of a Europe-wide register for damages caused by heavy rain events. Data on impacts of heavy rain events is limited across Europe and difficult to compare or aggregate. Starting a mechanism at the European level for collecting data on damages caused by these events would greatly benefit any efforts for assessing how impacts change over time. This would be valuable information for decision-makers when evaluating whether more or different actions need to be taken.

Facilitating exchange on how to increase risk awareness among citizens. Property owners are essential for dealing with heavy rain events: Measures on the property can reduce damage to the property itself but can also protect the surrounding areas when retaining water on the land. Changing the perceptions of property owners can also be a challenge. EU efforts for pooling and exchanging knowledge on what works to encourage citizens to take action would greatly benefit local decision-makers.

Transforming urban planning. One of the solutions to manage the risks of heavy rain events, especially for urban areas, lies in creating a patchwork of multifunctional areas that can also be used for water retention and implementing smart measures to direct rainwater towards them. For example, aiming to infiltrate rainwater runoff, instead of channelling it out of the city. Such green infrastructure further provides a number of co-benefits, including recharge of groundwater aquifers, recreational space and cooling effects in cities. Space is at a premium, however, at least in many of Europe's metropolitan cities. Other solutions include the use of green roofs, e.g. on large industrial buildings, to reduce and delay rainwater from entering the water drainage network, and thereby limit the risk of overwhelming the system. For these reasons, transforming urban planning requires increased coordination among the various authorities and stakeholders.

Sea-level rise

The melting of land ice due to climate change will lead to a global sea-level rise, although with geographical differences (EEA 2019). Warming seawater, which expands in volume, will reinforce this trend. Sea-level rise poses a threat to marine ecosystems and to humans in coastal areas through flooding and erosion of land and saltwater intrusion into coastal aquifers (UBA/KomPass 2012). Furthermore, low-lying marshlands may increasingly face the need for draining excess water that flows less effectively into the sea. The recent report of the IPCC, which sets special focus on the ocean and cryosphere in a changing climate, revised earlier estimations on the contribution of Antarctic land ice loss to sea-level rise. It projects a global mean sea level rise of 0.23 to 0.40m for 2050 and of 0.61 to 1.10m for 2100 in a high-emission scenario (Oppenheimer et al. 2019). Other model-based studies even project global mean sea level rise of 1.5 to 2.5m by the end of the century (Grinsted et al. 2015; Le Bars et al. 2017).

Additionally, temporarily extreme sea levels associated with storm surges, tides or wind waves are expected to occur more frequently. Especially under a high-emission scenario involving abrupt changes of the climate system, the impacts of sea-level rise and extreme sea levels for European coastlines might strongly intensify (Stammer et al. 2019).

Sea-level rise will affect fisheries, tourism and the transport sector, as well as natural habitats and human settlements in coastal areas (EC 2013). Along Europe's coastlines, entire cities, like Venice or Dublin, and larger areas in the Mediterranean, Belgium or the Netherlands are considered highly vulnerable to the impacts of sea-level rise (EEA 2019). Around 200 million people live in European coastal zones classified as being at risk from flooding (Vousdoukas et al. 2020). Without adequate adaptation efforts, the annual economic damage from coastal flooding in Europe could increase from around €1.4 billion today to almost €240 billion in a high-emission scenario by the end of the century (Feyen et al. 2020). However, around 95% of these impacts could be avoided through relatively simple measures such as raising dykes in coastal areas hosting human settlements and important economic activities.

Appropriate adaptation measures include the expansion of floodplains and waterfront structures. Nature-based solutions that expand and restore tidal marshes and wetlands can complement concrete-and-steel structures by attenuating wave impacts (Schoutens et al. 2019). Innovative solutions for coastal flood protection (like the Afsluitdijk in the Netherlands) include conservation features such as fish migration pathways built into dykes while being aesthetically and functionally designed in a way to support recreational activities. Salinization of coastal aquifers, which is caused by with sea level rise, can be tackled through artificial recharge. By replenishing groundwater, artificial recharge helps to build a buffer against intruding seawater. In many lowlands, there will be no other option in the long term than to relocate the local population and abandon land uses (UBA/KomPass 2012; EC 2013).

Adaptation strategies and measures at the EU, Member State and transboundary level

At the European level, several strategies address the impacts of sea-level rise and the need for coastal protection. In 2013, the EC published a proposal for a new EU directive that establishes a framework for maritime spatial planning and integrated coastal management. While the Directive for Maritime Spatial Planning came into force in 2014, no directive on integrated coastal management exists as of yet; it would be, however, better suited to regulate coastal protection. Among other things, the proposal aims at fostering consultation with and coordination among MS regarding to coastal management. The 2013 EU Adaptation Strategy highlights the vulnerability of particular regions to sea-level rise and extreme sea levels. Examples for existing adaptation efforts include the development and adaptation of infrastructure and the promotion of nature-based solutions (EC 2013). The latter is also reinforced by the Marine Strategic Framework Directive and the recent report on the Directive, pinpointing the advantages of effective marine protected areas and ecosystem-based approaches for increasing the resilience of the marine environment to the impacts of climate change (EC 2020). The current blueprint for a new, more ambitious EU strategy on adaptation accentuates the need to avoid maladaptation (e.g. as specific concrete-and-steel coastal protection structures have tended to just shift negative impacts to neighbouring areas) (EC 2020).

Several EU activities foster knowledge exchange and data compilation of marine data or case study results (e.g. OURCOAST, Marine Knowledge 2020 strategy, Climate-ADAPT, EU Covenant of Mayors, European Marine Observation and Data Network (EMODnet). In 2019, the Joint Programming Initiative Healthy and Productive Seas and Oceans (JPI OCEANS) established a Knowledge Hub on Sea-Level Rise, aiming at closing knowledge gaps and fostering information exchange between the relevant disciplines. The Hub intends to help policy-makers make well-informed decisions on adaptation measures. Further, assessments on the drivers of sea-level rise and specific policy options for the major ocean basins around Europe are planned.

There is a growing number of transboundary and national coastal protection activities. The Mediterranean Action Plan, for example, promotes integrated coastal zone management in the Mediterranean region (EC 2013). Several MS published national coastal strategies and policies, targeting activities like coastal and flooding defence structures, rehabilitation efforts and measures against coastal erosion. In Germany, for example, discussions between the government and the federal states have started to address sea-level rise. In the Netherlands, a Sea Level Rise Knowledge Programme was initiated to inform the Dutch Delta-Programme on the impacts of accelerated sea-level rise especially beyond 2050.

Required action and possible entry points for EU activities to enhance adaptation efforts in the EU Member States

Increase coordination at multiple political-administrative levels and across relevant sectors. Currently, no multilateral exchange and coordination exist at the European level that addresses the impacts of sea-level rise and the implications for coastal protection. Existing initiatives, such as informal expert groups on maritime spatial planning and integrated coastal management, should be strengthened to fill this gap. Besides highly vulnerable European coastal regions, an expanded exchange with the outermost regions (e.g. Canary Islands, Azores or Madeira) offers potential for increased cooperation, as especially island states face high vulnerabilities against the impacts of sea-level rise. It will be important that established cooperation formats include activities on monitoring and forecasting as well as on the development of transboundary risk assessments and adaptation strategies for all marine basins and island that are highly vulnerable to sea level rise. Furthermore, given the far-reaching ramifications for various economic sectors and society at large, adaptation efforts concerning sea level rise and coastal protection must be mainstreamed into adaptation strategies of other sectors. Furthermore, there is a need for vertical policy harmonisation including lower political-administrative levels, where adaptation measures are implemented (EC 2013).

Address remaining knowledge gaps. The recent IPCC special report on the ocean and cryosphere provided further insight in the complex dynamics of the melting of the Antarctic ice shield and its contributions to global sea-level rise. Still, knowledge gaps and uncertainty remain regarding the causes and consequences of global sea-level rise. The planned European research and innovation mission “Starfish 2030” provides opportunities in this regard. There is also a need for better mainstreaming of key findings into policymaking and implementation processes at all political-administrative levels (EC 2013). In doing so, the establishment of working groups or science-policy interfaces communicating experiences and best practice adaptation strategies can offer a valuable addition to the upcoming platforms for knowledge sharing. In the face of remaining uncertainties, fostering research on and implementation of low-regret and/or no-regret coastal protection measures will be important to ensure cost-effective adaptation and avoid maladaptation.

Need for more transformational change. In particular, projections on high-end scenarios of sea-level rise and the possible effects of crossing tipping points are limited and include high uncertainties. This also encompasses barriers of adaptation and transformative adaptation pathways. However, those low-probability, high-impact upper range projections should not be excluded in risk assessments and long-term adaptation planning, as there is a considerable risk that sea-level rise might even exceed current high-end projections (Jevrejeva et al. 2019; Grinsted et al. 2015).

For these reasons, enforced research on transformative adaptation pathways responding to high-end scenarios of sea-level change might address existing path dependencies and create opportunities for innovative solutions to the impacts of sea-level rise. Transformational adaptation might include establishing flood-resistant, extensive agricultural use of dyke hinterlands (e.g. paludiculture), designing infrastructure for exposure to regular flooding (e.g. cities on “stilts”) or the abandonment and planned retreat of entire coastal areas. Transformational change would incorporate a re-design of coastal infrastructure and economies, especially agriculture, and new strategies for tourism and nature conservation. However, against the backdrop of long adaptation periods in coastal systems and the rising projected damage costs of coastal flooding, a timely transition into transformative adaptation pathways might create comparative advantages.

Cluster 2: "too little water" – water scarcity and drought

Increasing water use, prolonged droughts[3] and heatwaves in the past decade have revealed Europe's vulnerability to reduced water availability. Water is a cross-sectoral matter. The availability and use of water consequently not only affects the status of water bodies and associated ecosystems, but also the supply of drinking water, agriculture, forestry, energy production and inland navigation. In this way, a water deficit can adversely affect the whole economy. In the summer of 2018, for example, the German Federal Government and its federal states paid farmers "drought aid" of up to 340 million euros. In recent decades (1981-2010), annual economic losses are estimated to amount to 9.0 billion € per year for the EU and the UK[4]. With some regional variation, economic losses have been highest for the agriculture, water supply and the energy sector. Losses in the transport sector relate only to inland water transportation and on represent only 1.5% of the total losses (Cammalleri et al. 2020).

According to the European Environment Agency, the frequency of meteorological droughts has increased since 1950 in the Mediterranean and Central Europe while it decreased in Scandinavia.[5] The Peseta IV study shows that hydrological drought intensity and frequency is expected to increase with global warming in the south-western parts of Europe, whereas an opposite signal is projected for north-eastern Europe. In this way, climate change could further polarise current water availability and drought conditions in Europe (Cammalleri et al. 2020).

With climate change, drought-driven economic losses in Europe are expected to increase. When accounting only for the effects of future climate change aggregated, drought-related damage in the EU is expected to only slightly increase to approximately 9.7 billion €/year at 1.5°C warming. With higher levels of warming damage further increases to approx. 12.2 billion €/year at 2°C warming and approx. 17.2 billion €/year at 3°C warming, corresponding to 0.07% - 0.14% of the EU's GDP in 2015 (including the UK). **Hence, a 3°C warmer climate applied on today's (2015) economy would result in a 90% increase of absolute drought-related losses in Europe** compared to present climatic conditions. There are, however, strong regional differences in the evolution of drought-related economic losses as the climate in Europe warms. The Mediterranean and Atlantic sub-regions of Europe could experience more than a two-fold rise in drought impacts unless mitigation and adaptation are taken. The strongest rise in drought-related economic losses under a 3°C warming scenario are projected to hit Ireland, Cyprus, Belgium, Greece, France, the Netherlands and Spain. The continental sub-region will see a reduction in drought-related economic losses of approximately 20% under the 1.5 and 2°C warming scenarios. Under higher warming, this trend is reversed and losses rise again to amount to 92% of baseline damages at 3°C warming (Cammalleri et al. 2020).

Water quality aspects related to scarcity and drought have often been neglected, but can put additional constraints on the availability of adequate water resources. As scarcity and droughts are often linked to changes in the flow regime, the dilution capacity of water bodies is lower. For this reason, temperature increases can lead to eutrophication, and when water bodies are altered in this way, invasive species can spread more easily. In addition, groundwater overexploitation and unsustainable land use often lead to desertification, which, in turn, result in loss of topsoil and vegetation, decreased capacity for water retention and increased erosion and pollution.

[3] https://www.eea.europa.eu/help/glossary/eea-glossary/drought

[4] This estimate also does not include damages to ecosystems and their services, which are even more difficult to quantify in economic terms.

[5] https://www.eea.europa.eu/data-and-maps/indicators/river-flow-drought-3/assessment

Adaptation strategies and measures at the EU, Member State and transboundary level

Several strategies and measures are in place across the EU, addressing often a combination of abstraction controls, ecological flows, drought management plans, water pricing, new storage systems, reduced water consumption and water reuse and desalinization. Most of them prioritise certain water uses in comparison to others and are based on social, economic and environmental criteria (OECD 2015). However, increasing water supply remains the easiest and often preferred option in the short term. More complex governance processes to respond to reduced water availability and overcome over-abstraction remain a major challenge, even for those areas suffering from water scarcity and drought on a regular basis.

In the past, responses to water scarcity in the EU have largely focused on increasing water supply and abstraction by drilling new wells, constructing dams and reservoirs or constructing large-scale water transfers infrastructure. There are still River Basin Districts (RBDs) where such actions are focused on. More than 7,600 (7%) of Europe's surface water bodies are affected by significant water abstraction pressures while 16% of the area of groundwater bodies is affected by overabstraction. 11% of the total area of surface and groundwater are in poor quantitative status (EEA 2018b). It should also be noted that even significant abstractions are not always metered and are often just estimated, e.g. based on surveys or cropping patterns, which can lead to significant uncertainties in estimations about real abstractions. Furthermore, non-authorised or illegal water abstraction pressures hamper sound water management, especially in the Mediterranean EU MS (OECD 2017)[6].

However, as Europe cannot endlessly increase water supply, more flexible approaches and demand management measures have also been adopted, including the use of economic instruments, water loss controls, water-reuse and recycling, increased efficiency of domestic, agricultural and industrial water use combined with water savings (Council of the European Union 2011). Given the huge potential for water savings in the EU, the European Commission's 2007 Communication on water scarcity and droughts laid down a water hierarchy. It ranked water demand management most important among measures and determined that alternative supply options should only be considered once the potential for water savings and efficiency has been exhausted: "[only] in regions where all prevention measures have been implemented according to the water hierarchy (from water saving to water pricing policy and alternative solutions) and taking due account of the cost-benefit dimension, and where demand still exceeds water availability, additional water supply infrastructure can in some circumstances be identified as a possible other way of mitigating the impacts of severe drought" (EC 2007a).

Measures to reduce the risk of water shortages include lowering water consumption through changes in production processes (including cropping patterns), water-saving technologies and management practices. The transformation of sectors, for example energy production, offers significant opportunities for a reduction of freshwater abstraction and consumption. However, there is evidence that water consumption is on the rise, partly as a consequence of adaptation efforts. EU investments and regulation have not led to sufficient results in actual water savings (EEIG Alliance Environment 2019). Instead, irrigation agriculture is expanded as one form of adaptation to a changing climate. At the same time, water-intensive cotton farming is still taking place in some of Southern Europe's water-scarce river basins and is even subsidized by the Common Agriculture Policy. Another widespread practice is the support for irrigation or intensification of traditionally rain-fed crops, such as olive yards and almond trees.

Moreover, water reuse and other alternative water supply options can provide sustainable solutions to secure water supply. Reuse of treated urban wastewater can further provide potential to reduce nutrient pollution of water bodies, but requires to be properly managed on a case-by-case basis in order to prevent risks for human and environmental health (Pistocchi et al. 2018), including soil and groundwater pollution, as well as failures in

[6] OECD (2017); https://www.fega.es/datos-campanas-clasificadas-por-actividad/actividad/Condicionalidad refers to an average of 8-10% of inspected farms in Spain not complying with abstraction permits.

water resource accounting. In May 2020, the EU Regulation on minimum requirements for water reuse has entered into force. It will, to some extent, harmonize the permission process and risk management across MS and aims to facilitate the use of treated urban waste water (reclaimed water) for agricultural irrigation.

Desalinization can also be considered as additional supply when environmental considerations and externalities are duly taken into account. This technique has been extended widely in the Mediterranean, and is being used for urban, industrial and irrigation water use. Production costs are approximately 0.5 Eur/m3, which are significantly higher than of traditional water supply options or even reuse. The desalinization infrastructure has to deal with brine discharge (and potential impacts to marine environments) and high energy demand as environmental concerns and avoid maladaptation through increased greenhouse gas emissions.

The WFD is an umbrella under which necessary measures to respond to water scarcity and drought could be addressed – in RBMPs and PoMs, at the national and transboundary level. Key measures in the WFD that address water scarcity and drought include: Article 11(3)(e) of the WFD, which explicitly requires controls over the abstraction of surface water and groundwater; those measures under Article 11(3)(c) to promote an efficient and sustainable water use; Article 11(3)(f) which refers to controls, including a requirement for prior authorisation of artificial recharge or augmentation of groundwater bodies; as well as those on water pricing considered under Article 10. Supplementary measures (Article 11(4)) can address other related topics, such as water reuse.

In its 2007 Communication, the European Commission advises MS to, among others, set up **drought management plans (DMPs)** and develop drought indicators in order to reduce drought risk on all time-scales. The 2007 Drought Management Plan Report (EC 2007b), as well as the work of a dedicated Expert Network within the framework of the CIS process, provides further guidance, and a set of EU-wide indicators has been developed until 2012. More recently, in the 'WFD Fitness Check report', the European Commission recommends DMPs as a key measure to cope with drought impacts. Recommendations linked to DMPs and climate change strategies are often highlighted in MS reports following the 5th Implementation report of the WFD (EC 2019).

Required action and possible entry points

The main challenge for addressing decreasing water availability remains in better preparedness and improved resilience to climate change – which means there is a need for more climate risk-informed water planning and management. Even in cases where there is no risk of severe drought, there is need to adopt inclusive, forward-looking and climate risk-informed water planning and management processes (including transparent water balances and accounts) and to adjust water allocations across environmental and human uses to long-term water availability in order to reduce negative effects on freshwater ecosystems. This refers especially to allocating water resources from those water bodies that should be considered as a strategic drinking water reserve. Competent authorities complain about the lack of resources to ensure updated, adaptive drought management planning, improved natural resource management and adequate information and stakeholder engagement for adaptation measures. The EU Guidance documents on water balances[7] and ecological flows[8] provide elements to address resilient water allocation. Further research, e.g. under the Horizon Europe mission on freshwater, might be useful to explore the innovative sharing of water resources in specific regions and communities.

Accounting for water scarcity and drought – a need for adaptive abstraction control. The 2019 EU implementation report on the WFD shows that key measures have generally been defined for regulating water abstraction, but their implementation is uneven across Europe. Pressures resulting from reduced precipitation and over-abstraction

[7] https://circabc.europa.eu/sd/a/820ec306-62a7-475c-8a98-699e70734223/Guidance%20No%2034%20-%20Water%20Balances%20Guidance%20%28final%20version%29.pdf

[8] https://circabc.europa.eu/sd/a/4063d635-957b-4b6f-bfd4-b51b0acb2570/Guidance%20No%2031%20-%20Ecological%20flows%20%28final%20version%29.pdf

are thus only slowly reduced. The fact that most MS exempt small abstractions from controls or registration is potentially problematic. A lack of control and registration can be of concern particularly in MS that already have water scarcity problems and in water bodies suffering from unsustainable water withdrawals, even more so in the face of climate change. According to the MS regulations, water permits must be periodically reviewed and, where necessary, updated. The granted permits are in place for very different timespans, ranging from short periods up to very long periods which hardly allow adapting abstraction permits to changing climate while ensuring thresholds required for achieving the WFD objectives. While most MS have reported to have done a climate proofing of the WFD Programmes of Measures (PoMs), the effectiveness of the climate proofing methodologies applied remains unclear.

Competing water uses of high economic or social relevance. Limited progress in addressing over-abstraction also stems from the fact that the concerned water uses are often of high economic and social relevance and that reducing the water allocation would require to address conflicting interests. In face of this, infrastructure to augment water supply such as dams, water transfers or desalinisation plants are generally easier to govern and finance. In parallel, their operational, environmental and resource costs are usually not fully recovered, so they seem less costly than reducing water use. One way to address conflicting water uses and prevent over-abstraction in times of drought are national regulations that stipulate priority water uses (such as drinking water, minimum environmental flows, and high value water uses) in times of water scarcity.

The value of water – water pricing. A number of MS have upgraded their water pricing policies 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. Steps were made in defining water services, calculating financial costs, metering, performing economic analysis and assessing both environmental and resource costs when calculating the cost recovery amounts for water services. However, significant gaps remain in translating these improved elements of economic analysis into concrete measures and achieving more harmonised approaches to estimate and integrate environmental and resource costs (EC 2019), and pricing alone will most likely not solve all water scarcity problems (Moss et al., 2020).

Incentive pricing deals with the way water users pay for their use and whether the right price signals are transmitted, i.e. it addresses the question of how water is being paid for and how the water price affects the behaviour of water users. Incentive pricing is not referred to in many of the RBMPs. Even when referred to, the information in the RBMPs is mostly unspecific and does not represent the situation in appropriate analytical detail. In most cases, a global explanation is provided, stating that the regulations and instruments in place guarantee that incentives are set. Across the EU, volumetric charges are in place for 58% of all reported water services. For 31% of the reported water services, volumetric charges are partially in place, and only for 11% of the reported water services, no volumetric charges are in place. The assessment of the incentive function of volumetric charges is not reported in detail, and only general statements regarding this issue are given in the RBMPs (EC 2019). Successful water pricing and management rely on the awareness of users and the public. The 2012 Flash Eurobarometer on Water survey shows that 68% of the population recognise that water-related problems are serious and worry equally about water quantity and quality (EC 2012c). Potentially, the monitoring and reporting of sustainable water uses, eco-labelling and the consideration of water use, saving and reuse in the energy sector as well as the implementation of the Industrial Emissions Directive and its revision might support the recognition of the value of water.

Preventive drought risk management, including drought monitoring and forecasting, is still insufficiently implemented by the MS. Although not explicitly mentioned in the Water Framework Directive, a key management measure to mitigate drought impact is a Drought Management Plan (DMP), including: i) indicators and thresholds establishing onset, ending, and severity levels of the drought; ii) measures to be taken in each drought phase; and iii) an organisational framework to deal with drought (Intecsa-Inarsa 2012). A growing number of MS have developed DPMs or similar tools, including such plans at municipal level. However, such plans have not been adopted in all relevant

RBDs. During the first RBMP cycle, up to 78 River Basin Districts (42%) had implemented DMPs or similar tools or had planned for it in the framework of PoMs. Since then, a few MS have progressed in advancing drought management, for example by developing drought indicators and extending the number of RBDs with Drought Management Plans (Slovenia, United Kingdom).

In practice, drought forecasting also remains a challenge. The European Drought Observatory, which is funded under the EU Adaptation Strategy, provides large-scale drought monitoring. However, for drought risk management in river basins and smaller management units, there is still a lack of improved drought indicators, monitoring and forecasting capacities. The same applies to national tools, such as the UFZ drought monitor[9]. Some RBOS have developed joint low water monitoring for rivers, like in the Meuse, Mosel-Saar or the Rhine basins. RBOs have also started to discuss how to cope with dry seasons in river basins in the future, including better data, joint assessments etc. (see e.g. the new "Rhine 2040" programme of the ICPR, which includes a chapter on those issues[10]).

Dealing with water scarcity and drought – managing water more wisely through integrated storage. Water storage systems are important to dealing with seasonal and inter-annual variability and can also provide a buffer against extremes. Under a changing climate more – and more diverse – physical storage systems are needed. These can be flexibly managed to accommodate varying levels of precipitation and hydrological flows. However, the alteration of hydrology has also negative effects on the status of water bodies. Integrated storage concepts that take into account grey, green and blue infrastructure, such as nature-based solutions for increased water retention in wetlands and agricultural soils, could play an important role here. Integrated storage concepts should combine a portfolio of surface and sub-surface storage options, including reservoirs, wetlands, soil moisture, ponds and aquifers, in order to achieve the best environmental and economic outcomes and avoid unnecessary evaporation – but also to heed minimum ecological flows, efforts for which can be accelerated under the EU Biodiversity strategy for 2030. The management of storage and abstractions is particularly relevant for areas which suffer from severe and continued groundwater overexploitation.

Systemic change in how water is valued is needed across sectors and society. Climate adaptation measures so far have not necessarily contributed to reduce water use to levels that are sustainable. This is caused through a combination of the measures being implemented and the weak water quantity governance in place (low awareness, lack of metering of water consumption, illegal abstractions, poor data on effective ecological flows, poor control and enforcement, lack of performance assessments), especially for groundwater (FAO 2017; European Court of Auditors 2014; Molle and Closas 2020). Especially – but not only – in the Mediterranean, there is a constant trend for expanding irrigation areas to increase agricultural production and resilience towards meteorological droughts (European Court of Auditors 2014). In addition, efficiency measures have contributed to "more crop per drop", but due to the "rebound effect" (or Jevons Paradox) not necessarily to reduced water consumption and overall sustainability. More transformational approaches will require an increased awareness of water users about sustainability and consistent sector strategies, as well as improved enforcement of water allocation rules. This will also entail a fundamental re-evaluation of water uses by various sectors, especially the agricultural sector, which accounts for the largest part of water withdrawals, water use increase due to the rebound effect and significant groundwater pollution. Systemic change also requires paying more attention to water quality, as quality can constrain water uses. Measures to control point-source and diffuse pollution need to be expanded across many RBDs in Europe, and the European Green Deal's Zero Pollution Action Plan and Farm to Fork Strategy can provide opportunities to address pollution more at their source.

[9] https://www.ufz.de/index.php?de=37937

[10] https://www.iksr.org/en/icpr/rhine-2040

Cluster 3: Achieving and maintaining good status of water bodies under a changing climate

The impact of climate change on the status of water bodies

Aquifers, rivers, lakes, wetlands, coastal waters and oceans are complex ecosystems and are affected by climate change in multiple ways. The WFD – the EU's primary legislative instrument to manage freshwater ecosystems sustainably – does not mention climate change explicitly. However, the WFD is a framework directive and therefore a rather flexible instrument that could cope with new or changing challenges. All existing river basin management plans (national and international) in the framework of WFD implementation address climate change and its effects. They partly include adaptation measures, especially no-regret measures, given uncertainties in predictions of future climate impacts.

Climatic changes in air temperature and precipitation distribution affect the surface water temperature, the water availability and quality of a water body. These are therefore important boundary conditions for numerous biological, physical-chemical, quantitative and also chemical processes in the aquatic habitat. The Netherlands analysed the impacts of climate change on the ecological and chemical status of water bodies based on a literature study and interviews with experts (RIVM, 2010). The conclusions will also be valid for many other RBMPs in the EU. These are:

- Climate change affects water temperature. Indirectly, physical and chemical processes related to temperature in the water column will change. Changes that are expected to occur include increased rates of (bio-) chemical processes, a decrease in oxygen concentration and changing stratification patterns. A changing hydrology will indirectly affect the physic-chemical water quality.
- Heavy precipitation events will increase soil erosion, which will lead to increased nutrient and pollutant run-off to surface waters. Water systems will become more eutrophic and as a result, water transparency will decrease. Droughts, as well as a rising sea level, can lead to the salinization of surface waters. In general, it is expected that climate change will reduce the physicochemical water quality.
- Climate change is expected to aggravate current problems such as eutrophication, pollution and habitat fragmentation.
- On a macro-scale, climate warming is mainly expected to cause changes in species phenology, physiology and species composition. Increased water temperature is an important cause of changes in aquatic species composition and diversity and lifecycle dynamics.
- Extreme weather events are expected to negatively influence the diversity of macroinvertebrates. Disturbed ecosystems are more vulnerable to invasive species. Invasive species can have devastating impacts on ecosystems, and some are expected to increase due to climate change.

All this will also have an impact on the implementation of the WFD, from typology, to status assessment, to measures to achieve good status (Quevauviller 2011). The MARS[11] and the GLOBAQUA[12] projects, funded by the 7th EU Research Framework Programme, have assessed and modelled the effect of extreme climate events such as heavy rainfall, heatwaves and water scarcity on aquatic ecosystems, reviewing the complex mix of stressors resulting from urban and agricultural land use, water power generation and climate change. The project results anticipate more complex decision-making and PoMs to address all relevant pressures.

Climate change will also affect groundwater aquifers in direct and indirect ways. Increased variability in precipitation and more extreme weather events can lead to longer periods of droughts and floods, which directly affects availability and dependency on groundwater. In long periods of droughts, there is a higher risk of depletion of aquifers due to decreasing recharging rates. At the same time, indirect climate change impacts such as the intensification of human activities and land-use changes increase the demand for groundwater.

CIS guidance document No. 24 River Basin Management under a changing climate

The WFD does not explicitly refer to adaptation to climate change. However, when drafting the CIS guidance document No. 24 River Basin Management in a Changing Climate (EC 2009), MS agreed that, from the second planning cycle onwards, climate-related threats and adaptation planning would be incorporated in the RBMPs. This is reinforced by the fact that almost all the elements that are included in the definition of WFD ecological, chemical and quantitative status are sensitive to climate change and, given to the step-by-step cyclical approach, are well-suited for adaptation action. The guidance includes:

- Assessing direct and indirect (primary and secondary) climate pressures in order to provide information for the pressures analyses.
- Assessing monitoring programmes to ensure early climate impact signal detection.
- Close monitoring of climate impacts in reference sites (sites with limited anthropogenic modification).
- Integration of potential additional pressures, impacts and constraints caused by climate change in the economic analysis of WFD.
- Undertaking a "climate check" of the Programs of Measures (PoM) by applying a transparent and fully documented methodology. The "climate check" of the PoMs is supposed to carry out a sensitivity analysis of the proposed measures based on a fully transparent methodology to evaluate long-term effectiveness and cost-efficiency under changing climatic conditions. The results of the climate check should be integrated in other RBMP processes.
- Outlining of specific adaptation measures with a preference for robust no-regret actions is further recommended.

The CIS guidance document should be updated accordingly and based on the implementation experience made so far and newer information on climate change impacts on water resources.

[11] http://www.mars-project.eu

[12] http://www.globaqua-project.eu/en/home

Consideration of climate change in WFD implementation

The assessment of the second RBMPs shows that various climate change aspects have been considered, as shown in Figure 9 (EC 2019b).

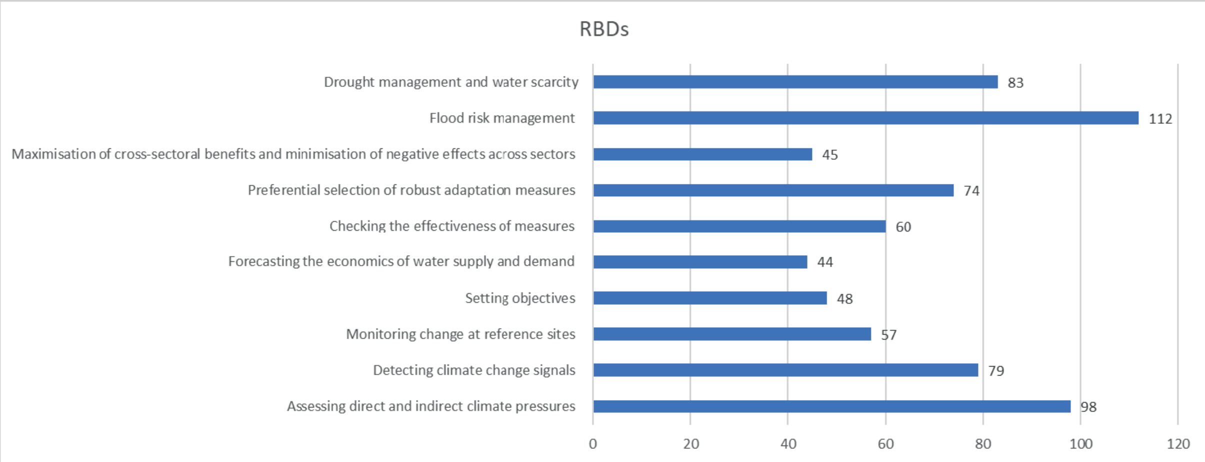


Figure 9: Climate change aspects considered in RBMPs (No. of RBDs considering each climate change aspect) (EC 2019b)

Climate change has been mostly considered in the context of flood risk management (112 RBDs) followed by the assessment of direct and indirect climate pressures (98 RBDs). The above-mentioned CIS Guidance on climate change has been used by most MS. A climate check of PoMs has been carried out in all RBDs, except for some RBDs in a few MS. However, assessment within the WFD Implementation report has not enabled the determination of the effectiveness of climate proofing methodologies. Specific sub-plans addressing the issue of climate change have been reported for a few MS. 32% of the MS (eight out of 25 assessed in the report) in one way or another adopted specific adaptation measures to climate change in their RBMPs. Moreover, due to mainstreaming efforts of climate change at EU and Member State level in recent years, several planned measures with a different objective will support adaptation (EC 2019a).

Maintaining ecological flows to reach good ecological status. Protecting and restoring the natural flow regime of rivers are important hydro-morphological measures to ensure rivers attain a good ecological status. Only an intact flow regime – that is, flows sufficient in volume, at adequate timing and of good quality – can sustain the river ecosystem and the services it provides to humans (such as fisheries). The critical role of ecological flows is recognized in EU policy and strategy documents. The WFD does not set any quantitative targets for surface water bodies, only for groundwater. However, provisions made in the WFD implicitly acknowledge the critical role of sufficient water availability and specific flow dynamics for achieving good ecological status of aquatic ecosystems and environmental objectives in the WFD. Beyond the sole consideration of minimum flows in dry periods, all flow components need to be included as operational targets for quantitative water management, from base flows (including low flows) to flood regime (magnitude, frequency, duration, timing and rate of change) (EC 2015).

In most MS, the work on defining and implementing ecological flows is still ongoing in the second RBMP cycle. Two-thirds of MS have mapped a total of 408 basic measures against the Key Type of Measure (KTM) – “Improvements in flow regime and/or establishment of ecological flows” (KTM 7). However, in the remaining RBDs, there are no plans to do so. Hungary and the Netherlands reported having fully defined and implemented ecological flows (EC 2019d). However, deficient monitoring of the ecological status makes it difficult to evaluate whether implemented ecological flows effectively preserve river ecosystems and their biodiversity.

Table 1 Derivation and implementation of ecological flows in the second RBMPs (EC 2019b)

Derivation and implementation of ecological flows		**Member States**
Ecological flows **derived**	**in all** water bodies	*All RBDs:* ES, CY, EE, HU, NL *In some RBDs:* FR (4 RBDs), IT (2 RBDs),
	in some water bodies (work is still ongoing)	*All RBDs:* CZ, AT, DK, RO, SE, SI *In some RBDs:* UK (Scotland, England, Wales, Northern Ireland), BE (1 RBD), BG (1 RBD), DE (7 RBDs), FI (7 mainland RBDs), FR (10 RBDs), PL (8 RBDs), PT (9 RBDs)
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:* CZ, ES, AT, EE, RO, SE, SI *Some RBDs:* UK (Scotland, England, Wales), BG (1 RBD), DE (7 RBDs), FR (2 RBDs), IT (2 RBDs), PL (8 RBDs), PT (8 RBDs)
Ecological flows derived **but not implemented** but there are plans to do so in 2nd cycle		*All RBDs:* DK *Some RBDs:* UK (Northern Ireland), BE (1 RBD), FI (7 mainland RBDs)
Ecological flows **not derived** but there are plans to do so in 2nd cycle		*All RBDs:* LV, LU, MT, SK, HR *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 2nd cycle*		DE (3 RBDs), FI (1 RBD), IT (1 RBD), PL (1 RBD)

Source: WISE reporting 2016; Note (*): For some of the RBDs, where there is no intention to derive ecological flows, this is due to the fact that no river water bodies are reported.

Therefore, a major pending question is to which extent the water allocation provisions or permits given to users are in line with established ecological (minimum) flows. These have been determined in an increasing number of River Basin Management Plans (RBMPs), but often without assessing their functionality or validating their actual effects in improving the status of water bodies. Also, it remains unclear how policy and technical requirements for ecological flows is to be amended to take into account climate change impacts.

Required action and possible entry points for EU activities to enhance adaptation efforts in the EU Member States

Adapting reference conditions

MS are required to identify the ecological status of water bodies by comparing the current status with near-natural or other reference conditions. Reference conditions must be established for each of the surface water types. The establishment of reference conditions is a basic prerequisite to allow a relative comparison of the ecological status at a specific point in time. To do so, there are currently over 300 aquatic ecological assessment methods in use across Europe. To ensure the comparability of methods, an intercalibration exercise was carried out by MS, where 260 methods were intercalibrated (Poikane et al. 2014) and published in EC Decision in 2013 (EC 2013c). The above-mentioned climate changes might lead to a change of the typology of a surface water body, e.g. for water bodies which are drying out regularly in drought periods in the past years.

The difficult part in defining new reference conditions is to distinguish primary impacts from secondary impacts. Primary impacts can be described as direct links between climate drivers and ecological response (e.g. increased metabolic rates due to higher water temperatures), while secondary impacts can be seen as indirect impacts on ecosystems due to societal responses to climate change (e.g. elevated water abstractions for irrigated agriculture or the construction of new flood defence infrastructure)(Moe 2008). When doing so, a coherent approach across the EU is needed based on jointly developed guidance or knowledge exchange.

Meeting WFD objectives in the future

Climate change will make it more challenging to meet the WFD's objectives by the end of the third management cycle in 2027. Climate change is not only affecting ecosystems directly, for example through changes in water available to them. The responses societies and economies adopt to deal with climate change impacts may increase pressures on water bodies in many locations across Europe indirectly. Ranging from elevated water abstractions for agriculture to the construction of dams to expand storage capacity, these pressures will further drive hydro-morphological changes or water quality problems unless adequate efforts are put in place to counter them. There is a large degree of uncertainty about these interactions between climate change and human-ecological system, which needs to be considered in the drafting of the RBMPs within the third management cycle.

With the economic analyses stipulated under Article 5, the WFD provides a tool that allows assessing future water use under climate change. However, as shown above, aspects such as forecasting future supply and demand are only assessed in about one-third of the basins in the EU. The ensuing challenge is that these forecasts need to predict the future hydrological conditions such as run-off and groundwater levels and the water quality of water bodies to guarantee that management measures meet the environmental objectives under Article 4 in the WFD.

Under Article 4.4, MS can extend the 2021 deadline that marks the end of the second management cycle under specific circumstances, one of them being "natural conditions" that impede improvements to state of the water body. Climate change could be such a "natural condition" as it will influence chances of reaching good ecological and chemical status. However, it is yet unclear, whether climate change or other large-scale pressures eventually qualify as a "natural conditions". This needs resolution. To be a legally valid reason, it needs to be proven that climate change either lowers the impact of measures or prolongs the time ecosystems require for recovery (WFD 2019).

The issue of extending deadlines should also encompass a debate about whether climate change can be factored in the justification of exemptions. Here in particular, exemptions related to Article 4.6 in the WFD will be the focus; according to these exemptions, climate change might be considered as exceptional or unforeseen events and in this way justify delays. That stated, Article 4.7 WFD could also be of relevance, as several MS might argue e.g. new impoundments as an important overriding public interest to adapt to climate change and ensure further socio-economic development.

Climate proofing of measures and addressing mitigation

To further improve their climate resilience, technical measures and infrastructure developed to meet WFD objectives should be based on climate risk assessments. Currently, the methods and approaches for climate proofing of PoMs vary widely across MS and results are difficult to compare. Similar EU-wide methods should be established to ensure comparability. The 2021 revised "ISO/DIS 14091 Adaptation to climate change – Guidelines on vulnerability, impacts and risk assessment" standard provides the basis for such an effort. The outcome of the work could be part of the revised CIS guidance 24.

In view of the Paris Agreement, climate proofing of PoMs should also consider emissions of greenhouse gasses (GHG) of the planned measures, e.g. from energy-intensive wastewater treatment or deterioration of freshwater ecosystems due to hydro-infrastructure. However, so far, most studies have focused on the potential impacts of climate change on water bodies and on adaptation to climate change-related risks. In contrast, the relationship between RBMPs and climate change mitigation is poorly addressed. To mainstream advanced climate proofing efforts that also consider climate mitigation, a thorough discussion is needed on EU level to get a better overview and exchange knowledge or provide EU-wide guidance.

Quantitative water management and conflicting water uses

With a growing water supply-demand gap in some regions, there will not only be increased competition for water within sectors, but also between sectors (e.g. agriculture, urban supply and forestry), including the flow requirements of nature.

Conflicting water uses need to be addressed not only on national level, but also through a basin-wide approach to water resource management, one that considers climate change and all the stakes involved. Based on water balances for supporting the implementation of the WFD (see EC, 2015), allocation mechanisms must address the variability of and uncertainty about water resources availability. Under Article 14, the WFD also provides a tool to mitigate user conflicts by calling for a public participation process before a RBMP is finalised. However, as of yet this aspect has not been fully considered in the current CIS guidance document 24. As more and more countries, including those in central Europe, are experiencing such conflicting uses and interests, exchanging on the lessons learned in the context of the CIS process could support mutual learning.

Boosting coordination for more transformative adaptation

Measures taken in the past to improve the status of water bodies, including groundwater, have delivered results at a slower pace than anticipated. As mentioned above, climate change will put yet more pressures on water bodies. In order to ensure that ecosystems remain resilient, their overall status needs to be maintained and improved. One approach could be to prioritise ecosystems with extraordinary functions for mitigation and adaptation, especially wetlands or peatlands, when implementing the restoration targets under the EU Nature Restoration Plan as promoted under the Biodiversity Strategy.

As water quality is often largely depending on land use practices in rural and urban areas, efforts targeting pollution will require increased coordination across the various authorities governing land-use and water management. Appropriate governance structures need to be established that can promote a more systemic change in how land and water are used. These should be designed to ensure that degraded socio-ecological systems are shifted to alternative, more desirable, or more functional regimes by altering the structures and processes that define the system, ensuring that good status is achieved. A revised CIS Guidance 24 or knowledge exchange supported by the EC could put up the aspect of transformational adaptation, providing more guidance on how to achieve such transformational adaptation processes, in particular together with the water-dependent sectors.

Cluster 4: Cross-cutting topics for a revised European Adaptation Strategy

Adaptation finance

The impacts of climate change are projected to cause significant economic and financial losses in the coming decades. In the EU, weather and climate-related events already cause annual economic losses of EUR 12 billion (European Commission, 2020). According to an estimate by the Joint Research Centre of the European Commission, even if climate change is limited to 1.5°C, this would inflict an additional annual loss of EUR 40 billion (European Commission, 2020). To adapt to these impacts and avoid human, natural and economic losses, large investments are required. Climate adaptation finance refers to local, national or transnational financing, drawn from public, private and alternative sources of financing, which support activities that increase climate resilience (UNFCCC). The Global Commission on Adaptation projects that the required global adaptation finance amounts to USD 180 billion annually from 2020 to 2030 (GCA, 2019). While the European Green Deal and Multiannual Financial Framework include ambitious targets for climate finance, public funding alone cannot sufficiently address the challenges.

In spite of the scale of adaptation finance needed, it receives much less public and political attention than financing mitigation actions. Considerations of adapting to the impacts to climate change are much less integrated in financial and economic decision-making than this is the case for climate mitigation. Many businesses and investors are not aware of how their activities or portfolios can be affected by climate change, leading to an underinvestment in adaptation. Many are also unaware of developments at political level regarding the financing of adaptation actions. One reason for this lies in the fact that it is much more difficult to differentiate adaptation finance clearly from other forms of financial flows. What constitutes adaptation finance is highly context-dependent since whether or not a certain investment has positive adaptation outcomes depends on the specific vulnerabilities (CPI, 2019). This issue is particularly prevalent for water-related adaptation finance, since in many cases adaptation activities are often implicit in new investments in the water sector but are not explicitly listed in budgets for water-related programmes. As in other sectors, it is not possible to produce a list of adaptation activities since adaptation investments often mean mainstreaming climate resilience into all public and private investment decisions (CPI, 2018).

Ongoing activities

There are currently a number of ongoing activities at the EU level to mainstream adaptation finance and integrate adaptation considerations in financial and economic decision-making. Through the implementation of the European Green Deal (EGD), the overarching goal of climate-neutrality of the EU by 2050 has been set. This long-term framework includes designating 25% of the Multiannual Financial Framework to climate action. As part of this framework, the legal requirements have been specified for the 2021-2027 European Regional Development Fund (ERDF) and Cohesion Fund (CF) budgets, which must allocate 30% and 37% respectively to climate action. This includes both climate mitigation and climate adaptation. In the ERDF and CF context, water-related adaptation finance focusses explicitly on the intervention fields (IF) of floods (IF 35) and droughts (IF 37). Moreover, IF 40 targets water management and water resource conservation. The EU Recovery and Resilience Facility (RRF), which builds the centrepiece of the EU's economic recovery efforts in the wake of the Covid-19 crisis, contains an overall climate spending target of 30%. This target again focuses mainly on the decarbonisation of the economy and does not present climate adaptation as separate and complementary to mitigation expenditure. To access funds under the

RRF, MS have to prepare recovery and resilience plans (RRP), which contain investment agendas for the period from 2021 to 2024. The Commission assesses these RRPs based on criteria such as growth potential, job creation, contribution to the green transition and economic and social resilience (Szazadveg Foundation et al, 2020). This offers an opportunity for MS to expand their investment in adaptation to climate change by integrating aspects of climate resilience into their RRPs, for instance through large-scale investments in enhanced nature-based solutions against flooding or storage facilities for excess-water.

While these policies and frameworks only affect climate expenditure by public authorities, new activities are increasingly targeting the private sector. One key policy regarding climate finance in this context is the Sustainable Finance Action Plan and the newly developed EU Taxonomy. This taxonomy is a classification of economic activities and provides criteria to determine if an economic activity contributes to one of six environmental policy objectives, including climate change adaptation. Organisations that have to disclose in how far their activities are aligned with this taxonomy comprise financial market participants and large companies that are subject to reporting obligations under the Non-Financial Reporting Directive (NFRD) (TEG 2020: 26). An initial set of criteria has been published to measure whether an activity is contributing to the climate adaptation objective. Here, two types of contributions are defined: "adapted activities" which represents an economic activity that is itself adapted to physical climate risks, and "activities enabling adaptation of an economic activity" which represents an activity that reduces the climate risks of other activities or addresses systemic barriers to adaptation (TEG 2020b:21). Part of the technical screening criteria, which are meant to determine whether an economic activity contributes to the climate adaptation objective, includes the reduction of material physical climate risks that "have been identified through a risk assessment". All companies subject to the NFRD will have to disclose from 2022 onward what proportion of their activities fulfil these criteria and thereby contribute to climate change adaptation.

Gaps & entry points

Existing definitions of adaptation activities differ across EU policy documents. For example, the criteria for adaptation activities recommended by the Technical Expert Group on Sustainable Finance (TEG) under the taxonomy[13] differ from the definitions in the ERDF and CF. A uniform definition at the EU level of what constitutes adaptation finance would be an important step, as it would

- support the allocation of financial and non-financial resources to adaptation activities,
- enable tracking and mainstreaming of adaptation finance and
- provide clarification for all relevant actors.

[13] On the basis of these TEG recommendations on Taxonomy criteria, Commission services have started drafting a first Delegated Act under the Taxonomy Regulation, due for adoption end-2020. The Commission is not bound by the TEG recommendations.

National and sub-national authorities in all MS could then apply such an EU-wide definition to allocate and track their funding of adaptation activities. In addition to such a definition, establishing standardised procedures, criteria and risk assessment approaches at EU level will

- benefit actors that are required to report by unifying and simplifying reporting requirements across MS,
- provide all actors with the necessary guidance
- while at the same time make the reporting against the taxonomy[14] more comparable and informative.

This process can be linked to the development of the new European Adaptation Strategy by incorporating a standardised definition of adaptation finance into this revised strategy. In addition, once the criteria of the EU Taxonomy (which will determine under which conditions an economic activity substantially contributes to climate change adaptation) have been adopted in a Delegated Act, these criteria should then be included in other EU policy documents and uniformly applied.

The allocation of significant shares of budgets from EU funds such as the ERDF and CF to climate change adaptation can also serve to raise the profile of climate adaptation. Until now, the majority of funding earmarked for climate action has been flowing into mitigation activities. By specifying that a certain share of climate finance must be allocated to adaptation, these funds can serve as examples for mainstreaming adaptation action into public finance allocation and increase the share of adaptation finance. Specifically regarding water-related adaptation finance, this can be strengthened through existing national water programmes such as the Flood Risk Management Plans (FRMP) and River Basin Management Plans (RBMP). While these already mention climate change adaptation, they remain vague about adaptation finance and funding sources.

A further approach contains the development and dissemination of new instruments for de-risking adaptation investments, such as specific loans for infrastructure projects that accrue additional costs due to the integration of climate resilience in their design (CPI 2018). Integrating such financial instruments into public financing programmes and policies can have an important impact on investment levels.

Due to the context-dependent nature of climate adaptation, determining whether an investment falls under the category of adaptation should be based on the outcome of a climate risk assessment: If the investment addresses the risks identified in the assessment, it can be regarded as falling under the category of adaptation. Enabling private actors, infrastructure operators or public authorities to conduct such risk assessments is therefore an important step for promoting adaptation finance. Detailed guidance and information should be provided, including example assessments from different sectors. Given the fact that the results of a climate risk assessment can vary depending on the methods applied, scenarios and data used, a more uniform approach for such assessments should be promoted. This could be done by specifying that that risk assessments that may be required by the Taxonomy criteria must be conducted following the international standard ISO 14091 Adaptation to climate change — Guidelines on vulnerability, impacts and risk assessment. This ISO standard will be published in 2021 and represents an international consensus on the steps to follow when executing a climate risk assessment. This standard should be supported by further guidance documents to provide additional detail on such assessments. Efforts should also be made to extend requirements of climate risk disclosure to the public sector entities, in order to address barriers for adaptation funding related to awareness of climate risks.

[14] The Taxonomy Regulation introduced an obligation to disclose the share of Taxonomy-aligned activities applying to large listed companies (more precisely, those covered by the Non-Financial Reporting Directive) and to financial market participants offering financial products.

Water-relevant data and Climate Services

Engineers require year-to-year robust data for designing dams or irrigation projects that can cope with increasing variability in rainfall while water utility operators are in need of real-time climate data for managing more frequent storm water events within urban drainage systems. Ensuring climate resilience of water systems requires water-related data (such as data on water quality and discharge of rivers over long time periods) and climate data (such as modelled data on future changes in rainfall and temperatures). Both types are necessary to understand how climate change is interacting with the water cycle and to effectively design adaptation measures for affected water users. The term Climate Services (CS) refers to climate-related data and information that has been translated into projections, trends or economic analyses to enable climate-informed decision-making for specific users such irrigated agriculture or hydropower operators. They exist not only in the context of water management, but in various sectors affected by climate change.

The Global Framework for Climate Services (GFCS), an initiative by the World Meteorological Organisation (WMO), provides the framework for organising all national efforts on CS. At the EU level, such a framework for CS is the European Research and Innovation Roadmap for Climate Services, which was developed in 2015 (EC 2015). It articulates an agenda and shared approach that guides actions by European, regional and national CS programmes and investments of the Horizon2020 and other funding programmes, ultimately seeking to stimulate growth of the EU's CS market. The 2013 Adaptation Strategy describes the need to develop further climate information and CS with respect to adaptation.

There are different types of CS service providers, including national meteorological services, public climate service centres, universities, and private-sector companies. At the international level, the Group on Earth Observation (GEO) is important as it leads efforts to build a Global Earth Observation System of Systems (GEOSS). In Europe, the European Space Agency (ESA), The Joint Research Centre (JRC), European Environment Agency (EEA) are involved in activities related to CS. Other important organisations include the European Centre for Medium-Range Weather Forecasts (ECMWF) and the CMCC Foundation Euro-Mediterranean Center on Climate Change.

Ongoing activities

In recent years, a range of initiatives, programmes, and projects have emerged that drive CS applications, many of which also target water as a sector (Cortekar 2020). Copernicus, the European Earth Observation Programme, is the EU's most important initiative. Now being in the phase of operationalisation, it is developing "an advanced satellite and ground-based observation system for the EU, as well as a continental operational CS". The programme's tools and data are free and open-access. Other important initiatives with respect to CS over the past years include the Joint Programme Initiative (JPI)-Climate, which intended to align national research priorities of 14 EU MS. Climate-KIC aims to increase the adaptation capacity and resilience of societies, infrastructure, and cities through services and products of its Climate Adaptation Services (CAS) Challenge Platform. Meanwhile, an increasing number of national and sub-national Climate Service Centres have emerged, such as GERICS Climate Service Center Germany.

A few platforms for exchange of CS have evolved in the EU. Among them, Climate-ADAPT may be the best known. It offers data on climate change impacts and the vulnerability of sectors and regions and has an online visualisation tool for climate observations and projections. The Water User Interface Platform (Water UIP) is intended to offer the needed structure and processes to identify and cater to the needs of the water sector at all levels, in order to improve the sector's performance and management through a more widspread use and understanding of climate information. The EU Covenant of Mayors also acts as a knowledge and capacity-building platform for water-related adaptation actions in European local authorities, including through tools such as the Urban Adaptation Support Tool (UAST) hosted on Climate-ADAPT.

In recent decades, the EC has made large investments into CS through its Framework Programmes (FPs) for Research and Technological Development. Some projects have laid the foundation for climate modelling upon which CS have been based on (EC 2014). Nowadays, Copernicus and H2020 are the largest sources of funding for CS, and they have funded a host of water-related CS projects. For example, the Copernicus Climate Change Service (C3S) for Water demonstrator project (SWICCA) provides pan-European indicators of water-related climate change impacts to allow quick integration of results from pan-European studies into regional-scale assessments. The IMPREX and BINGO projects have demonstrated improved forecasting and climate projection especially for the water and water-dependent sectors. The SOSRHINE project aids logistic decisions for inland waterway transport on the Rhine and provides seasonal streamflow forecasts focusing on the low-flow seasons.

Gaps & entry points

While several initiatives are ongoing, CS remain a specialised sector, still in its infancy. Assessment and consultations, such as the one conducted for carrying out the EU Roadmap for CS (EC 2015), the evaluation of the EU Adaptation Strategy or a recent report by ClimateEurope with recommendations to inform HorizonEurope (ClimateEurope 2019), provide insight into persisting challenges, barriers and future demand for research and funding relating to CS products, conditions of the market, and users of CS. To remain a frontrunner in CS, the EU needs to maintain a high level of investment and support.

Persistent data gaps impede building the CS in demand by the water community. There is a need for more systematic water-related data and better integration with other data to understand how climate change is interacting with the water cycle. Within respect to the water sector, for example, there are large data gaps for parameters that are key for guiding management decisions, such as local river discharge or run-off. This is caused by a disinvestment in hydrological and climate monitoring systems (Hall et al. 2014), among other things. Simultaneously, data describing important climate change effects remains insufficient and uncertain, despite an increasing overall availability (e.g. through the EU's Earth Observation Programme Copernicus). Collecting, archiving, processing and modelling data upstream in the CS value chain typically requires the operation of expensive devices. To remain a frontrunner in CS, EU-funded initiatives such as Copernicus[15] and EURO CORDEX[16] should, therefore, continue to fund them.

Demand for CS remains low, especially from the private sector. As of now, CS are rarely considered in decision-making. Moreover, they are merely integrated into existing processes in many cases while users are reluctant to adopt new models or methods (EC 2014). There are also challenges residing with the users of CS. In many cases, they lack the capability and expertise to make effective use of CS. While users associate improved strategic or operational decision-making or risk management with CS, they generally underestimate the monetary value they can gain from using CS (Tart et al. 2020). This low awareness partially arises from poor demonstration of the monetary benefits of CS on the provider's side.

CS products are often not fit for purpose. Low demand for CS is partly rooted in weaknesses of existing CS products, as is highlighted in the blueprint for the new EU Adaptation Strategy (EC 2020). For example, CS and investment cycles have different timescales, making it challenging to use CS for the evaluation of the climate risks implied in investment decisions. Similarly, water-management actors often require climate information at different spatial resolutions, forecasting periods or for other variables than are offered by available CS. The evaluation of the EU Adaptation Strategy revealed that CS are deficient particularly with respect to decision-making and policymaking support tools and assessments as well as to dealing with uncertainties. Furthermore, the majority of CS is still at the stage of technology development and lack proof-of-concept from testing in real-life settings (ClimateEurope 2019).

[15] https://www.copernicus.eu/de

[16] https://www.euro-cordex.net/

Poor accessibility and navigability of existing CS platforms. Providers seem inappropriately aware of the needs users have (Tart et al. 2020) while there is insufficient information for users to navigate the CS market effectively, although there are a range of initiatives seeking to provide an overview, including Climate Knowledge Hub, the European Climate, and Adaptation Platform Climate-ADAPT (Bessembinder et al. 2019). Moreover, research providers and users often are poorly aware in which countries CS are developed and available and how to access them, which may result in duplication.

There is no national, international or EU certification or quality assurance process for CS. Only 60% of CS providers use some form of quality assurance process (EU-MACS 2017). Guidelines and principles have been proposed by different organisations, although they have the character of a "code of good conduct" rather than providing regulations for good scientific practice. For example, the Climate Services Partnership's ethics working group has published the white paper "Toward an ethical framework for climate services"[17]. It constitutes an important attempt to establish principles for ethical practice of CS and foster further discussions.

The CS market in the EU is still dominated by public providers and is much smaller in Eastern European countries. Private CS often adopt a more market-oriented approach and put greater emphasis on the needs of the end consumer than public CS providers do (EU-MACS 2017). They develop consumer-friendly and competitive products that meet the needs of the market. However, publicly funded CS providers, such as weather services, universities or other CS providers, have better access to research and data infrastructure. National weather services in particular have a well-developed network of observational facilities and high computer capacities. Therefore, a combination of key competencies of private and public providers is needed to create the most effective and efficient CS.

Cross-border cooperation in climate adaptation

Most climate change impacts are cross-border in nature and therefore require cross-border cooperation to be effectively addressed. This makes adaptation planning even more complex and challenging. However, MS can also gain decisive advantages, as a collaborative approach can be more effective than solo action and provides considerable synergies. While river basins are a prominent example, cross-border cooperation on adapting to water-related climate impacts is key in other transboundary contexts like marine and mountain regions.

There are 75 transboundary river basins in the EU. These account for 60 % of the EU's territory, half of which is made up of the six largest transboundary river basins – the Danube, Rhine, Vistula, Elbe, Oder, and Nemunas. Consequently, cross-border cooperation among MS and with non-EU countries is critical to the climate-resilient management of Europe's river basins. The WFD[18] together with other Directives such as the FD, is the main legal instrument for mainstreaming climate adaptation in transboundary basins. While the WFD does not explicitly address climate change, the cyclical planning process for river basin management allows for integrating climate change impacts progressively into practice. The need to follow a basin-wide approach requires MS doing so through transboundary cooperation. The Convention on the Protection and Use of Transboundary Water Courses and International Lakes by the United Nations Economic Commission for Europe (UNECE) establishes additional basic principles and procedural rules specifically for transboundary cooperation in river basins. The Water Convention, which is a global instrument since 2013, is a tool to promote and operationalize the 2030 Agenda for Sustainable Development and its SDGs. It directly supports implementation of target SDG 6.5, which requests all countries to implement integrated water resources management, including through transboundary cooperation, as appropriate,

[17] https://climate-services.org/wp-content/uploads/2015/09/CS-Ethics-White-Paper-Oct-2015.pdf

[18] https://ec.europa.eu/environment/water/water-framework/index_en.html

see reporting on SDG indicator 6.5.2[19]. International conventions are important for driving adaptation in other transboundary contexts as well, for example in the Baltic Sea, where the Helsinki Convention on the Protection of the Marine Environment of the Baltic Sea forms the overarching framework for cooperation.

Transboundary institutions, such as river basin organisations (RBOs) or secretariats of cross-border conventions, play a crucial role for adaptation. Many of the EU's larger transboundary river basins have established RBOs, as a recent EC assessment shows (EC 2019a). The WFD and FD require MS to coordinate their management plans or to develop joint international RBMP (iRBMPs) and international flood risk management plans (IFRMPS). The UNECE further recommends riparians to a basin to have joint adaptation strategies in place, which are ideally developed through RBOs (UNECE 2015). Climate-related threats and adaptation strategies identified therein should be integrated into RBMPs from the second planning cycle onwards. UNECE has emerged as a key player in guiding and actively supporting the MS with the organisation of transboundary river basin management, including adaptation efforts[20]. Some of the EU's transnational regions have macro-regional strategies in place, which address common challenges and often include aspects of climate adaptation.

Ongoing activities

In the field of climate change, the EU supports MS in cross-border cooperation with pan-EU data and studies, opportunities for exchange and guidance on good practice examples, as well as in establishing iRBMPs. The EU can also facilitate agreements with neighbouring countries that share basins with EU MS and support cross-border adaptation measures through research, regional development or agricultural funds.

The EU Adaptation Strategy is viewed to have initiated cross-border climate adaptation efforts among MS, especially in river basins and alpine areas (EC 2018). Looking at river basins, a European Overview of the second River Basin Management Plans by the EC (2019b) finds that climate change is increasingly addressed in iRBMPs, yet with large differences from basin to basin. The International Commission for the Protection of the Rhine (ICPR) has conducted vulnerability and risk assessments, informed by extensive stakeholder consultations, and developed scenario-based studies for water management to inform a concrete action plan, some parts of which are already under implementation. Similar studies were conducted for the international Danube river basin district by the International Commission for the Protection of the Danube River (ICPDR), and for the international Sava river basin by the International Sava River Basin Commission (ISRBC), or Baltic Sea. Generally, adaptation efforts are more advanced in transboundary regions that have established physical institutions such as RBOs (EC 2019b,c). The International Sava River Basin Commission, for example, has developed a sophisticated international Sava Flood Forecasting and Warning System in the Sava River Basin (Sava FFWS).

The EU's main support mechanism for transnational cooperation is the INTERREG programme, which tackles common issues including climate change adaptation. For example, the INTERREG Baltic Sea Region programme financed several projects, one of which (Baltat Project) produced the region's adaptation strategy while the Interreg Danube Transnational Programme funded projects that stimulate cross-border cooperation in the context of river basin management and flood risk prevention (JOINTISZA) and drought-related risks (DriDanube). Specifically relating to climate adaptation in transboundary river basins, UNECE's main support vehicles comprise a task force on climate and water, pilot projects to strengthen the adaptive capacity of riparian states and a platform for sharing experiences and best practices. The pilot projects, for example, train representatives of the riparian countries to develop vulnerability assessments or adaptation strategies (UNECE, 2016).

[19] http://www.unece.org/water/transboundary_water_cooperation_reporting.html

[20] http://www.unece.org/env/water/water_climate_activ.html

The support of EU-Institutions also encompasses the provision of data and information as well as strategic and operational guidance for implementation. Climate-ADAPT, for example, contains an element on policy frameworks and adaptation efforts in transnational regions. Meanwhile, regional web-based knowledge-sharing platforms, centres, and networks have also emerged in some transboundary regions, like the Wadden Sea Climate Change Adaptation Information Platform (EEA 2018). With respect to adaptation in water management, the EU developed several guidance documents that provide some information on transboundary cooperation (for example the CIS for the WFD on the issue of climate change). Arguably, many of the adaptation measures relevant for national basins (such as monitoring of various hydrological parameters) are equally relevant in transboundary basins. UNECE (2009, 2015) provides additional guidance documents containing measures and recommendations particularly relevant for transboundary basins and provide information at higher level of detail.

Gaps & entry points

Progress on adaptation differs substantially between EU transnational and macro-regions, making further efforts necessary. More generally, climate change adaptation projects in the EU's transnational regions often focus on regionally specific climate change challenges or sectors (such as water management in river basins). There are fewer projects that approach adaptation from a cross-sectoral or integrated perspective, as the evaluation of the EU Adaptation Strategy shows (EC 2018) This is, however, a precondition for successful adaptation projects. Moreover, EU-funded projects often focus on knowledge generation and dissemination, awareness-raising, capacity-building, networking and cross-country exchange, yet components relating to on-the-ground implementation actions are rather weak. At the same time, generated knowledge is often not fully exploited because engaged stakeholders have no sense of ownership, commitment or clear responsibilities for making proper use of the results (EEA 2018). While many finance instruments for climate adaptation are geared towards national efforts, finance for transboundary projects with neighbouring countries to implement adaptation plans is even harder to access.

A more close-up view at river basins reveals additional issues, some of which may apply for other EU's transnational regions as well. Smaller transboundary basins generally lag further behind in the adaptation process. Their RBOs – if they exist – often lack in adaptation strategies or formulated adaptation measures in iRBMPs, let alone details on how they seek to implement these through cooperation. Similarly, mostly only large transboundary river basins such as the Rhine or Danube have started to implemented adaptation measures defined in their iRBMPs. While governance structures were further formalised over recent years, there are still multiple transboundary basins lacking full-fledged RBOs and iRBMPs. Their absence hampers progress on adaptation (EC 2019b). More general problems are that methodologies used for ensuring the "climate-proofing" of adaptation measures are often inconsistent, while transboundary aspects are rarely integrated into national adaptation plans (UNECE 2015).

While EU-institutions offer support for adaptation in transboundary river basins (e.g. through the CIS guidance document No. 24 "River Basin Management in a Changing Climate"), information specifically related to transboundary cooperation appears to be sparse and is often unspecific. For example, Baranyai (2019, 2020) identifies a need for better operative guidance for MS on short-term measures with respect to hydrological extremes and especially for dealing with droughts in transboundary river basins. Lastly, the legal framework is considered unfit to address some particular challenges resulting from climate change. While the WFD Art 12 foresees a mechanism for conflict resolution, Baranyai (2019, 2020) notes it is unsuited to handle the growing inter-state competition for water in regions where climate change intensifies water scarcity.

Global interlinkages and international cooperation

While the developed world is responsible for the largest part of greenhouse gas emissions, the impacts of climate change affect all countries – especially the poor, who are least able to adapt. Climate change effects may also hamper achieving internationally agreed goals on poverty, health, food security and ecosystems – above all the Sustainable Development Goals (SDGs). The UN's Sustainable Development Goals Report 2019 concludes "the impacts of climate change are undermining progress on the sustainable development agenda, threatening to reverse many of the gains made over the last decades that have improved people's lives" (UN 2019). Increasing resilience to climate change is therefore a global responsibility. Indeed, adaptation is also recognized as one of the key cross-cutting issues in the 2017 European Consensus on Development "Our world, our dignity, our future"[21], the EU's response to the United Nations (UN) 2030 Agenda for Sustainable Development.

Moreover, in a globalised world, climate change effects in other parts of the world can have significant repercussions on the EU. No matter how robust adaptation planning is within the EU, it will remain vulnerable to the impacts of climate change outside the EU. Spill-over effects occur in particular in trade, supply chains, migration, but also energy transmission. Water-related climate risks worldwide will have consequences on the EU, e.g. if prolonged droughts impact agricultural production and, as a result, food supplies and global prices, when flood-events disrupt international transportation routes and other critical infrastructure, or when water scarcity and pollution limits production of critical supplies in global value chains. There is a growing number of examples where the climate-related disruption of food and water systems, for example through floods and droughts, has destabilised countries and jeopardized regional peace and security.

The findings of PESETA IV confirm that international spill-over effects could increase the internal EU welfare loss by approximately 20% (Feyen at al. 2020). A detailed analysis of agricultural crop yields shows that the agricultural spill-overs can reach between 2 billion € (at 1.5°C global warming) and 8 billion € (at 3°C global warming) additional to the impacts on GDP within the EU, with most agricultural spill-over effects originating in the Americas and Asia (Szewczyk et al. 2020). Climate change impacts on energy in the rest of the world show a negligible spill-over effect on Europe (Szewczyk et al. 2020). This may however change, if more energy is transmitted or fuels transported across long distances, e.g. renewable energy from Northern Africa.

Ongoing activities

Climate change adaptation and strengthening resilience, in particular in the most vulnerable countries, have been mainstreamed into EU development policy and actions (EC 2018a), e.g. in the European Consensus on Development. To date, the EU and its Member States is the largest contributor of international public adaptation finance, with the most prominent example of EU support to policy dialogue and climate action in developing countries being the Global Climate Change Alliance (GCCA+) initiative (EC 2018a). Moreover, the EU and its MS are committed to further increase financial assistance in the future (EC 2020). DG DEVCO has published guidelines[22] in 2016 to provide a framework for strengthening the contribution of the EU's international cooperation and development policy to sustainable development, by integrating environmental and climate change considerations into the different phases of the EU programme and project cycle. Besides international cooperation also takes place within the framework of the H2020 research programme, e.g. in projects like Afrialliance[23] that aims to strengthen cooperation

[21] https://www.consilium.europa.eu/media/24004/european-consensus-on-development-2-june-2017-clean_final.pdf

[22] https://europa.eu/capacity4dev/public-environment-climate/documents/new-guidelines-integrating-environment-and-climate-change-eu-international-cooperation-0

[23] https://afrialliance.org/

between African and European stakeholders in order to better prepare Africa for climate change challenges or under a specific call on CS for Africa. Moreover, the European Space Agency (ESA) as well as the Copernicus programme provide climate and geospatial data in support of adaptation efforts in developing countries.

Many bilateral and international development cooperation programmes have developed guidance, shared knowledge and provided technical assistance to increase water-related climate resilience in developing countries. International knowledge sharing platforms and networks, like weADAPT[24], Adaptationcommunity[25] and Alliance for Global Water Adaptation (AGWA)[26] provide access to tools and guidance. Major international initiatives further include the Global Commission on Adaptation[27] initiated by the Netherlands, which published a report focussing on the interlinkages between Climate Adaptation and Water (Adaptation's Thirst). The German Federal Government has set up the International Climate Initiative[28] (IKI) as one of its most important instruments for international climate financing. From 2008 to 2019, IKI approved more than 730 climate and biodiversity projects with a total funding volume of EUR 3.9 billion in more than 60 countries. A dedicated funding area "Adapting to the Impacts of Climate Change" supports particularly vulnerable countries and regions in increasing their capacity to adapt to the effects of climate change, focussing on ecosystem-based adaptation (EbA), instruments for the risk management of climate-related extreme events (e.g. innovative insurance solutions), as well as the development and implementation of national adaptation strategies. Looking at the spill-over effect of climate change impacts outside Europe on the EU, several studies have been undertaken. Besides the above-mentioned analysis of spill-over effects in the PESETA projects, the EEA has highlighted how climate change impacts have had spill-over effects on Europe through regional and global markets and supply chains (EEA 2017). The Horizon 2020 IMPREX project has analysed the EU's vulnerability to climate change outside its borders in terms of water resources especially, by applying the concepts of virtual water and water footprints. Initial studies that analyse potential spill-over effects, mainly via agricultural trade, do exist. But the 2018 Evaluation of the EU Climate Adaptation Strategy assumes that the issue most likely has not been addressed in any national adaptation strategies.

Water-related climate risks can also significantly affect supply chains of companies. This has been recognised by business leaders who joined the UN Global Compact CEO Water Mandate[29] to address global water challenges through corporate water stewardship. Tools and approaches for analysing corporate climate risks have been developed and tested, e.g. the WWF Water Risk Filter[30]. Moreover, Water Footprint assessments applied to supply chains, allow the identification of water-related risks. Principles, requirements and guidelines related to water footprint assessment of products, processes and organizations have been standardised in the ISO 14046:2014. On the other hand, the corporate sector can also play a role in increasing water-related climate resilience in developing countries by fostering resilient water management in the supply chains, e.g. though Water Stewardship approaches, following the guidelines of e.g. the Alliance for Water Stewardship[31].

[24] https://www.weadapt.org

[25] https://www.adaptationcommunity.net

[26] https://www.alliance4water.org/

[27] https://gca.org/global-commission-on-adaptation/adapt-our-world

[28] https://www.international-climate-initiative.com/de?iki_cookie_check=1

[29] https://ceowatermandate.org

[30] https://waterriskfilter.panda.org/

[31] https://a4ws.org/

Gaps & entry points

There is a continuous need to strengthen water-related climate resilience in those countries that are most vulnerable to climate change impacts through financial and technical cooperation as well as knowledge-sharing. International cooperation has an essential role to play in promoting climate-neutral and resilient development worldwide. In doing so, internationally agreed policies and development goals, especially those formulated with the SDGs, the Paris Agreement and the Sendai Framework for Disaster Risk Reduction, should be addressed in an integrated manner to exploit synergies and avoid trade-offs. In addition to providing funding for sustainable development, resilience and adaptation, there is a need to further develop integrated and resilient solutions and approaches. For this, the EU and its Member States can build on knowledge and experiences developed in the course of implementing the European Green Deal, including approaches to foster the transition to inclusive green and circular economies, solutions that build on conservation and sustainable use of ecosystems, including nature-based solutions and ecosystem-based approaches to adaptation and mitigation.

Awareness and understanding of Europe's vulnerability to climate change impacts outside Europe need to be further increased. As the 2018 Evaluation of the EU adaptation strategy concludes, there is a need for the EU to review existing evidence and invest in further research. Since then another H2020 project has been funded: CASCADES[32] analyses the trade, political and financial channels through which climate change impacts outside Europe might cascade into Europe. The project further supports the design of a coherent European policy framework to address the resulting challenges. With earth observation data from e.g. the Copernicus programme, and advanced global modelling approaches, the available understanding of the global interconnections is increasing (see e.g. project ViWA[33]). Based on an enhanced knowledge base, more awareness needs to be created among MS. Moreover, there is a need for guidance on how to address these global interdependencies through EU trade policy and targeted international cooperation activities to increase resilience in regions of importance to European food supply and economy, as well as in bilateral trade relationships and national adaptation strategies.

Businesses are often unaware of the water-related climate risks in their supply chains. There is therefore a need to encourage and support European businesses that are reliant on international supply chains to map their dependencies and better understand the water-related vulnerabilities. This will require access to relevant data and information on climate impacts on water resources in key regions as well as further research and guidance on how to make best use of existing tools and concepts such as on water risks and the water footprint for accessing climate risks in supply chains.

[32] https://www.cascades.eu/

[33] https://viwa.geographie-muenchen.de

Conclusions

Water and climate change are inextricably interlinked. As rising temperatures spur the hydrological cycle, climate change will affect water availability and quality, hydrological variability and extremes such as floods and droughts. Yet, despite substantial advancement in climate research, it remains impossible to predict the precise impacts of climate change on water resources.

Indeed, one of the main ways in which humans experience climate change is through its impact on water resources and water-related ecosystems. In turn, climate resilient water management has an important role to play in fostering climate resilience across many sectors and for society at large. However, resilient water management is also dependent on water and other resources' use in other sectors. There is, therefore, a continuous need to raise awareness of the value of water including for overall climate resilience, but also to better mainstream water-related issues into other sectoral strategies and adaptation plans in order to prevent negative impacts on water security.

The previous chapters have summarised various approaches to increase climate resilience through sustainable water management that have been developed and adopted at the EU, Member State and transboundary level. Progress has been made in increasing water-related climate resilience through improved infrastructure and technologies, increased knowledge for informed decision-making as well as policy instruments and institutions. Nevertheless, significant gaps remain in terms of data and knowledge on climate change impacts and effectiveness of adaptation measures, innovative solutions including nature-based approaches, financial and regulatory instrument to foster more resilient water management, guidance and capacity development for decision-makers at various levels and cross-sectoral coordination.

What is more, the current incremental approach to adaptation may prove insufficient in the future, especially under high-end climate scenarios. There is increasing agreement that more transformational change will be required in order to maintain water-related resilience in the future, as water resources and water-related ecosystems are under increasing pressure – not only from climate change but also other drivers, including population growth, economic development and urbanisation.

Transformational adaptation is characterised as being restructuring, path-shifting, innovative, multiscale, system wide, and persistent (Fedele et al. 2019). In other words, transformational adaptation occurs when fundamentally new and innovative responses are required and historic approaches are insufficient for current or anticipated climate risks. As of yet, however, transformational strategies have often failed to materialise, because of: (i) social and cultural values, particularly place attachment and identity; (ii) institutional reliance on technical expertise which fails to look beyond traditional technocratic approaches and; (iii) institutional and regulatory practices (Clarke et al. 2017).

Some of the fundamental questions to be addressed for increasing water-related climate resilience will, therefore, have to be: How to raise awareness of the intrinsic value of water? How to ensure effective cross-sectoral coordination at all levels? And how to overcome barriers for transformational change?

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