Literature review on the potential Climate change effects on drinking water resources across the EU and the identification of priorities among different types of drinking water supplies

Final report - ADWICE project

European Commission DG Environment
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<td>ASR</td>
<td>Aquifer Storage and Recovery</td>
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<td>BWD</td>
<td>Bathing Water Directive</td>
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<tr>
<td>CAMS</td>
<td>Catchment Abstraction Management Strategies</td>
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<tr>
<td>CAP</td>
<td>Common Agricultural Policy</td>
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<tr>
<td>CC</td>
<td>Climate Change</td>
</tr>
<tr>
<td>CCI-HYDR</td>
<td>Climate Change Impacts on Hydrological extremes along rivers and urban drainage systems</td>
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<tr>
<td>CIS</td>
<td>Common Implementation Strategy</td>
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<tr>
<td>DRB</td>
<td>Danube River Basin</td>
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<td>DW</td>
<td>Drinking Water</td>
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<td>DWD</td>
<td>Drinking Water Directive</td>
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<td>DWPA</td>
<td>Drinking Water Protection Area</td>
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<tr>
<td>EC</td>
<td>European Commission</td>
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<tr>
<td>EEA</td>
<td>European Environment Agency</td>
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<tr>
<td>EECCA</td>
<td>Eastern Europe, Caucasus and Central Asia</td>
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<tr>
<td>EQSD</td>
<td>Environmental Quality Standard Directive</td>
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<td>EU</td>
<td>European Union</td>
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<td>EUWI</td>
<td>European Union Water Initiative</td>
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<td>FD</td>
<td>Flood Directive</td>
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<td>GCM</td>
<td>General Circulation Model</td>
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<td>GHG</td>
<td>Greenhouse gas</td>
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<tr>
<td>GiCC</td>
<td>Gestion et Impacts du Changement Climatique</td>
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<tr>
<td>GWD</td>
<td>Groundwater Directive</td>
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<tr>
<td>GWLRM</td>
<td>Ground Water Level Response Management</td>
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<tr>
<td>GWR</td>
<td>Groundwater Recharge</td>
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Literature review on the potential Climate change effects on drinking water resources across the EU and the identification of priorities among different types of drinking water supplies

IPCC | International Panel on Climate Change
IPCR | International Commission for the Protection of the Rhine
KNMI | Koninklijk Nederlands Meteorologisch Instituut
KUL | Katholieke Universiteit Leuven
MAR | Managed Aquifer Recharge
ML | Mega Litres
MS | Member State
ND | Nitrates Directive
NWRM | Natural Water Retention Measures
PPP | Polluter Pays Principle
RAL | Remedial Action List
RB | River Basin
RBF | Riverbank Filtration
RBMP | River Basin Management Plan
RCM | Regional Circulation Model
RExHySS | Ressources en Eau et Extrêmes Hydrologiques dans les bassins de la Seine et la Somme
SPZ | Sanitary Protection Zone
SRES | Special Report on Emissions Scenario
SUD | Sustainable Use of pesticide Directive
UNFCCC | United Nations Framework Convention on Climate Change
UWWTD | Urban Wastewater Directive
WFD | Water Framework Directive
WHO | World Health Organisation
WS&D | Water Scarcity and Droughts
Introduction

Executive summary

The Blueprint to safeguard Europe’s water resources underlines vulnerability of water resources as a key concern. The focus is on drinking water, a key resource for society, and which provision may be impacted by climate change (CC). This study explores the vulnerability of drinking water (DW) to CC, to assess the knowledge base and help identify what measures can be taken in this context. The main risks for DW abstraction are competition for use, pollution, floods as well as water scarcity and droughts. Understanding how CC will impact these risks is important to identify measures to be implemented in the future; similarly identifying how much, when and from what sources DW is abstracted will have bearing on the measures to be chosen.

Review of the potential effects of climate change on drinking water resources

The literature review carried out in this study identifies few articles and reports that focus specifically on the impacts of CC on drinking water bodies within the EU, but relevant literature does investigate the impacts of CC on water bodies. Such articles and reports conclude that CC will have many direct and indirect impacts on both water quantity and quality. These impacts will differ depending on the type of water resources (groundwater, bank filtrates and surface water are distinguished) and the region (both because CC will not have the same impacts and because the demand for water is different and comes from different sources). In order to analyse the literature, a conceptual model was built, based on previous frameworks (Figure 7). The review also identifies concrete examples in the different MS.

Legend: D: Drivers, P: Pressures, S: States, I: Impacts, R: Responses

Figure 1: ADWICE Conceptual Framework
In relation to **water quantities**, changes in temperatures, precipitation patterns, including intensity and seasonality of rain events, snow cover, erosion, etc. will have various impacts on river flows, groundwater recharge, lake levels, soil moisture, timing of and vulnerability to extreme events, and more globally impact ecosystem services.

<table>
<thead>
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<th>Driver</th>
<th>Pressure on water quantities</th>
<th>Change in the State of water quantities</th>
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<tr>
<td><strong>Increase in temperature</strong></td>
<td>Increased evaporation and evapotranspiration, higher water use by the vegetation</td>
<td>Reduced river flows, Reduced aquifer recharge, Reduced snow cover, maximum runoff earlier in the year, Decreased soil moisture content</td>
</tr>
<tr>
<td></td>
<td>Increased water demand</td>
<td>Higher abstraction rate</td>
</tr>
<tr>
<td></td>
<td>Increased biological activity in soil, reduced infiltration</td>
<td>Reduced aquifer recharge</td>
</tr>
<tr>
<td><strong>Changes in precipitation patterns</strong></td>
<td>Increase in the intensity of rains, on short periods</td>
<td>Reduced water infiltration in soils, reduced soil moisture, reduced groundwater levels/recharge</td>
</tr>
<tr>
<td></td>
<td>Variability in patterns</td>
<td>Variability of water resources availability</td>
</tr>
<tr>
<td></td>
<td>Increase in the frequency and intensity of droughts</td>
<td>Reduced snow cover, Reduced river flows, Reduced aquifer recharge</td>
</tr>
<tr>
<td></td>
<td>Increase in the frequency and intensity of floods</td>
<td>Increase in groundwater levels</td>
</tr>
<tr>
<td><strong>Sea level rise</strong></td>
<td>Saline intrusion into surface freshwaters, but more importantly into groundwater systems</td>
<td>Reduced freshwater availability</td>
</tr>
<tr>
<td></td>
<td>Erosion of sand dunes</td>
<td>Reduced protection against floods from the sea</td>
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**Water quality** will be impacted more indirectly, but some direct impacts include improved conditions for microrganisms, and changes in the physico-chemical conditions, that lead to changes for biodiversity and ecosystem services. Indirect impacts are mainly related to reduced dilution, increased leaching of pollutants, need for increased water treatment and modified water infrastructures, etc.
### Introduction

<table>
<thead>
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<th>Driver</th>
<th>Pressure on water quality</th>
<th>Change in State of water quality</th>
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| **Increase in temperature**| Improved conditions for waterborne bacteria, parasites (such as amoeba) and viruses to thrive; increased bacterial growth in lakes and coastal waters, especially if the water is allowed to stand in the pipes for considerable times.  
Changes in temperature-dependent biological and chemical processes → e.g. lower oxygen dissolution  
Increased release of particles from pipes and plumbing systems of drinking water network  
Increased evaporation → Reduced river flows, reduced aquifer recharge → Reduced dilution of potential pollutants, increase in turbidity and sedimentation  
Increased forest growth → Increased stores of organic material in the soil → Increased leaching of humus  
Increased and altered pest pressure on agricultural fields → Increased and changed use of pesticides  
Greater soil movement as a consequence of wetting and drying cycles → Damage to water supply and treatment infrastructure (pipe systems for drinking water supply more prone to cracking)  
Increased degradation rate of some pesticides and other organic pollutants  
Lower efficiency of some pollutant treatment processes | Degradation of drinking water quality parameters (physical, chemical and biological), in particular:  
- Pathogens  
- Taste (due to a higher content of microorganisms and of particles released from pipes and plumbing systems)  
- Oxygen level  
- Nutrients (N, P)  
Possible decrease in concentrations of some organic pollutants, due to increased degradation rate  
Reduced drinking water supply due to damaged infrastructure |
| **Changes in precipitation patterns** | Increase in the frequency and intensity of droughts → Reduced river flows, reduced aquifer recharge → Reduced dilution of potential pollutants, increase in turbidity and sedimentation, increased water temperature (due to less dilution of thermal discharges from cooling circuits)  
Increase in the frequency and intensity of floods → Increased load of pollutants washed from soils (in particular agricultural soils, contaminated soils, landfills), from urban areas and from overflows of sewage systems  
Increase in the frequency and intensity of floods → Higher risks of damage to water supply and treatment infrastructure  
Reduced snow cover → Increased leaching of soil nutrients (nitrogen, phosphorus)  
Increase in groundwater levels → Increased risk of pollutant releases from contaminated soils and landfills | Degradation of drinking water quality parameters (physical, chemical and biological) |
Introduction

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<td>Sea level rise</td>
<td>Saline intrusion into surface freshwaters, but more importantly into groundwater systems</td>
<td>Increase in salt concentration</td>
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In terms of future risks, the review classified them into regions with higher risks (e.g. Northern Europe may need to change its water treatments, Mediterranean countries or the UK will become more vulnerable in the future than today), topographical characteristics that increase risks (such as mountainous areas, that are water towers for other areas, coastal areas and urban areas). Priority issues and gaps are identified.

Vulnerability assessment

The vulnerability assessment uses indicators and existing modelling exercises to identify those EU regions that are most vulnerable to CC, based on aggregated vulnerability scores for a range of seven indicators. In parallel to that exercise, case studies allow to show the differences that exist due to the type of water resources.

The vulnerability methodology indeed allows to depict the situation at EU level, but insufficient information about the types of water resources limits the preciseness of the vulnerability assessment. The vulnerability score map (Figure 42) shows higher scores for RBs in the SCENES socio-economic scenario 'Economy First' that in 'Sustainability eventually', and scores increase with time (except in Northern Europe). Southern, North Western and South Eastern Europe are considered most vulnerable to CC, while Scandinavia, Baltic countries and parts of Central Europe have low vulnerability scores. It must be recognised that a high score must be interpreted differentially as high scores may come from any of the factors chosen as indicators in the assessment.

Local and regional case studies were identified to illustrate the responses from different types of water bodies in the MS of the EU. These case studies show a differential response from e.g. endorheic vs. lakes benefiting from inflows and shallow vs. deep lakes to CC, due to their intrinsic characteristics, making endorheic lakes more vulnerable to CC than those lakes benefiting from inflows, and shallow lakes more vulnerable than deep lakes. In addition, the case studies showed different types of uses and management of the water resources. This demonstrates the need to go further than the vulnerability maps at EU level, which are very beneficial to gather a broad brush picture, but must be accompanied by further information on the type of the resource, and its topography/geography, so that its actual vulnerability can be assessed.
Introduction

Policy review at EU and national levels

At EU level, few water policies explicitly refer to CC, with the exception of the Floods Directive, and certain Communications from the Commission. The cyclical approach by the Water Framework Directive however introduces a cyclical planning that allows for adaptive management. The vulnerability and the need to protect water resources from the impacts that will be modified by CC are required and a strategy for EU adaptation to CC is also in the making.

In the MS, protection of DW resources currently mainly address preventing deterioration of their quality, while quantitative issues relate to permitting abstraction volumes. Quantitative measures derived from individual potential vulnerability scores for water resource competition, average summer headroom, average winter headroom, average change in low flows, changes in severe droughts, landuse pressures, change in severe flood events

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Derived from individual potential vulnerability scores for water resource competition, average summer headroom, average winter headroom, average change in low flows, changes in severe droughts, landuse pressures, change in severe flood events
for drinking water directly linked to CC seem less developed. An issue identified is also how policies apply in transboundary basins, to ensure that measures are coordinated for an efficient and effective adaptation and mitigation of impacts. Several task forces or other group address the issues of CC in several bodies involved in such transboundary issues.

**Adaptation measures**

Numerous adaptation measures were identified, which often may have synergistic benefits for different aspects of water management. Different types of measures were identified, to address different types of needs, including understanding the impacts, ensuring sufficient supply, guaranteeing the quality of DW, and minimising impacts of adaptation measures to the environment and socio-economic activities. It is also important to remember that adaptation measures are not necessarily new, as the impacts from CC will mostly exacerbate existing problems; that multiple actions across scales and sectors are needed, to ensure efficient and coordinated actions; that adaptation measures should be dynamic to cope with changing future circumstances; and adapted to the fact that water is both a location and time-specific issue, with issues that are different across seasons, years and geographical areas. Therefore, a toolbox of measures are identified, that need to be carefully selected at local level, to address the specific needs of a particular water body (including its location, uses, etc.). Different stakeholders may also be able to implement only certain types of measures, and both coordination and collaboration are key to success. The development of a decision-tree tool to help decision-makers at local level identify measures adapted to their own situation, that would consider all relevant local conditions, would be beneficial.

**Draft research roadmap and action plan for decision-makers**

This study shows that understanding the vulnerability of DW resources to CC requires a good understanding of a variety of factors, including the geography, the topography, the type of water body, and the competition for water, in addition to the actual impacts from CC (Figure 44). Research about the effects of CC on DW resources is relatively recent, and there is obvious need for further research, but already actions can be taken at a variety of levels. Before taking action though, points raised during the course of the study were the fact that CC is not necessarily the main threat to DW, and that separating DW issues from other water issues is not necessarily required, as especially decision-makers have to take decisions based on all uses, not only DW use.
Introduction

In terms of research, the main areas for future studies include increasing the understanding of multi-stressor conditions of water resources, through multi-disciplinary research, improving our understanding of impacts and vulnerability of water resources to CC (including filling data gaps, refining indicators and methodologies) and improving water management and developing efficient mitigation and adaptation options, through better valuation of ecosystem services, and strengthening governance. The actions that decision-makers can implement must be tailored to the local situation, considering all pressures to DW (CC, but also pollution, etc.), and prioritising win-win situations, no-regret measures and measures increasing the resilience of water bodies to CC. At EU level, exchange of information, through the cyclical process of the RBMP, will effectively require that CC is increasingly taken into account, and the second round is expected to ensure climate-proofing of proposed measures. Best practices may also be learned from the UK, which requires water managers to have a 25 year planning horizon. Possible actions at EU level may involve better implementation of water policies, and link with other environmental policies, including climate change; disseminating information; supporting and guiding decision-making at lower scales, through robust framework and exchange of experiences; and reinforcing measures that have as additional benefit a reduction in the vulnerability to CC.

The national level is an important actor, at the interface between the EU level and the RB level, and deciding orientations that are relevant at that scale. At that scale also, requests for reporting by private stakeholders may be decided. It is at RB level that actions must be refined, targeted and tailored to be effective and efficient. Large amounts of measures are already implemented, but may be cross-fertilised by exchanging information on measures already implemented in other RB. The main actions implemented at RB level include diagnostic, design of policies and their impact assessment, and communication. Other stakeholders may play a role such as cities and water managers, but also land-owners, that impact the vulnerability of DW resources and may implement measures.
Introduction
Chapter 1: Introduction

In brief: Vulnerability of water resources is underlined as a concern in the Blueprint to safeguard Europe's water resources. Drinking water is a key resource for society and thus merits specific attention, in particular in the context of climate change, where current pressures are expected to be exacerbated. This report explores the impacts of the climate change on drinking water resources in the European Union, their vulnerability to CC, and identifies possible measures to take to reduce this vulnerability.

1.1 Objectives

This report reviews existing knowledge on the potential effects of Climate Change (CC) on Drinking Water (DW) resources across the European Union (EU). It also proposes a methodology to assess the vulnerability of drinking water resources in the EU. In addition, it reviews the policy framework and the mitigation and adaptation measures available to stakeholders, so that adverse effects are reduced. It finally provides possible avenues for further scientific research and actions that may be taken by decision-makers at different levels, based on the identified gaps and issues.

Processes of CC may have a significant influence on the natural recharge of drinking water resources and the circumstances of their abstraction as well as their quality. Climate change Drivers, including the increase in the number and intensity of extreme weather events, changes in amounts and distribution of precipitation, may indeed lead to fluctuations of the watercourse levels, infiltration rates as well as runoff conditions and thereby, to significant modifications on the quantitative and qualitative parameters of drinking water production. In order to propose consistent measures that maintain the safety of drinking water resources in the different EU regions, a comprehensive understanding of the impacts of CC on water bodies is necessary. A thorough vulnerability assessment allows the provision of recommendations to assist decision-makers to develop policies and adaptive measures, which foster a better planning and a safer designation of drinking water resources in the future.

1.2 Drinking water abstraction and use in Europe

With the publication of its flagship communication "A Blueprint to safeguard Europe’s Water Resources", the European Commission (EC) underlines the issues related to water exploitation and use in the EU and calls for a better implementation and increased integration of water policy objectives into other policy areas. A full section is dedicated to vulnerability of EU waters in particular to CC and the need to increase the resilience of water bodies to its impacts. In addition, the EC is developing its strategy for CC adaptation, expected in Spring 2013. This section provides some context into the situation with regards water exploitation in the EU, and water abstracted for DW purposes.
1.2.1 Drinking water issues in the EU

1.2.1.1 Water exploitation

Sufficient resources of water of potable quality is a key need for humankind. In order to account for the vulnerability of water resources an integration of water abstraction and water availability is required. A commonly used metric of this is the Water Exploitation Index (WEI), which is calculated from the mean annual total water consumption divided by the long-term average freshwater resources. Figure 4 shows the national Water Exploitation Indices at River Basin (RB) level (the smallest available data disaggregation) for European Member States (MS), showing that Cyprus (64 %), Belgium (32 %) and Spain (30 %) have the highest WEI in Europe, with high values also for Italy, Malta and Turkey.

Figure 4: Regional Water exploitation Indices (WEI), taken as annual total water abstraction as a percentage of available long-term freshwater resources

Introduction

1.2.1.2 Water pollution

An important threat to drinking water is pollution. The Drinking Water Directive requires as a general obligation that "Member States shall ensure that the measures taken to implement this Directive in no circumstances have the effect of allowing, directly or indirectly, either any deterioration of the present quality of water intended for human consumption so far as that is relevant for the protection of human health or any increase in the pollution of waters used for the production of drinking water" (Article 4). The Water Framework Directive (WFD) requires protection, for the “aim of avoiding deterioration in their quality in order to reduce the level of purification treatment required in the production of drinking water” (Article 7.3). The Blueprint reports that whereas improvements have been made, the chemical status of water bodies is insufficiently known, and the situation with regards priority substances is below expectations. This may mean that in the future, the number of water bodies potentially available to abstract drinking water from may diminish.

Water treatment allows to remove pollutants from water extracted for drinking water purposes, but as highlighted above, the WFD aims to reduce treatment where possible. Climate change may have impacts on these treatments and on the kinds of pollutant to be removed (e.g. new pathogens).

1.2.1.3 Floods and water scarcity and droughts

Floods and water scarcity and droughts (WS&D) are catastrophic events that may have important socio-economic impacts on populations, and environmental impacts. Their occurrence is likely to become more frequent and intense in the future due to CC. With regards to drinking water, the events may lead to impacts in the form of increased pollution of water bodies due to increased washing off from pollutants from soils (floods) or reduced dilution (WS&D). Reduced availability may also become an issue. All these impacts are described in more details in the next chapter.

1.2.2 Water abstraction for public water supply

1.2.2.1 Amount of freshwater abstracted

The share of the public water supply sector in total water abstraction varies in each Member State (MS) and can be relatively small. According to Eurostat, most EU Member States have annual rates of freshwater abstraction of between 50 and 100 m³ per capita (see Figure 5), the extreme numbers reflect specific conditions. For example, in Ireland (141 m³ per capita) the use of water from the public supply is free; in Bulgaria (129 m³ per capita) there are particularly high losses in the public water distribution network. Abstraction rates were also rather high in some Nordic and Alpine non-member countries, notably Iceland, Norway and Switzerland, where water resources are abundant and supply is hardly restricted. At the other end of the scale, Estonia and Lithuania reported low abstraction rates, in part resulting from below-average connection rates to the public supply, while Malta and Cyprus have partially replaced groundwater by desalinated seawater.
1.2.2.2 Type of water abstracted for drinking purposes

The Member States have different abstraction patterns with regard to their freshwater supplies. Indeed, whereas Austria, Denmark or Latvia exclusively depend on groundwater abstraction, Bulgaria, Spain and Ireland mainly rely on surface water. In addition, Cyprus and Malta rely on significant amounts of desalinated water in order to respond to the DW demand, as seen in Figure 6. In general, drinking water mainly comes from groundwater. Fifteen MS out of 27 rely on groundwater for more than 50% of their drinking water needs, and in the remaining MS except Spain and Ireland less than 66% of the drinking water comes from surface water.

There has been a recent increase in interest in water resources of the Carpathian region. It is considered an important “water tower” for Europeans (Walczykiewicz et al. 2007). Groundwater in the Carpathian region is extracted mostly from porous (intergranular) and karstic aquifers. Over 80% of human water consumption in the Carpathians is supplied by groundwater. Freshwater is thus abundantly available, particularly in the mountain areas of the Carpath (UNEP, 2007).
Introduction

Figure 6: Share of water types for drinking water resources

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Some information is available in the scientific literature about the impacts of climate change on water resources, but very few sources specifically investigate drinking water issues. Climate change is expected to impact both the quantity and the quality of water resources in the future, however, such impacts will vary according to geographical location (because of direct impacts from CC and indirect impacts on water use patterns), type of water resource, etc. In general, the impacts from climate change are likely to exacerbate the current water problems in many parts of the EU. Most vulnerable areas are mountains, islands, coastal areas, urban areas.

Climate change impacts on hydrology is a well-studied current topic (Ahmad et al. 2011, Dong et al. 2012, Garfin et al. 2011, Grillakis et al. 2011, Halofsky et al. 2012, Jin and Sridhar 2012, Lavado Casimiro et al. 2011, Ryu et al. 2011, Shrestha et al. 2012). Many studies have assessed the impacts of CC on European RB hydrology (such as Mozny et al. 2012, Sperna Weiland et al. 2012, Verzano et al. 2012, Wong et al. 2011). Previous studies, however, predominantly focused on water resources in general or extreme hydrological events i.e. flooding and droughts. Few studies have currently focused on the impacts of CC on European drinking water resources: two rare examples are Meuleman et al. (2007) and Ramaker et al. (2005) who both focused on adaptive strategies of Dutch drinking water resources to CC. Meuleman et al. (2007) identified four key effects: increase of temperature, increasing sea levels, decreasing river runoff, and increase of extreme events. While these are CC impacts that have the potential to negatively affect drinking water resources, Meuleman et al. (2007) failed to include any social impacts on drinking water resources; they only focused on water availability and ignored the water demand side. The impact focus of most current and previous studies is likely to lead to an overestimation of the scale of the problem, as it ignores the ability of human society to adapt, but also fails to identify those vulnerability hotspots, where impacts are high and adaptive capacity is low.

2.1 Conceptual framework

Following an initial review of the literature, a conceptual framework was developed (see Figure 4) to enable a comprehensive understanding of the driving forces and potential effects of CC on drinking water resources. This also helped defining the scope of the study and refining the structure of the literature review. The framework builds on a preliminary model that was developed in the ClimWatAdapt study and has been adapted in particular to drinking water resources. It follows the DPSIR methodology (Drivers, Pressures, States, Impacts, and Responses as indicated by the purple pathway) and integrates the three vulnerability components used by the Intergovernmental Panel...
Review of the potential effects of climate change on drinking water resources on Climate Change (IPCC) and European Environment Agency (EEA). These vulnerability components are defined as follows:

- **Exposure**: nature and degree to which a system is exposed to significant climatic variations
- **Sensitivity**: degree to which a system is affected, either adversely or beneficially, by climate-related stimuli
- **Adaptive capacity**: ability or potential of a system to respond successfully to climate variability and change, including adjustments in behaviour, resources and technologies.

Legend: D: Drivers, P: Pressures, S: States, I: Impacts, R: Responses

**Figure 7: ADWICE Conceptual Framework**

**Drivers and pressures** related to exposure and sensitivity may bring out a change in the **state** of the drinking water resources as given by indicators of availability, quality and demand. The new state is induced by local hydrological processes as well as water use patterns (which may or may not reflect the transition towards a resource-efficient society).

The change in the state of a water body may lead to **impacts** when tolerance/triggers/thresholds – which depend on the type of drinking water resource among other aspects – are exceeded. The typology of drinking water resources (see Chapter 5) can stand as a relevant filtering function (green box in Figure 7) to determine the range of impacts that may be induced by a change in water quality, availability and/or demand.
Review of the potential effects of climate change on drinking water resources

Likewise, the intrinsic adaptive capacity of a water system (also in a green box in Figure 7) can be considered as a filtering function to assess whether the implementation of adaptation measures is likely to affect exposure and sensitivity components.

- **Drivers and Pressures**

With this approach, it is proposed to distinguish climatic and physico-chemical components (related to exposure) and societal components (related to sensitivity), which is consistent with the ClimWatAdapt study.

- **States**

The state of a drinking water resource is characterised by two main components:

  - Water Quality (including biological, chemical and physical parameters)
  - Water Quantity, resulting from Availability (including storage capacity, etc.) and Demand.

- **Impacts**

Impacts can be classified into environmental, economic and social impacts. Sub-categories could be identified depending on which State component has evolved and/or which Driving force is exerted.

- **Response**

Society can adapt to the Drivers and Pressures or mitigate them, so that State changes are minimised or that in particular the sensitivity\(^2\) decreases to reduce impacts.

2.2 **Main Climate change drivers affecting water resources**

It is difficult to make precise predictions of how climate will change in Europe because of a high degree of uncertainty on data and modelling parameters. However, there is a general agreement on the fact that CC (mainly temperature and precipitation change) will bear different characteristics in different parts of Europe. In particular, as seen in Figure 8, it is likely that mean annual temperatures will increase throughout Europe, with the highest increases expected in Southern and Eastern Europe. With regard to precipitation, some contrasting results are observed between Northern Europe, in which annual rainfall is expected to increase, and Southern Europe, in which it is expected to decrease.

\(^2\) In the conceptual framework, and in line with the ClimWatAdapt framework it builds upon, sensitivity is understood as the socio-economic drivers and pressures, hence vulnerability can be reduced mostly by adapting that component.
Review of the potential effects of climate change on drinking water resources

Figure 8: Changes in mean annual temperature and in mean annual precipitation by the end of this century

The effects induced by CC can be broadly categorised by regional zones, as illustrated in Figure 9.


Figure 9: Regional identification of the potential effects on CC on water
Review of the potential effects of climate change on drinking water resources

In this report, four geographical zones have been chosen that reflect the main changes with regard to impacts from CC on water, to illustrate the variety and amplitude of identified impacts:

- Continental land
- Northern Europe (boreal regions)
- North-Western Europe
- Mediterranean region

In addition and only where relevant, the following geographical zones are also identified:

- Islands
- Mountains
- Coastal zones

As illustrated in Figure 8 and Figure 9, CC will have a heterogeneous effect on the EU territory. A full understanding of potential impacts requires the consideration of local conditions and constraints. Based on the literature review, regional examples have been identified, revealing a range of potential future impacts.

2.2.1.1 Effects of CC on precipitation regime – regional examples

“Climate model simulations for the 21st century are consistent in projecting precipitation increases in high latitudes (very likely) and decreases in lower mid-latitude regions (likely)” (IPCC, 2008). Table 1 provides an overview of these effects and Annex 1 presents the identified examples in more details.

<table>
<thead>
<tr>
<th>EU region</th>
<th>Effect</th>
<th>Example of river basins or countries identified in the literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continental land</td>
<td>Decreased precipitation (especially in summer)</td>
<td>Austria, Czech Republic, Hungary, Poland, Rhine catchment</td>
</tr>
<tr>
<td></td>
<td>Increased precipitation (mostly in winter)</td>
<td>Austria, Bulgaria, Hungary, Luxembourg, Slovenia, Romania, Rhine catchment</td>
</tr>
<tr>
<td></td>
<td>Increased extreme precipitation events</td>
<td>Austria, Hungary, Poland, Romania</td>
</tr>
<tr>
<td>Northern countries</td>
<td>Decreased precipitation</td>
<td>Latvia</td>
</tr>
<tr>
<td></td>
<td>Increased precipitation (mostly in winter)</td>
<td>Estonia, Finland, Sweden</td>
</tr>
<tr>
<td></td>
<td>Increased extreme precipitation events</td>
<td>Latvia, Baltic Sea region</td>
</tr>
</tbody>
</table>
Review of the potential effects of climate change on drinking water resources

<table>
<thead>
<tr>
<th>EU region</th>
<th>Effect</th>
<th>Example of river basins or countries identified in the literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>North-Western countries</td>
<td>Decreased precipitation (especially in summer)</td>
<td>Belgium, France</td>
</tr>
<tr>
<td></td>
<td>Increased precipitation (mostly in winter)</td>
<td>Belgium, France</td>
</tr>
<tr>
<td></td>
<td>Increased extreme precipitation events</td>
<td>Belgium</td>
</tr>
<tr>
<td>Mediterranean countries</td>
<td>Decreased precipitation (especially in summer)</td>
<td>Spain</td>
</tr>
<tr>
<td>Islands</td>
<td>Decreased precipitation:</td>
<td>Malta</td>
</tr>
</tbody>
</table>

### 2.2.1.2 Effects of CC on temperature and sea level – regional examples

“Higher water temperatures and changes in extremes, including floods and droughts, are projected to affect water quality and exacerbate many forms of water pollution”. In addition, water use generally increases with temperatures. In addition, “Sea-level rise is projected to extend areas of salinisation of groundwater and estuaries, resulting in a decrease of freshwater availability for humans and ecosystems in coastal areas” (IPCC, 2008).

However, the effects of CC on water are uncertain in terms of the weight it has on changing water use patterns, there is no evidence of climate-related long-term trend of water use in the past, partly due to the fact that water use is mainly driven by non-climatic factors (IPPC, 2008). In another report (fourth assessment report, 2007), the IPCC reports that “land-use changes have a small effect on annual runoff as compared to climate change in the Rhine basin […] in other areas, […] land-use and climate change effects may be more similar”.

Table 2 provides an overview of these effects and Annex 1 presents the identified examples in more details.

Table 2: Regional effects of changed temperatures and sea level

<table>
<thead>
<tr>
<th>EU region</th>
<th>Effects</th>
<th>Example of river basins or countries identified in the literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continental land</td>
<td>Temperature rise</td>
<td>Austria, Bulgaria, Germany, Hungary, Romania, Slovenia, Rhine catchment</td>
</tr>
<tr>
<td></td>
<td>Increased evapotranspiration</td>
<td>Austria, Danube catchment</td>
</tr>
<tr>
<td></td>
<td>Reduced snow cover</td>
<td>Bulgaria, Danube catchment</td>
</tr>
<tr>
<td></td>
<td>Sea level rise</td>
<td>Romania</td>
</tr>
</tbody>
</table>
Review of the potential effects of climate change on drinking water resources

<table>
<thead>
<tr>
<th>EU region</th>
<th>Effects</th>
<th>Example of river basins or countries identified in the literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern Europe</td>
<td>Temperature rise</td>
<td>Estonia, Latvia, Baltic region</td>
</tr>
<tr>
<td></td>
<td>Reduced snow cover</td>
<td>Estonia</td>
</tr>
<tr>
<td></td>
<td>Sea level rise</td>
<td>Estonia, Latvia</td>
</tr>
<tr>
<td>North-Western Europe</td>
<td>Temperature rise</td>
<td>France, Netherlands</td>
</tr>
<tr>
<td></td>
<td>Increased evapotranspiration</td>
<td>Belgium, France, UK</td>
</tr>
<tr>
<td></td>
<td>Disappearing glaciers</td>
<td>France, Alps</td>
</tr>
<tr>
<td></td>
<td>Reduced snow cover</td>
<td>France, Alps</td>
</tr>
<tr>
<td></td>
<td>Sea level rise</td>
<td>Belgium, Netherlands, UK</td>
</tr>
<tr>
<td>Mediterranean region</td>
<td>Sea level rise</td>
<td>Italy</td>
</tr>
<tr>
<td>Islands</td>
<td>Sea level rise</td>
<td>UK</td>
</tr>
</tbody>
</table>

### 2.2.1.3 Main drivers increasing water demand due to Climate change

Climate change will not only influence quantitatively and qualitatively the status of surface water and groundwater bodies through changes in precipitation, temperature, and sea level, it will also influence the water demand\(^3\), increasing the vulnerability of water bodies. The EEA (2009) reports that 44% of total water abstraction in the EU is for energy production, 24% for agriculture 21% for public water supply and 11% for industrial purposes. The FP7 project ClimateWater estimates that on average, 42% of total water abstraction in Europe is used for agriculture, 23% for industry, 18% for urban use and 18% for energy production. However, sectoral water use varies considerably across Europe (Figure 10). Agriculture, in particular, accounts for up to 80% (or more) of total water abstraction in Southern Europe, while cooling for electricity production is the dominant use in Western Europe (EEA, 2009). In case of water scarcity, it is likely that the most impacted sectors will be those that use the greatest water quantities.

\(^3\) Although as mentioned above, according to IPPC (2008) the water use is mainly driven by non-climatic factors, expectations are that the combination of climate-related changes and other drivers will increase water use in the future, see projections from a variety of authorities below.
Demand for water is likely to increase in the context of a changing climate, especially during summer and with projected increases in population (Malta Resources Authority, 2010; Water UK, 2008; UK Environment Agency, 2009b; UK Environment Agency, 2008; UK Environment Agency, 2005; RIA, 2007). This generalised increase in water use caused by CC could lead to conflicts amongst water users and ultimately could threaten the supply of DW in some parts of Europe, such as the Mediterranean region. The increased demand, coupled with the aforementioned shortages could increase water supply costs.
2.3 Impacts related to changing water quantities

2.3.1 Main mechanisms affecting water availability

Table 3 synthesises the main drivers and pressures that affect water availability.

<table>
<thead>
<tr>
<th>Driver</th>
<th>Pressure</th>
<th>Change in State</th>
</tr>
</thead>
</table>
| **Increase in temperature**   | Increased evaporation and evapotranspiration  
  -> higher water use by the vegetation | Reduced river flows  
  Reduced aquifer recharge  
  Reduced snow cover  
  Reduced streamflow  
  and maximum runoff earlier in the year  
  Decreased soil moisture content |
|                               | Increased water demand                                                  | Higher abstraction rate                                                          |
|                               | Increased biological activity in soil  
  -> reduced infiltration        | Reduced aquifer recharge                                                        |
| **Changes in precipitation patterns** | Increase in the intensity of rains, on short periods  
  Variability in patterns  
  Increase in the frequency and intensity of droughts  
  Increase in the frequency and intensity of floods | Reduced water infiltration in soils  
  Reduced soil water moisture, reduced groundwater levels/recharge  
  Reduced snow cover  
  Reduced river flows  
  Reduced aquifer recharge  
  Increase in groundwater levels |
| **Sea level rise**            | Saline intrusion into surface freshwaters, but more importantly into groundwater systems | Reduced freshwater availability                                                  |
|                               | Erosion of sand dunes                                                   | Reduced protection against floods from the sea                                   |
2.3.2 Main impacts on surface and groundwater

- **Surface water**

Surface water quantities (both flowing, i.e. rivers, and standing i.e. lakes and reservoirs) are affected by precipitations, snowmelt (in particular for glacier-supported rivers), temperature, geology, and local vegetation. In addition, when the precipitation patterns change with more intense and less frequent rainfall events, the response from storage systems may not be adequate (in terms of storage capacity or recharge conditions) to address the amount of runoff. This could lead to some water losses and less water will be available for drinking water purposes.

The IPCC (2007) reported that many studies have been performed about the impacts from climate change on river flows between the third and fourth assessment reports, virtually all being based on the use of hydrological model driven by scenarios based on climate model simulations. The main reported effects show that runoff change will generally increase between 10 and 40%, and decreasing runoff will occur in the Mediterranean. Warming will lead to changes in the seasonality of river flows, where much precipitations currently falls as snow. Effects are more important at lower elevations. Peak flow will occur at least a month earlier than current patterns. Winter flows will increase while the summer flows will decrease. For glacier-supported rivers, as glaciers retreat due to global warming, river flows will increase in the short-term, but the contribution of glaciers will decrease in the longer-term. Where snowfall is rare, changes in runoff mostly depend on changes in precipitation patterns rather than on temperature changes. Flow seasonality will increase, with higher flows in the peak flow, and lower or dry periods during low flow season. The timing of the peaks will change little. With regard to lakes, they depend on changes in river inflows, precipitations and evaporation and will depend on individual situations.

<table>
<thead>
<tr>
<th>EU region</th>
<th>Effect</th>
<th>Example of river basins or countries identified in the literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continental land</td>
<td>Minor changes in discharge rates and low flows</td>
<td>Rhine RB (overall – in 2050)</td>
</tr>
<tr>
<td></td>
<td>Increased annual discharge</td>
<td>Rhine catchment tributaries (e.g. Main) – in 2050</td>
</tr>
<tr>
<td></td>
<td>Decreased annual discharge</td>
<td>Rhine catchment tributaries (e.g. Main – in 2050) and overall – in 2100, the Alps area, Austria, Bulgaria, Slovakia, Czech Republic, Hungary, Danube catchment, Bulgaria</td>
</tr>
</tbody>
</table>
Review of the potential effects of climate change on drinking water resources

<table>
<thead>
<tr>
<th>EU region</th>
<th>Effect</th>
<th>Example of river basins or countries identified in the literature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Decreased summer level/Increased low flows in summer</td>
<td>Austria, Hungary (lakes), Bulgaria</td>
</tr>
<tr>
<td></td>
<td>No or insignificant changes in lake levels</td>
<td>Austria</td>
</tr>
<tr>
<td>Northern Europe</td>
<td>Decreased annual discharge</td>
<td>Latvia, Estonia</td>
</tr>
<tr>
<td></td>
<td>Decreased summer level</td>
<td>Lithuania, Estonia (lakes), Baltic countries</td>
</tr>
<tr>
<td></td>
<td>Increased winter levels</td>
<td>Baltic countries</td>
</tr>
<tr>
<td></td>
<td>No or insignificant changes in lake levels</td>
<td>Lithuania</td>
</tr>
<tr>
<td>NW Europe</td>
<td>Decreased annual discharge</td>
<td>UK, Ireland, France</td>
</tr>
<tr>
<td>Mediterranean region</td>
<td>Decreased annual discharge</td>
<td>Italy</td>
</tr>
<tr>
<td>Islands</td>
<td>Decreased annual discharge</td>
<td>Cyprus</td>
</tr>
<tr>
<td>Mountains</td>
<td>Increase in snow melting -&gt; increased river flows in the medium-term, but reduced in the long-term</td>
<td></td>
</tr>
</tbody>
</table>

**Groundwater**

The impact of CC on the recharge of groundwater resources is the result of a complex and sensitive interaction between the changes in precipitation patterns, temperature, local geology and soil and plant physiological response to atmospheric CO$_2$ concentrations. The predicted general increase in annual average temperatures and the decreases in summer precipitation lead to higher soil moisture deficits and a later return of the soils to field capacity\(^4\). Meanwhile, the largely unchanged spring precipitation and warmer temperatures mean that soil moisture deficits are likely to develop earlier in spring, resulting in a generally shorter winter recharge period. Whether this shortened recharge period leads to reduced recharge depends on whether it is outweighed by the expected increased winter precipitation. The increased variability in precipitation, temperature and evapotranspiration will therefore have varied effects on different aquifers and different locations.

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\(^4\) Defined as the amount of soil moisture or water content held in soil after excess water has drained away.
Review of the potential effects of climate change on drinking water resources

It is widely acknowledged that there remains considerable uncertainty in the predicted spatial and temporal patterns in predicted future precipitation and temperature. This uncertainty in the key drivers propagates into uncertainties in predicted evapotranspiration, runoff and recharge, affecting an accurate understanding of the effects of CC on groundwater systems. In the areas in which the limits of groundwater sustainability are being reached because of abstraction, even small climate-induced changes in recharge, discharge or groundwater storage may have economic or environmental consequences. Hiscock et al. (2008) presented projections for groundwater recharge in Europe, using a broad range of scenarios of projected future climate until the end of the 21st century, in comparison with the 1961–1990 control period. Their results showed increases in annual potential groundwater recharge for Northern Denmark (28%), Southern England (32%) and Northern France (60%), and decreases for Northern Italy (22%) and Southern Spain (78%), although these results are not consistent with other studies for Northern Europe. The only study which provides a spatial overview of impacts on groundwater in Europe is Doll et al. (2009) who show changes in long term average groundwater recharge (GWR) in the 2050s using two climate models (ECHAM4 and HadCM3) and two greenhouse gas emissions (A2 and B2), which demonstrate the significant climate uncertainty which hampers generalisations about future impacts:

- **A2 scenario:**
  - ECHAM4 – a NE to SW gradient in the change, with increases of +10 to +30% in Scandinavia (Norway, Sweden, Finland, Baltic); little change in a band through northern UK, Denmark, Germany to northern Poland; decreases of -10 to -30% in Southern UK and France; and decreases of -10 to -70% in Spain, Italy, Greece and central Europe.
  - HadCM3 – little change in long term average GWR across most of Europe, with localised areas of low decreases (-10 to -30%) in Eastern Europe and areas of increases in Spain.

- **B2 scenario**
  - ECHAM4 – small increases of +10 to +30% in northern UK and Scandinavia (Norway, Sweden, Finland, Baltic MS); little change through the remainder of western Europe, and variable but generally small decreases of -10 to -30% in Spain, Italy, Greece and central Europe.
  - HadCM3 – largely unchanged with the exception of small increases of +10 to +30% in the north of Scandinavia and the Baltic area; small decreases in the Pyrenees area, and general increases in Spain.

**Karstic and fractured (hard rock aquifers)**

The high transmissivity and low storage capacity (due to water being largely stored within the fissures and fractures as a consequence of their low intergranular porosity) makes these aquifers particularly sensitive to changing climate and variability in precipitation. Cambi and Dragoni (2000) forecasted decreases in the discharge of the Bagnara spring in Italy. Hrkal et al. (2009) showed that a fractured aquifer within crystalline rocks, in which groundwater flows through and is stored in a
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relatively shallow aquifer zone, is very vulnerable to CC. The low storage capacity means that reductions in precipitation and infiltration can lead to significant declines in groundwater levels.

**Boreholes in groundwater discharge areas**

Hrkal et al. (2009) suggest that boreholes located in groundwater discharge areas, in other words near rivers, lakes etc., would experience reduced declines in groundwater level due to the control exerted by the surface water levels. Van Roosmalen et al. (2007) showed that simulated groundwater level changes by about 2m at the water divide and by < 0.5m along the rivers and streams. Other non-European studies (e.g. Scibek & Allen, 2006; Allen et al., 2004) have also shown how the responses of geologically similar aquifers to CC can differ according to the degree of interaction with surface water.

**Shallow wells and boreholes (i.e. with limited water column depths)**

Many studies (e.g. Goderniaux et al. 2011; Van Roosmalen et al. 2007; Bloomfield et al. 2003) predict declines in groundwater levels, especially in late summer and autumn and in sites located away from surface water controls. Water abstraction sites with either limited water column depths (such as hand dug wells, and wellpoint systems) or at shallow depth below the water table (some horizontal wells and infiltration galleries) may be at risk from reduced groundwater levels.

- **Link between surface and groundwater**

Hydrological connectivity means that impacts on groundwater may in turn affect surface waters and vice versa. Indeed, in many cases, groundwater sustain rivers in periods of low flows, and any reductions in the water tables may lead to a reduction or disappearance of this mechanism. Similarly for surface water that allows groundwater recharge through infiltration.

### 2.3.3 Region-specific issues

Table 5 synthesises the impacts from CC on groundwater, and identifies in which regions these impacts have been identified in the reviewed literature.

<table>
<thead>
<tr>
<th>EU regions</th>
<th>Effect</th>
<th>Example of river basins or countries identified in the literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continental land</td>
<td>Decreased groundwater recharge</td>
<td>Austria, Belgium, Germany, Hungary, Romania, Slovenia</td>
</tr>
<tr>
<td></td>
<td>Decreased soil moisture content</td>
<td>Danube catchment, France (earlier drying)</td>
</tr>
<tr>
<td>Northern Europe</td>
<td>Increased groundwater recharge</td>
<td>Estonia</td>
</tr>
</tbody>
</table>

Note the regions and countries are thus not necessarily exhaustive.
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<table>
<thead>
<tr>
<th>EU regions</th>
<th>Effect</th>
<th>Example of river basins or countries identified in the literature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Decreased soil moisture content</td>
<td>Finland (depends on the soil type), Estonia</td>
</tr>
<tr>
<td>NW Europe</td>
<td>Decreased groundwater recharge</td>
<td>France, UK, Ireland</td>
</tr>
<tr>
<td></td>
<td>Decreased soil moisture content</td>
<td>France, Ireland</td>
</tr>
<tr>
<td>Mediterranean region</td>
<td>Decreased groundwater recharge</td>
<td>Spain</td>
</tr>
<tr>
<td>Islands</td>
<td>Decreased groundwater recharge</td>
<td>Malta</td>
</tr>
</tbody>
</table>

2.3.3.1 Flowing surface water: changes in annual discharge

Continental land

According to a study of the International Commission for the Protection of the Rhine (ICPR), in the Rhine RB, there will be mostly moderate changes of the discharge in 2050 (compared to 1961-1990). The average discharge and the low flow in summer remain almost unchanged. The evaluations result in slightly differing findings for tributaries. For example, for the Main, many projections show an increase of average discharge and low flow in summer. In the contrary, up to 2100 (compared to 1961-1990), average discharge and low flow in summer are expected to considerably fall, mostly by -10 % and -30 % (ICPR, 2011).

In Bulgaria, the results of a study by Alexandrov & Genev (2003) showed that the annual river runoff is expected to decrease by up to 14% in 50 years and to be 20% lower at the end of the century with regard to the current situation. In the case of a severe drought period, the expected decrease in annual runoff in Bulgaria would be between 39 and 45%. In the Bulgarian Struma RB, changes in mean annual runoff differ both spatially and temporally. Each area of the basin will respond differently to changes in climate in 2025 (e.g. decreases in runoff in high mountain areas versus increases in runoff at intermediate altitudes). Runoff at some intermediate elevations substantially increases due to precipitation increase during seasons with lower evapotranspiration. In 2085, however, because the Struma RB will be getting warmer, runoff is expected to decrease in most areas of the basin as a result of increases in evapotranspiration. Although the basin will have no significant changes in mean annual precipitations (changes in mean annual precipitations vary from +1.9% to +4.3% by 2025 and from -4.5% to +0.1% by 2085), changes in seasonal distribution of precipitations play an important role for determining changes in mean annual runoff (Chang et al., 2002). In the Bulgarian Struma RB, the seasonal distribution of runoff is important. Summer runoff is expected to significantly decrease around 2085 (by about a half with regard to the baseline period, except in high elevations of the Eastern border). This significant reduction is due to decreases in summer precipitations and increases in summer temperatures, which result in increases in summer evapotranspiration. It should be noted that the spatial pattern of summer runoff differs from that of annual runoff. A slight increase in summer runoff in Eastern mountain areas may be related to consistent snowmelt on steep slopes throughout the summer months.
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(Chang et al., 2002). The same study demonstrated changes in monthly streamflow under baseline climate and CC scenarios for the years around 2025 and 2085. In years around 2025, there is a shift expected in the magnitude of maximum runoff in April. The seasonal distribution of runoff will also change; summer and fall streamflow will decrease, while winter streamflow will increase. A slight decrease in streamflow after the maximum flow month is also predicted, especially from June through October. Increases in winter runoff are mainly due to increases in winter precipitation and temperature. Temperature increases would result in less snow from precipitation and thus produce more winter runoff. In 2085, the month of maximum runoff will move further forwards. Significant decreases in runoff are predicted throughout April and October when water is needed most (Chang et al., 2002).

The hydrologic regime of the Danube River, in particular the discharge regime, is distinctly influenced by the regional precipitation patterns. In terms of the surface water contribution from each country to the cumulative discharge of the Danube, Austria shows by far the largest contribution (22.1 %) followed by Romania (17.6 %). This reflects the high precipitation in the Alps and in the Carpathian mountains (ICPDR, 2005). The Tysa RB is the largest sub-basin in the Danube RB and the longest tributary of the Danube. By the flow volume is the largest (after the Danube) in this region. The typical for the Tysa is the wide fluctuation between low water levels and high water levels (Walczykiewicz et al., 2007).

The Carpathians is a water “reservoir” for surrounding areas. The distribution of precipitations is highly variable, with strong effects on the surface run-off and the discharge in the streams. The groundwater quantities also are highly variable and the wetlands represent valuable drinking water reserves for many people. In the Carpathian region, it is expected that temperatures will increase by 2080 of between 2.0 and 2.6°C. This may have important impacts, such as increasing drought stress, more frequent forest fires, increasing heat stress. Mountain areas including Carpathians and surrounding floodplains are the most vulnerable zones in Europe. CC is expected to increase the frequency of extreme flood events in Europe, in particular the frequency of flash floods (Walczykiewicz et al., 2007).

To assess the CC impacts on water resources and their management for Buzau RB district (Romania) (CECILIA project), three models were used, ECHAM3/OPYC4 climate (Germany), H-HadCM3 (England), N-NCAR-PCM (USA), considering three intensities of CC phenomena: low (optimistic scenario), medium (medium scenario) and high (pessimistic). Scenarios are made for the years 2025, 2050 and 2100. Mediated changes using climatic parameters for each of the 17 basins were simulated. Monthly variations of flow for the periods 2021-2050 and 2071-2100, for two sections upstream (Buzau river – g.s. Nehoiu and Ialomita river – g.s. Moroeni) and for sections close to the two RBs (Buzau river – g.s. Racovita and Ialomita river – g.s. Tandarei), are shown in Figure 11.
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Within the CLAVIER project (investigating Hungary, Romania and Bulgaria) the analysis of the mean seasonal and annual discharges simulated time series for Tisza River and its tributaries and Mures and Arges rivers for periods 1961-1990 and 2021-2050 with the A1B scenario was performed based on the hydrological simulations and show the following impact:

- Slight increase in Upper Tisza and tributaries (less than 5%)
- No change or general decrease of the mean annual discharges, down to 15 % for Central Tisza and Southern basins; and a general decrease of the mean annual discharges, with -10 to -15 % for all the basins in Mures and Arges rivers
- The mean seasonal discharges are increasing only in the winter season, in all the basins but with significant variations (3 to 42 %), with greater values in the medium part of the Mures and Arges RB;
- For the spring – autumn period, the hydrological simulations indicate a decrease of the mean discharges for most of the catchments in Southern basins of the Tisza River and its tributaries and of the Mures and Arges rivers between -15 and -20 %, with the exception of the lower part of the Arges RB in autumn, where the mean discharges are decreasing only with -4 to -7 %

In order to estimate the A1B CC scenario impact on the hydrological regime, the variations of the mean monthly simulated discharges for selected 30 years periods (1961 – 1990 as reference period and 2001 – 2030, 2011 – 2040, 2021 – 2050 as representative periods for the future) were also analysed in the CLAVIER project. The preliminary results in most cases indicate slight decrease of annual mean flow throughout the region, with significant spatial variability and even some increase for the high elevation zones in the Upper Tisza sub-catchments. The decrease of spring runoff is compensated by the flow resulting from thaw during late winter. Similar analyses were carried out
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for some selected representative hydrometrical stations from the Mures and Arges RBs. The comparison of the mean monthly simulated discharges, for the selected 30 years future periods and the reference period, indicate the following impacts of the A1B scenario:

- General decrease tendency of the mean monthly discharges respectively for the March –November period in the Mures – Arad basin⁶, and April –October period for the Arges – Budesti basins⁷, in the future periods compared with the reference period;
- Indication of significant decrease of the mean monthly discharges for all the selected future periods, for August, September and October in the Mures – Arad basin and for April, May, July and September in the Arges – Budesti basins;
- There is a clear continuous decreasing tendency, as we go in the future, for June, November and December in the Mures – Arad basin and for April, May, June, November and December, and a small increasing tendency for August in the Arges – Budesti basins;
- Compared with the reference period, the simulated mean monthly discharges variations indicate an increase only in the winter season months, especially for February and December in both areas, and for November in the first two future periods in the Arges – Budesti basins; and
- The most stable regime is for the mean monthly discharges in January in the Mures – Arad basin and there are small variations in the future, around the values from the reference period, for January, March and August in the Arges – Budesti basins.

Another study in the Mures RB focuses on the Tarnava RB (Mare & Mica rivers), applying the hydrological model MEDL. This model is based on the balance between rainfalls, soil accumulations, evapotranspiration and runoff at the gauging stations: Zetea, Odorheiul Secuiesc, Medias, Bezid, Tarnaveni and Mihalt, for the period 1961-2000. The study emphasised the impact of climatic changes on water resources, on the assumption of doubling the amount of the CO₂ equivalent in the atmosphere. The most significant changes for the Mihalt station on the Tarnava River are the following (A. Galie, 2006):

- The average annual discharge increases by 0.9%;
- The average annual discharge variation records an increase of about 71.7% in the period October-February, in July and August and a decrease of about 30.2% in the period March-June and in September. The average multiannual discharge is expected to be less variable taking into account CC than it is presently;
- The minimum outflow increases in the period December to February with a variation of 156.9% and decreases during spring, summer and autumn with variation of 19.4%;
- The flash floods resulting from snow melting are expected to occur earlier, usually in January and will be about 21.4% more intensive; pluvial floods will also change.

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⁶ basin area = 27280 km²; mean basin altitude = 618 m
⁷ basin area = 9328 km²; mean basin altitude = 442 m
Further negative impacts of CC on hydrological systems in Central and Eastern Europe are expected to include an increase in winter flows and decrease in summer flows of rivers, with summer flows decreasing by as much as 50% in South Eastern Europe (IPCC, 2008; IPCC, 2007b). In connection to this, risk of snowmelt floods is expected to shift from spring to winter (IPCC, 2008), contributing to the lengthening of the dry season in the summer.

As for already occurring local effects, analysis of long-term monthly averaged flows of smaller rivers showed significant decrease during all months (except for May and June) in Middle and Southern Slovakia, while in Western Slovakia decrease in summer and autumn and increase in winter river flows has been experienced (Lapin et al. 1997, 2004; Škoda et al., 2005). An assessment of the historical floods in the rivers of the Bodrog RB in Eastern Slovakia indicated an increased extremeness of the flood regime on the Uh River (Halmova, 2001)(reported in CEU, 2008).

In the Blsanka RB, Czech Republic, several rivers are located in a low precipitation region and their hydrological conditions have deteriorated during the last two decades, which are probably already affected by impacts of initial stages of CC. The main problems occur during drought periods. When river discharges drop below minimum ecological flows, the river water is excessively polluted by waste water discharges from urban areas and the water resources are insufficient for meeting water use requirements for the purposes of agriculture, which is a very important economic sector in this region. In order to make decisions about effective measures, it was necessary to derive volumes of water, which are missing during drought events (deficit volumes) to ensure effective dilution of waste water and for maintaining the required ecological flows to keep the ecological function of the stream. Results of the application of deficit volume method (Tallaksen & Lannen, 2004), using the EXDEV computer programme, showed that the storage capacity for ensuring ecological flows during the period 1969 – 2008 would be 530 mega litres (ML) (with a deficit in 2007). Including scenarios for CC in the model suggests that the deficit volume will increase in range from 3 260 ML (according to scenario RCAO B2) to 5 750 ML (scenario HIRHAM A2) until the year 2085 (EC, 2009).

The future low flow situation depends also on changes in water use, which could worsen or improve the general trend. Increase in low flow periods may occur as a result of more summer droughts, especially in the South Eastern parts of the Danube RB. Increase in 100-year frequency is expected in most parts of the DRB, except in Alpine areas, which show a decrease in low flow frequency. In mountain regions, there is a possible shift of low flow events from winter (in the past) to the end of summer / autumn (in the future).

In the middle part of the DRB, the projections show a possible increase in the frequency of low flow. In the Tisza RB, more intense and longer low flow periods are possible; while in Hungary, longer low flow periods and a shift of low flow events from autumn to earlier months is expected. In the Lower Danube River Basin, it is prognosticated that there will be an increase in low flow frequency in the river-system Dyie-Jihlava (Czech Republic) (Mauser et al. 2012).

**Northern Europe**

Simulations in five RBs in Latvia (Bërże, Iecava, Imula, Salaca, Vienziemie) mostly show a decrease in runoff by 1-9% in the spring season, according to both A2 and B2 scenarios. During the second half of the year, due to decreased precipitation and increased air temperature and evapotranspiration, river runoff is forecasted to decrease, particularly in the autumn season, by 3-10% according to A2 and 1-8% according to B2 (Apsite et al., 2010). However, results differ greatly depending on the study, as illustrated by a review compiled by Apsite et al. (2011). In the Lielupe
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RB, Butina et al. (1998) found that the river flow was predicted to increase by 11 to 83% on average, depending on the emissions scenario used in the model. In contrast, Rogozova (2006) identified both increasing (from +15 to +17%, GCM ECHAM4/OPYC3) and decreasing (from −7 to −2%, GCM HadAM3H) trends in annual river runoff for two Latvian RBs, the Irbe and Gauja. In the latter study, the climate data series were based on the RCAO RCM8 using two different GCMs and emission scenarios (A2, B2) and the HBV hydrological model9. It was concluded that prediction in runoff changes may depend on the chosen GCM and emissions scenario in the RCAO RCM. Apsite et al. (2010) also note that changes in temperature and precipitation regime will lead to increased runoff in the winter season by 7-18% according to A2 scenario and 4-12% according to B2 scenario. In addition, the major part of the total annual river discharge will be generated in the winter season (39-49% in winter according to A2, 35-45% in winter according to B2), while today it occurs in spring and accounts for a slightly smaller portion of total discharge (typically 32-41%). According to both scenarios, a higher river discharge in winter and a lower river discharge in autumn can be expected for two upland basins: the Vienzieme and Imula.

In various studies related to the Baltic countries, it was predicted that the increase in river runoff would be marked during winter due to the shortening of the period with snow and ice cover, whereas the spring runoff maximum would mostly decrease and shift to earlier periods. However, there are diverging predictions concerning the total annual river runoff at the end of this century. An increase in runoff is predicted in early studies and to some extent by Rogozova (2006), but a decrease is forecasted in the most recent studies. The model put forward by Apsite et al. (2011) predicts that the majority of total annual river runoff will be generated in winter because of the warmer and wetter climate, followed by spring, autumn and summer. The spring maximum discharge will mostly decrease and shift to earlier periods. Autumn will become warmer and drier followed by stream flow decrease. No considerable change in runoff is predicted for the summer. The ASTRA Project (2007a) highlighted changes of the River Salaca water discharge, featuring a clear increase in the winter discharge, and a decrease of the water discharge in the summer season during the 1927-2004 period.

In Estonia, according to Estonia's Fifth National Communication (Estonian Ministry of the Environment & Estonian Environment information Centre, 2009), the earlier melting of the snow cover causes changes in the hydrological regime. For instance, rivers reach their point of maximum runoff earlier and the magnitude of such runoff is generally smaller. The main changes in flowing surface water will be:

- Increased winter runoff (increase in the contribution to the annual runoff in the winter season by 24%-34%), leading to a decrease in spring floods.
- Decreased and earlier runoff in spring (decrease in the contribution to the annual runoff in the spring season by 4%-10%), leading to a decrease in spring floods and a decreased washout of sediments from catchment area; however, it will also lead to a longer minimum runoff period in summer, diminishing water capacity in soil.

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8 Rossby Centre Atmosphere Ocean Regional Climate Model
9 The Hydrologiska Byråns Vattenbalansavdelning (HBV) model is a computer simulation used to analyse river discharge and water pollution
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- Increased minimum runoff in summer, leading to an increased leaching of nutrient from fields.
- Increased runoff in autumn, which may lead to increased water amounts in lakes for the winter period.

**North-Western Europe**

In the UK, scientists produced cumulative flow curves for seven major catchments across England and Wales - the Bedford Ouse, the Dee, the Medway, the Mersey, the Severn, the Thames and the Yorkshire Ouse. The maps showing the change in mean monthly river flow suggest that nowhere in England and Wales is likely to escape the effects of reduced river flow. Wales and the North and West of England are predicted to see significant reductions in river flow throughout the summer months (June, July and August). The South and East of England see the same percentage reduction but not until later in the year (September and October), with river flows in November dropping to almost half their current volume. This delayed reaction is due to the predominance of underground aquifers in the South and East, which help to support river flows until later in the year. However it also means that the start of the recharge season would be delayed which could affect groundwater storage as well (UK Environment Agency, n.d-a). The overall drop in annual river flows is up to 10-15% by 2050 (UK Environment Agency, 2009b; UK Environment Agency, 2008; UK Environment Agency, n.d-a). River flows in the late summer and early autumn could fall by over 5%, and by as much as 80% in some catchments. The number of months where river flows increases will be less than the number of months where river flow decreases (by 2050, river flows in winter may increase by 10 to 15 % but with lower flows in most rivers from April to December). When combined with increased temperatures – and hence increased evaporation – this pattern is likely to affect the total annual river flow. If effects of this magnitude occur, this will probably be the biggest challenge that needs to be overcome to ensure that there is enough water for people and the environment (UK Environment Agency, 2009b; UK Environment Agency, 2008; UK Environment Agency, n.d-a).

Similarly, in Ireland, decreases in summer rainfall, coupled with a rise in rates of evaporation, would lead to persistent low flows. The greatest reductions in streamflow are likely to occur during the autumn months (UK Environment Agency, 2005). Simulations indicate that all catchments will experience decreases in streamflow, with greatest decreases in the majority of catchments likely to occur in the late summer and autumn months, when water provision is already problematic in many areas, especially for the Ryewater and Boyne. Unfortunately these catchments are the most heavily populated in the analysis and comprise a substantial proportion of the Greater Dublin Area (GDA)” (RIA, n.d.). In Ireland, two broad responses to increased evaporation and low precipitation exist:

- for runoff dominated catchments such as the Boyne the most extreme reductions in monthly streamflow were shown for the summer and autumn months;
- for catchments with large groundwater storage capacity (e.g. the Suir, the Blackwater and the Barrow) reductions in flow during summer months were offset by contributions from storage, however, in these catchments substantial reductions were also found for autumn months.

In the Seine RB, according to the project GICC - REHySS, from 2050 there will be a rather sharp decrease in the discharge of the Seine around the village Poses for all months (-126 m³/s, that is to say -23%). The reduction is more pronounced in autumn (-30% in October). In winter, there is a high uncertainty on the evolution of discharge since there are about the same number of scenarios
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leading to an increase and a decrease. By 2100, the decreasing trend in discharges is even more pronounced throughout the year (157 m$^3$/s, i.e. 29%). In autumn, by 2100, the decrease reaches -40%, while in winter it averages -15%. However, a small number of scenarios predict an increase in winter discharges (Agence de l’eau Seine Normandie et al., 2011).

A study by Météo France in the Adour Garonne RB showed that scenarios predicted relatively homogeneous decreases in low flows (between July and October) by 11% in 2050-2060 (compared to 1985-1995). The autumn and spring discharges are also expected to decrease. The strongest impacts would occur in July, with discharge decreases by 15%. Indeed, CC will have a different impact on fast and slow flows: fast flows are more sensitive to changes in precipitation and temperatures than slow flows. Flows of July correspond to the last flows caused by precipitation and snowmelt, combined with the base flow. On the contrary, during the low flow, discharge is minimal and corresponds to the base flow, that is to say the destocking of temporary natural reservoirs (perched aquifers, alluvial aquifers, etc.). Indeed, the increase in winter precipitation implies that deep natural reservoirs have a more favourable winter recharge than currently. This allows a higher summer base flow, which limits the impact of CC and of the summer precipitation decrease. This support however does not occur until the end of the low flow, which leads to greater impacts at the end of the low flow period (October) and maximum in November. The decrease in spring discharges will cause an advance of about one month of the low flow. This implies a greater impact on July discharge than on later months whose discharge will be supported by the increased base flow (Agence de l’eau Adour Garonne, 2003).

**Mediterranean region**

In Southern and South Eastern Europe, the annual discharge of the rivers is generally expected to decline.

The Integrated Project CIRCE (CC and Impact Research: the Mediterranean Environment) compiled a complete picture of the water cycle budget for the Mediterranean region, by examining the projected changes in river discharges. Figure 12 below shows the predicted changes in runoff and river discharge for five rivers with estuaries located in the Mediterranean sea (Ebro (Spain), Rhone (France), Po (Italy), Maritsa (Balkans), and Nile (Egypt)). In addition, the Jordan River was considered in order to examine its change in flow rate at the estuary of the Dead Sea. These predictions are based on the MRI (Meteorological Research Institute) of the Japan Meteorological Agency river model.

Figure 12a shows a clear decrease in the runoff over the continent of the North Mediterranean region, with a mean value of approximately -10 m$^3$/s (between 1979-2003 and 2075-2099), primarily as a result of decreasing precipitation in the region. As a consequence, the flow rate of most of the rivers in this area is decreasing (Figure 12b).
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Legend: Six rivers are considered - Ebro (Eb), Rhone (Rh), Po (Po), Maritsa (Ma), Jordan (Jo) and Nile (Ni)

Source: Jin et al. 2010, supported by the EU-CIRCE and GLOWA-JR projects

Figure 12: Predicted changes in runoff (a) and river discharge (b) by 2075-2099 compared with 1979-2003 (in m³/s)

Except for the Nile River, a decreasing trend of monthly mean river discharges is projected for the future (see Figure 13 below). For the rivers located in the EU, the most dramatic decreases in river discharge are found for the rivers Ebro and Maritsa. The magnitude of the decreases in annual average discharge for the rivers Ebro, Rhone, Po and Maritsa are of 108, 307, 146 and 184 m³/s, corresponding to decreases of 46%, 26%, 18% and 54% respectively.

Jin et al. (2010) conclude that a transition to drier climate over the Mediterranean by the end of the 21st century might be inevitable, leading to a possible water crisis.
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Figure 13: Changes of monthly mean river discharge of six rivers by (1979-2003) compared to (2075-2099). Except to the Jordan River, all rivers flow into the Mediterranean (m³/s).

Islands

In Cyprus, the predicted decreasing rainfall will result in a river discharge decrease of 10-30% by the end of the 21st Century and a significant reduction in the availability of freshwater for the Eastern Mediterranean and Middle East, with important social and economic implications, especially in agricultural areas.

Mountains

In the Alps, low flows and droughts should be more frequent during the summer because of reduced summer precipitation and increased evapotranspiration. In the short term, the rivers fed by glaciers (which represent significant stocks of water) could experience a clearing of low water in summer with an increased melting of glaciers. In the longer term, once the glaciers will have lost much of their volume (and / or their surface) and, thus, their function as water storage, summer flows of these rivers should also decrease (ONERC, 2008). Zierl and Bugmann (2005) assessed a 50% summer flow reduction to the glacier retreat.

In the Austrian Alps (West), according to the adaptation strategy, the scenario calculations show a significant increase, by about 10-25%, in the low flows for the period 2021-2050 (compared to 1976-2006). This increase affects the winter and spring. In the low Austrian areas such as the foothills of the Alps (East), the scenario calculations show variable results. In some RBs, a slight increase is calculated (e.g. Mühlviertel). In other basins, a decrease in the low flow of about 10-15% is calculated for the period 2021-2050 (compared to 1976-2006) (e.g. Weinviertel). In exceptional cases, the decrease is somewhat higher. This decrease affects all seasons (BMLFUW et al., 2011).
In **Bulgaria**, a study also shows that in mountainous areas the annual river runoff will decrease (Alexandrov & Genev 2003).

CC affects snow cover, glaciers and permafrost, especially in mountain regions from **Danube RB**. Future decrease in snow precipitation and snow cover together with an earlier snowmelt will cause a shorter snow season at all altitudes. This in turn will trigger a shift of the runoff peak from summer to spring in head watersheds of the Alps and the Carpathian Range, which will also change the regimes in the lowlands. However, some findings for mountainous areas state no trend or even a slight increase of snowfall due to a possible increase in winter precipitation. All studies considering glaciers show a significant retreat in the DRB. CC leads to the total disappearance of glaciers in all mountainous areas of the Middle DRB. An increase in glacier melt has only relevance for the summer runoff situation in the head watersheds and has almost no influence on the runoff regime of larger river systems (Mauser et al., 2012).

### 2.3.3.2 Surface stagnant water: no changes or decreased levels in summer

Water levels in lakes at mid and low latitudes are projected to decline, due to the combined effects of drought, warming and human activities. Endorheic (terminal or closed) lakes are most vulnerable to a change in climate, because of their sensitivity to changes in the balance of inflows and evaporation. Changes in inflows to such lakes can have very substantial effects and, under some climatic conditions, they may disappear entirely (Bates et al., 2008). This, in turn, may cause severe problems to drinking water supply in case these lakes are used as drinking water reservoirs.

**Continental land**

In **Austria**, according to the adaptation strategy, the summer level of the lake Constance could decrease in the future. For the Neusiedler Lake, since the water balance is the difference between two approximately equal-sized figures (precipitation and evaporation), the predictions of the water balance of the lake are very uncertain. One scenario results in an increase in air temperature by about 1°C in 2021-2050 (compared to 1976-2007) and an increase in precipitation around 5%. Under these conditions, the lake level would remain approximately equal (BMLFUW et al., 2011).

In **Hungary**, According to the National CC Strategy 2008-2025 (2008), the water balance of lakes may also change as a result of the climate becoming more arid, of the increased evaporation and of the reduced flow of rivers. Increasing evaporation may reduce the surface of several lakes, especially for small ones and may extinct many of the lakes in the Great Plain. The water turnover in the three largest natural lakes, Lake Balaton, Lake Velencei and Lake Fertő, may slow down and the period of water exchanges may increase.
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**Northern countries**

In **Lithuania**, no major changes are forecasted in the balance of lake water by 2020 either. It is likely that lake water supplies will be replenished earlier during snow melting, but the level will be lower. However, during the sinking period in summer and autumn, the level will slightly increase. Accordingly, the annual amplitude of the water level is expected to be lower than at the end of the 20th century. The general change of water supplies in lakes will be rather insignificant and will differ depending on the geographical location of each lake, physical and geographical characteristics of the respective basin and the relative size of the basin (AAA & LGT, 2010d).

According to the **Estonia’s** Fifth National Communication (Estonian Ministry of the Environment & Estonian Environment information Centre, 2009), the main changes in stagnant surface water will be:

- Decreased water level in the lakes throughout the year
  - Positive influence: decreased flooded areas around rivers and lakes
  - Negative influence: decreased water level in the middle of the summer in small lakes
- Changes in the storage of the lakes
  - Positive influence: increased storage capacity during winter period
  - Negative influence: decreased storage capacity of small lakes during the second part of the summer

### 2.3.3.3 Impacts on the recharge of groundwater bodies

The groundwater levels depend on both the effective recharge from precipitation, and the infiltration of river water. Moreover, the dynamics of the aquifer is very different depending on whether it is captive or free, or located near a river.

**Continental land**

Krysanova et al. (2005) simulated the impacts of CC on the **German** part of the large Elbe RB, which includes the large urban areas of Berlin and Hamburg and has the second lowest water availability per capita in Europe. The climate is expected to warm by 1.4°C and average annual precipitation to decrease by -17% by 2050. Groundwater recharge showed a decreasing trend, with an average decrease of -37%. Groundwater recharge decreased almost everywhere, with the lowest absolute changes being simulated in the loess area, where baseline recharge is already very low due to soil properties.

Wegehenkel and Kersebaum (2008) assessed impacts of CC on groundwater recharge in the lowland Ucker catchment in NE **Germany**. The A1B scenario used to 2055 projected an increase in mean annual temperature of 1.4°C and a decrease in annual precipitation of 8%. Whilst the results showed a significant decrease in groundwater recharge, the results were strongly dependent on land use and, in some case, soil type. Recharge under arable and deciduous woodland for 2003-2055 were reduced by 18-24% and 50-69%, respectively, compared to the baseline. Under coniferous forests, groundwater recharge declined by 44% on the sandy soils and 94% on loamy soils (due to their larger soil water holding capacity).
Krüger et al. (2001) suggest that groundwater recharge in the plains of Northrhine-Westfalia region of Germany will decrease by 15-25% by 2050, but with much smaller decreases in the mountainous parts of the region.

In Austria, according to the adaptation strategy, analyses of long-term development of groundwater levels show that the trend in successive decades (1961-70, 1971-80, 1981-90, 1991-00, 2001-2006) is often contrarian. Therefore, trends are highly dependent on the chosen time window. The analysis between 1976 and 2006 of 2376 groundwater bodies showed that 24% of them had a decreasing trend in the annual average groundwater level and 10% an increasing trend. The analysis over the last 50 years of 656 groundwater bodies showed that a larger percentage (42%) had a falling trend. (BMLFUW et al., 2011)

According to projections, runoff is expected to decrease in Central and Eastern Europe, while groundwater recharge is likely to be reduced, with greater reduction occurring in valleys and lowlands (e.g. in the Hungarian Great Plain) (IPCC, 2007b). This will have serious consequences, as groundwater plays a key role in water consumption. In general, decrease in surface, ground and soil water availability will be expected in the future (CEU, 2007).

According to projections results of CC-WaterS project, the groundwater resources located in porous aquifers is expected to considerably decrease in Hungary – from 22 % to 40% in Nyírség area and slightly decrease in Romania – 5% in Banat Plain and from 14% to 24% in Oltenia Plain by 2100 compared with the available groundwater resource from 1961-1990 period.

Northern Europe

In the rainfall-dominated regions of Northern Europe, the response of groundwater to CC depends on the changes to the temporal balance of precipitation and evapotranspiration.

According to Estonia’s Fifth National Communication (Estonian Ministry of the Environment & Estonian Environment Information Centre, 2009), as a result of CC, groundwater recharge will increase by 5–75%, depending on the hydrogeological conditions of catchments. Groundwater recharge will be the most intensive in the heights of Upper Estonia, whereas toward the lowlands the incremental infiltration rate will be less intensive. The safe yield of wells tapping the upper aquifers will be augmented up to 20% on average in Upper Estonia. It will make the public water supply cheaper and at the current water consumption rate, the reserves of the Estonian groundwater aquifers will suffice for hundreds of years.

According to a UNEP study (CICERO, 2000), in Estonia, the predicted increase of groundwater recharge and the rise of the groundwater table will simultaneously be conducive to and complicate water management in Estonia, where a large portion of the rural population gets their domestic water from shallow wells. The wells are commonly only a half-meter deeper than the mean low groundwater table under natural conditions. In hot summers and in cold winters, many of these wells become unfit for water supply, or even run dry. Such a situation is quite common in the limestone plateau of Northern Estonia and especially in the region of oil shale mines. To guarantee an adequate yield, the deepening of shallow wells has been recommended up until now. A rise in the groundwater table will significantly improve both the productivity and reliability of shallow wells. As a result of the general increment of groundwater recharge, the safe yield of bored wells

http://www.ccwaters.eu/
mentioned will augment by some 20% or even more. Thus groundwater can be obtained by means of fewer wells and reduced drawdown at pumping. Consequently, the extraction of groundwater from upper confined aquifers will become cheaper as a result of projected CC impacts. The situation will be different for many towns and villages in Northern Estonia along the coast of the Gulf of Finland, which get their drinking water from deep aquifers that belong to the zone of passive water exchange. Pumping conditions of deep groundwater aquifers (will not be altered by CC).

Van Roosmalen et al. (2007) looked at the effects of CC in Denmark on two geologically different regions. The A2 and B2 scenarios to 2100 showed a significant increase in mean annual precipitation of 9-16% and increases in reference evapotranspiration of 13-19%. Despite the greater increase in reference evapotranspiration, the increasing seasonality of the precipitation meant that net precipitation (precipitation less actual evapotranspiration, also referred to as Hydrologically Effective Precipitation) increased by up to 30%, particularly in the winter precipitation. In the Jylland area, which is characterised by sandy soils and large interconnected aquifers, this resulted in significantly increased groundwater recharge and an increase in mean groundwater heads of up to 0.5m (although locally up to more than 2m). On Sjaelland, where the soils are less permeable and the aquifers are protected by thick clay layers, only minor increases of up to 0.2m in mean annual groundwater heads were predicted.

In the Seine RB (France), according to the project GICC - RExHySS, groundwater levels show a decreasing trend in 2050 and 2100. However, the spatial variability of this decrease is very high because of various constraints affecting the aquifers. For example, in some cases, mainly in the centre of the Seine RB, there are very small increases in groundwater levels, very homogeneous among scenarios. This can be explained by the proximity to a river or by the fact that the piezometer is captive. At the edges of the RB, the amplitudes of variations are stronger, and the dispersion between the scenarios too. These are for parts uplands where groundwater recharge is changing considerably. In 2100, some piezometers indicate a possible increase in the groundwater level but these results are obtained for the wettest scenario. Overall, the groundwater level tends towards a greater decrease than in 2050 (Agence de l’eau Seine Normandie et al., 2011).

North-Western Europe

Several studies have investigated the impacts of CC on groundwater resources of the chalk aquifer of the Geer Basin (Belgium), which provides drinking water for the city of Liege and its suburbs. Brouyere et al. (2004) found that CC will have a long-term impact on groundwater resources in the Geer Basin with groundwater levels declining due to decreased recharge, but with little impact on seasonal differences in groundwater levels. This is likely to be due to the smoothing of the seasonal changes in percolation within the thick unsaturated zone.

Goderniaux et al. (2009) used climate data from six regional climate models (RCM) and the A2 emissions scenario to look at the impacts on groundwater levels. They found that no clear changes could be identified during 2011–2040, with large uncertainties in the direction of change for mean groundwater hydraulic head. However, significant decreases are expected in the groundwater levels by 2041–2070, with even larger decreases of -2 to -8 m depending on location by 2071–2100. Goderniaux et al. (2011) increased the complexity of the representation of future climate within the modelling, and found that mean groundwater levels for all RCMs and observation points showed a decreasing trend between 2010 and 2085. By 2085, groundwater levels were projected to have declined by between 4 and 21 m, depending on locations.
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Jackson et al. (2011) conducted a comprehensive analysis of the effect of CC on UK chalk groundwater resources, using an ensemble of 13 Global Climate Models (GCMs) to allow an assessment of the uncertainty. The ensemble average from the 13 GCMs suggests a 5% reduction in annual potential groundwater recharge across the study area, but was not statistically significant at the 95% confidence level. However, the results for simulated changes in annual potential groundwater recharge range using individual GCM outputs ranged from -26% to + 31% by the 2080s, with ten predicting a decrease and three an increase. Whilst annual recharge is not found to change significantly, the multi-model results suggest that the seasonal variation in the groundwater resource will be greater, with higher recharge rates during a reduced period of time in winter.

Several studies have studied Eastern England to assess the impact of CC on hydrologically effective rainfall (Holman 2006; Herrera-Pantoja and Hiscock 2008), potential recharge (Holman et al. 2005; Holman et al., 2009) and actual recharge (Yussoff et al. 2002). These have generally shown reductions, with decreases with time and with increasing greenhouse gas emissions scenario.

Bloomfield et al. (2003) suggest that CC may cause a reduction in annual minimum groundwater levels in some boreholes in the chalk aquifer of Southern and Eastern England by up to about 2 m by the 2080s.

CC has significant implications for aquifer levels (UK Environment Agency, 2005). In the UK and Ireland, it is likely that overall recharge to aquifers will decrease and that there will be a general lowering of groundwater levels (FAO, 2006; UK Environment Agency, 2009b; UK Environment Agency, 2008; UK Environment Agency, 2005), with a more marked reduction further away from rivers in Ireland and the UK (UK Environment Agency, 2009b; UK Environment Agency, 2008). In Ireland, the most significant reductions in groundwater storage are suggested in areas which strongly rely on groundwater supplies (RIA, n.d.). In particular, groundwater attenuation is the greatest in the Suir, Blackwater and Barrow catchments (UK Environment Agency, 2005). This can be due to decreases in rainfall during the summer and autumn months, which result in a delay to the seasonal recharge of aquifers (FAO, 2006; UK Environment Agency, 2005). The late autumn and winter recharge period is critical to sustaining groundwater levels throughout the year. Significant reductions in storage during this time of the year would increase the risk of severe drought, as the failure of winter or spring precipitation may result in prolonged drought periods where the groundwater system is unable to recover from previous dry spells (UK Environment Agency, 2005).

"Lower levels of recharge and thus lower groundwater levels are likely to result in a shift in the nature of groundwater-surface water dynamics for entire rivers (Scibek & Allen, 2005). For each of the catchments elevated water levels persist into the early summer months. However, from late summer to the end of the year, water levels are generally lower than at present. Given the magnitude of changes for many of the catchments analysed, the possibility exists for low-lying streams to become perched above the water table during times of low groundwater storage and thus loose water to groundwater (UK Environment Agency, 2005).

Mediterranean areas

Panagoulia and Dimou (1996) investigated CC impacts in the central mountain region of Greece with a geology of hard limestones and flysch. They found that the warmer and wetter climates resulted in more rainfall than snowfall, increasing recharge during winter and early spring at the expense of late spring and summer. This produced a definite phase shift in groundwater storage,
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with increased winter levels peaking in March (as opposed to April under baseline conditions) and reading a lower minimum in October.

Guardiola-Albert and Jackson (2011) highlighted the vulnerability of Mediterranean aquifers, supporting the results of a number of previous studies in Spain. They modelled the effects of CC on the Almonte-Marismas aquifer in Spain. The results suggested that a medium-high emissions climate by the 2080s would lead to a reduction in mean recharge of 14-57%, decreases in groundwater levels of 0-17m, reduced coastal groundwater discharge of up to more than 50% and reduced discharge from the aquifer in to the RB of -25 to -68%. Importantly they identified that the climate-induced reductions in groundwater discharge to the surface are generally larger than current groundwater abstraction rates, highlighting the great vulnerability and need for effective adaptation strategies.

Islands

In Malta, the lower replenishment of groundwater may also be due to a sudden increase in water flows, provoking run-off rather than infiltration. Prolonged rainfall is more effective at recharging groundwater levels, however, CC is likely to result in shorter, more intense periods of precipitation becoming more frequent, thus decreasing the amount of water that is infiltrated to storage (Arnell & Reynard, 1996) (Malta Resources Authority, 2010).

Mountainous aquifers

Mountainous areas where much winter precipitation falls as snow can experience different responses. Earlier snowmelt, due to increased air temperatures, may result in increased soil water contents at a time when potential evapotranspiration is relatively low which may increase infiltration and potential winter recharge in mountainous regions. However, there is considerable uncertainty of both the direction and magnitude of the net effects of warming in such regions, making it difficult to predict the responses of mountain groundwater systems to CC. Krüger et al. (2001) predicted that recharge to a lowland aquifer in Germany would decrease by up to 30%, while recharge in nearby mountainous regions were predicted to be largely unchanged. Okkonen et al. (2010) suggest that, in areas of steep topography, a snowmelt period of long duration may enhance groundwater recharge whereas a short intensive snowmelt might decrease recharge, due to increased runoff.

Eckhardt and Ulbrich (2003) assessed the impacts of CC on recharge in a Central European low mountain range of schists and greywackes in the Rhenish Massif in Germany. Using a revised version of the SWAT model to better represent the effects of CO2 fertilisation, they found that the effect on mean annual groundwater recharge was small (declines in annual recharge of 3-7.5%), as increased CO2 levels reduced stomatal conductance offsetting the increasing potential evapotranspiration caused by the temperature rise and the decreasing precipitation. However, due to reduced proportion of precipitation falling as snowfall, winter recharge is increased, whilst the reduced spring snowmelt peak and earlier start of the growing period leads to a reduced spring recharge. Summer recharge is reduced by more than 50% and the increase in recharge in autumn is delayed due to the high soil moisture deficits and longer growing season.

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11 Passage of carbon dioxide (CO2) entering the stomata of a leaf
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A monitoring and modelling study on groundwater levels within the hard rock aquifers in the Bohemian Massif (Hrkal et al., 2009), also in Central Europe, showed that a shallow fractured aquifer within crystalline rocks is very vulnerable to the declines in precipitation and infiltration anticipated due to CC. Groundwater flows through, and is stored in, a relatively shallow aquifer zone (locally reaching up to several tens of metres) formed by weathered rocks containing open fractures. The vulnerability is partly dependent on well location, with decreases in groundwater level of the order of 10m recorded in recharge areas and on steep slopes, but smaller decreases of a few metres in the discharge areas due to the water level controls exerted by the local streams.

Gremaud and Goldscheieder (2009) studied glacier-aquifer interactions in the Tsanfleuron-Sanetsch area, Switzerland, where a rapidly retreating glacier overlies a karst aquifer drained by a spring used for drinking water supply and irrigation. Under equilibrium conditions (no retreat or advancement), glaciers influence the variability of connected freshwater resources by delivering meltwater during warm periods but do not exert great influence on the long-term water budget, as there is balance between accumulation and the losses which contribute to runoff and recharge. However, retreating glaciers do alter the water balance, as the melting releases a transient quantity of water that is available today but will be missing when the glacier disappears. Their preliminary predictions of the future availability of spring water after disappearance of the glacier suggest that the discharge may decrease by 20–30%, with nearly all of this loss occurring in summer and autumn, resulting in temporary water shortage.

### Decreased soil moisture content

The EEA indicator assessment reports future projections regarding soil moisture content at EU level according to the IPCC A2 scenario (2071-2100), compared with the period 1961-1990. The summer soil moisture is illustrated in Figure 14 and shows a reduction in most of Europe, with different trends at regional levels. The Mediterranean region is expected to see significant reductions while the North Eastern part of Europe will experience an increase in summer soil moisture.

![Simulated soil moisture by ECHAM5/T106L31 for the baseline period (1961-1990) (left) and relative changes in % under the IPCC A2 scenario (2071-2100) (right)](image)

Source: EEA, 2008b

Figure 14 - Simulated soil moisture by ECHAM5/T106L31 for the baseline period (1961-1990) (left) and relative changes in % under the IPCC A2 scenario (2071-2100) (right)
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There are two phases for water in soil, both affected by CC:

- the growing season (spring/summer), mostly affected by the increase in evapotranspiration;
- the recharge of water resources (fall/winter), mostly affected by the increase in precipitation.

**Continental land**

Nearly all regions of the Danube RB show a possible decrease of soil water content. Longer dry soil periods are predicted especially for the Middle DRB and Lower DRB regions during summer droughts. In these regions, soil degradation is also possible; changes in precipitation patterns and an increase in torrential rain and flash flood events can lead to more intense soil erosion. The physical, chemical and biological processes of the top soil layers will be affected by an increase in soil temperature. Consequently, changes in soil quality regarding biodiversity, nutrient and water cycles and soil forming processes are possible. Moreover, sedimentation in river system is likely to increase due to more extreme events and thawing permafrost. The longer dry soil periods leads to decrease in soil humidity and to less leachate (esp. in summer and autumn). Concerning the soil quality, erosion and sedimentation resulted that droughts intensify the soil salinisation processes and less soil humidity contributes to an increase of pollution frequency and of water supply restrictions (Mauser et al. 2012).

In Hungary, CEU (2007) also predicts lower soil water availability in the future.

**North Western Europe**

According to a study in Bourgogne in France, in spring, CC could be experienced by an earlier soil drying. The second part of the growing season would then depend more heavily on the regularity and intensity of precipitation. In the current climate, the water reserves in soils are still large late April, with the exception of shallow soils like those of karstic plateaus. The drying starts in May, goes on in June and continues throughout the summer. In the future climate, the water reserve will tend to empty earlier on a wider part of the territory. In April, shallow soils will already have strongly altered water reserves. Only part of the Morvan could still benefit from good water reserves in soil. In summer, the drying is very marked, both now and in the future. Only a few storms occur. In summer, when evapotranspiration still significantly exceeds precipitation, it is necessary to refine the results using a shorter time step. Indeed, the precipitation accumulated monthly blurs potential punctual precipitation events, which can be very beneficial for vegetation. The difficulty of obtaining data on precipitation intensity and frequency did not allow identifying areas vulnerable to violent storms. In September, the recharge of reserves begins. Depending on the year, it does not operate on the same geographic areas. Good stream and groundwater recharge is easier with early saturation of soils. The results observed in the fall season are due to the annual variability, not to CC. They show the importance of the precipitation volumes for the saturation of soils and the recharge of groundwater (Alterre Bourgogne, 2010).

In Ireland, reductions in soil moisture storage will occur throughout the summer and autumn months (RIA, 2007).
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*Permafrost and boreal areas*

Sub-permafrost groundwater is highly climate dependent (Haldorsen et al., 2010) and may experience increased recharge as permafrost thawing enhances infiltration. For example, CC is expected to reduce snow cover and soil frost in boreal environments of *Finland*, causing the maximum recharge and groundwater levels to occur earlier in the year in unconfined aquifers (Okkonen et al., 2009; Okkonen & Klove, 2010).

Most aquifers used for water supply in *Finland* are eskers (glacio-fluvial deposits) composed of well-sorted gravel and sand deposits. It is expected that CC will change the distribution of winter rainfall/snowfall, the snow cover period and depths, date of snowmelt, amount and duration of soil frost, increase evapotranspiration rates and increase the soil moisture deficit by up to 30% (Okkonen et al., 2010). Water table fluctuation patterns as a result of climatic conditions in Finland can be divided into two distinct types. In Northern Finland, which is classified as having a mid-boreal climate, the water table fluctuation pattern has a single minimum (occurring immediately prior to the spring snowmelt in April-May) and a single maximum (occurring immediately after the spring snowmelt in May). In the remainder of the country, two annual maximums occur earlier in the spring (due to earlier snowmelt) and at the end of the year (due to increased precipitation and lower evapotranspiration). Annual minima occur in the summer and late winter.

In a warmer future climate, snowmelt infiltration in partially frozen soils will be dependent on soil material, with the sandy and gravelly esker soils being able to infiltrate most of the melt water and increase aquifer recharge, whereas other soils types may promote increased runoff. Nevertheless, in cold regions where the period of snow cover and soil frost is long such as in Northern *Finland*, a shift in the overall amount and timing of recharge is expected. The water table fluctuation pattern will increasingly resemble the current patterns in more temperate areas, with higher risks of summer low water-table levels (Okkonen et al., 2009; Okkonen and Klove, 2010).

![Figure 15: Schematic of changes to the groundwater fluctuation patterns in Northern Finland](image.png)

According to the *Estonia’s* Fifth National Communication (Estonian Ministry of the Environment & Estonian Environment Information Centre, 2009), the water content of the soil will be comparatively smaller in the future.
2.3.3.5 Groundwater salinisation

Coastal aquifers

Increased sea level due to thermal expansion of the oceans is likely to lead to increased salinisation of some coastal aquifer. However, salinisation of groundwater is already experienced due to high abstraction rates (see section 2.4 on water quality impacts and the Cyprus case study).

In the Danube RB, higher sea levels are likely to increase salinisation of estuaries and land aquifers with saltwater intrusions (Mauser et al., 2012).

2.3.4 Resulting impacts: scarcity, floods, competition for water resources

<table>
<thead>
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<th>EU regions</th>
<th>Effect</th>
<th>Example of river basins or countries identified in the literature</th>
</tr>
</thead>
<tbody>
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<td>Water scarcity and drought</td>
<td>Luxembourg, Czech Republic, Hungary, Romania, Danube Catchment</td>
</tr>
<tr>
<td></td>
<td>Floods</td>
<td>Austria, Czech Republic, Hungary (esp. damages increase), Romania, Rhine</td>
</tr>
<tr>
<td></td>
<td>Increased frequency of floods</td>
<td>Rhine, Danube (esp. Lower), Mountain areas</td>
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<tr>
<td></td>
<td>Increased intensity of floods</td>
<td>Danube RB</td>
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<td></td>
<td>Increased summer floods</td>
<td>Middle Danube RB</td>
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<td></td>
<td>Increased winter floods</td>
<td>Alps, Tisza RB (Danube RB)</td>
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<tr>
<td></td>
<td>Decreased spring floods</td>
<td>Mountain areas, Alps</td>
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<tr>
<td></td>
<td>Increased sea floods – on coasts</td>
<td>Romania</td>
</tr>
<tr>
<td></td>
<td>Sectoral competition increases</td>
<td>Bulgaria, Slovenia, Hungary, Danube catchment</td>
</tr>
<tr>
<td></td>
<td>Desertification</td>
<td>Hungary, Serbia, Romania, Bulgaria</td>
</tr>
<tr>
<td>Northern Europe</td>
<td>Water shortages and drought</td>
<td>Sweden, Finland, Lithuania, Estonia, Denmark</td>
</tr>
<tr>
<td></td>
<td>Floods</td>
<td>Estonia, Finland, Denmark, Sweden (less emphasised)</td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th>EU regions</th>
<th>Effect</th>
<th>Example of river basins or countries identified in the literature</th>
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</thead>
<tbody>
<tr>
<td></td>
<td><em>Increased summer floods</em></td>
<td>Finland</td>
</tr>
<tr>
<td></td>
<td><em>Decreased spring floods</em></td>
<td>Finland, Estonia, Sweden</td>
</tr>
<tr>
<td></td>
<td><em>Increased sea floods – on coasts</em></td>
<td>Estonia, Denmark</td>
</tr>
<tr>
<td></td>
<td>Sectoral competition will not be an issue</td>
<td>Estonia, Finland, Sweden, Denmark</td>
</tr>
<tr>
<td>North Western Europe</td>
<td>Water scarcity and drought</td>
<td>Belgium (Flanders, water stress in Wallonia), UK</td>
</tr>
<tr>
<td></td>
<td>Floods</td>
<td>Belgium (esp. Wallonia)</td>
</tr>
<tr>
<td></td>
<td><em>Increased sea floods – on coasts</em></td>
<td>Belgium, Netherlands, Germany, France</td>
</tr>
<tr>
<td></td>
<td>Sectoral competition</td>
<td>France, UK, Ireland, the Netherlands (in case of prolonged dry conditions)</td>
</tr>
<tr>
<td></td>
<td>Damage to water management infrastructure</td>
<td>UK, Ireland</td>
</tr>
<tr>
<td>Mediterranean region</td>
<td>Deficits in water availability</td>
<td>Mediterranean area</td>
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<tr>
<td></td>
<td>Floods</td>
<td>Italy (<em>esp. sea floods</em>)</td>
</tr>
<tr>
<td></td>
<td>Sectoral competition</td>
<td>Italy, Spain</td>
</tr>
<tr>
<td>Islands</td>
<td>Water scarcity and drought</td>
<td>Malta</td>
</tr>
<tr>
<td></td>
<td>Sectoral competition</td>
<td>Cyprus</td>
</tr>
</tbody>
</table>

#### 2.3.4.1 Water scarcity and drought

**Water scarcity** occurs where there are insufficient water resources to satisfy long-term requirements. It reflects long-term water imbalances, combining low water availability with a level of water demand exceeding the supply capacity of the natural systems. CC is likely to worsen the imbalances, through affecting both water resource availability and water demand. By the 2050s, the area of land subject to increasing water stress due to CC is projected to more than double the area with decreasing water stress (IPCC, 2008).

**Droughts** can be considered as a temporary decrease of the average water availability due to e.g. rainfall deficiency. Droughts can occur anywhere in Europe, in both high and low rainfall areas and in any seasons. The impact of droughts can be high when they occur in water-scarce regions or where water resources are not being properly managed.
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As a result of higher temperatures, decreased precipitation and longer, more frequent dry spells, some European regions will be subject to an increase in the frequency and intensity of droughts.

**Continental land**

In Luxembourg, CC will involve an increase in the variation of surface water discharge and groundwater levels. Indeed, a prolonged period of precipitation below the average can lead to hydrological drought which results in a depletion of available water in water courses, lakes and groundwater. Although groundwater resources are less affected by periods of summer drought since the recharge takes place mainly during the months from November to March, a shift in precipitation during winter can change the renewal regime of groundwater: the increase in both surface discharge following heavy precipitation and high evaporation, would be at the expense of groundwater recharge. Therefore, experts predict a likely increase in the frequency of natural phenomena such as droughts or pronounced low flows. When the drought period coincides with a period of high consumption of drinking water, it is conceivable that the needs of the population can no longer be fulfilled (AGE, 2011).

In the Czech Republic, the national CC programme foresees a higher risk of droughts in the future.

In Hungary, according to the National CC Strategy 2008-2025 (2008), as the climate becomes more arid and warmer, the frequency of droughts is expected to increase, especially in the Great Plain. In Hungary, two of the droughts with the highest extension occurred in 2003 and 2007. In order to cope with the water insufficiency and droughts, the first thing to achieve is to make industrial and household water uses efficient and economical.

Water scarcity is expected to cause serious problems for grassland ecosystems in the Danube RB. Droughts have already been affecting the Duna-Tisza koze, Tiszai-Alfold and Dunatul regions of Hungary (CEU, 2008).

The majority of the Carpathians is not significantly endangered by drought; the problem is more relevant to South Eastern Europe, and therefore to Southern Carpathian slopes, as well as foothills in the Western, Eastern and mostly Southern Carpathians (UNEP, 2007).

In the MIDMURES project\(^2\), the scenarios made in the Pecica area, Romania, demonstrate that droughts can have widespread effects on the entire aquifer. However, the excessive use of the shallow aquifer for irrigation will determine drastic effects upon the piezometric levels, with higher impacts than a succession of dry years.

Within the Danube RB, drought and low flow events as well as water scarcity are likely to become more intense, longer and more frequent. Thereby, frequency could increase especially for moderate and severe events. Due to less precipitation in summer these extreme events will be more severe in this season, whereas they will become less pronounced in winter. In some parts of the DRB, the drought risk will increase drastically in the future leading to possible economic loss, increase in water conflicts and water use restrictions. The Carpathian Area, particularly the Southern parts of Hungary and Romania as well as the Republic of Serbia, Bulgaria and the region of the Danube Delta are likely to face severe droughts and water stress resulting in water shortages. The future low flow situation depends also on changes in water use, which could worsen or improve the general trend (Mauser et al. 2012).

\(^2\) Mitigation Drought in Vulnerable Area of the Mures Basin
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In the Middle Danube RB Mauser et al. (2012) report that there will be an increase of annual drought events and water scarcity, hiding a decrease of drought events in winter, and an increase in summer. It is possible that the intensity frequency of droughts will increase, with more frequent and intense summer droughts, associated with a decrease in rainfall amount in this season. Regions in Southern Hungary and the Republic of Serbia are also expected to experience desertification (Mauser et al. 2012).

In the Lower Danube RB droughts will become more frequent, longer and more intense. Serious droughts during summer in Romania (esp. in the South/South East) will increase and regions in Romania and Bulgaria are expected to experience desertification and extreme water shortages (Mauser et al. 2012).

Northern Europe

In both Sweden and Finland, a risk for seasonal water shortages has been highlighted for the Southern parts of the countries (the South Western parts of Finland, and the South Eastern parts of Sweden). Though not as common as in the Southern parts of Europe, in Sweden the dry periods during the summer are considered one of the most serious threats to water resources with regard to water quality, biodiversity and vegetation. Longer summer season increases the drought-related risks especially in Southern and Central Finland. Further reductions are expected in the low water flows during the summer season, which are significant in terms of water supply. In the driest summers, irrigation and supply of water for other purposes may become much more difficult. The average summer water flow is estimated to decrease by 10–40 % in the watercourses of South Western Finland and Ostrobothnia.

The Danish Nature Agency CC portal states: “dry and warm summers will increase the risk for water shortages. The problem regards especially areas which do not have deep groundwater wells and magazines. The risk is increased by competition between water uses in dry periods. However, while other countries may face great problems because of this, the problem is not as big in Denmark”.

In Lithuania, despite forecasted slight changes in average irrigation conditions, the likelihood of droughts during the coming twelve years might increase. A preliminary forecast of irrigation conditions in individual months during the period from May through August showed that dry months can be expected in 20-25 % of cases. Meanwhile very dry months (severe droughts) can occur once in 3-4 years. There is a shortage of data to maintain that droughts in Lithuania will have a significant impact on the water flow of rivers. More intensive CC processes in Lithuania are forecasted for later future, that is, after the year 2020 (AAA & LGT, 2010d).

According to the Estonia’s Fifth National Communication (Estonian Ministry of the Environment & Estonian Environment Information Centre, 2009), drought conditions appear earlier. Drier climatic conditions in spring and in the first half of summer are projected for Estonia in the future.

North Western Europe

In Belgium, CC will induce a decreased water discharge in summer. Changes in mean river discharge are either positive or negative, according to the different CC scenarios. The result is determined by the balance between increased precipitation and a higher rate of evapotranspiration, which largely depends on the RB catchments. Parts of Belgium will increasingly need to import water from other areas. In parts of the country, specifically in Flanders, the availability of water per capita is low. Water management is already an important concern in Flanders, which imports a significant
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fraction of its drinking water from Wallonia. CC will represent additional pressure on water resources, especially in summer (National Climate Commission, 2010). In Wallonia, water availability is good. However, it is the quantitative aspect which may be most impacted by CC, notably due to a possible decrease of the resource, mainly of surface water (less certain, however, for groundwater). Indeed, CC will result in a greater risk of low flows in summer. The Meuse basin is particularly vulnerable to these changes. Analysis of historical data in this basin (AMICE project, 2010) shows that the months of August, September and October were the most subject to water stress during the past century. Projections indicate an amplification of this trend (Agence Wallonne de l’air et du climat, 2011).

In the UK, saline intrusion in groundwater, resulting from the lowering of groundwater head, could result in licence holders not being able to abstract, for example, for irrigation, forcing them to relocate. This could have consequences for other areas that already have no further water available for abstraction. In an area where water resources are already stressed, any reduction in availability is likely to increase the risk of failure to meet the Water Framework Directive objectives (UK Environment Agency, 2009e).

In the Netherlands, according to the RB management plans, an expected change in continental air circulation patterns will also result in more and longer periods of drought during the summer (Ministerie van Verkeer en Waterstaat et al., 2009a, b, c and d).

According to the Dutch Ministry of Infrastructure and the Environment, at present there are few restrictions on the water intake for drinking water. The groundwater resource in the Netherlands is very large. The availability of drinking water is therefore usually not in danger. Under prolonged dry conditions that occur in some scenarios, there may however be a conflict between groundwater for drinking and other functions, notably agriculture and ecology. The availability of surface water at the time of dry summers also an issue. It may involve quantity and / or quality. The water companies must address their buffers. Usually that is large enough to bridge dry spells. Even if the prolonged drought persists, there is currently no problem with the drinking water supply (Rijkswaterstaat, Rense, 2009).

Mediterranean region and islands

The Maltese Islands are likely to be subject to an increase in temperature coupled to an overall decrease in precipitation; hence the possibility of drought periods. Given that trends in temperature and precipitation are already evident from observational data, such changes in climate are expected to take place in the short/medium term. (Malta Resources Authority, 2010)

By 2070, significant deficits in water availability are projected for large parts of the Mediterranean. Water scarcity is to be expected for most of the Mediterranean islands with decreases in water availability of at least 50% (Lange & Donta, 2005).

2.3.4.2 Excess water causes flooding

In the EU, floods are projected to vary in their impacts depending e.g. on temperature projections. The PESETA EC-JRC project used the LISFLOOD model to estimate impacts for two climate scenarios considering an average temperature increase in the EU of 2.5 and 3.9 °C (Figure 16). Under both scenarios, projections predict that flood damages will rise across much of western, central and Eastern Europe, as well as in Italy and northern parts of Spain. In the North-Eastern
parts of Europe, damages will decrease. Differences between the scenarios are observed in Ireland, northern and western parts of the UK, southern Baltic regions, northern parts of Greece, Belgium, the Netherlands, western and central parts of Germany, and northern parts of the Czech Republic. For these regions damages are projected to decrease under the 2.5°C scenario, whereas an increase is projected under the 3.9°C scenario. For Romania the opposite is observed (PESETA final report 2009).

Many of the sources consulted report a very high uncertainty in the flood impacts, with projections predicting increase in some cases and decreases in other cases (see regional examples below).

![River floods: relative change in expected annual direct damage between scenario (2071-2100) and a control period (1961-1990) for a 2.5°C (left) and a 3.9°C (right) average temperature increase in the EU](image)

Source: PESETA final report 2009

**Continental land**

According to a study of the ICPR, in the Rhine RB, downstream of the Kaub gauging station, there will be an increase in “frequent” (-5% to +15%), “mean” (0% to +20%) and “extreme” floods (-5% to +25%). Up to 2100, regarding floods, many projections indicate rising levels for the gauging stations downstream of Kaub (up to +30%). However, some projections also indicate opposite developments, so that, partly, considerable ranges of variation result for the entire ensembles (-20% to +45% in Trier) (ICPR, 2011).

In Austria, forecasts of floods changes are not possible in the current state of knowledge, since the future development of the extreme values of the climate cannot be calculated with sufficient reliability. Scenario calculations from the literature on future changes to the flood of Austrian rivers are very different. Since climate models cannot make statements about future extreme rainfall, the uncertainties are great, especially in small areas. Scenarios that reflect the different mechanisms of flood generation and their seasonality (change of winter / summer precipitation, increasing the snow line, increasing the share of convective precipitation) show changes in one-hundred-year floods between -4 and +10% for a 2021-2050 compared to 1997-2007. These scenarios show that the following mechanisms are partly responsible for the changes:
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- snow line rises: from 0 to +4%
- shifting the timing of floods (earlier spring floods, more winter floods)
- earlier snowmelt, higher evaporation: -5 to +2%
- change in the winter / summer precipitation: -3 to +2%
- increase in convection: +2 to +10%
- compensation between the effects of different mechanisms, so that the total change is not equal to the sum of its influences. (BMLFUW et al., 2011)

CC will modify the intensity, frequency and seasonality of floods in the Alps. The increase in winter precipitation and the reduction of the buffering effect of snow cover (linked to higher altitudinal limit of the rain / snow) should lead to increased winter floods (in terms of both intensity and frequency). Depending on the topography of the watershed, these impacts can be of major importance, especially if the pool consists of large areas at medium altitude (1000 to 2500 m) with a consistent snow cover. On the other hand, the intensity of spring snowmelt flooding should be reduced due to a more gradual melting of the reduced snow cover. This melting peak could also occur a month earlier (ONERC, 2008).

In the Czech Republic, the national CC programme foresees a higher risk of floods in the future, due to more intense summer storms.

In Hungary, according to the National CC Strategy 2008-2025 (2008), the importance of flood protection in water management is expected to grow; also because the total property value at risk in areas exposed to flood inundations is more than HUF 5,000 billion. Flood protection is encumbered by the facts that 95% of the surface water resources is of non-Hungarian origin and that water turnover means 112 km$^3$ and 118 km$^3$ of water arriving and leaving with the Danube, the Dráva and the Tisza, respectively. In addition to large and medium-sized rivers, small montane and foothills watercourses will also have an increased risk of floods due to the higher frequency of rainstorms.

According to the partially contradicting findings of the investigated research projects and studies on floods, there is no clear tendency in the development of future flood events for the Danube RB as a whole. Most studies predict an increase in flood intensity and frequency, especially in winter. Small and medium flood events are likely to be more frequent in future. However, other findings show no clear trend for changes in the return periods. Seasonal changes are triggered by changes in precipitation and snow cover. Within the Danube RB there are different local tendencies, especially for the development of extreme flood events. The uncertainty of flood prediction is especially high in small catchments, since the resolution of climate models is relatively low for the task of flood predictions (Mauser et al., 2012).

There are high uncertainties in flood projections in Middle DRB, so that no clear picture can be drawn about possible changes of flood conditions. However, an increase of flood hazard probability and magnitude as well as increase in vulnerability are expected, especially in small catchments and headwatersheds. The development of flood events will largely depend on changes in precipitation patterns, extreme weather events and snow cover, in particular flood peaks may occur earlier because of rain/snow changes. In Tisza, an increase of flood frequency in winter is likely to occur. Torrential types of hydrological extremes such as flash floods are likely to be more frequent and
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severe (e.g. in small catchments / headwatersheds of the Tisza, Sava and Mureş). Summer floods may increase due to more extreme precipitation events (e.g. Mureş) (Mauser et al. 2012).

In the Lower Danube RB, the very few studies made show that flood risk may increase, in particular flood frequency and frequency of short-term flood events due to flash floods. The risk of early spring floods will be lower because of reduced snow coverage (Mauser et al. 2012).

In Romania, over time the chroniclers recorded regularly catastrophic floods: 10 in the sixteenth century, 19 in the eighteenth century, 26 in the nineteenth century and 42 in the twentieth century. The frequency of floods and their extent increased, due mainly to CC and a reduced transport capacity of beds, generally through development of major towns in the bed of watercourses. The floods have led to deterioration of water bodies used for drinking water.

Northern Europe

Flood risk seems to be an occurring issue already today in Finland, which is predicted to increase with CC. It is an issue commonly dealt with in risk assessments and high on especially the Finnish CC adaptation agenda. Floods can be caused by heavy rains, predominant in the South, or snow and ice melting, predominant in the north (Ministry of Agriculture and Forestry, 2005). The flows and water levels of rivers and lakes in the winter are going to rise considerably, causing winter flooding. Spring flooding is in turn going to decrease especially in Southern and Central Finland. In winter the water levels of the central lakes of the main watercourses, such as Lake Saimaa and Lake Päijänne, will rise considerably from the present, thus increasing the risk of winter floods. The increased heavy rains in the summer will lead to more frequent summer flooding, especially in small watercourses and in urban areas (Ministry of Agriculture and Forestry, 2011).

Denmark as an island state is particularly concerned by the increased flood risk and its effect on the society, including drinking water supply and other health concerns.

Similarly (but less emphasised) for Sweden, it is predicted that the flood risk will increase in the future (for 86 % of the water sources). More and more intensive rain periods are expected in the northern parts of the country, especially in wintertime. However, CC will lead to smaller spring floods due to smaller volumes of water stored frozen. Thus, high flows will increase in certain areas but not in others.

According to the Estonia’s Fifth National Communication (Estonian Ministry of the Environment & Estonian Environment Information Centre, 2009), the impact of the sea level rise is considered to be the most influential factor for flood damage. When several unfavourable conditions (wind speed and direction, general water level and long waves in the Baltic Sea) coincide, a short-time sea level rise of 1–2 meters may occur and several places may be flooded. The areas most influenced by this are the coastal zones of shallow bays in Western Estonia with natural landscapes and dispersed settlements. Besides, increased air temperature has caused a decrease in the maximum discharge of spring floods and their earlier beginning. Before the 1960s the average beginning time of flood was the end of March or the beginning of April, whereas after the 1960s the floods have begun in February and for the last decade even in January. If the tendencies continue, Estonia can expect earlier and lower spring floods, smoothing the boundaries between the seasonality of river flow. More frequent flooding during winter may have an impact on the infrastructure, because the

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current structure was designed for past climate conditions with stable winters and higher spring floods.

**North-Western Europe**

In **Belgium**, a direct effect of CC is an increased probability of flooding, especially from the sea (coastal regions) but also from water courses (Nationale Climate Commission, 2010).

The **Wallonia** in Belgium is particularly susceptible to flood hazards (6% of land in hazard area with 1% severe hazard zone). A high recurrence of major floods has been observed recently, the latest date from 2010 and 2011. The vulnerability of Wallonia to this hazard is largely due to increasing soil sealing, loss of natural overflow areas, and outdated state and sizing of water drainage. The flood risk is expected to increase due to the CC. (Agence Wallonne de l’air et du climat, 2011)

**Mediterranean region**

An increased flood risk is expected in **Italy**, in particular for the Po RB. Brunetti et al. (2001) performed a study aimed at investigating precipitation intensity and extreme events, analysing seasonal and annual precipitation and number of rainy days. They considered a daily precipitation dataset, for the period 1920–1998, comprising seven stations located in North Eastern Italy. Their results show a negative trend in the number of wet days associated with an increase in the contribution of heavy rainfall events to total precipitation. This is in agreement with a reduction in return period for extreme events since 1920. The authors underline that the decrease in return period may be relevant to design standards for infrastructure like drains, bridges, roads and dams. This is very important for areas such as Northern Italy that are frequently affected by heavy rain and flooding.

**Mountain areas**

A smaller proportion of winter precipitation is expected to fall as snow due to warming trends in mountainous regions of Europe (Ekhardt and Ulbrich, 2003), leading to increased winter flood risk and reduced spring snowmelt peaks (Green et al., 2011). Mauser et al. (2012) also report a possible increase in frequency and magnitude of flood events in mountain areas.

**Coastal areas**

Changes concerning coastal flooding in Romania might be severe (Mauser et al. 2012). Coastal flooding was investigated through deriving storm surge heights of a 100-year return event in DIVA projections (Vafeidis et al. 2005). For assessing the impacts of CC, it was assumed that these storm surge heights would increase by one metre due to sea level rise. Using the global digital elevation model Hydro1k (USGS 2010), the area additionally inundated by coastal flooding was calculated (beyond the 1961-1990 inundated areas). The results show that for most coastal regions, changes in inundated area will be rather marginal. However, for some regions more severe changes can be expected, the most severe ones occurring in some regions of **North Eastern Italy** and a **coastal region in Romania**, and severe changes occurring in areas such as the **Dutch and German coastlines** but also in **Denmark and France** (ESPON, 2011).

**2.3.4.3 Competition between sectors induced by CC**

Water-using sectors, such as public water supply, agriculture, industry and tourism compete for the finite freshwater amounts available in a given RB. Water balance is not only determined by CC but
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also by agriculture, industry and households consumption. Overall, in the future, the impact of CC on water availability is expected to lead to a stronger competition between sectors. However, according to the IPPC (2008), current trends show a higher weight from changes in water demand by these sectors than by climate change. The regional examples below show in some cases reduced demand due to CC, due to e.g. changes in the growing season of crops, in others that CC indeed will not be the main factor impacting water balance, compared to water demand, and in others that CC will increase the demand, leading to more competition.

**Continental land**

Together with the pronounced water scarcity in the Middle DRB, the Lower DRB and some areas of the Upper DRB during summer, the assumed increase in water demand from households, industry and agriculture is likely to lead to high water stress, resulting in potential conflicts. In addition, the water quality may decrease in some parts of the Danube RB and an increase in water temperature may result in an increased risk of water shortages and an over-exploitation of aquifers in the future. However, future water demand is not only driven by CC impacts, but also by anthropogenic impacts and political regulations and restrictions (e.g. pricing). Predicting future changes in water demand in the water-using sectors (energy, industry, households and agriculture) is difficult, due to many factors (Mauser et al., 2012).

In Slovenia, future water availability for public water-supply has been tested in two areas: Mura valley and Ljubljana field (CC-WaterS, 2012). Different scenarios were tested for the future. The results show no higher weight from CC on determining the water balance than agriculture, industry and households consumption.

In Hungary, future water availability for public water-supply has also been tested in two areas: Bükk and Nyírség (CC-WaterS, WP6, 2012). The periods of evaluation are 2021-2050 and 2071-2100. There were optimistic, pessimistic and plausible scenarios. The results show an increase in imbalance between supply and demand, driven by climate change for household demand in the Bükk area, but by economic development for other demands. In the Nyírség area the imbalance also grows, due to the combined result of the diminishing water resources and increasing water demand by all sectors.

**Northern Europe**

According to the Estonia’s Fifth National Communication (Estonian Ministry of the Environment & Estonian Environment Information Centre, 2009), the results of the analysis of water supply and demand do not indicate any impact of CC on the public water use in Estonia.

The possible trend toward more efficient water use may however reduce water demand in the future. For example Finland has reduced the demand for freshwater in several industrial branches, water consumption from waterworks has decreased considerably in recent years and industries have increased their resource efficiency, including water consumption (Finnish Ministry of the Environment, 2012). Similar trends in reduced water consumption in households and industry were described for Denmark. However, as the water consumption is already low in Denmark it is not expected to significantly decrease further. In the government’s initiative for Green Growth, “Vekst med omtanke”, competition between demands is pointed out as a potential challenge for municipalities.
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**Islands**

Because of the current climate conditions, in *Cyprus*, agriculture is the dominant consumer of water with up to 80% of the total consumption whereas tourism and households comprise relatively moderate consumption rates (up to 37% of the total consumption). CC could increase competition between sectors (Lange & Donta, 2005).

**2.3.4.4 Water demand from the agriculture sector**

**Continental land**

In *Bulgaria*, as a result of projected warming and precipitation deficit the simulated irrigation demands increased, however the total water amount for irrigation decreased due to considerable shortening of the maize crop-growing duration (Alexandrov & Genev, 2003).

According to the National CC Strategy 2008-2025 (2008), with the increase in global warming, irrigation will be necessary at higher frequencies, in higher quantities and in more places in *Hungary*. On the other hand, when shaping the strategy of irrigation related to water management, it can be expected that plant growing practices will also adapt to CC, for example, through sowing crops with a higher drought tolerance. Irrigation projects based on smaller local water sources may face problems because small watercourses will dry up more often, to a greater extent and for longer periods, which may reduce the safety of water supply. Intensively sinking groundwater levels in summers may have the same consequences. Under such circumstances, water reservoirs ensuring the safety of irrigation will play a more important role. CC will force a wider use of water-saving irrigation technologies and various micro-irrigation methods in any case.

The vulnerability to CC in agriculture rises from the North Western part to South Eastern area of the *Danube RB* because water availability is the limiting factor. Because of warmer and drier summers, water demand for livestock and irrigation will rise. In the South East of the catchment, precipitation deficits during the warm seasons will lead to a high vulnerability of crops in non-irrigated areas. The possible consequences are set-aside and aridification. In the Middle Danube RB, drier and hotter summers will decrease maize and sunflower yields, and the water demand for irrigation will increase. In the Lower Danube RB, the main climatic factor impacting winter wheat will be increasing temperature, and not precipitations amounts (Mauser et al. 2012).

**Northern Europe**

In Finland and Sweden, the potential impact of agricultural water demand was not highlighted as a major challenge for drinking water management. In Denmark, higher summer temperatures and longer periods of drought may increase the need for irrigation of sandy soils. This could have a spillover effects on water flow in streams (Danish Ministry of the Environment et al., 2012).

**North Western Europe**

The project RExHySS shows that, on average in the *Seine* basin, there will be a general increase in volume of water needed for irrigation. For the same rotation, a farmer will need between 50 and 60% more water to irrigate crops under CC. Depending on the year, the volumes drawn for irrigation throughout the Seine basin represent only between 7 and 15% of total withdrawals in groundwater. Therefore, an increase in 50 to 60% of these volumes as a result of CC may seem insignificant. However, there are high regional contrasts since the current irrigation covers only...
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2.7% of the agricultural area of the basin. The consequences of this increased water demand on groundwater resources has been analysed in the Beauce region, assuming that the water withdrawals increased as the needs (60%) and that the irrigated area would not change. This induced dewatering exceeding 3 m locally, but remaining well below the dewatering directly induced by CC scenario without modification of the irrigation demand (Projet RExHySS, 2009).

The predicted changes in temperature and precipitation patterns, especially increased temperatures and decreased summer rainfall, will have important impacts on agricultural yields and increase the demand for irrigation in the UK (Zhou et al., 2010). CC will enhance groundwater's importance for drought-proofing agriculture but simultaneously increase the threat to the resource. However, farmers do not always use all of the water that they are entitled to abstract under the terms of their licence. For example, farmers in the UK typically use less than 50% of their licensed volume in normal years. In theory, CC might cause them to use more of their water in future years, thereby increasing the stress on groundwater resources (UK Environment Agency, 2009b). Yorkshire and North East Region are not perceived as being under hydraulic stress.

In Ireland, reductions in soil moisture storage may mean that irrigation is necessary to sustain crops, including pasture; areas most likely to be affected are the South and East of the country (RIA, 2007).

Mediterranean region

In Italy, agriculture represents the greatest water use sector. In Northern Italy, water for agricultural use is directly supplied by surface water, while in Southern Italy and in the islands (Sardinia and Sicily) it mainly comes from artificial RBs. This situation is changing because of the decreasing contribution of precipitations together with an increased water use by other human activities. This problem is particularly serious in Southern Italy and in the islands. A particularly critical situation occurred in Sardinia in January 2002, when water availability within the 31 Sardinian reservoirs was just enough for drinking water supply (EEA, 2009).

In Spain, agriculture mainly resorts to irrigation. Andalucía is one of the Spanish regions where irrigation is widely used and has significantly increased over the years (around + 5% of irrigated areas between 1997 and 2003, and around + 50% between 1990 and 2010). In 2010, around 24% of the national agricultural surface area where irrigation is used is located in Andalucía (Junta de Andalucía, 2010). The demand for water in agriculture is already high, with 5.028 million m$^3$ in 2009 which represents around 82% of the total demand (Junta de Andalucía, 2010), and this phenomenon is expected to become stronger with both the increase in evapotranspiration and the continuous development of irrigated areas.

2.3.4.5 Water demand from households and tourism

North Western Europe

In the UK, the potential impacts of CC and a growing population will also result in an increased demand for water in the future in North West Region (UK Environment Agency, 2009c). Herrington (1996), in studying the impact of CC on water consumption in the UK, suggests that a rise in temperature of about 1.1°C would lead to an increase in average domestic per capita demands of approximately 5%. Peak demands are likely to increase by a greater magnitude, while the frequency of occurrence of current peak demand is also likely to increase (Zhou et al., 2010). From the
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Simulations conducted, it is during times of the year that demand is greatest (summer and autumn), that the greatest reductions in surface water resources are likely (RIA, n.d.).

Because of current residential pressure, household water use in the Thames Region is particularly high compared with other parts of the UK with water companies in this region reporting figures ranging from 157-175 L/cap/day in 2008. By 2020, public water supply could rise by 3% in the Region if no action is taken. This could mean an extra 116 million litres of water will be needed every day (UK Environment Agency, 2009f).

To account for CC uncertainties, the UK Environmental Agency developed four scenarios for the water demand following various mitigation/adaptation responses to water challenges in the context of changing climate (UK Environment Agency, 2009f). The output of the 2050s water scenarios project was four possible futures of water for the 2050s. The results describe, in broad terms, two scenarios where water demand decreases and overall environmental water quality improves, and two scenarios where water demand increases and overall environmental water quality deteriorates (UK Environment Agency, 2009f).

**Mediterranean region**

In the Mediterranean region, the number of foreign tourists has risen from 58 million in 1970 to 228 million in 2002, with France, Spain and Italy combined welcoming about 72% of the current influx. Specifically for Italy, a growth of the tourist flux of about 2.0-2.5% per year is expected. Because of the recent world’s economic crisis, it is no longer sure whether these estimates can still be considered reliable; but in case they would be, a considerable further increase in drinking water use should be expected (EEA, 2009). In addition, it is a well-known fact that tourist water use is generally higher than water use by residents. A tourist consumes around 300 litres per day, while European household consumption is around 150-200 litres. In addition, recreational activities strongly correlated to tourism, such as swimming pools, golf, and aquatic sports contribute to putting pressure on water resources that will be more significant in areas where CC already causes water scarcity (ClimateWater, 2010, WP2, Thematic focus report on water supply).

**Islands**

In Mediterranean islands, water scarcity related to an increase in water demand may have significant impacts for tourism and households because of an already limited consumption and (particularly in the case of tourism) enhanced consequences for the economy and the labour market of each island. Thus, the vulnerability to water scarcity will be higher for those islands that depend more strongly on tourism as a major contributor to the island’s GDP.

**2.3.4.6 Impacts on abstractions**

**North Western Europe**

Impacts of increasing water demand on water abstractions and river flows have been particularly investigated in the UK and Ireland, at the catchment scale. In areas where water resources are already stressed, any increase in overall demand or reduction in availability is likely to increase the risk of failure to meet the Water Framework Directive objectives (UK Environment Agency, 2009e, UK Environment Agency, 2009j, UK Environment Agency, 2009h, UK Environmental Agency, 2009i).
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The Bournemouth and West Hampshire water area within the South West RB District is currently water stressed. CC is likely to worsen the impacts caused on water by climatic conditions and water demand. Abstraction issues are of widespread concern, particularly in the chalk rivers in the East of the District and in a number of rivers draining from Dartmoor (UK Environmental Agency, 2009i). Abstraction and other artificial flow pressures were also considered a significant issue for the Severn RB District, with unsustainable abstractions and over licensing of available resources in parts of the RB district (UK Environment Agency, 2009h).

Some types of abstraction will also need more water due to increased output (for example, the expansion of the soft drinks industry) (UK Environment Agency, 2009b) resulting in a higher pressure on water bodies.

Many catchments within Eastern area are classed as “Over licensed” or “Over abstracted” under Catchment Abstraction Management Strategies (CAMs) (UK Environment Agency, 2009e). Saline intrusion could result in licence holders not being able to abstract, for example, for irrigation, forcing them to re-locate. This could have consequences for other areas that already have no further water available for abstraction.

Although flow pressures are not considered a significant issue yet, future trends in water availability are of concern in the Northumbria RB District (UK Environmental Agency, 2009g) and in the Humber RB District (UK Environment Agency, 2009a). There is no further surface water available for large-scale abstraction during periods of low flow in several areas. Efficiency measures must be taken in order to accommodate growth in the district. Elsewhere water is available for abstraction throughout the year.

2.3.4.7 Impacts on energy production

Continental land

The impacts from CC on water dependent energy production depend largely on changes in water availability and hydrological extreme events. Hydropower for example is strongly related to changes in mean annual discharge as well as flood and low flow events. In the Danube RB, future mean annual hydroelectric power generation is therefore likely to decrease, because of a decrease in summer, even if in winter it will increase. The range will differ regionally and locally, and depends e.g. on the type and strategy plans of each hydropower station, but the decline will be more pronounced in the South Eastern parts. Seasonal shifts are possible in mountains due to changes in precipitation and snow cover with a more balanced production over the year. CC will also affect cooling of thermal power plants, because it is largely affected by changes in water temperature and low flow conditions. Therefore, many studies predict a decrease of the energy production of thermal power in summer. In addition, extreme events may impair the whole energy production and transport infrastructure, with negative effects e.g. on energy prices and possible energy shortages (CEU, 2008).

North Western Europe

According to the Walloon CC adaptation strategy, water availability is good. However, it is the quantitative aspect which may be most impacted by CC, notably due to a potential increase in demand (particularly in summer). The problem of shortages of cooling water for thermal power stations and nuclear reactors in Wallonia may arise, especially for the period until 2025, closing date
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of the last reactor of Tihange (Agence Wallonne de l’air et du climat, 2011). Besides, models project higher temperatures in summer, so that it is not impossible that external pressures on resources due to high temperatures (e.g. needs of the energy sector) ultimately weigh more than the direct effects of CC on the water resource.

2.3.4.8 Damage to water management infrastructure

North Western Europe

In Ireland and the UK, reservoirs will be impacted in terms of operation, quantity, quality and structure, in particular because of increased evaporation (Water UK, 2008; RIA, n.d.). This may lead to reduced water being available for drinking water.

In addition, impacts from droughts and floods on wastewater infrastructures may result in water quality issues (see below).

2.4 Impacts related to reduced water quality

2.4.1 Main mechanisms affecting water quality due to CC

Three main types of Drivers induced by CC are reported to negatively affect the quality of drinking water: changes in temperature, changes in precipitation patterns (including frequency and intensity) and sea level rise. The associated pressures and consequences described in the literature are summarised in Table 7 below.

<table>
<thead>
<tr>
<th>Driver</th>
<th>Pressure</th>
<th>Change in State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase in temperature</td>
<td>Improved conditions for waterborne bacteria, parasites (such as amoeba) and viruses to thrive; increased bacterial growth in lakes and coastal waters, especially if the water is allowed to stand in the pipes for considerable times</td>
<td>Degradation of drinking water quality parameters (physical, chemical and biological), in particular: - Pathogens - Taste (due to a higher content of microorganisms and of particles released from pipes and plumbing systems) - Oxygen level - Nutrients (N, P) Possible decrease in concentrations of some organic pollutants, due to increased degradation rate Reduced drinking water</td>
</tr>
<tr>
<td></td>
<td>Changes in temperature-dependent biological and chemical processes → e.g. lower oxygen dissolution</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Increased release of particles from pipes and plumbing systems of drinking water network</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Increased evaporation → Reduced river flows, reduced aquifer recharge → Reduced dilution of potential pollutants, increase in turbidity and sedimentation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Increased forest growth → Increased stores of organic material in the soil → Increased leaching of humus</td>
<td></td>
</tr>
</tbody>
</table>
## Literature review on the potential Climate change effects on drinking water resources across the EU and the identification of priorities among different types of drinking water supplies

<table>
<thead>
<tr>
<th>Driver</th>
<th>Pressure</th>
<th>Change in State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased and altered pest pressure on agricultural fields → Increased and changed use of pesticides</td>
<td>Greater soil movement as a consequence of wetting and drying cycles → Damage to water supply and treatment infrastructure (pipe systems for drinking water supply more prone to cracking)</td>
<td>supply due to damaged infrastructure</td>
</tr>
<tr>
<td>Increased degradation rate of some pesticides and other organic pollutants</td>
<td>Lower efficiency of some pollutant treatment processes</td>
<td></td>
</tr>
<tr>
<td>Increase in the frequency and intensity of droughts → Reduced river flows, reduced aquifer recharge → Reduced dilution of potential pollutants, increase in turbidity and sedimentation, increased water temperature (due to less dilution of thermal discharges from cooling circuits)</td>
<td>Increase in the frequency and intensity of floods → Increased load of pollutants washed from soils (in particular agricultural soils, contaminated soils, landfills), from urban areas and from overflows of sewage systems</td>
<td>Degradation of drinking water quality parameters (physical, chemical and biological)</td>
</tr>
<tr>
<td>Increase in the frequency and intensity of floods → Higher risks of damage to water supply and treatment infrastructure</td>
<td>Reduced snow cover → Increased leaching of soil nutrients (nitrogen, phosphorus)</td>
<td></td>
</tr>
<tr>
<td>Increase in groundwater levels → Increased risk of pollutant releases from contaminated soils and landfills</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saline intrusion into surface freshwaters, but more importantly into groundwater systems</td>
<td></td>
<td>Increase in salt concentration</td>
</tr>
</tbody>
</table>

The vast majority of expected impacts of CC on the quality of EU drinking water resources are negative from an environmental, economic or social point of view. They include the following:
Review of the potential effects of climate change on drinking water resources

- Non-compliance with Drinking Water Directive or national standards (if more stringent)
- Adverse effects on aquatic life and ecosystems (e.g. eutrophication, algal growth, ecotoxicity, biodiversity loss)
- Adverse effects on human health (e.g. increase in pathogens, increased exposure to toxic compounds)
- Decrease in available drinking water supply, due to non-compliant water supply sources, and associated economic losses
- Increase in water treatment costs (due to additional treatment required and/or repair of damaged infrastructure).

Limited potential benefits have been reported, in particular a decreased environmental and human health exposure to hazardous substances, which may be induced by:

- A faster degradation of some organic pollutants (e.g. some pesticides) at higher temperatures
- A possible lower velocity favouring the natural transformation of certain pollutants at higher temperatures (e.g. better nutrient assimilation by aquatic plants or complexation of heavy metals on suspended matter followed by settling)
- In certain cases, a reduced concentration of pollutants caused by floods (Delpla et al., 2009).

However, overall the negative impacts of CC on freshwater systems and – as a consequence – on drinking water supplies that rely on freshwater, are expected to outweigh the potential benefits (Bates et al., 2008).

2.4.2 Impacts by type of drinking water resources

2.4.2.1 Surface water

Scientific literature investigating the effects of CC on surface water resources used for drinking water mostly discusses the negative impacts of an increased temperature, of more frequent high-intensity rainfall events and of lower river flows caused by increased water abstraction from other uses (e.g. agriculture).

According to all the IPCC scenarios, the average global air temperature is predicted to increase during the 21st century. A temperature increase of 10°C can double the kinetic of many chemical transformations according to the Arrhenius relation. This is the reason why chemical processes such as dissolution, solubilisation, complexation or degradation of chemical species will befavoured by a water temperature increase. In general, this phenomenon leads to an increase in the concentration of dissolved substances in water but also to a decrease in the concentration decrease of dissolved gases and in particular of oxygen, whose saturation concentration decreases of almost 10% with a

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14 COUNCIL DIRECTIVE 98/83/EC of 3 November 1998 on the quality of water intended for human consumption
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A 3°C temperature increase. Increasing water temperatures might worsen the water quality and can also lead to an increased algal bloom. More frequent flooding and flash floods can cause a higher mobility of particle-associated pollution and changes of the redox balance of inorganic compounds cause release of organic colloids.

An increased temperature may also negatively affect the efficiency of water treatment, which may result in a deterioration of drinking water quality. In particular, a number of recent studies are related to the fate of pharmaceuticals in wastewater. These substances are partially removed by wastewater treatment plants, depending on the efficiency of the plant; residual quantities may remain in the treated water and it is possible to find them in drinking water. The removal efficiency of these substances in wastewater treatment plants is influenced by temperature and weather in particular; for example, it has been reported that diclofenac removal rates can vary from 17 to 100% depending on these two parameters (Delpla et al., 2009). This demonstrates the potentially large influence of CC on the presence of these substances in water used for human consumption. CC may also affect the destruction of cyanobacterial toxins (a broad class of natural micropollutants) in drinking water treatment processes: a water treatment particularly effective in destroying cyanobacteria and in removing cyanotoxins is ozonation, however it has been reported that the effectiveness of this process greatly depends not only on the reactant concentration, but also on temperature and pH, both variables which may be influenced by CC.

Apart from temperature increase, pH variations could influence the sorption of contaminants on mineral phases.

Because it is forecasted that high-intensity rainfall events will be more frequent, causing increased runoff and erosion, more sediments and chemicals will be transported into streams, impairing surface water quality and causing deterioration in water treatment performance (Adams & Peck, 2008). It is reported that, especially during rainfall events, the mobilisation of mineral particles could lead to high concentrations in water bodies, with direct impacts on coagulant demand during water treatment. Moreover, in temperate areas, altered drought-rewetting cycles consequent to an intensified hydrological cycle can negatively affect drinking water quality by enhancing decomposition and flushing of organic matter into streams.

In many surface water bodies, CC may also lead to reduced flows and therefore a reduced dilution of pollutants, which may negatively affect water quality. Reduced river flows can be the direct consequence of increased temperatures and changing precipitation patterns, but can also be due to increased surface water abstractions for agricultural uses and for municipal or industrial purposes induced by higher temperatures (Kabat et al., 2002).

Other impacts of CC affecting surface level waters include earlier ice melt and longer growing seasons in lakes and rivers that freeze, higher risk of algal bloom in lakes, salinisation, species loss and lowering of the water table (IPCC, 2007b; IPCC, 2008). Enhanced nutrient loss from cultivated fields may lead to higher concentrations of dissolved organic matter in inland waters, which in turn will intensify the eutrophication of lakes and wetlands (IPCC, 2007b; IPCC, 2008).

The literature reviewed shows that the expected negative impacts of CC on surface water used for drinking water production will require more robust water treatment processes, while the effectiveness of these processes may also be compromised by some of the predicted changes. Greater variability of river flows, in addition, will make it more difficult to plan and design appropriate facilities for treating and distributing drinking water (Breuer, 2002).
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As an example, in the Danube RB the most likely impacts related to surface water resources will include more frequent flooding, longer periods of drought, an increase in water temperature, which will in turn indirectly contribute to deteriorating water quality, limitation of groundwater recharge, spread of invasive species, disconnection of functional habitats, as well as harming natural biodiversity and overall river integrity (WWF, 2008).

2.4.2.2 Groundwater

Most CC studies have investigated impacts on groundwater resources (recharge, discharge, storage and flows), with relatively few focused on the groundwater quality even though groundwater quality can be expected to change in response to climate and associated human activities. For example, Mauser et al. 2012 predicted that since CC will result in less infiltration, this may decrease water quality. In addition, it states that groundwater quality will probably be affected by changes in annual rhythms of water levels caused by a decreased snow melting. Another study expects that the vulnerability of fresh groundwater bodies will rise, due to reduced turnover times and accelerated groundwater flow. Saline intrusion in coastal aquifers may increase due to sea level rise, leading to water being unsuitable for drinking. Further increases in groundwater temperature will also raise the salinity of groundwater because of increased evapotranspiration losses, increased soil CO2 pressures and increased water — rock interaction (EEA/JRC/WHO, 2008). In areas such as Southern Europe, in which river flow and groundwater recharge may decrease, dilution of pollutants may diminish, leading to reduced water quality. Similarly, higher intensity and frequency of floods and more frequent extreme precipitation events are expected to increase the load of pollutants (organic matter, nutrients, and hazardous substances) washed from soils and to increase overflows of sewage systems to water bodies (EC, 2009).

Groundwater quality is a subjective value-laden concept because the quality of water is related to legislative requirements and specific water use standards, which may change in the future.

Three key types of aquifers may be expected to be sensitive to climate-induced direct or indirect impacts on groundwater quality, as described below.

- Coastal aquifers

The IPCC has a very high confidence that rising sea levels, changes in precipitation and evapotranspiration as well as increased groundwater abstraction will result in more saline intrusion of groundwater in coastal aquifers. Such changes have been observed – for example, over-pumping combined with a dry spell led to significant decline in groundwater quality in many Greek coastal aquifers (Lambrakis & Kallergis, 2001); whilst extreme flow discharges in the River Rhine in 2003 resulted in groundwater seepage of seawater to the low-lying delta (Kabat et al., 2005).

Numerical modelling of a low-lying coastal aquifer system in the Netherlands by Oude Essink et al. (2010) showed that fresh groundwater volumes will decrease due future changes in climate, land subsidence and sea level. Although the fresh groundwater volume in the whole area is expected to decrease by less than 1% by 2100, the absolute loss of fresh groundwater in 2100 for all four CC scenarios ranges between ~200 and ~2750 million m². The impact of sea level rise is limited to areas within 10 km of the coastline and main rivers. They report that increasing salinisation of fresh groundwater resources used for drinking water purposes is already a problem, as groundwater abstractions in the dune systems have already been closed due to upcoming of saline groundwater, with river water from the Rhine being artificially infiltrated into the aquifers to secure fresh
Review of the potential effects of climate change on drinking water resources

groundwater volumes. However, they expect saline groundwater upcoming and the decrease of fresh water volumes to continue due to the future changes.

Werner and Simmons (2009) used two conceptual models to assess changes in sea water intrusion in coastal unconfined aquifers, in response to sea-level rise. In the flow-controlled model, in which fresh groundwater discharge to the sea is kept constant in spite of sea level rise of up to 1.5 m, the maximum increase in sea water intrusion is 50 m for typical values of recharge, hydraulic conductivity, and aquifer depth. In contrast, the groundwater head-controlled systems, whereby groundwater abstractions or surface features keep the head conditions in the aquifer constant despite sea-level changes, the saline intrusion migrates from hundreds of metres to several kilometres inland for the same range of sea-level rise. This study suggests the importance of having groundwater management that allows groundwater levels to rise in conjunction with sea level rise to minimise saline intrusion.

A GCM-scale soil water balance was used by Ranjan et al. (2006) to derive groundwater recharge in order to model the saltwater-freshwater interface in the Mediterranean region of Europe. Ranjan et al. (2006) estimate that the Mediterranean region will experience a long-term annual fresh groundwater loss of 0.0005-0.028% per year to 2100. This arises as a consequence of decreased precipitation, increased temperatures and sea level rise. They equate this to an average annual fresh groundwater loss of about 81 m³.km⁻².yr⁻¹.

Yechieli et al. (2010) showed that the effect of sea level rise depends on the coastal topography next to the shoreline: a slope of 2.5‰ is associated with an inland migration of the interface by 400 m after 100 years for a sea level rise of 1 m, whereas a vertical slope will yield no shift. Reduced recharge due to CC or overexploitation of groundwater also enhances the inland shift of the interface, indicating the importance of both climate and non-CCs on saline intrusion.

Multi-layer aquifer systems

Increased groundwater abstraction as an indirect result of CC could affect the vertical hydraulic heads in many aquifers, potentially allowing the upward migration or leakage of poorer-quality groundwater from deeper aquifers. Oude Essink et al. (2010) show that upward migration of saline groundwater from deeper aquifers could be more significant in increasing saline loads to surface water bodies than that caused by sea level rise.

Aquifers located in intensive agricultural areas

Groundwater beneath such areas can be vulnerable to pesticide and nitrate leaching. The overall effect of CC on pesticide fate and transport is likely to be highly variable and challenging to predict (Bloomfield et al., 2006), because of the uncertainties in our understanding of future changes in rainfall seasonality/intensity and evapotranspiration and the indirect effects of climate and non-CC on land use and management, and pest and disease prevalence. However, such responses may be relatively insensitive in the short- to medium-term because of the lagged responses of groundwater systems to historical inputs.

Krysanova et al. (2005) simulated the impacts of CC on the agricultural nitrate losses in the German part of the large Elbe RB, which includes the large urban areas of Berlin and Hamburg. They found simulated future nitrogen losses are lower in all soils except organic soils that are under CC. On average, nitrogen leaching and wash-off in the 2046-2055 is 9.4 kg N.ha⁻¹.yr⁻¹ lower compared to the reference period. They conclude that impact of a warmer and drier climate on diffuse pollution
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from agriculture is expected to be positive, because of the correlation of this type of pollution with hydrological process intensity.

Bloomfield et al. (2006) reviewed how CC may impact the fate and transport of pesticides in surface and groundwaters. They assert that the overall effect of CC on pesticide fate and transport is likely to be very variable and difficult to predict because of uncertainties in the climate predictions, the complexity of the natural environment and, most importantly, because of the range of competing climate-sensitive processes that may have conflicting implications for pesticide fate and transport. Groundwater is usually a minor pesticide receptor due to high pesticide losses in the soil and dilution and dispersion in the saturated zone. However, they identify the main effects of CC on groundwater pathways as likely to be (i) an increase in the seasonality of pesticide concentrations arriving at the water table, (ii) an increase in the frequency of high pesticide concentrations at the water table in response to individual rainfall (by-pass flow) events particularly in the late winter and spring, and (iii) an increase in the frequency of seasonally high pesticide concentrations at the water table associated with high inter-annual groundwater levels. Fractured/karstic aquifers with rapid preferential flow pathways and limited potential for diffusive exchange of pesticides between the macropore/fractures and the matrix may be more vulnerable.

Bloomfield et al. (2006) identify the increased risks to groundwater sourced posed by increased surface water flooding of groundwater as a potentially important issue. Many groundwater sources are located in river valleys that may be increasingly prone to flooding, and the implications for pesticide exposure (and water quality in general) at groundwater sources under these circumstances are uncertain.

The CC impacts on nitrate leaching to groundwater are not yet well enough understood to be able to make useful predictions without more site-specific data, but the few studies reviewed by Stuart et al. (2011), which address the whole cycle, show likely changes in nitrate leaching ranging from limited increases to a possible doubling of aquifer concentrations by 2100.

Ducharne et al. (2007) showed that for the Seine Basin under current practices the aquifer concentration would increase by around 50% on average from the present under an SRES A2 scenario, although changes are lower where the aquifer is confined. Under a moderate to high emissions scenario, this could be as much as 100%.

2.4.2.3 Water from riverbank filtration (RBF)

Temperature and precipitation are the main CC factors affecting RBF performance in terms of water quality. Lower river flows and warmer surface water temperatures during the summer will make the management of RBF waterworks more challenging. However, during the very dry summer of 2003 when the water level of the River Rhine dropped 2 m below its annual mean and water temperatures reached up to 25°C, abstraction rates were maintained from vertical RBF wells from a site in Germany (Eckert et al., 2008).

The fate of contaminants in RBF systems is determined by a numbers of physical, chemical and biological processes, including straining, sorption, ion exchange, precipitation and dissolution, redox zonation, biodegradation and inactivation or die-off that are differentially affected by CC. Sprenger et al. (2011) reviewed a number of studies of removal efficiency from RBF sites with different travel times or travel distance of bank filtrate and evaluated the likely effects of drought or flood scenarios on removal processes (see Table 8 below).
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Table 8: Predicted vulnerability of RBF systems to drought and flood

<table>
<thead>
<tr>
<th>Water quality</th>
<th>Overall removal efficiency</th>
<th>Vulnerability to drought</th>
<th>Vulnerability to floods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physico-chemical</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suspended solids</td>
<td>Good</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Dissolved Oxygen</td>
<td>Good</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Content (DOC)</td>
<td>Moderate</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Nutrients</td>
<td>Inconsistent</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Inorganics (metals)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biological</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protozoa</td>
<td>Good</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Bacteria</td>
<td>Good</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Viruses</td>
<td>Good</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Microcystins</td>
<td>Good</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Micropollutants</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pesticides</td>
<td>Inconsistent</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Pharmaceuticals</td>
<td>Inconsistent</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Hydrocarbons</td>
<td>Inconsistent</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Endocrine Disruptors</td>
<td>Moderate</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>

Source: adapted from Sprenger et al., 2011

Drought conditions are considered by Sprenger et al. (2011) to promote anaerobic conditions within RBF systems, to the water quality detriment of those parameters which are more susceptible to degradation under aerobic conditions (e.g. algal toxins, dissolved oxygen content (DOC), ammonia). Low flow velocities and low dilution within surface waters are also likely to give rise to increased pathogen, disinfection by-products, endocrine disrupting substances and polyaromatic hydrocarbon (PAH) contamination and increased occurrence of toxic algal blooms (e.g. mycotoxins), which may pose an increased risk due to reduced elimination potential of RBF systems under anaerobic conditions (Sprenger et al. 2011). As river discharge peaks are also often accompanied with contaminant concentration peaks, the anticipated increasing seasonality of precipitation and river flows may increase the frequency of such contaminant peaks, with an increased transport of industrial (e.g. combined sewer overflows containing microbiological contaminants, organics, ammonium, pharmaceuticals, etc.), urban (micropollutants e.g. PAH) and agricultural (e.g. nitrates and pesticides) contaminants. Contaminants may include suspended solids and associated pathogens in RBF wells mobilised during high discharge. Sprenger et al (2011) consider that the increased dilution and water turbulence may help to counteract the deterioration in surface water quality but, although redox conditions are not expected to change, increased flow velocities and shortened flow paths are likely to reduce travel times and the efficiency of subsurface degradation processes with associated risks to RBF raw water.

Bloomfield et al. (2006) identify the increased risks to groundwater sourced posed by increased surface water flooding of groundwater as a potentially important issue. RBF groundwater sources are inevitably located in river valleys that may be increasingly prone to flooding. The implications for pesticide exposure (and water quality in general) at groundwater sources under these circumstances are uncertain but RBF wells whose sanitary seals do not have structural integrity may be at increased risk of wellhead contamination during such flood inundation events and a
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breakthrough of contaminants, such as pesticides and microbiological pathogens (Sprenger et al., 2011).

Whilst RBF systems have some vulnerability to CC, they are similarly vulnerable to non-CC impacts associated with human activities such as effluent.

An overview of how CC may affect the RBF process is presented in Figure 17 below.

![Figure 17: Schematic diagram of the CC impact the bank filtration (BF) process](source: KWB, 2009)

### 2.4.3 Region-specific findings

This section provides more region-specific findings concerning the main types of impact discussed in the literature.

#### 2.4.3.1 Overview

<table>
<thead>
<tr>
<th>EU regions</th>
<th>Effects</th>
<th>Example of river basins or countries identified in the literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continental land</td>
<td>Saline intrusion</td>
<td>Czech Republic, Hungary</td>
</tr>
<tr>
<td></td>
<td>Eutrophication and/or pollutant concentration</td>
<td>Danube catchment</td>
</tr>
<tr>
<td></td>
<td>Spread of pollutants</td>
<td>Hungary</td>
</tr>
<tr>
<td></td>
<td>Damage to water management infrastructure</td>
<td>Hungary</td>
</tr>
<tr>
<td>Northern</td>
<td>Saline intrusion</td>
<td>Estonia, Latvia, Sweden,</td>
</tr>
<tr>
<td>EU regions</td>
<td>Effects</td>
<td>Example of river basins or countries identified in the literature</td>
</tr>
<tr>
<td>--------------</td>
<td>--------------------------------------------------</td>
<td>-------------------------------------------------------------------</td>
</tr>
<tr>
<td>Europe</td>
<td>Eutrophication and/or pollutant concentration</td>
<td>Estonia, Finland, Latvia, Lithuania, Sweden</td>
</tr>
<tr>
<td></td>
<td>Spread of pollutants</td>
<td>Estonia, Sweden,</td>
</tr>
<tr>
<td>NW Europe</td>
<td>Saline intrusion</td>
<td>Belgium, Netherlands, Portugal</td>
</tr>
<tr>
<td></td>
<td>Eutrophication and/or pollutant concentration</td>
<td>Netherlands, Portugal, UK</td>
</tr>
<tr>
<td></td>
<td>Spread of pollutants</td>
<td>Belgium</td>
</tr>
<tr>
<td></td>
<td>Damage to water management infrastructure</td>
<td>UK</td>
</tr>
<tr>
<td>Mediterranean region</td>
<td>Saline intrusion</td>
<td>Italy</td>
</tr>
<tr>
<td></td>
<td>Eutrophication and/or pollutant concentration</td>
<td>Italy</td>
</tr>
<tr>
<td></td>
<td>Spread of pollutants</td>
<td>Italy</td>
</tr>
<tr>
<td>Islands</td>
<td>Saline intrusion</td>
<td>Malta</td>
</tr>
<tr>
<td></td>
<td>Spread of pollutants: Malta</td>
<td>Malta</td>
</tr>
</tbody>
</table>

### 2.4.3.2 Impacts due to saline intrusion

Salinisation is likely to be exacerbated due to CC but there is wide agreement that this effect already occurs because of excessive abstraction in water bodies, not linked to CC (ClimateWater, 2011).

**Continental land**

In the Czech Republic, the national CC programme mentions eutrophication as a significant issue due to decreased river flows and increased water temperature.

In Hungary, according to the National CC Strategy 2008-2025 (2008), simultaneous increases in the average salt content and in the saline character of Hungarian lakes may also occur. Nutrient levels will probably rise, which will have unfavourable effects on oxygen levels and will thus improve the survival rate of bacterial pathogens.

Higher sea levels will likely increase salinisation of estuaries and land aquifers with saltwater intrusions in the Danube RB (Mauser et al. 2012).
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Northern countries

Saltwater intrusion, though not common, may be an issue in some areas of the region. In Southern parts of Sweden, the risks include salt water intrusion in water reservoirs in coastal areas due to rising sea levels (Swedish government, 2007a).

The West Estonian coast is a case study area of the BaltCICA project. The high Cl content varies mainly between 220 and 500 mg/l and in some cases is up to 2000 mg/l. The EU Directive 1998/83/EC on the quality of water intended for human consumption gives a limit of 250 mg/l.

Tallinn, the capital of Estonia, is located on the Southern coast of the Gulf of Finland. Tallinn’s shoreline is almost 70 km long and is divided into several peninsulas and minor bays at the mouths of ancient buried valleys. In the area of the buried valleys, 26 to 32 km² of the coastal land has a maximum elevation of 3 to 5 meters above sea level. These areas are extremely vulnerable to storm surges. The buried valleys cut the Cambrian Vendian aquifer, which is the main groundwater source for Tallinn and mainly feeds via the buried valleys. In the bays, intrusion of seawater into the groundwater occurs. According to the Astra project (n.d.), sea-level rise will lead to the intensification of seawater intrusion into this Cambrian-Vendian aquifer.

Intensive water abstraction from groundwater during the past decades causes a significant issue, because marine waters are intruding groundwater in Lithuania. This issue is critical in the territory of Liepāja city (VARAM, 2009), but has also been observed in downtown Riga and in Jūrmala.

North-Western Europe

CC increases the risk of salinisation of groundwater and surface water in two ways: via the sea level rise and via the river low flows in estuaries (Rijkswaterstaat, Rense, 2009). According to the four Dutch RBMPs, coastal and transitional water will not be significantly affected by salinisation, whereas stagnant, running and groundwater will be sensitive where the phenomenon occurs (Ministerie van Verkeer en Waterstaat et al., 2009-a, b, c and d).

In Belgium, increased phenomena of soil erosion and rapid infiltration of water into the ground could result in deterioration in the quality of surface and groundwater (AGE, 2011).

Saline contamination due to aquifer recharge reduction and to sea level increase is expected in coastal areas of Portugal (Veiga da Cunha, 2007).

Mediterranean countries

Italian coasts are reported to be very vulnerable to sea water intrusion in the coastal aquifers caused by sea level rise, together with a decrease in beach solid debris replenishment, caused by low river flows (see Section 3.2.1.3).

Islands

While the development of regional scenarios for sea level change in the Maltese Islands was not possible, local observations from June 1992 to December 2006 indicate a fall in sea level at an average rate of 0.50 ± 0.15 cm/year. The time-period of such observational data is too short to allow appropriate identification of trends in the mean sea level in the Maltese Islands and interpretation of such data should be done with caution. While there are many uncertainties associated with sea level rise, a precautionary approach is being applied in this case and an increase in mean sea level around the Maltese Islands is being assumed in the long-term, based on global scenarios. The sea level of the Mediterranean Sea is expected to rise by up to 96 cm by 2100 (FAO, 2006).
Recent results have shown that in the central regions of islands, like Malta, particularly around major pumping stations, the freshwater-seawater interface has reached levels close to the mean sea level; thus, any relative change in the mean sea level will have more pronounced effects in these regions (FAO, 2006).

**Coastal areas**

Saline intrusions might occur in coastal aquifers in the Danube RB (Mauser et al. 2012).

### 2.4.3.3 Impacts due to higher temperatures and/or decreased precipitation

**Continental land**

In the Danube RB areas, warmer air temperatures due to CC will result in a remarkable increase of the water temperature of the top lake layer. The lake stratification and its energy balance may thus change. In addition, the probability of later freezing and earlier ice melting in the year is higher. The redox potentials may change and the water quality of lakes could worsen, showing eutrophic conditions and a possible increase in blue-green algae. Especially in summer, the levels of lakes may also decrease (Mauser et al. 2012).

**Northern Europe**

The increased temperature leads to soil less commonly being covered by snow and ice, and less commonly freezing. For the Kymmene älv RB, in Finland, it is reported that lower flows in smaller groundwater bodies can lead to low oxygen levels and high levels of iron, manganese and other metals.

The lack of snow on the ground (as pointed out for Finland and Sweden) will probably lead to increased leaching of nutrients, though the effects vary depending on geographic location, management, whether particulate or soluble phosphorus is regarded, etc. In general, Finnish reports suggest that increased leakage can be expected for agricultural fields for (particulate) phosphorus and nitrous nitrogen, and for forests mainly in terms of nitrogen; this effect is especially predicted in the South Western parts of Finland (Kymmene älv RB).

Forest production will increase with CC. The stores of organic material in the soil will increase; this combined with the increased runoff to water bodies will lead to increasing humus loads in the water, which may affect the quality of freshwater used for drinking water supply.

As described in the Danish CC adaptation strategy, a longer growing season, will allow the introduction of new crops and increased yields and thus higher productivity in agriculture and the need for increased fertilization are expected. In addition, there are expected changes in precipitation patterns. An increased and altered pest pressure is expected to result in increased and changed use of pesticides.

Increased nutrient levels in general in the water, in combinations with higher temperature can increase eutrophication extent in surface waters or coastal areas. Increasing water temperature increases the (blue green) algal growth. Eutrophication is expected to occur mainly through the summer season. The Southern parts of Finland and Sweden are expected to be more impacted than the northern parts. Although similar effects are expected in Denmark, it is pointed out in the Danish climate portal that the effect of this pressure is not yet well known. Increased nutrient leakage may lead to increased algal growth, oxygen depletion and reduction in e.g. eelgrass.
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growth, etc. However, it can be noted that e.g. in the Stockholm area, most drinking water is abstracted different depths than where the algal masses occur.

In Lithuania, as a result of the expected rise of weather temperature, an ice cover on lakes is likely to be formed later than today and last for a shorter time than at the end of the 20th century. Years with a highly unstable ice cover might occur much more frequently because the average weather temperature in winters will be gradually approaching 0°C under the most scenarios. Higher temperature of the warm season should determine increase of the lake water temperature, which would be most noticeable in thermally shallow and non-stratified lakes. Changes in the thermal and ice regime of lakes can affect intensity and eutrophication processes as well as water quality of the lakes. Changes in the composition of the specific ecosystem of lakes are likely to start occurring. A larger amount of primary production, more intensive denitrification, changes in the phosphorus-nitrogen ratio are expected due to a longer vegetation period and rising water temperature. No major impact of the changes brought about by CC on eutrophication of lakes and water quality is expected (AAA & LGT, 2010d).

In Latvia, the European Environment Agency (EEA, 2010) points out that the main cause of inadequate surface water quality is eutrophication. Eutrophication in lakes and the sea and the related deterioration of ecological quality is a risk factor for excessive propagation of cyanobacteria, especially in the Southern area of the Gulf of Riga (VARAM, 2009). Drivers include CC and pollution (VARAM, 2010) and they are addressed by Goal 7 of the Strategic Plan of the Convention on Biological Diversity in Latvia; this Plan concerns biodiversity rather than drinking water resources, but it nevertheless links CC to a decrease in water quality and, more specifically, to eutrophication of coastal and inland water threatening biodiversity, hence potentially also threatening drinking water resources.

According to the Estonia’s Fifth National Communication (Estonian Ministry of the Environment & Estonian Environment Information Centre, 2009), an analysis of the water temperature of Lake Peipsi shows its increase; it is probably caused by the increase in air temperature. The increase in water temperature of the lake in turn affects the water quality by supporting an earlier and longer eutrophication period. This may be the reason for the continuation of the eutrophication problem and the increase of cyan bacterial blooms in the lake despite the reduction of nutrients emissions in recent years.

**North Western Europe**

In the UK, substances including pesticides and polycyclic aromatic hydrocarbons could exceed set limits due to a lower dilution of pollutants (UK Environmental Agency, 2009a).

According to the Dutch Ministry of Infrastructure and the Environment, the water quality of surface water, notably from the Rhine and Meuse, can decrease significantly during a heat wave and the low flow accompanying it. Indeed, impurities are less diluted. This happened for example in the summer of 2003: the waste discharges of the DSM manufacturing plant, in combination with low river discharges, led to high concentrations of toxic substances and the quality of the water was too bad to produce drinking water (Rijkswaterstaat, Rense, 2009).

According to the Dutch RBMPs, the sensitivity of running waters to eutrophication will be low or strongly dependent on local conditions, whereas coastal, transitional and groundwater will be sensitive where the phenomenon occurs, and stagnant waters will be almost always sensitive. The greatest impact of low river discharge is the rise in water temperature induced by a lower dilution of
thermal discharges (from cooling circuits). Stagnant and transitional waters will be the most sensitive to this phenomenon, depending on local conditions, and running water will also be sensitive where the phenomenon occurs. A rise in the temperature of drinking water abstracted from these types of resources may therefore occur, favouring the growth of micro-organisms and pathogens (Ministerie van Verkeer en Waterstaat et al., 2009-a, b, c, d).

Algal growth due to increased temperatures is expected to be particularly of concern in Southern European countries. For example, in Portugal where solar irradiation is one of the highest in the world and where most GCMs project a temperature increase of 4 to 7°C, the cyanotoxin problem could be aggravated for surface water (Techneau, 2006).

**Mediterranean countries**

In the Como and Pusiano lakes, in Northern Italy, the results from the EU CIRCE Integrated Project (CC and Impact Research: the Mediterranean Environment) suggest an average annual increase of 0.04°C/year and 0.03°C/year (over the first 20 m of the water column) for the periods 1970-2000 and 2001-2050, respectively. This means that, on average, the first 20 m of the water column have increased their temperature by about 1.2°C between 1970 and 2000 and that a further increase of 1.5°C is expected by the middle of the 21st century.

The magnitude of the projected temperature increases is sufficient to cause significant variations in the growth rate of phytoplankton populations and, in particular, of *Planktothrix rubescens*, a filamentous and potentially toxic cyanobacterium that has recently started invading many European lakes. Assuming a linear relationship between temperature and *P. rubescens* growth rate, it was estimated that an average increase of 2°C in lake temperature would lead to around 40% increase in the growth rate of the cyanobacterium; this may put at risk the use of the water resource, especially for drinking supply and bathing.

Also within the framework of the EU CIRCE Integrated Project, the average yearly nutrient (phosphorus and nitrogen) river loads under present climate conditions and under CC have been assessed in the Po River catchment. Different numerical models were used to feed the MONERIS model. Current nutrient loads were estimated at 170,000 t/year of nitrogen and 8,000 t/year of phosphorus. Approximately 70% of the nitrogen load is from diffuse sources while 65% of the phosphorus load originates from point sources. Nutrient load projections for 2100 (under different IPCC scenarios) allowed to estimate that both nitrogen and phosphorus loads are strictly dependent on the resident population which is responsible for a 61% increase in nitrogen load and a 41% increase in phosphorus load. Projected nutrient load variations were found to be negligible when holding the resident population constant. Coupling this result with the decreased Po river discharge for the same time horizon (2100) (see Section 3.2.2.1), an increased concentration of both nitrogen and phosphorus can reasonably be predicted. Finally, the phosphorus load is markedly influenced by the efficiency of the urban waste water treatment plants (WWTPs).

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http://www.circeproject.eu/; a book is about to be published with the results of the CIRCE project

MONERIS (MOdelling Nutrient Emissions in River Systems) is a semi-empirical, conceptual model for the quantification of nutrient emissions from point and diffuse sources in river catchments
2.4.3.4 Impacts due to increased precipitation and flooding

Continental land

In the Bukk mountains, Hungary, increased turbidity and bacterial growth in karstic aquifers are reported to be the main effects of increased precipitation and flooding (CC-WaterS Project, 2009-2012).

Studies show that flash floods will increase much particularly in the Middle DRB, as a consequence of more extreme weather events (torrential rainfall) in small basins, e.g. in the Carpath range or the Sava and Tisza headwaters. Flood frequency is expected to increase in the Lower DRB, according to the few studies available. In small catchments, uncertainty of flood predictions is especially high because of low spatial resolution of climate models (Mauser et al. 2012).

Northern countries

Within the VASTRA project (Water strategic research programme), Sweden’s water quality in a future climate is described as follows:

- On average, nitrogen leaching from arable land would increase by 15–40% depending on which climate scenario is used; this increase would be primarily due to the increased runoff and increased mineralisation during the winter when nitrogen is not absorbed by crops
- Even if the growing season is extended and the timing of e.g. soil tilling, harvesting and maintenance is adapted to the new climate, this would not compensate for the increase in leaching; the increased ground leaching would lead to an increase in nitrogen concentrations in watercourses of 7–20%, depending on the scenario, and an increase of 20–50% in the annual nitrogen transport, which would also affects sea water.

According to the Estonia’s Fifth National Communication (Estonian Ministry of the Environment, Estonian Environmental Research Centre, 2009), the increased flow in winter will improve the water quality of rivers. On the other hand, the earlier and shortened spring and the longer low flow period after spring may deteriorate water quality.

According to an UNEP study (CICERO, 2000), in Estonia, the increase of groundwater circulation may favour the transport of pollutants in the water-bearing formation. The movement of pollutants may gather speed and the pollution plumes enfold greater areas than today. As a result, a portion of wells kept pure so far may become polluted. Therefore, the isolation and liquidation of groundwater point-pollution sources will be more expensive in the future.

North Western Europe

According to the Belgian CC adaptation strategy, possible consequences of floods include an alteration in water quality and quantity, with its economic and safety impacts, notably the increased penetration of salt water into the inland, affecting its salinity (National Climate Commission, 2010).
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Mediterranean region

The consequences of CC on water quality in Italy were assessed by running the SWAT hydrological model in Sardinia and Campania regions. The simulated scenarios considered, among other parameters, an increase in the frequency of intense rainfalls. Significant changes in the hydrological balance and in water quality, as well as a reduction of the annual flow volumes, together with an increase in nutrient and sediment transport, were predicted by this model. Similar results were obtained for a RB in the Apennines mountains, in Central Italy.

Islands

An increase in heavy rainfall events is expected in Malta, which will lead to increased run-off, which can have various effects including increased erosion, decreased groundwater recharge and increase in the load of nutrients to waters (Malta Resources Authority, 2010).

Mountains

In mountain areas, the frequency and magnitude of flood events may increase (Mauser et al. 2012).

Coastal areas

Coastal flooding in Romania might include severe changes (Mauser et al. 2012).

2.4.3.5 Impacts due to damage to water management infrastructure

Continental land

In Hungary, according to the National CC Strategy 2008-2025 (2008), the CC will only affect municipal and industrial water management in an indirect way and in the longer run. However, when establishing wastewater treatment capacities, the fact that the water discharge rates and “natural self-purification abilities” of the watercourses serving as the recipients for treated wastewaters may generally decrease, should be taken into account. Another factor to consider is that biological treatment technologies are primarily temperature-dependent and temperature increases may modify the efficiency coefficient of the treatment technologies in the future.

The consequences of damages to water management infrastructure due to flood waves may be severe. Examples exist in the Tazlău River, in which high flood-waves destroyed the Belci dam in July 1991 and resulted in 25 deaths (Stănescu 1995). In 1991, flood-waves destroyed 47 km of dams and nearly 117 km of maintained river banks, killing 110 people. The collapse of dams may also have cross-border effects. For example, in April 2000, the dam across the Crişul Alb river near the Hungarian border failed and flooded the Ineu-Chişineu Criş sector (UNEP, 2007). Such impacts may occur more often in the future, due to more intense and frequent extreme events.

In the Danube RB, higher sea levels will reduce coastal protection of dams and quay walls (Mauser et al., 2012).

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86 SWAT (Soil and Water Assessment Tool) is a RB scale model developed to quantify the impact of land management practices in large, complex watersheds (http://swatmodel.tamu.edu)
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**North Western Europe**

Assets on the coast or in flood plains (that covers most of them – networks, water and wastewater treatment works, pumping stations) will be at increased risk from flooding, storm damage, coastal erosion and rises in sea levels in the UK (Water UK, 2008).

2.5 Future risks

The fact that water resources are already under stress renders the potential impacts of CC even more serious (Malta Resources Authority, 2010; Zachariadis, 2010; UK Environmental Agency, 2009e). In this respect, additional pressures induced by CC may hinder attempts to restore water bodies to good ecological, chemical and quantitative status (Malta Resources Authority, 2010; UK Environmental Agency - Western Wales River, 2009) i.e. increasing the risk of not achieving Water Framework Directive objectives (UK Environment Agency2009c; UK Environmental Agency, 2009d).

2.5.1 Regional risks

**Northern Europe**

In countries where low water treatment are currently the norm (due to naturally high quality water), water production is sensitive to increased pollution loads, which may lead to risks in the future (linked or not to CC) (**Sweden, Finland, and Denmark**). This increases the need for protection of water bodies. Particularly in **Sweden**, waterborne parasites may increase leading to the need to adapt water treatment, and pollution risks following excess water events may increase.

**Denmark** and **Sweden** discuss the need to adapt planning for extreme weather events or other crisis situations occurring due to CC, e.g. pumping flooded water.

**Sweden** conducted and assessment in 2007 of the Consequences of CC and Extreme Weather Events (Government Official Report SOU 2007:60), as well as an in-depth assessment of certain larger lakes serving as water sources (e.g. Mälaren). Related to drinking water more specifically, the importance of cooperation between agencies and regional/local representatives is highlighted by the Swedish Emergency Management Agency, due to the increased risks from CC. However, the results have been debated^{a}. In **Denmark**, comments during the stakeholder consultations showed that expectation to take into account the impacts of CC were high, especially regarding increased nutrient leakage. This will be taken into account for the second round of RBMPs.

Shallow groundwater sources which stand in relation to surface or coastal waters or nature areas, need special attention from a qualitative and quantitative perspective (Danish Government, 2009)

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^{a} E.g. see blog.moderna-myter.se/200710/klimat-och-srbarhetsutredningen-skit-in.html [Accessed online 02/04/2012]
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**Mediterranean countries**

While there is no compelling statistical evidence of CC affecting the water resources of the Maltese Islands (FAO, 2006), water resources are considered highly vulnerable to changing climatic conditions (Malta Resources Authority, 2010).

Likewise, the inherent water scarcity in Cyprus is expected to deteriorate under CC conditions (Zachariadis, 2010).

**North Western Europe**

In the UK, the amount of abstractions and flow levels in the Dee and Western Wales RB Districts, which are not yet identified as significant water management issues, are likely to become significant pressures in the context of a changing climate (UK Environment Agency, 2009a; UK Environmental Agency, 2009d).

### 2.5.2 Topographical risks

**Mountains**

Mountainous areas may be *a priori* seen as less important in terms of their vulnerability, as the population directly relying on mountain water may be lower than in plains (in general cities are rarely located in mountainous areas). However, their role as water towers (see e.g. Liniger and Weingartner, 1998) should not be underestimated. All the major rivers of the world have their headwaters in highland and more than half of humanity relies on the freshwater that accumulates in mountain areas (Liniger and Weingartner, 1998). For example, the contribution of the Swiss mountains to the flow of the River Rhine in the Netherlands varies from 30% in winter to 70% in summer, and similar amounts are observed for the River Rhone and Po.

**Coastal areas**

Many cities are located close to coasts, and a lot of economic activities such as tourism are also concentrated on coastal areas. Therefore, exposition of coastal areas is important for water resources. In addition, some risks are mainly relevant for such areas, such as salinisation, whether due to over-abstraction or climate change (increasing abstraction and through sea level rise).

**Urban areas**

In 2008, around 50% the EU population was living in urban areas and this share is expected to reach 70% in 2050 (WssTP, 2010). Therefore, cities are particularly exposed to the water implications of CC. In addition, with population concentration in urban agglomerations, buildings were constructed in flood- and/or landslide-prone areas. Interactions between humans and the environment have become increasingly complex, and the damage incurred by extreme events is ever-greater. Specific adaptation measures will be required to deal with the specific water challenges posed in urban areas.

Foreseen CC impacts that could affect urban areas are:

- Drier and hotter summers will increase demands when water resources are at its minimum
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- The higher number and intensity of extreme precipitation events will cause sewer capacity problems, increasing the risk of floods and worsening water quality of receiving bodies due to polluted overflows.
- High flows on watercourses due to an increase of rainfall and sea level rise may cause discharge difficulties to sewer systems
- Water discharged through Combined Sewer Overflows (CSO) may be of a modified quality and the design of CSOs may need to be modified to account for changes in precipitation patterns, extreme events, etc.
- Warmer temperatures may cause quality, odour problems and impacts on the water and wastewater treatment processes

As an illustration, intense rain falling on small surfaces had catastrophic effects (120 mm/m² fallen rain in 40 minutes near Buzau-Cuculeasa on June 22, 1999 and 285 mm/m² rain fallen in 30 hours in Bucharest on September 21-22, 2005), which represents 60% of yearly precipitation. This lead to an overload the city’s sewer system, and caused a discharge of the system.

2.6 Identification of priority issues – vulnerable resources and gaps

2.6.1 Vulnerable geographic areas

Islands

Most small islands are especially vulnerable to future changes and distribution of rainfall because they have a limited water supply, and water resources. The range of adaptive measures considered, and the priorities assigned, are closely linked to each country’s key socio-economic sectors, environmental concerns, and areas most at risk of CC impacts such as sea-level rise.

Mediterranean islands such as Cyprus face a number of specific challenges including (Lange & Donta, 2005):

- their isolation, which implies that the use of trans-boundary water to compensate for temporal or seasonal water shortage, which is frequently practiced in continental situations is virtually impossible,
- the extensive exploitation of natural reservoirs on the islands to the point where they cannot be consumed as potable water anymore,
- the extraction of water in coastal reservoirs beyond the natural recharge potential, leading to the intrusion of sea water into the aquifer thereby rendering its water useless for human consumption. In Malta, the construction of further infrastructure for water storage to cope with CC challenges may result in geomorphological changes and water flow modification within valley systems (Malta Resources Authority, 2010), and
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- unresolved conflicts between different users, deficits and inefficiencies in institutional water management and the non-compliance with existing rules and regulations. (Lange & Donta, 2005)

Coastal areas

Many of the most important European towns where million people live are located close to the coast lines. As a consequence, many urban water supply reservoirs are located in these areas. Sea flooding from wind driven storms is forecasted to become more significant in coastal areas. Wave heights are also projected to increase (by over 0.4m in the North Eastern Atlantic by 2080, IPPC 2007); these combined effects will cause these areas to become more at risk.

Coastal aquifers will be most vulnerable, because of the combined effects of increasing sea levels, reduced recharge and often high abstraction pressures. This is probably likely to be most extreme in Southern Europe.

Areas already under stress

Serious impacts may occur, including as a consequence of not particularly severe changes, in individual catchments located in arid regions.

It is likely that in those areas in which the limits of groundwater sustainability are being reached through abstraction, even small climate-induced changes in recharge, discharge or groundwater storage may have disproportionately significant economic or environmental consequences.

Mediterranean areas

Whilst there is still considerable climate uncertainty, Spain, Southern Italy and Greece appear to be at risk of decreased groundwater recharge.

Mountainous, permafrost and boreal areas

Seasonal disruption might occur also in the water supplies in mountainous areas where, mainly because of increased temperature, the amount and duration of snow cover can be affected. The Alps have been estimated to be particularly vulnerable to this consequence of the CC.

Increasing temperatures in mountainous, permafrost and boreal areas lead to changes in snow accumulation and melting, with resultant impacts on groundwater recharge and discharge.

Intensive agricultural areas

In intensive agricultural areas, an intensified hydrological cycle with less frequent, but particularly intense rains can be responsible for an increased agrochemical transport towards surface waters.

In intensive agricultural areas, an increase in aridity caused by CC can be responsible for increased withdrawals to satisfy an increased demand for irrigation, which can, in turn, exacerbate conflicts with drinking water supply.

Reduced recharge may lead to lower dilution of excess nitrate, leading to higher groundwater concentrations.

North Western Europe

A number of studies suggest decreased groundwater resources in parts of Germany, Belgium, England.
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*Less developed or depressed areas*

There is general agreement that development can, by its very nature, build adaptive capacity, helping poor countries to become less vulnerable to the impacts of CC. This is the reason why less developed or depressed areas have to be considered particularly vulnerable.

### 2.6.2 Vulnerable types of water resources

- **Surface water**
  - Endorheic (terminal or closed) lakes are most vulnerable to a change in climate because of their sensitivity to changes in the balance of inflows and evaporation. Changes in inflows to such lakes can have very substantial effects and, under some climatic conditions, they may disappear entirely (Bates et al., 2008). This, in turn, may cause severe problems to drinking water supply in case these lakes are used as drinking water reservoirs. The consequences of CC on these mountains have to be considered particularly significant due to the role they play in accumulating and supplying water to the continent.
  - Temporary rivers, during the low flow periods, more frequent because of a changing climate.
  - Water stored in dams located in river channels. Dams designed for drinking water supply are vulnerable particularly if there is limited overtopping capacity. In case of flooding, if the spillway and waste gates are inadequate, there is a risk that the dam could collapse, causing a disaster and enormous additional losses as a result of the avalanche of stored water.

- **Groundwater**
  - Karstic and fractured (hard rock) aquifers – the high transmissivity (ability to allow flow) and low storage capacity (due to water being largely stored within the fissures and fractures and a relatively thin weathered zone) as a consequence of their low intergranular porosity are particularly sensitive to CC. Their limited storage means that they cannot buffer the phase shift in groundwater recharge (finishing earlier in the spring and starting later in the autumn);
  - Shallow wells and boreholes – drinking water supplies abstracted from wells and boreholes with a shallow standing water column, or horizontal wells/adits at shallow depth below the water table will be vulnerable to declines in summer minimum groundwater levels.

- **River Bank Filtration**

  The vulnerability of RBF to CC is highly complex, as such systems are integrating and (in the case of water quality) biogeochemically modifying the impacts of CC on surface and groundwater systems, with the relative importance of the two systems to the abstracted water being dependent on a large number of site-specific factors.

  RBF sites are likely to be vulnerable to CC, where:
  - There is an increased incidence of low river levels in summer
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- There is increasing frequency of flood events, combined with associated increased pollutant peaks (combined sewer overflows, pesticide runoff etc.)
- Wells are insufficiently deep to cope with reduced summer groundwater and surface water levels
- They are associated with small alluvial aquifers

2.6.3 Gaps

The need to monitor water bodies, to ensure that baseline conditions are known, allowing to compare the impacts from CC in the future, is highlighted. In particular, this will help characterising groundwater bodies, validating the risk assessment, defining natural background and assessing trend developments (Groundwater Guidance, 2010). For transboundary RB agreements on data monitoring and exchange is required for implementing a coherent monitoring approach.

- **Surface water**

  Only a few articles dealing with water quality and in particular only one paper, dealing with CC and water quality, in relation to drinking water production was found (see Delpla et al., 2009). The reason might be that the impacts on water quality are mainly a consequence (indirect impacts) of changes in water quantity (e.g. drought that causes less pollutant dilution) and are for this reason more difficult to forecast.

  Apart from this lack, other points observed reviewing the literature concerning CC and surface water were:

  - The difficulty to separate CC from other pressures caused by human activities that are also causing impacts on surface water. This point is particularly significant in densely populated areas, such as many European regions.
  - The need to improve the ability to estimate the costs and benefits of non-structural management options, such as demand management and water-use efficiency, in the context of a changing climate.
  - The need to highlight the uncertainty inherent in global climate models, together with the need to reduce it and to increase reliability of the projections.
  - The need to improve the ability of global climate models to provide information on how water availability will change, to evaluate overall hydrologic impacts, and to identify regional impacts.
  - The need to consider CC in combination with land surface conditions (land use, soil moisture) and with water use practices; all these factors contribute, in fact, to determine the magnitude of the impacts on surface water bodies.
  - The need to improve the methods to downscale climate information so to improve our understanding of regional and small-scale processes that affect water resources.
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- The need to increase and to widespread hydrologic monitoring systems, so to obtain more site specific information on the consequences of CC on particular water bodies.

**Groundwater**

Given the importance of groundwater and the many services it provides, it was disappointing that the Fourth Report of the Intergovernmental Panel on CC (IPCC) still reported that there had “been very little research on the impact of CC on groundwater” and that “the few studies of climate impacts on groundwater for various aquifers show very site-specific results” (Kundzewicz et al., 2007). Whilst there has been an increase in published research since then, there is still a general paucity of impact studies on groundwater in Europe. As a consequence, a comprehensive understanding of the response of the diverse types of aquifer systems across Europe to CC is lacking.

Furthermore, there are very few studies looking, in particular, at impacts on groundwater quality, with the exception of saline intrusion. Whilst there are general review papers for nitrate and pesticides, the only papers directly assessing CC impacts on groundwater quality are for nitrate.

There is a widespread underlying assumption that the climate is the only component of the system changing, with non-climate pressures remaining constant. Therefore, most studies are assuming constant land uses (agricultural, urban and non-agricultural) and land management practices, which is unlikely as vegetation and agriculture autonomously adapt to the changing climate.

The uncertainty in both the magnitude and direction of CC impacts on groundwater, as a consequence particularly of GCM uncertainty, should be highlighted. The limited use of different climate models and emissions scenarios means that many of the available studies will not adequately capture this uncertainty. This highlights the need for studies to better follow best practice (e.g. as described in Holman et al., 2011) and for adaptive management frameworks to be developed.

Whilst it may be included within articles that have not considered CC, the research which has assessed flooding has tended to assume that flood events remain within the river channel. The vulnerability of RBF to out-of-bank flood events appears uncertain.

**River Bank Filtration**

There appears to be comparatively little research about the CC impacts on RBF, although a small number of studies (mostly associated with a single dry period on the Rhine) have used historical climate analogues. There appears to be a research gap assessing the impact of the likely increasing frequency and severity of floods and droughts in some regions i.e. RBF systems might be resilient to a single event, but it would be useful to investigate the impacts in case that type of event happens more often.
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To identify the vulnerability of EU water resources to climate change, existing modelling results from ClimWatAdapt were used and vulnerability was mapped using a set of indicators and their thresholds. In combination, several case studies were investigated to analyse the effect of climate change on specific types of water bodies at a finer scale. The mapping shows high vulnerability in Southern, North Western and South Eastern Europe, but to understand the reasons for the score, one must go back to the specific indicators that form the vulnerability score.

### 3.1 Overview of the methodology

There are many different definitions of vulnerability, dependent on the framing of the problem that is being considered (for example Jun et al. 2011, Laugesen et al. 2012, Vörösmarty et al. 2000). An extensive review by the ADAM project (Hulme et al., 2009) on how vulnerability is defined and used in over 100 case studies showed rather inconclusive results, partly because the concepts upon which it is based are themselves vaguely defined (e.g. adaptive capacity). The broadest definitions of Vulnerability consider it to be a function of exposure, sensitivity and adaptive capacity (see, for example, Birkmann (2006) who examines more than 25 different definitions, concepts and methods to systematise vulnerability). The vulnerability definition that is often used in the context of adaptation to CC, e.g. by the IPCC and EEA, is considered to have three components:

- **Exposure**: nature and degree to which a system is exposed to significant climatic variations, such as changes in temperature and precipitation amounts and seasonality
- **Sensitivity**: degree to which a system is affected, either adversely or beneficially, by climate-related stimuli
- **Adaptive capacity**: ability or potential of a system to respond successfully to climate variability and change, including adjustments in behaviour, resources and technologies.

UNECE (2009) considers exposure as an external dimension of vulnerability and sensitivity and adaptive capacity as internal dimensions. In line with this interpretation, ClimWatAdapt related Exposure to the effects of exogenous climate variability and change on the hydrological (biophysical) sub-system and Sensitivity is related to the effect on the endogenous socio-economic sub-system. The exposure part therefore represents the resource side while the sensitivity part represents the “demand” side associated with the way people deal with or manage these resources.

For the purpose of this project, ADWICE has adopted this interpretation of exposure and sensitivity within the ADWICE conceptual framework (Figure 7 on page 26), in line with ClimWatAdapt. This builds on a preliminary model that was developed at the margins of the ClimWatAdapt study, but has been further developed at the early stage of the current study to better reflect drinking water resources.
In the exposure part:

- **Driving force**: CC is considered as an exogenous driving force.
- **Pressures**: Changes in hydrological and climate extremes and in long-term average climatic and hydrological variables, such as precipitation, temperature, and sea level rise.
- **State**: Water availability, river flow regime (including low flow, high flow, etc.), water quality, salt water intrusion, etc.

In the sensitivity part:

- **Driving forces** are slowly changing variables such as demography, technology, preferences, etc.
- **Pressures**: Land use changes, change in resource efficiency, management practices, etc.
- **States**: Water demand, people and production in flooding zones, etc.

Biophysical and socio-economic sub-systems are in reality coupled and together form a natural-socio-economic system. The interrelations of exposure and sensitivity result in impacts such as water stress, and losses of biodiversity. The system will take some measures to reduce these impacts, and it will depend on its adaptive capacity to what extent the impacts will turn to vulnerabilities.

Understanding the vulnerability of drinking water resources to CC, rather than water resources more generally, requires a holistic consideration of factors. This arises because drinking water vulnerability can arise from multiple factors (associated with changes in annual and seasonal water availability, competition for water from other sectors, extreme events, environmental constraints, water scarcity, water quality constraints, sea level rise, pollution) and relates to both the type of resource (e.g. groundwater, surface water, etc.) and the infrastructure required to store and abstract water from that resource (reservoirs, boreholes, off take points, etc.) and the operating treatment schemes. Figure 18 outlines the ADWICE vulnerability method. It aggregates European-scale spatial modelling results from ClimWatAdapt, local to regional scale literature-based case studies and adaptation potential. It is important to note that the scope of the study does not include the broader vulnerability of drinking water supply systems i.e. including the water distribution infrastructure to move water from the point of abstraction/treatment to the point of consumption.
Vulnerability assessment

There are three main components to the methodology:

- **Spatial mapping of undesirable State changes and Stresses, based on ClimWatAdapt outputs:**
  Changes in climatic pressures such as changes in temperature and precipitation (*Exposure*) and non-climatic pressures such as changing water demand (*Sensitivity*) will lead to a change in State of drinking water resources and associated stresses. Such changes in state may represent changes in flow dynamics, water resource availability, water quality, water stress, etc. Drinking water vulnerability relates to both changes in the resource and changes in the ability to abstract from and properly treat that water resource due to, for example, environmental flow constraints. Drinking water resources will potentially be affected by all of these, so a quasi-Vulnerability score has been developed which aggregates undesirable changes in State of, and stresses on, drinking water resources.

- **Case studies of local scale Impacts on different typologies of drinking water resources**
  Not all changes in State represent an Impact, as the characteristics of the drinking water resources can provide a buffering capacity. The literature review (see Chapter 2:) has been used to develop a typology of drinking water resources according to those physical characteristics which increase or decrease the susceptibility to Impacts. A series of detailed local and regional case studies, based on pre-existing literature, has been used to illustrate the Potential Impacts of CC.
Consideration of the Adaptation options available to reduce Potential Impacts.

Finally, whether Potential Impacts of CC result in actual impacts depends on the efficacy of Adaptation responses. Based on analysis of ClimWatAdapt adaptation inventory and expert opinion, a matrix will be developed which differentiates adaptation measures depending on the impacts which they address (e.g. low flows, recharge, water quality, etc.), and on whether they act upon the resource (aquifer, river flow, etc.) or on the infrastructure required to abstract and treat the drinking water (borehole, reservoirs offtakes, water treatment plant, etc.).

3.1.1 Exposure (climatic Pressures and States)

The CC scenarios used in ClimWaterAdapt were developed in the ENSEMBLES project (van der Linden and Mitchell 2009). These scenarios are based on Regional Climate Model (RCM) runs driven by the outputs of different GCMs using the IPCC SRES A1B emission scenario, as climate in the first half of the 21st century is not highly sensitive to the choice of emissions scenario (Déqué et al. 2007). Dosio and Paruolo (2011) applied a statistical bias correction technique to correct the ENSEMBLES climate time series which was used within the LisFlood simulations.

River-basin scale datasets consisting of projections of precipitation and temperature (annual and seasonal averages) for the baseline (1961-1990) period, 2025s and 2050s were derived by ClimWatAdapt for 11 GCM-RCM combinations. Within ADWICE we have used the multi-model ensemble median scenario (Figure 19 and Figure 20).

3.1.1.1 Precipitation

The projected patterns of average annual, summer and winter precipitation are similar between the 2025s and 2050s (Figure 19). Annual average precipitation tends to be largely unchanged in North Western and Central Europe, with small increases (5-15%) in Scandinavia and the Baltic countries and small decreases of -5 to -15% in Spain and other parts of the Mediterranean region.

Average winter precipitation is largely unchanged in the Mediterranean region (although there are local areas of slight increases and decreases), with the remainder of Europe having small projected increases (5-15%). There is greater regional contrast in summer precipitation with Scandinavia having projected small increases (5-15%), Central Europe being little changed, decreases of -5 to -15% in North Western, Mediterranean and South Eastern Europe in the 2025s increasing to around -15 to -30% in the 2050s.

3.1.1.2 Temperature

Average temperatures in the 2025s and 2050s increases in all seasons in all parts of Europe, with increases being generally greatest in Scandinavia, Central and Southern Europe (Figure 20). Increases in the average annual temperature in the 2025s are typically between 0.5 and 1 °C, although South Eastern and Northern Europe have temperature increases of 1-2 °C. Average summer temperature increases are similar, although most of the Southern half of Europe has projected temperature increases of 1-2 °C.

In the 2050s, the increases are in average temperature are larger, with almost all areas having increases of at least 1 °C. Increases of 1-2 °C are common in average annual temperature in Spain,
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Eastern, Central and Southern Eastern Europe and Scandinavia, and in average summer temperature much of Southern Europe and parts of Scandinavia.

Figure 19: Changes in average annual and seasonal temperature and precipitation within the 2020s (multimodel ensemble median and A1B emissions scenario)
3.1.1.3 **Annual water availability**

The expected higher temperatures shown in Figure 20 will increase evapotranspiration nearly everywhere. The inter-acting effects of increased evapotranspiration (tending to decrease average river discharge) and changing precipitation (either increasing or decreasing the average river discharge) produce a spatially variable net increase or decrease in future average annual water availability. Figure 21 shows that the changes in climatic pressure (temperature and precipitation) lead to moderate increases in annual water availability in Scandinavia and some parts of the Northern European and Eastern Europe and to decreases in the Mediterranean region. This regional contrast increases from the 2020 to the 2050s, with increasing magnitude and areal extent of the increases and decreases.
3.1.2 Sensitivity (non-climatic Pressures and States)

Instead of downscaling regional scenarios from IPCC (IPCC 2000), ClimWatAdapt made use of the SCENES\textsuperscript{19} scenarios for Europe (Kämäri et al. 2008, Kok et al. 2011). The main scenario drivers had been developed in SCENES on a sub-regional level (Europe was sub-divided into 6 sub-regions) and then downscaled to national scale, so that the future water uses were then modelled by WaterGAP\textsuperscript{20}, considering the socio-economic and land use scenario input from SCENES.

One of SCENES’ major objectives was to develop and analyse a set of comprehensive scenarios of Europe’s fresh waters up to 2050. Four different scenarios were developed within the SCENES project (Economy First, Fortress Europe, Policy Rules and Sustainability Eventually), of which the Economy First and Sustainability Eventually scenarios were analysed within ClimWatAdapt because these two scenarios span the broad variety of the SCENES scenarios:

- **“Economy First” (EcF)** is a SCENES scenario where a globalised and liberalized economy pushes the use of all available energy sources and an intensification of agriculture where profitable. The adoption of new technologies and water-saving consciousness are low. Thus, water use increases. Only water ecosystems providing ecological goods and services for economies are preserved and improved. Curtailed infrastructure, poor treatment and intensified agriculture lead to increased pollution. Poisoning incidents catch the interest of media and public. This and social tensions lead to upheaval in the 2040s. This triggers new cooperation to restore economic prosperity and make ground for social coherence.

- **Sustainability Eventually (SuE)** is a SCENES scenario that sketches the transition from a globalizing, market-oriented Europe to environmental sustainability, where

\textsuperscript{19} www.environment.fi/syke/scenes

\textsuperscript{20} www.usf.uni-kassel.de/cesr/index.php?option=com_project&task=view_detail&agid=47&lang
local initiatives are leading and where the landscape becomes the basic unit. This fundamental change in human behaviour, governance structures, and level of decision making, is projected to come about through a phase of strong top-down policies ("quick change measures"), accompanied with a set of "slow-change" measures that bear fruit in the long run.

3.1.2.1 Annual water withdrawals

The SCENES scenarios describe the Drivers and Pressures on water demand and use. Figure 22 and Figure 23 show the percentage change in water withdrawals compared to the baseline for the two scenarios. This represents the water abstracted, but a proportion of this (depending on the resource efficiency of the scenario) will be returned to the environment.

Within Economy First, all sectors show a general increase in withdrawals of around 10-100% in the 2020s, with localised areas of decreases in the domestic sector (far Northern Scandinavia), agriculture (Spain and Baltic) and electricity generation (Southern Norway). By the 2050s, domestic water withdrawals have decreased compared to the baseline in significant areas of Scandinavia, Baltic and Mediterranean. However, the other sectors show general further increases in withdrawals compared to the baseline of 50 to more than 100%.

Sustainability Eventually shows widespread decreases in domestic and electricity generation withdrawals and regional decreases and increases in the agriculture (decreasing in central and Eastern Europe) and industry and manufacturing (decreasing in North Western and Central Europe) in the 2020s. In the 2020s, all sectors show significant decreases of often greater than 50% with the exception of agriculture in which there are increases in North Western Europe.

![Figure 22: Change (%) in sectoral water withdrawals in the 2020s for (upper) Economy First and (lower) Sustainability Eventually]
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3.2 Spatial mapping of undesirable hydrological State changes and stresses,

3.2.1 Introduction

The spatial mapping of hydrological State changes has been based on pre-existing outputs from the ClimWatAdapt database, which were previously derived using the WaterGAP and LisFlood models:

- The WaterGAP model (Water - a Global Assessment and Prognosis\(^{21}\)) aims to investigate current and future world-wide water availability and water use (Döll et al., 2003). The model combines a hydrological module for the determination of global water resources and water availability, and a water use module to quantify water consumption from different economic sectors, including a sub-model for an assessment of global irrigation requirements.

- LISFLOOD\(^{22}\) is a GIS-based hydrological rainfall-runoff-routing model that is capable of simulating the hydrological processes that occur in a catchment (De Roo et al., 2000; Van der Kniff et al., 2010). The specific development objective was to produce a tool that can be used in large and transnational catchments for a variety of applications, including flood forecasting, and assessing the effects of river

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\(^{22}\) http://floods.jrc.ec.europa.eu/lisflood-model
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regulation measures, land-use change and CC. The model’s general structure is illustrated in Figure 24.

- Int - Interception of rainfall by vegetation
- EWint – Evaporation of intercepted water
- Dint - Leaf drainage
- ESa - Direct evaporation from the soil surface
- Ta - Water uptake and transpiration by plants
- INFact - Infiltration
- Dpref,gw - Preferential flow through macro-pores
- Rs - Surface runoff
- D1,2 - Gravity-driven vertical flow within the soil()
- D2,gw - Gravity-driven vertical flow out of the soil
- Quz and Qlz – Rapid and slow groundwater runoff, respectively

Source: floods.jrc.ec.europa.eu/lisflood-model

Figure 24: General structure of LISFLOOD

The ClimWatAdapt project investigated a number of model-based vulnerability indicators, based on model metrics of Exposure (from LisFlood) and Sensitivity (based on WaterGAP) to assess the separate vulnerability to scarcity, drought and floods.

However, given the broad scale of the ClimWatAdapt modelling approach and the multi-dimensional nature of vulnerability, these indicators do not provide an holistic reflection of water resource vulnerability. Jun et al. (2011) developed a new framework to quantify spatial vulnerability for sustainable water resources management in Korea which combined multiple hydrologic indices (potential flood damage, potential drought damage, potential water quality deterioration) into a vulnerability index which they called the Watershed Evaluation Index.

ADWICE has taken this multi-dimensional approach further, considering that vulnerability of drinking water resources arises from a greater range of factors than extreme events and water quality. To provide a more comprehensive overview of the effects of CC on drinking water resources, we have considered that undesirable changes in Sensitivity and Exposure States will contribute to increased vulnerability of drinking water resources (Figure 25). In particular, arising from changes in:

- competition for water from different sectors, as indicated by the long term average balance between water resource availability and water abstraction,
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- seasonality in water resource availability and consumption - given by indicators of headroom in both summer and winter, and decreases in the summer low flows,
- extreme events - given by indicators of the increase in drought and flood severity,
- water quality - given by indicators of diffuse and point pollution sources, risk of salt water intrusion, change in magnitude of flood events and rising temperature.

3.2.2 Description of indicators long term average water stress

This section describes the indicators used in the derivation of a broad-scale potential vulnerability score:

**Competition for scarce water resources**: changes in the long-term balance between water resource availability and water abstraction is likely to lead to increasing competition for water, because of limited availability and/or changes in the quality of water through abstraction and subsequent return flows. The Water Exploitation Index, which is defined as the ratio of total water withdrawals to water availability, was selected as an indicator of resource competition, although it was used by ClimWatAdapt to provide an overall level of water scarcity. Using the commonly used WEI thresholds (e.g. Raskin, 1997; Cosgrove and Rjisberman, 2000) for RBs under low (WEI ≤ 0.2), medium (0.2 < WEI ≤ 0.4) and severe (WEI > 0.4) water stress, Figure 26 indicates those RBs in which a large overall proportion of available water (defined as the accumulated water flowing out of the river channel(s) within the basin) is abstracted. Such high stress RBs are at potential risk of
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interruption of water supplies or restrictions due to resource competition. However, there are two drawbacks with using this indicator in isolation:

- As noted within ClimWatAdapt Appendix 3, this indicator takes into account all withdrawals, and because part of these withdrawals are returned to the rivers, it can overestimate water scarcity and resource competition. However, this is considered acceptable as some of the water returns can potentially occur within different RBs due to the inter-connectedness of public water supply distribution systems. It must be noted that this is only one of the indicators being used within ADWICE to map potential vulnerability, and that other indicators take into account water returns and environmental needs.

- The water availability is based on accumulating all of the LISFLOOD river discharge (m³/s) in each grid cell within the RB. This is likely to significantly over-estimate water availability (and under-estimate resource competition) as it assumes that all water at any flow rate at any time of the year is available for abstraction. However, the environmental needs of water are included within the seasonal water availability indicators.

Source: ClimWatAdapt

Figure 26: Water Exploitation Index, as an indicator or water resource competition, for different time slices and socio-economic scenarios with ensemble median climate
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Currently this indicator suggests that only RBs in Scandinavia and selected catchments across mid Europe are under low resource competition. Most RBs are under medium water resource competition with selected catchments in England, Benelux, Southern Spain, Italy and Greece under severe water resource competition. Under the Sustainability Eventually scenario, water resource competition is likely to decrease with time so that only a few RBs in England, Southern Spain, Italy and Greece under medium or severe water resource competition. Under the Economy First scenario, water resource competition tends to increases with time, so that by the 2050s it is apparent that most of Europe (with the exception of Scandinavian countries, Republic of Ireland, parts of the United Kingdom, and some areas of the Baltic) are experiencing medium or severe water resource competition.

The WEI+ indicator is currently being developed to overcome some of the limitations of the WEI indicator. WEI+ is formulated as follows:

\[ \text{WEI+} = \frac{(\text{Abstractions} - \text{Returns})}{\text{Renewable Water Resources}} \]

The WEI+ indicator is not being used within ADWICE. Although the environmental needs should be conceptually considered in the WEI+, the available guidance suggests that they should be left out of the WEI+ formula itself (due to the absence of a harmonised and comparable method for calculation) and considered instead in the definition of the relevant thresholds. However, agreed thresholds for the WEI+ do not currently exist\(^2\).\(^3\)

3.2.3 Description of indicators of changing seasonality

3.2.3.1 Changes in Headroom

This index is regularly used in water resources management planning. It reflects the difference between the water available for use (including water imports and exports) and demand (dry year annual average unrestricted demand) (Dessai and Hulme, 2007). Given the availability of data, here headroom is calculated as the difference between water availability and water withdrawals within the RB. Given the important seasonality of both supply and demand, changes in headroom in the winter and the summer are considered:

- **Summer**—summer water abstractions pose the greatest pressure on drinking water resources, as water availability is low at the time of greatest demand. The difference between the summer (June, July and August) water availability from LisFlood and summer water withdrawals from domestic, electricity production, irrigation, livestock and manufacturing industry (from WaterGAP) within the RB are used as an indicator of summer water supply stress under average conditions. Figure 27 shows that a significant number of RBs in Southern Europe have negative headrooms, indicating that summer water withdrawals are greater than water availability – the difference will be provided by drawing down reservoirs and aquifers. Within the Sustainability Eventually scenario, the headroom deteriorates in a number of RBs in the 2020 before improving in the 2050 by which time only a

few RBs in Southern Europe have a negative headroom. This is in significant contrast to the Economy First scenario, where the headroom deteriorates in much of Southern, North Western and Central Europe.

- **Winter** - the availability of precipitation in excess of evapotranspiration and water demand in the winter season is important for allowing the recovery of groundwater levels in aquifers from their summer/early autumn minima and for the re-filling of reservoirs. The difference between the winter (December, January, February) water availability from LisFlood and winter water withdrawals (from WaterGAP) within the RB are used as an indicator of impact on groundwater recharge and reservoir filling. Figure 28 shows that the headroom is greater than 50% in most areas of Europe under the baseline and both scenarios, indicating the potential for significant excess-water to help refill reservoirs and recharge aquifers under average conditions. There are a small number of RBs in Eastern and North Western Europe with small winter headrooms under the Economy First scenario.

![Figure 27: Summer headroom for different timeslices and socio-economic scenarios with ensemble median climate scenario](image)

Source: ClimWatAdapt database

24 Calculated from the difference between summer water withdrawals and summer water availability, expressed as a percentage of summer water availability
3.2.3.2 Changes in Low flows/levels

Summer river flows or groundwater levels are important for the ecology or rivers and wetlands. Decreases in the future Q95 (that is the daily river flow which is exceeded 95% of the time) compared to the baseline Q95 represent increased potential stress on surface water aquatic ecosystems and are indicative of declining groundwater levels, as the Q95 flow is predominantly comprised of baseflow (groundwater). In order to maintain and improve the functions of European aquatic ecosystems, the Q95 has been proposed as a critical threshold where no abstractions out of the river should be allowed (Acreman et al., 2008). Simulated CC-induced reductions in this important threshold within abstraction licencing represent a significant concern for the sustainability of drinking water resources. Figure 29 shows the Q95 expressed in mm per day in

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25 Calculated from the difference between water availability, and total water consumption within the RB, expressed as a percentage of water availability. Water availability is defined as the difference between the total water availability and an environmental allocation based on the baseline Q95 flow

Figure 28: Winter headroom\(^{25}\) for different timeslices and socio-economic scenarios with ensemble median climate scenario
order to normalise for the very different RB areas. It shows modest increases and decreases in Northern and Southern Europe, respectively.

![Map showing vulnerability assessment](image)

**Figure 29**: The low flow Q95 (flow exceeded 95% of the time) indicator with ensemble median climate (compared to baseline)

### 3.2.4 Description of indicators of changing extreme events

In comparison to water scarcity which is based on long term averages, droughts are temporary decreases of the average water availability which can impose significant stresses on drinking water resources through, for example, enhanced aquifer over-exploitation or competition from other sectors. A decrease in the minimum river discharge with a given recurrence interval in comparison to the same recurrence interval under the baseline conditions indicates that drought severity is increasing. ClimWatAdapt provides minimum river discharges with a recurrence intervals of 10 years, 20 years and 50 years, for the flow entering the RB from upstream basins, for the runoff generated within the RB itself and for the flow leaving the RB. In Figure 30, the larger of the change...
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in river flow leaving the basin (representing the change in discharge in the main river) or runoff generated within the basin (representing the potential change in the tributaries feeding the main river) has been used.

There are very similar spatial patterns in the percentage change in minimum river discharges across the recurrence intervals for a given timeslice and between the timeslices (Figure 30). In general, these drought discharges are unchanged or increasing in Scandinavia and Eastern and Central Europe, and are decreasing in Western Europe and the Mediterranean.

Changes in the severity of floods are considered in the following sub-section.

<table>
<thead>
<tr>
<th>10 year recurrence Interval</th>
<th>20 year recurrence Interval</th>
<th>50 year recurrence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source: ClimWatAdapt database</td>
<td></td>
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</tr>
</tbody>
</table>

Figure 30: Change in the minimum river discharge with recurrence intervals of 10, 20 and 50 years for 2020s (upper) and 2050s (lower)
3.2.5 Description of indicators of changing water quality

Changing drinking water quality can arise from many factors, which have been considered within the indicator below:

3.2.5.1 Diffuse and point source pollution

Given the identified changes in low and high flows, with consequent effects on flow dilution and pollution mobilisation and transport, changes in pollution from both diffuse (predominantly agricultural) and point (predominantly urban) sources is likely to exert a significant pressure on drinking water. In the absence of modelled changes in indicators of river and groundwater quality, land cover as given by the CORINE 2000 land cover map\(^{26}\) and the changes in landcover classes under the SCENES scenarios for 2050s have been used as surrogate for water quality pressures (Figure 31). The proportions of land under the following land cover classes in each RB have been used as a surrogate:

- Intensive arable - CORINE land cover classes 2.11 (Non-irrigated arable land), 2.12 (Permanently irrigated land) and 2.13 (rice fields)
- Intensive grassland - CORINE land cover class 2.31 (Pasture)
- Urban - CORINE land cover classes 1.11 (Continuous urban fabric), 1.12 (Discontinuous urban fabric), 1.21 (Industrial or commercial units), 1.22 (Road and rail networks and associated land), 1.23 (port areas), 1.24 (airports), 1.31 (mineral extraction sites), 1.32 (dump sites) and 1.33 (construction sites).

Within SCENES, land use changes were modelled with LandSHIFT (Land Simulation to Harmonize and Integrate Freshwater Availability and the Terrestrial Environment\(^{27}\)) on the basis of CLC 2000 for the base year 2000 and the 2050s using the four SCENES socio-economic scenarios (EcF, FoE, PoR and SuE) and two different climate projections (IPCM4-A2 and MIMR-A2). Average values of landuse change for the dominant European SCENES region (Eastern Europe central, Eastern Europe Eastern, Northern Europe, Southern Europe and Western Europe) within each RB for the EcF and SuE scenarios were applied to the basin-level CLC classes, as the differences in land use between the IPCM4-A2 and MIMR-A2 driven model simulations are small.

For all regions and scenarios, an increase in “urban and settlement” area is simulated, whilst crop lands decrease (EcF shows the minor changes, SuE the highest).


3.2.5.2 Flooding

Flooding *per se* does not necessarily produce significant long-term impacts on drinking water resources, but can mobilise pollutants and inundate water abstraction/treatment plants causing short term interruptions to drinking water availability. For example, the inundation of the Mythe Water Treatment works on the River Severn in England during the 2007 floods, which normally serves a population in excess of 350,000, caused a loss of potable drinking water supplies for over two weeks and required the distribution of 6 Ml per day of bottled water - equivalent to the average daily consumption of bottled water for the whole of the UK. As such, the change in the maximum daily flow with a 100 year return period will be used as a surrogate for the flood impacts, to identify those RBs with an increasing likelihood of more intense flood events. ClimWatAdapt produced three value of the maximum daily flow with a 100 year return period, for the flow entering the RB from upstream basins, for the runoff generated within the RB itself and for the flow leaving the RB.

Source: CORINE – EEA; EcF and SuE – SCENES webservice

Figure 31: Percentage of urban, arable and pasture CORINE 2000 landcover classes within each RB for baseline (top), Economy First in 2050s (middle) and Sustainability Eventually in 2050s (lower)
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In Figure 32, the larger of the change in river flow leaving the basin (representing the change in discharge in the main river) or runoff generated within the basin (representing the potential change in the tributaries feeding the main river) has been used.

![Change in river flow and runoff](image)

Source: ClimWatAdapt database

Figure 32: Change in the maximum river discharge with recurrence interval of 100 years for (left) 2020s and (right) 2050s

3.2.5.3 Saltwater intrusion

The risk of a shift in freshwater-seawater balance due to CC is highest in summer and lowest in winter, which increases the potential for (1) the upstream migration of saline wedges / tidal limit within rivers affecting drinking water abstraction points that are close to the current tidal limits and (2) increased groundwater salinity due to saltwater intrusion into fresh groundwater within coastal aquifers.

Transitional (estuary) waters may be adversely impacted by CC due to increasing saltwater intrusion caused by sea level rise and reduced freshwater outflows from their RBs. Estuaries in Southern European rivers are particularly threatened, with the impacts likely to be greatest in the summer when river discharges are at their lowest. During the low flow season, Europe’s biggest rivers are affected, e.g. Danube, Rhine, Elbe, Tagus, and Loire (Florke et al., 2011). Figure 33 shows the ClimWatAdapt indicator of the risk of saltwater intrusion into transitional water due to sea level rise and change in river discharge.

Highly urbanised coastal areas rely in particular upon aquifers sensitive to saline intrusion for domestic water supply, and are thus highly vulnerable sea level rise may impact. Ferguson and Gleeson (2012) show that coastal aquifers are more vulnerable to groundwater extraction than to predicted sea-level rise under a wide range of hydrogeological conditions and population densities, so that human water use is a key driver in the hydrology of coastal aquifers. Only aquifers with very low hydraulic gradients are more vulnerable to sea-level rise and these regions may be impacted by saltwater inundation before saltwater intrusion (Ferguson and Gleeson 2012). Werner et al. (2012) consider that seawater intrusion vulnerability varies depending on the causal factor, and therefore...
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vulnerability composites are needed that differentiate vulnerability to such threats as sea-level rise, CC, and changes in seaward groundwater discharge.

Source: ClimWatAdapt database

Legend: yellow = low risk; orange = high risk

Figure 33: Risk of saltwater intrusion into transitional waters due to sea level rise and change in river discharge (for 50 largest transitional water in Europe) in (left) 2020s and (right) 2050s

3.2.5.4 Temperature rise

The relationship between increasing air temperatures (Figure 19 and Figure 20) and drinking water vulnerability are complex, as increasing temperatures will impact on drinking water resources and treatment in multiple ways. Water temperature will have a strong influence on a number of water quality parameters as it can change raw and treated water quality, changing the solubility and/or reactivity of a number of contaminants, particularly those that are formed in the treatment plant itself.

Algae, which can be a particular problem in raw water from lakes and reservoirs, prefer warmer conditions so issues associated with their treatment together with taste and odour problems associated with their degradation/biology are likely to increase. A study of shallow lakes ranging from subarctic Europe to Southern South America showed that, while warmer climates do not result in more phytoplankton biomass, the percentage of cyanobacteria in shallow lakes increases steeply with temperature (Kosten et al. 2012). Cyanobacteria generally grow better at higher temperatures (often above 25°C) than do other phytoplankton species such as diatoms and green algae, giving cyanobacteria a competitive advantage at elevated temperatures (Paerl and Huisman, 2008; Jöhnk et al. 2008). This is especially so when nutrient availability is high. Further, they show that CC and enhanced nutrient loading seem to work synergistically. In other words, the proportion of cyanobacteria relative to the total phytoplankton community increases with warming as well as with eutrophication (Kosten et al. 2012). Some cyanobacteria have substantially expanded their geographical ranges. For example, Cylindrospermopsis raciborskii was originally described as a tropical/subtropical genus, but appeared in Southern Europe in the 1930s and colonized higher latitudes in the late 20th century (Wiedner et al. 2007) and is now widespread in lakes in Northern
Increasing temperature also affects the efficiency and by-products of certain water treatment processes, including ozonation and chlorination. In an ozonation experiment using River Seine water, von Gunten (2003) reported that (for the same ozone dose), the degree of disinfection of bacteria and bacterial spores (such as Bacillus subtilis) is higher at lower temperatures, but is smaller for protozoa (Cryptosporidium Parvum), indicating less efficient bacterial removal but more efficient protozoa removal at higher temperatures. The volatility of chlorine will also increase with increasing temperature, so taste and odour problems may increase.

Particular problems with increasing temperature relate to the production of disinfection by-products- either formed when chlorine reacts with organic compounds in the raw or treated water or when ozone reacts with bromide to form bromate. There are clear relationships between disinfection by-product (DBP) formation and water temperature (e.g. Sohn et al., 2004; Hua and Reckhow, 2008; Roccaro et al. 2008; Von Gunten, 2003), with higher temperatures leading to increasing risk of DBP limit failures.

The effects of temperature on ozonation efficiency and BDP production can combine, with von Gunten (2003) showing decreasing activation efficiency and increasing bromate production with increasing temperature during ozonation of Lake Zurich water.

A final lesser problem is that the solubility of some metals commonly found in water sources (Al, Fe and Mn), will also increase making them slightly more difficult to remove, but removal processes also improve.

### 3.3 Deriving Potential Vulnerability

#### 3.3.1 Allocation of thresholds for Potential Vulnerability

In order to derive an overall potential vulnerability score, it is necessary to normalise the previous indicators:

- **Water resource competition** - the commonly used WEI thresholds (e.g. Raskin, 1997; Cosgrove and Rjisberman, 2000) for RBs under low (WEI ≤ 0.2), medium (0.2 < WEI ≤ 0.4) and severe (WEI > 0.4) water stress have been used;

- **Headroom** - Target headroom is the minimum buffer that should be allowed between water available for use and demand in order to account for uncertainties in supply and demand (Dessai and Hulme, 2007). Current targets for levels of headroom are around 15%, however in the future target headroom should be around 20% (Arnell and Delaney, Carnell et al., 1999). Thresholds have therefore been set for low (>20%), medium (10-20%) and high (<10%) potentially vulnerability due to headroom;

- **Low Flows** – given proposal that the Q95 should be used as a critical threshold where no abstractions out of the river should be allowed (Acreman et al., 2008), a decrease in the Q95 represents a significant concern. However, it is unlikely that no
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change in Q95 will be allowed, so proposed thresholds have therefore been set for low (> -10%), medium (-10 - -25%) and high (< -25%) potentially vulnerability due reductions in the Q95.

- **Drought** – increasing drought impacts are expected where the recurrence interval for a given minimum flow decreases- in other words that the likelihood of a given severity of drought has increased. Florke et al. (2011) suggests that a significant drought is projected if the future minimum flow with a recurrence interval of 20 years is lower than the baseline minimum flow with a recurrence interval of 50 years, and that a severe drought is projected if the future minimum flow with a recurrence interval of 10 years is lower than the baseline minimum flow with a recurrence interval of 50 years.

- **Flooding** – an increase in the maximum flow with a recurrence interval of 100 years may increase the potential impacts on water quality and water storage and treatment infrastructure, the latter depending on the level of flood protection afforded. Given the importance of site-specific factors and the absence of defined thresholds of flow increases, it has been assumed that an increase in the maximum flow with a recurrence interval of 100 years of less than 5% is not significant; an increase of 5-20% is moderate, whilst an increase of more than 20% is severe.

- **Diffuse and point source pollution** – whilst is it recognised that many factors such as soils, geology, farmer behaviour and sewage treatment standards influence water quality, diffuse and/or point source pollution of surface and groundwaters is likely to be greatest in those RBs with a high proportion of urban, arable or intensive grassland. For example, in rivers where arable land covers more than half the upstream catchment, nitrate levels are three times higher than in rivers where the upstream arable land cover is less than 10 % (EEA, 2005). A pollution vulnerability score (PVS) has been derived, based on an average of the assessments for urban, arable and pasture landcovers using the differing landcover proportions within each RB (Table 9).

Table 9: Qualitative assessment of potential pollution vulnerability according to the percentage of urban, arable and pasture landcovers within a RB

<table>
<thead>
<tr>
<th>Urban (%)</th>
<th>Arable (%)</th>
<th>Pasture (%)</th>
<th>Potential pollution vulnerability score</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 5</td>
<td>0 – 10</td>
<td>0 – 20</td>
<td>0</td>
</tr>
<tr>
<td>5 – 15</td>
<td>10 – 50</td>
<td>20 – 75</td>
<td>0.5</td>
</tr>
<tr>
<td>15 – 55</td>
<td>50 – 95</td>
<td>75 – 90</td>
<td>1</td>
</tr>
</tbody>
</table>

Although relevant for identifying drinking water potential vulnerability hotspots, it has not been possible to include the following indicators within the current assessment:
- **Temperature** – although increasing air temperature is likely to affect a number of processing influencing raw and treated drinking water quality, there are no clear thresholds for increasing vulnerability. Therefore, given that temperature is projected to increase everywhere, albeit by different amounts, it has not been possible to include this water quality factor within the vulnerability assessment.

- **Saltwater intrusion** – although saltwater intrusion is potentially important, it is difficult to derive a suitable indicator which adequately captures the spatial impacts arising from saline intrusion of coastal aquifers (Werner et al., 2012) and upstream saline migration in rivers. As a result, although ClimWatAdapt have produced an indicator of the risk of saltwater intrusion into transitional water due to sea level rise and change in river discharge, it has not been possible to include such an indicator within this component of the vulnerability assessment. However, a qualitative assessment is discussed below in the context of water stress.

The allocation of scores to each of the previously described indicators is shown in Table 10, although it must be recognised that all of the thresholds, including those based on published studies (such as for water stress, droughts and headrooms), are subjective.

### Table 10: Allocation of scores to the individual potential vulnerability indicators

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water resource competition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WEI ≤ 0.2</td>
<td></td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>Drought</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Qmin-20yr_{future} &gt; Qmin-50yr_{baseline}</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Qmin-20yr_{future} &lt;= Qmin-50yr_{baseline}</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Changes in Low flows</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>∆Q_{95} &lt; -10%</td>
<td></td>
<td>-25 &gt; ∆Q_{95} &gt; -10%</td>
<td>∆Q_{95} &lt; -25%</td>
</tr>
<tr>
<td>Summer Headroom</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;=20%</td>
<td></td>
<td>10-20%</td>
<td>&lt;10%</td>
</tr>
<tr>
<td>Winter Headroom</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;20%</td>
<td></td>
<td>10-20%</td>
<td>&lt;10%</td>
</tr>
<tr>
<td>Flooding</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>∆Q_{max-100yr} &lt; 5%</td>
<td></td>
<td>∆Q_{max-100yr} = 5-20%</td>
<td>∆Q_{max-100yr} &gt; 20%</td>
</tr>
<tr>
<td>Diffuse source pollution pressure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td></td>
<td>0&lt;PVS&lt;0.5</td>
<td>PVS≥0.5</td>
</tr>
</tbody>
</table>
3.3.2 Spatial assessment of indicators of potential vulnerability

Applying the potential vulnerability scores in Table 10 to the results presented in Figure 26 to Figure 33 yields assessments of the potential vulnerability of drinking water resources to each of the indicators. Individual illustrative resultant spatial maps are shown in Figure 19 and Figure 20 for the Sustainability Eventually socio-economic scenario combined with the hydrological outputs for the ensemble median climate scenario for the 2050s. These show that:

- **Water resource competition** – the combined effects of CC and socio-economic change on the relative balance of water withdrawals and availability results in extensive areas of high vulnerability due to either reduced availability or increased withdrawals. Areas of high potential vulnerability occur across the Mediterranean region, together with selected highly urbanised catchments in North Western Europe (Figure 34). This is likely to increase the potential risk of saline intrusion within Mediterranean coastal catchments (Figure 35), but not further enhance the risk in coastal catchments in North Western coastal catchments, where the water stress is low.

![Figure 34: Potential drinking water vulnerability due to high water resource competition (as indicated by average annual water stress)](image-url)
Vulnerability assessment

- **Summer headroom** – low summer headroom will increase the vulnerability of drinking water resources to saline intrusion and restrictions due to risk of environmental degradation. High drinking water vulnerability due to low summer headroom is found in the 2020s throughout most of Spain, Italy and Greece, and within the urbanised catchments of the UK and the Benelux countries (Figure 36). In the 2050s, the areas of high vulnerability decline under the Sustainability Eventually scenario and are confined to part of Spain, Italy and Greece. However, under the Economy First, extensive areas of the UK, France and Southern Eastern Europe become highly vulnerable. greatest in Western, Southern and South Eastern Europe.


Figure 35: Salt water intrusions into groundwater in Europe (1999)
Vulnerability assessment

Figure 36: Potential drinking water vulnerability due to low summer headroom

- **Winter headroom** – localised adverse changes in a very small number of small coastal catchments dispersed throughout North Western Europe and the Mediterranean (Figure 37). However, the larger catchments are less vulnerable due to the reduced spatial concentration of water withdrawals.
Changes in Low flows— the potential vulnerability of drinking water resources to declines in the Q95 (with the inherent risk of abstraction restrictions due to potential damage to aquatic and groundwater-dependent ecosystems) is greatest in western and Southern Europe and increase from the 2020s to the 2050s (Figure 37). By the 2050s, drinking water resources in significant areas of France, Spain, Greece, the Benelux countries are potentially vulnerable. Localised areas in the United Kingdom, Italy and Bulgaria are also potentially vulnerable.
Vulnerability assessment

Figure 38: Potential drinking water vulnerability due to changes in low flows (Q95)

- **Drought** – there is small spatial increase in the areas of potential drinking water vulnerability due to changes in the drought flows between the 2020s and the 2050s with medium potential vulnerability developing in RBs in Central and South Eastern Europe (Figure 39). There are no areas of high potential vulnerability, as given by a severe impact of drought as defined by Floerke et al. (2011).

Figure 39: Potential drinking water vulnerability due to decrease in minimum river flows due to increasing drought intensity
- **Flooding** - Figure 40 shows that potential drinking water vulnerability due to increase in the maximum daily flow with a 100 year recurrence interval will occur locally throughout Europe, although the increases are slightly spatially more extensive in the 2050s. By the 2050s, drinking water resources in much of the UK, Southern Spain, coastal France and catchments around the Adriatic Sea may experience significantly increased flood flows.

Figure 40: Potential drinking water vulnerability due to increase in the maximum daily flow with a 100 years recurrence interval

- **Diffuse and point source pollution pressure** – greatest in North Western Europe, although moderate pressures throughout remainder of Europe with the exception of much of the Nordic area. There is little spatial difference between scenarios or timeslices.
Vulnerability assessment

3.3.3 Description of vulnerability score map

The individual scores from each of the potential vulnerability indicators have been summed to give an overall impression of the potential vulnerability of drinking water resources to CC under an ensemble median climate and the two SCENES socio-economic scenarios. It has not been considered appropriate to differentially weight each of the indicators according to their perceived contribution to drinking water resource vulnerability, so each factor has been weighted equally to given an overall aggregated potential vulnerability score (Figure 42). It must be recognised a high score cannot be interpreted similarly across RBs, as the drivers will be very different - a high score indicates those RBs in which multiple factors that can contribute to overall vulnerability are affected by CC. The maps therefore indicate whether the drinking water resources are potentially vulnerable but does not indicate what measures must be taken without more information.

It is apparent that the relatively simple spatial structure of climate-change-induced changes in annual and seasonal precipitation (Figure 19 and Figure 20) are not reflected in the aggregated potential vulnerability score due to the interaction of the sensitivity and exposure components.
The figure shows that RBs tend to have higher score (indicating the contribution of either a greater number of individual indicators or higher scores for certain indicators) under the Economy First scenario than the Sustainability Eventually, with scores increasing with time (with the exception of Northern Europe). The areas with the highest potential vulnerability score are in Southern, North Western and South Eastern Europe, in particular Spain, France, Italy, Greece, United Kingdom, the Benelux countries, Bulgaria and Romania. Areas with low aggregated vulnerability scores under all timeslice-scenario combinations include Scandinavia, the Baltic countries and parts of Central Europe.

Figure 42: Aggregated potential vulnerability scores for RBs across Europe

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28 Derived from individual potential vulnerability scores for water resource competition, average summer headroom, average winter headroom, average change in low flows, changes in severe droughts, landuse pressures, change in severe flood events
3.4 Local and regional case studies

Broad scale modelling tools such as LisFlood and WaterGAP cannot incorporate the detailed response of individual drinking water resources, given the diversity of river types, groundwater bodies and reservoirs. Whilst all drinking water sources will be exposed to some degree of CC by their very nature, the potential impacts will differ according to their nature. For example, the sensitivity of a reservoir will be different from that of a river due to the buffering effects of storage, but also the sensitivity of rivers will differ depending on the nature of their catchment’s soils and geology (e.g. hard rock vs. chalk). Therefore, a typology of drinking water resources has been developed using the insights gained from the literature review, which captures the key physical factors which affect whether a CC-induced change in State leads to an impact on the drinking water resource. The typology is based upon (1) type of drinking water resource; (2) physical characteristics of the drinking water resource and (3) geographical characteristics which increase vulnerability or resilience.

3.4.1 Drinking water resources typology and illustrations

Studies identified during the literature review have been used to illustrate the differing response of the different typologies (Table 11).
<table>
<thead>
<tr>
<th>Type</th>
<th>Physical characteristics</th>
<th>Geographical characteristics</th>
<th>Vulnerability (H: high, M: medium, L: low)</th>
<th>Case study country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundwater</td>
<td>Confined aquifer</td>
<td>Coastal / island</td>
<td>H (saline intrusion)</td>
<td>Netherlands</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inland</td>
<td>L (Long lagged responses to change in recharge)</td>
<td>UK</td>
</tr>
<tr>
<td></td>
<td>Unconfined aquifer</td>
<td>Coastal / island</td>
<td>H (saline intrusion)</td>
<td>Cyprus</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inland - karstic or hard rock aquifers</td>
<td>H (Limited groundwater storage due to low primary porosity; large changes in groundwater level)</td>
<td>Czech Republic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inland - high storage aquifers (chalk, sands, etc.)</td>
<td>M (Small changes in groundwater level)</td>
<td>Belgium</td>
</tr>
<tr>
<td>Flowing water (rivers)</td>
<td>High baseflow index</td>
<td>Glacier-supported</td>
<td>L→H (Increased meltwater contribution to flow in short term, but leading to loss of storage in longer term)</td>
<td>Alps</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other types</td>
<td>L (High g/water buffering from chalk/limestone aquifers)</td>
<td>Seine (France )</td>
</tr>
<tr>
<td></td>
<td>Low baseflow index</td>
<td>Glacier-supported</td>
<td>M→H (Increased meltwater contribution to flow in short term, but leading to loss of storage in longer term)</td>
<td>Rhine watershed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other types</td>
<td>H (Low groundwater buffering from hard rock or low productivity aquifers)</td>
<td>Danube catchment</td>
</tr>
<tr>
<td>Riverbank filtration</td>
<td>River systems</td>
<td></td>
<td>L (high buffering from large river flows)</td>
<td>Rhine valley (Germany)</td>
</tr>
</tbody>
</table>
## Vulnerability assessment

<table>
<thead>
<tr>
<th>Type</th>
<th>Physical characteristics</th>
<th>Geographical characteristics</th>
<th>Vulnerability (H: high, M: medium, L: low)</th>
<th>Case study country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake systems</td>
<td></td>
<td></td>
<td>M (medium buffering from lake levels)</td>
<td>Lake Tegel (Germany) and Nainital (India)</td>
</tr>
<tr>
<td>Standing water (lakes / reservoirs)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Endorheic lake (terminal closed)</td>
<td></td>
<td></td>
<td>H (very sensitive to changes in water balance)</td>
<td>Lake Neusiedl (Austria and Hungary)</td>
</tr>
<tr>
<td>Small lakes</td>
<td></td>
<td></td>
<td>H (Low storage to cope with fluctuations)</td>
<td>Lake Bolsena (Italy)</td>
</tr>
<tr>
<td>Large lakes</td>
<td></td>
<td></td>
<td>M (Low storage to cope with fluctuations)</td>
<td>Lake Balaton (Hungary)</td>
</tr>
<tr>
<td>Small reservoirs</td>
<td></td>
<td></td>
<td>H (Low storage to cope with fluctuations)</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Large reservoirs</td>
<td></td>
<td></td>
<td>M (Low storage to cope with fluctuations)</td>
<td></td>
</tr>
</tbody>
</table>
3.4.2 Analysis of case studies

Depending on their typology, water bodies may present inherent strengths and weaknesses in the context of changing climate.

Key features likely to play on the vulnerability of water bodies include:

- Surface vs. groundwater;
- Nature and amount of inflows;
- Overall water capacity;
- Shallowness (for lakes);
- Filtration capacity;
- Proximity to saltwater.

In addition to these inherent factors, anthropogenic pressures also influence vulnerability:

- Intensity and seasonality of water abstraction;
- Design of abstraction infrastructures.

The influence of these anthropogenic factors are not developed here. They are investigated in the chapter on adaptation measures.

The vulnerability of water bodies can be assessed independently based on their physical properties. Yet, physical interactions between water bodies (e.g. unconfined aquifers, lakes recharged by inflows from rivers) and/or possible substitutions between sources of abstraction (e.g. groundwater vs. surface water) show that these various vulnerabilities may be interrelated.

The assessment of regional impacts of CC on water bodies is still subject to high uncertainties, in particular due to modelling exercises. The magnitude of these impacts is still debated in several cases (e.g. case study on the significance of CC impacts on Lake Balaton), which has implications on decisions related to adaptation and mitigation measures. However, the case studies allow better understanding the typologies and mechanisms leading to vulnerability (the detailed case studies are available in Annex 2). Based on the cases studies, vulnerability of drinking water bodies is mostly questioned in the context of decreases in precipitations associated to increased temperatures. The impact of high precipitations/water levels on water quality is rather investigated in relation to lake and river bank filtration.

3.4.2.1 Lakes

In order to understand the CC impacts on lakes, various typologies were analysed in case studies:

- Endorheic lake
- Shallow lake
- Artificial reservoir
Vulnerability assessment

A major issue regarding lakes is how they buffer fluctuations of the water level due to imbalance between evaporation and recharge capacity. Evaporation depends on:

- climatic conditions in the area, but also
- the lake shallowness and
- its thermal buffering capacity.

Recharge capacity depends on:

- direct precipitations,
- the presence of pipes or natural flows to recharge the lake and/or
- inflows intensity.

**Endorheic lakes** (e.g. Lake Neusiedl, at the Austrian and Hungarian border) are particularly sensitive to CC because their water level is only determined by precipitations and evaporation. There is no natural flows to recharge the lake and sustain the water level. **Lakes benefiting from inflows** from other water bodies present a higher buffering capacity with regard to fluctuations of water level. However, in dry periods, these lakes also have to face lower inflows due to reduced precipitations, and therefore reduced recharges which can end up impacting water levels significantly.

**Shallow lakes** (e.g. Lake Balaton in Western Hungary) are also particularly sensitive to CC because of their high evaporation potential. Because they present a better thermal buffering capacity and water capacity, **deep lakes** are less vulnerable to CC than shallow lakes. However, when these lakes are used as reservoirs (e.g. Lakes IJsselmer and Markermeer in the Netherlands) and have to face intensive abstraction to meet water demand, their overall sensitivity increases.

Impacts of CC on certain water bodies can be anticipated through historical observations. Low lake water levels, with possibly dramatic environmental and socio-economic impacts, could already be observed in dry periods (e.g. year 2003), with low precipitation patterns and high evaporation rates. The severity and duration of this phenomenon is expected to be exacerbated in the context of a changing climate. For example, in Lake Neusiedl, the return period for reaching critical lake levels for sailing has changed from around 30 years in 1961-1990 to 12 years in 1991-2004. Furthermore the sensitivity of vulnerable lakes to CC is likely to increase with the magnitude of CC (e.g. increase in frequency, magnitude and/or duration of extreme events).

The modification of water levels can have great impacts on **water supply**, in particular when the lake is used as a reservoir. For example, in the Netherlands, assuming conditions of water level regime and current land uses, in a very dry year only 70% of the water demand could be met by 2050.

Modification of water levels can also have great impacts on **water quality** and therefore on public health. This is particularly remarkable for shallow lakes, which are confronted with decreased dilution rates and increased water temperatures, and are therefore vulnerable to pollution and eutrophication. When abstraction pressures are combined with dry climate, salinisation issues also occur and may pose particular problem for the water quality of reservoirs. Lastly, low water levels can also result in reduced outflows, with direct implications on water renewal time, which is another factor making the lake susceptible to pollution. For example, in Lake Bolsena, in Central Italy, a
Vulnerability assessment

reduction of outflows from $100\times10^6$ m$^3$ y$^{-1}$ to less than $25\times10^6$ m$^3$ y$^{-1}$ was observed between, 1960 and nowadays.

Beyond impacting the amount and quality of water supplies, fluctuations of lake water levels have a range of **socio-economic and environmental implications**. In the endorheic Lake Neusiedl, a water level decrease slightly below the 2003 level$^{29}$ would drop the value added from agriculture and tourism of almost 13 Mio Euro. In case of lakes connected to other water bodies, such as lake Balaton, the possibility to manage inflows to supplement lakes and sustain water levels may allow avoiding severe socio-economic impacts. However, unless extreme events such as drought and floods occur, with deleterious effects on biota, water-level fluctuations are natural patterns that are necessary for the survival of many species and support biodiversity (e.g. lake Balaton). Supplementing lakes to sustain water levels may disturb their ecological balance (both through the limitation of fluctuations and the introduction of foreign organisms).

3.4.2.2 Water regimes in watersheds

River flows are regulated through the combination of:

- a good soil water retention capacity (the soils mostly consist of silt and quaternary clay),
- the drainage of numerous aquifers (which forms the baseline for the flows), and
- regular precipitations throughout the year.

Vulnerability of rivers to CC is strongly dependent upon their base-flow index. Base-flow consists in groundwater seepage into a stream channel. Many rivers are highly dependent on base-flow from groundwater to keep running through dry times. By impacting the processes of dilution, retention and sedimentation, river flows may have significant impact on water quality, e.g. with remarkable consequences on human health and/or ecosystems through eutrophication. Low flows increase water pollution due to agricultural practices, industrial activities and increasing urbanisation through lower dilution rates and higher residence time of the contaminants (lower speed with lower flows). On the other hand, higher flows may compensate the likely increase in nitrate concentration due to increased temperatures$^{30}$ through high dilution.

**Low base-flow index rivers** (e.g. Rhine catchment) are likely to be more vulnerable to drought in summer than **high base-flow index rivers** (e.g. Seine RB), which have higher support from groundwater to buffer water level fluctuations in dry periods. Because of this higher support from groundwater, high base-flow index rivers may however be more vulnerable to floods than low-base flow index rivers. Glacier-supported rivers, which benefit from the contribution of meltwater in summer, will show less vulnerability in summer in both cases.

The Rhine catchment, with low base-flow index, would present a high vulnerability to CC if higher temperatures and significant decreases in precipitations in summer (mostly by -10% and -30% in 2050) were not compensated in the short term by the increased meltwater contribution to the river.

$^{29}$ considered as one of the driest year

$^{30}$ e.g. because of the reduction of the nitrate reductase enzyme activity with high temperatures.
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flows. The Rhine catchment will show an increased vulnerability to CC with time because of the decrease of snow stock leading to a decreased contribution of meltwater.

High base-flow index rivers in the Upper Danube present decreasing trends in water run-off (5 to 35% in 2006 according to the GLOWA-Danube scenario) due to increased evapotranspiration and decrease of precipitations in summer. The share of snow in run-off will also lower significantly, and will disappear between 2040 and 2050. Consequently, the available water resource will become rarer. However it is not expected to be scarce. The high base-flow index river in the Upper Danube therefore present an overall low vulnerability to CC, which is however likely to increase with the decreased contribution of meltwater.

The case of the Seine river, high base-flow index river which benefits from the drainage of numerous aquifers that are regularly recharged through infiltration of precipitations, confirms the generally lower vulnerability of this typology of water bodies in case of drought. Risks of water shortages are significantly limited in dry seasons, although CC may eventually provoke severe low flows possibly requiring adaptation of dams management and design (ClimAware, 2010).

Overall, the impact of CC on high base-flow index rivers is more likely to be due to increased water temperatures (inducing bacteria development and oxygen depletion) than changes in river flows.

### 3.4.2.3 Bank filtration

Bank filtration systems, from lake and/or river present inherent advantages in the context of a changing climate. Through their thermal absorption capacity, they allow buffering changes in water temperature. They also decrease turbidity, significantly contribute to bacteria removal (e.g. Escherichia coli) and favour the sorption of metallic elements such as iron and manganese. For example, in Düsseldorf (Germany), a river bank filtration system showed a good buffering effect where river water quality was impacted during warm and low flow periods.

Although water abstracted from lake and bank filtration systems is less vulnerable to CC than other typologies of water bodies, they are still sensitive to climatic threats.

**River bank filtration** (e.g. in Düsseldorf) is particularly sensitive to higher river levels due to increased precipitations. The resulting hydraulic gradient within the aquifer was shown to allow flux of E.Coli into the aquifer, because it exceeded the removal capacity of filtration and biological processes. The case of the lake bank filtration in Düsseldorf shows that appropriate infrastructures also help mitigate the potential impacts of dry seasons (low river levels). This results in insignificant abstraction impacts, even from siphon wells, that are the most vulnerable because of their delivery heights limitation. It is to be noted that good quality from filtration systems is also partly due to river water quality contributing to the aquifer. The anticipated lower river flows/levels and warmer river temperature during the summer, and increased flooding during the winter associated with CC will make the management of river bank filtration waterworks more challenging.

**Lake bank filtration** is more threatened by surface water warming than changes in precipitation excess (e.g. Lake Tegel in Berlin and Lake Nainital in Northern India). Most infiltration occurs in the shallow zones of highest water temperature. Yet, increasing water temperatures will lead to a decrease of oxygen concentrations (due to the intensification of metabolic processes) and the probability of increased anaerobic conditions in bank filtration zone. There, self-purification is decreased and higher dissolved manganese, iron and (potentially) hydrogen sulphide
concentrations can occur because anaerobic microbial community is less effective and metabolic processes are slower. The efficiency of bank filtration systems at lakes also strongly depends on the type of deposits in the lake. A change in lake level due to CC may lead to short-term changes in lake infiltration until wave action has removed accumulated deposits. This may require the installation of additional conventional treatment to secure acceptable drinking water quality.

### 3.4.2.4 Aquifers

Aquifers present different sensitivity to CC, whether they are:

- confined/unconfined,
- low or high storage,
- coastal or inland.

**Unconfined aquifers** consist of aquifers where the water table is exposed to the atmosphere through openings in the overlying materials, with possible recharge from precipitation, artificial recharge and/or river leakage (e.g. Akroti and Kokkinochoria aquifers within the Cyprus Island; chalk aquifer located in the Geer basin in Eastern Europe; aquifer located in the Bohemian Massif in Czech Republic). The water level in a well is the same as the water table outside the well. On the contrary, **confined aquifers** are completely saturated aquifer whose upper and lower boundaries are impervious geologic units (e.g. confined alluvial multi aquifer system within the coastal Dutch Delta; confined chalk aquifer within the South East of UK). Water is held under pressure and the water level in wells stands above the top of the aquifer.

Confined aquifers will react in a slower way than unconfined aquifers, resulting in longer response time in terms of impacts, but also of reversibility of the effects.

The **storage capacity** of aquifers is another factor influencing the vulnerability of groundwater bodies to CC. The **low storage capacity** of shallow hard rock aquifers makes their groundwater levels highly sensitive to changes in atmospheric precipitations and infiltration, through changes in the amount and/or timing of groundwater recharge. Reductions in the amount of recharge or increasing seasonality to the recharge will lead to greater reductions in the thickness of the groundwater body in the recharge areas (interfluvces), away from local streams compared to in the discharge areas (e.g. valley bottoms) where groundwater levels can be controlled by the local surface water network. In the crystalline shallow aquifer in the Bohemian Massif Significant, spatial differences can be observed in water table decline of up to 10m in the recharge areas and steep slopes and only around 1m in the discharge zone. Reducing groundwater body thickness has significant implications for groundwater abstraction from wells and boreholes.

**High storage aquifers** are expected to be less vulnerable to CC than shallow aquifers, because of smaller changes in groundwater levels. The thick unsaturated zone will notably smooth out seasonal changes in percolation, making it difficult to observe any clear variation in seasonal changes of groundwater levels between the baseline and the CC simulations. In this respect, the geology also contributes to regulating recharge fluxes. In the case of the unconfined chalk aquifer in the Geer basin in Eastern Belgium, the chalk\(^3\), with an overlying loess layer controlling the

\(^3\) soft, white, porous sedimentary rock, a form of limestone composed of the mineral calcite
infiltration to the chalky aquifer, favours smoothed recharge fluxes at the groundwater table. However, significant decreases in groundwater levels in these aquifers can still be expected in the context of changing climate. In the aforementioned chalk aquifer for example, significant decrease in groundwater levels and flow rate is projected by 2041–2070 and 2071–2100, such that mean groundwater levels are expected to decrease by 2–8 m by 2071–2100. These projected declines would represent a major impact on groundwater abstraction and the requirement for a reconsideration of the groundwater extraction policy in the basin.

**Coastal aquifers** can be impacted by both CC and sea level rise. They can be highly vulnerable to saline intrusion arising from changes to the aquifer water balance as a consequence of natural or man-made changes to recharge (e.g. land subsidence), over-abstraction (such as lake reclamation and water level management) and relative sea level rise. In Cyprus, tectonic uplift is counter-acting sea level rise, so the increases in saline intrusion in the unconfined aquifer are predominantly a consequence of reduced groundwater recharge and over-abstraction. In particular, the damming of the surface waters as a response to drought represents unintended negative impacts. In confined aquifers, the propagation of future sea level rise into coastal aquifers is determined by the geo-hydrological setting. In coastal confined aquifers where the confining layer is thin and permeable (e.g. in the Dutch Delta), the effects are strongly attenuated as the increase in pressure due to sea level rise can easily be released resulting in locally high (brackish) seepage rates and also in a small zone of influence.
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Chapter 4: Policy review at EU and national levels

In brief:
The EU water policy framework rarely refers to climate change in an explicit manner, but it does consider the threats to water bodies that will be exacerbated by climate change and the recent Blueprint to Safeguard Europe’s waters considers actions in the context of climate change. In the Member States, the protection of drinking water resources currently focuses on protection against pollution and water quantity issues is given less importance for the moment, other than through allocation policies. Adaptation strategies are being set up in several countries and at EU level, and sometimes focus on water issues in particular.

4.1 Review of EU water policies

This section analyses how current European water policies integrate the risks induced by CC to drinking water resources. A more detailed assessment of each policy is available in Annex 3.

The recently published “Blueprint to safeguard Europe’s Water Resources” (EC, 2012a) and the accompanying “Fitness check of EU Freshwater Policy” provide much information on the state of water bodies in the EU and objectives of the policies. The Blueprint underlines the successes of EU water policy, including for drinking water resources, as “Europeans can safely drink tap water”. However, it does not specifically refer to drinking water in other parts of the document except in reaching Millennium development goals. The measures proposed however will benefit and help reduce issues linked to drinking water, including efficiency, preparedness to droughts, etc. The Blueprint highlights as the first of the causes of negative impacts on water status climate change, before land-use, economic activities, urban development and demographic change. It emphasises the need to adapt to CC and to take measures in the water sector, that can bring growth and associated benefits for other environmental goals (e.g. biodiversity), and increase resilience. A section is dedicated on vulnerability, especially to catastrophic natural events.

4.1.1 Water quality

The preservation and restoration of the quality of EU water bodies is covered by the Water Framework Directive (WFD, 2000), providing a common framework for the other water policies.

4.1.1.1 Quality requirements

The WFD provides quality requirements to be met (in terms of “good chemical status” and “good ecological status” which includes hydromorphological, biological and physico-chemical parameters) and states (Article 7) that water bodies used for abstraction of drinking water must also meet the Drinking Water Directive (DWD, 1998) quality requirements after water treatment. The DWD, which applies to all water intended for human consumption apart from natural mineral waters and waters which are medicinal products, requires MS to meet binding quality standards to ensure safe...
drinkable water from the tap (using microbiological and chemical parameters in addition to a set of other indicators, including radioactivity and absence of micro-organisms and parasites).

The **Groundwater Directive** (GWD, 2006) and the **Environmental Quality Standard Directive** (EQSD, 2008) are daughter Directives to the WFD, providing additional quality objectives to be implemented within the WFD rule framework. More specifically, the GWD establishes groundwater quality standards, threshold values for groundwater pollutants and indicators of pollution, and makes compulsory the reversal of trends which present a significant risk of harm to ecosystems, to human health or to uses of the water environment (Article 5.2).

### 4.1.1.2 Protection of drinking water resources

Under the WFD, bodies of water used for the abstraction of drinking water must be identified: they acquire the status of protected areas and they are consequently mapped and added to a national register of protected areas which is kept up to date and under review.

Through the implementation of the WFD, Groundwater Protection Zones can be defined so as to manage land use and human activities in catchment areas. Figure 43 gives an example of protection zones in Wallonia. Zones delineation and restrictions are however subject to variations among states. The **WHO Guidelines “Protecting Groundwater for Health”** gives a detailed account of existing options on that matter.

![Protection zones defined in Wallonia, Belgium](source: environnement.wallonie.be)

**Figure 43: Protection zones defined in Wallonia, Belgium**

The **Urban Wastewater Treatment Directive** (UWWTD, 1991) and the **Nitrates Directive** (ND, 1991) are older Directives controlling specific pollution sources, whose measures are to be integrated into those of the WFD, but are not altered by the WFD. The **Sustainable Use of pesticides Directive** (SUD, 2009) is a more recent Directive focusing on pesticides.

The UWWTD seeks to prevent potential contamination of freshwater resources with urban wastewater, by imposing urban wastewater collection and secondary treatment prior to discharge.
Moreover, it states the urban wastewater to be discharged in sensitive areas (e.g. surface freshwater intended for the abstraction of drinking water) need more stringent treatment prior to discharge.

The ND requires MS to identify water bodies that could be affected by nitrate pollution, in particular those used or intended for abstraction of DW. All zones that contribute to pollution should be designated as vulnerable zones. Action programmes for such zones shall be implemented, including measures such as prohibiting or limiting the land application of fertilizers, ensuring storage capacity for livestock manure, etc.

The SUD stresses that MS must take appropriate measures to protect drinking water supplies from the impacts of pesticides through a number of selected measures. In particular, pesticides cannot be used or stored in areas used for the abstraction of drinking water.

Vulnerable areas identified under the ND and sensitive areas identified under the UWWTD are included in the national register of protected zones created under the WFD.

4.1.1.3 Monitoring requirements

The WFD requires the protected areas to be monitored at least 4 to 12 times (depending on the size of the community served) per year. It also establishes groundwater monitoring networks so as to provide a comprehensive overview of groundwater chemical and quantitative status. The DWD makes it compulsory to MS to monitor whether the drinking water standards are complied with (providing requirements for the monitoring process) and to inform consumers and the public accordingly.

4.1.1.4 Limitations and risks

However, in the public consultation on policy options for the Water Blueprint it was noted that under CC, increasing temperatures and changes in precipitation patterns is expected to invalidate the boundary setting and the values for biological quality elements that are the basis for the definition of good ecological status.

More generally, although it provides an adaptable framework to deal with the issue (cyclical approach to RB management, etc.), the WFD does not specifically mention CC or makes provisions against its potential impacts on water quality. This is also true of the DWD and the GWD.

4.1.2 Water quantity

4.1.2.1 Existing measures

The European Commission adopted in 2009 an official Communication on Water Scarcity and Droughts (WS&D), which aims to further address expected increasing impacts of WS&D in next decades. The Communication is a non-binding text that presents a range of possible options for managing the problems of water resource scarcity and drought, and quotes a certain number of good practices existing in various countries thereby stressing that water saving must become the priority.
It also recommends drafting Drought Management Plans, provides support to establishing a European Strategy, proposes to establish a European Drought Observatory (developed by JRC in 2012) and introduces the possibility of using European funds for countries suffering prolonged droughts. It states that all possibilities to improve water efficiency must be explored, and that policymaking should be based on a clear water hierarchy: only after all water-saving and water efficiency measures have been exhausted should additional water supply infrastructures be considered as an option.

The WFD addresses some WS&D issues raised by the WS&D, such as encouraging integration of drought management plans into RBMPs and monitoring groundwater quantities. The programmes of measures for water resource management of the WF&D have to include a series of measures regarding water availability, demand management, such as abstraction controls, demand management measures, efficiency and reuse measures, etc.

Dealing with excess rather than lack of water, the Floods Directive (2007) establishes a legal framework for the assessment and management of flood risks across Member States, aiming at reducing the adverse consequences of floods to human health, the environment, cultural heritage and economic activity. The Directive requires Member States to produce the first flood risk management plans (FRMPs) in 2015 in those areas for which potential significant flood risk has been assessed. FRMPs should provide adequate and coordinated measures to reduce this flood risk, taking into account the possible impact of CC. The core elements of the flood risk management cycle are preliminary flood risk assessment, flood hazard and risk maps and flood risk management plans. In contrast to the WFD, CC is explicitly included in the Floods Directive, and Member States are clearly expected to take into account the likely impacts of CC on the occurrence of floods.

4.1.2.2 Limitations and risks

The Fitness Check of EU Freshwater policy has highlighted a number of gaps, particularly with concerns related to water quantity:

- While the WFD requires action to address water availability and tackle water demand, there is concern that quantitative objectives are not clear enough, making WS&D issues under-addressed within EU legislation. There is no consensus and no clear majorities for future regulatory action on droughts, but widespread agreement on the need for increased “soft” policy coordination. Processes such as water accounting and target setting are not explicit and cannot provide a basis for effective and targeted water protection measures.

- EU Member States enjoy considerable autonomy and flexibility with regard to issues such as adequate pricing of water use. Flexibility allows Member States to adopt measures adapted to their own specific circumstances. However, economic instruments focusing on efficiency in water supply are not widely used in Europe.

- An effective approach to better integrating water concerns into key sectoral policies is still missing, particularly with regard to increasing the efficiency of using water in agriculture and buildings. A prioritisation of competing water uses would be helpful, but is missing. Stakeholders have raised concerns that lack of EU standards on the quality of waste water intended for re-use in agriculture is a
potential gap in the EU policy framework that may inhibit its wide use (as would EU standards for use of sludge products).

4.1.3 Climate change adaptation

Although CC is not explicitly included in the text of the WFD, the step-wise and cyclical approach of the WFD RB management process makes it well suited to handle CC (EEA Technical Report on CC and Water Adaptation Issues, 2007\(^3\)). The guidance document RB Management in a changing climate\(^3\) claims that “CC should be comprehensively considered in the different steps of the WFD implementation and RBM planning and implementation process, such as characterisation, analysis of pressures and impacts, economic analysis, monitoring, design of the programmes of measures and the default and water body objective setting processes. Thus the second RB management plans due in 2015 should be designed to be robust to the impacts of CC and climate variability. As such, it must be ensured that measures are either flexible enough to be adjusted appropriately to changing climate conditions or that those of a fixed nature with a longer term design life incorporate climate projections in their design”. In addition, for the implementation of the Floods Directive, coordination with the implementation of the WFD is required by its Article 9 from the second cycle of the WFD RB management plans (RBMP) onwards. There is an opportunity through alignment to deliver alternative more cost-effective and sustainable catchment based approaches that deliver multiple benefits for flood risk management, WS&D management and RB management outcomes. The requirement to coordinate the two Directives therefore establishes an appropriate framework for implementation, so that differing and conflicting interests can be properly balanced and maximum synergies gained\(^3\).

Changes in precipitation pattern may also put wastewater treatment infrastructures at stress by creating capacity overloads in treatment plants and a general increase of strains on the sewerage system: while this issue is not directly addressed by the UWWTD, it specifies that treatment plants should be designed and maintained with regards to climatic conditions. However, according to the public consultation on water policies, it is also an illustration that existing instruments are unable to address climate challenges, for it does not take into account the carbon implications (energy use) of secondary or tertiary treatment and whether these may, in some instance, outweigh the environmental benefits of this additional treatment. In addition, MS do not have the infrastructure to address the issue of waste water storm overflow that could occur from an increase of extreme weather events. For an industry association, the main challenges are in relation to sewage sludge which should be pro-actively managed as a resource for energy production. The most common comment from the public consultation was that much water legislation was written before CC issues had begun to be included into policies. Consequently, there is a gap in integrating CC adaption through the existing policies. The WS&D communication and the White Paper on

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\(^3\) Ibid
climate adaptation do address CC, but the fact that these are non-binding documents is seen as a drawback by some.

Mainly concerned with scarcity and drought issues, the **WS&D communication** recommends that all possibilities to improve water efficiency must be explored, and that policymaking should be based on a clear water hierarchy, so as to tackle the impacts of a changing climate. The WS&D served as a building block for developing the CIS guidance on drought management for RB Management in a Changing Climate\(^{35}\), which was the importance of a common implementation of the WFD and the WS&D policy initiatives.

The **White Paper on CC adaptation** (2009) includes objectives and actions to increase the resilience of EU water systems. Specific emphasis is given to the proper implementation of the WFD, the Floods Directive as well as the WS&D for the delivery of adaptation with regard to water.

Table 12 presents specific water-related actions (on EU and Member State level) proposed in the White Paper, and their level of achievement:

Table 12: water-related actions proposed in the White Paper, and current implementation

<table>
<thead>
<tr>
<th>Measure</th>
<th>Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Develop guidelines and a set of tools (guidance and exchange of best practices) by the end of 2009 to ensure that CC is built into further implementation of RB Management for the WFD.</td>
<td>CIS guidance document n°24: RB Management in a changing climate.</td>
</tr>
<tr>
<td>Ensure that CC is taken into account in the implementation of the Floods Directive.</td>
<td>Required by Article 14.4 of the Floods Directive</td>
</tr>
<tr>
<td>Assess the need for further measures to enhance water efficiency in agriculture, households and buildings.</td>
<td>Several reports, see <a href="http://ec.europa.eu/environment/water/quantity/building_blocks.htm">ec.europa.eu/environment/water/quantity/building_blocks.htm</a></td>
</tr>
<tr>
<td>Explore the potential for policies and measures to boost ecosystem storage capacity for water in Europe.</td>
<td>Special issue on NWRM in <em>Science for Environment Policy</em> (May 2012).</td>
</tr>
<tr>
<td>JRC study on the evaluation of effectiveness of NWRM.</td>
<td></td>
</tr>
<tr>
<td>Look for possibilities to deliver adaptation actions which deliver multiple-benefits for flood risk management, water scarcity and drought management and RB management through better alignment of planning and implementation and catchment based approaches.</td>
<td></td>
</tr>
<tr>
<td>Establishing a Clearing House Mechanism as a database</td>
<td>Adaptation measures databases:</td>
</tr>
</tbody>
</table>

\(^{35}\) *Tbid*
Several respondents to the public consultation also called for acknowledging the contribution from hydropower to flood and drought protection through the RB Management Plans.

It was suggested by some respondents that an essential adaptation to CC requires having an economic approach to water scarcity by taking further steps towards recognising the value of water (which is different from the value of the service of providing water).

The WFD states that water pricing policies must take into account the recovery of water services and that in doing so MS may take into account several socio-economic, geographical and climatic conditions. CC and its consequences may therefore be appreciated when designing a water pricing policy.

### 4.1.4 Water pricing and costs

#### 4.1.4.1 Existing measures

Economic instruments are frequently used in environmental policies across Europe as complement for regulation or communication tools. Economic instruments use market price mechanisms to internalise the environmental and social costs and benefits associated with water services into the decision-making process of economic actors. Compared to traditional command-and-control instruments, their main advantage lies in their cost-efficiency and in the flexibility that they offer to polluters in achieving environmental targets.

The adoption in RB management of two strong economic principles, the Polluter Pays Principle and the principle of cost-recovery, is an important feature of the **WFD**:

- the Polluter-Pays Principle (PPP) states that the polluter should bear the cost of measures to reduce pollution according to the extent of either the damage done to society or the exceeding of an acceptable level of pollution.
- the principle of cost-recovery requires that the costs of water services be recovered by the authorities, and paid by those who cause them, in accordance with the PPP.

The costs of water services include not only operational and maintenance costs of water supply and treatment but also the costs invested in infrastructure as well as environmental and resource costs associated with damage or negative impact on the aquatic environment. The WFD calls for an “adequate contribution to the different water uses, disaggregated into at least, industry, households and agriculture”. Thus, cost-recovery calls for water services to be charged at a price that fully reflects the services provided. Together with the PPP, it forms the legal framework enabling the implementation of economic instruments in order to ensure that polluters and users pay for the natural resources they use and the environmental damages they generate.
The WS&D communication takes the same stance and notes that mismanagement of water resources is often a result of ineffective water pricing policies, which generally do not reflect the level of sensitivity of water resources at local level.

In line with this rationale, the WFD requires Member States to ensure that by 2010 water-pricing policies provide adequate incentives for users to use water resources efficiently, however it was stressed in the Fitness Check that their use is limited by the ambiguous wording of Article 9 and the definition of water services in Article 2.38 of the WFD. The principle of cost-recovery remains widely and controversially discussed, as it has not been sufficiently defined. The external costs of water services (which include environmental and resource costs) are, by nature, much more difficult to define and quantify than financial costs. A 2009 OECD study found that they are seldom reflected in water tariffs.

The Fitness Check further notes that “an adequate contribution of users to the recovery of costs of water services has not yet been achieved in many MS and progress is slow. In particular, there are concerns over the failure of the agriculture sector to pay the true price for the water it uses”. It is also feared that higher water prices may lead to illegal and unmonitored water abstraction from the agriculture sector. This would seriously impair the effectiveness of any pricing policy, as emphasized by the WS&D communication: “pricing policies that may appear to be very well designed can prove totally ineffective if most water abstraction is not even metered or registered by the authorities”.

Another issue is that of access to water and demand elasticity: although the WS&D communication states that the “user pays” principle needs to become the rule as an incentive to use water resources more efficiently, it is not clear to what extent demand management can be influenced by an increase in costs. At present, as the price elasticity of water is low, pricing structures fail to establish a clear relationship between the water used and the tariff paid. Furthermore, it is acknowledged that private households should, irrespective of their available financial resources, have access to adequate water provision.

Finally, the policy framework does not address water use rights, their duration, revision etc. This is a source of uncertainty for industry and investors.

4.1.4.2 **Limitations and way forward**

- The principle of cost-recovery remains widely and controversially discussed, as it has not been sufficiently defined. Furthermore, authorities need to be aware of the costs and benefits of measures in order to move beyond a focus on cost recovery.

- The price elasticity of water is considered low, which triggers concerns over the efficiency of increasing costs to mitigate demand, and raises the issue of equitable access to water. Moreover, rising costs increase the risks of illegal and unmetered water abstraction, especially from the agriculture sector.

- The idea of pricing ecosystem services (i.e. giving a monetary value to the services of ecological systems and to the natural capital stocks that produce them, and potentially remunerating stakeholders for the preservation of such assets) is currently under investigation.
4.2 Measures taken by Member States to protect DW resources

In the EU, Article 7 of the WFD requires MS to identify the bodies of water used for the abstraction of water intended for human protection (both current use, if they provide more than 10 m³ a day or serve more than 50 persons, and future use). The MS should monitor these water bodies and ensure they meet the criteria of the DWD. Protection shall be ensured by MS to avoid quality deterioration, in order to reduce the level of purification treatment required in the production of drinking water. Safeguard zones may be established by the MS.

The DWD defines “water intended for human consumption” as:

(a) all water either in its original state or after treatment, intended for drinking, cooking, food preparation or other domestic purposes, regardless of its origin and whether it is supplied from a distribution network, from a tanker, or in bottles or containers;

(b) all water used in any food-production undertaking for the manufacture, processing, preservation or marketing of products or substances intended for human consumption unless the competent national authorities are satisfied that the quality

The Directive sets quality standards to ensure that the quality of such water is wholesome and clean.

Several guidance documents have been produced by the Common Implementation Strategy (CIS) for the WFD, which introduce definitions and methods relevant for this section. In particular, according to the CIS guidance document on Groundwater in Drinking Water Protected Areas (DWPA):

- a safeguard zone is understood as “normally, an area within a groundwater body (designated as DWPA) that may be significantly smaller than this body, where measures can be focused to protect groundwater that is abstracted for human consumption from deterioration in groundwater quality”. In some circumstances, for example in karstic aquifers, safeguard zones may be as large as or may extend beyond the boundary of a groundwater body. Safeguard zones may also cover the whole territory of a MS (Recital 15 of Directive 2006/118/EC)

- although differences in interpretation exist across MS, for the purpose of the guidance:
  - DWPA are understood as being whole water bodies,
  - DWPAs are understood as covering actual abstraction zones (safeguard zones) and other zones of potential abstraction;
  - Protection measures are focused on safeguard zones, normally linked to existing drinking water abstractions that are at risk of deterioration. This does not rule out wider measures over the entire DPWA, if a MS wishes to provide protection, for example, to an area that is identified for future abstractions; and
As noted in the Groundwater Directive, safeguard zones may be part of a groundwater body (i.e. DWPA), may cover parts of two or more bodies, or cover the whole territory of a MS.

According to the EEA glossary, a DWPA is defined as an “Area surrounding a water recovery plant in which certain forms of soil utilisation are restricted or prohibited in order to protect the groundwater”. This limits DWPA to groundwater sources, which is not fully in line with the WFD.

The World Health Organisation provides training to help protect water bodies. For groundwater, it presents the notion of Groundwater Protection Zones, originally developed in Germany and the Netherlands, where acceptable land uses are defined in order to protect the underlying groundwater. The zones are generally defined according to the length of time a substance or organism takes to become non-harmful and the distance this represents under groundwater flow conditions. As exemplified below, this notion is much used in the EU.

This section reviews DW resources and their protection by the MS.

4.2.1 General protection measures used by the MS

- **Designation of protection areas**

Protected areas have been found to be defined quite specifically, with three zones, or more generally with reference to a protected area, notably for groundwater protection. Water protection zones can be implemented to mitigate, counteract and limit pollution of drinking water sources from a short- and long-term perspective. Regulations can specifically apply in these zones, e.g. pesticide handling or limiting certain developments. The protection is not necessarily definitive but is an important tool for protecting DW.

Where designation is quite specific, the designation of areas generally include three zones (with a fourth optional zone in some countries), called Source Protection Zones (SPZ), in which specific activities are regulated (Belgium, France, Ireland, Italy, Lithuania, Luxembourg, Slovakia, Sweden, UK, Romania; and Portugal for groundwater):

- The immediate protection area (also called inner protection zone) protects the water catchment from pollution and damage. It is often fenced and the only activities allowed are those safeguarding the water catchment or directly relating to drinking water production;
- The close protection area (also called outer protection zone) particularly ensures the protection against microbial contamination and prevents constructions or operations from damaging the groundwater flow (Luxembourg). It typically covers tens or hundreds of hectares to a few kilometres upstream for surface water catchments (France) and activities can be prohibited or regulated (e.g. in

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36 See [http://www.nzdl.org/gsdlmod?e=d-00000-00----off-ofnl2%2e%5b2--00-0----0-10-o----01-0-1-0-1-0-4--0-0-1-10-0-outfZz-8-108-a-d&c=fnl2.2&cI=CL3.71&d=HASH018718b0ccc3000030ef8f747.13](accessed 16/04/2012)
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Luxembourg industry and commerce, waste management, housing and transport, etc.);

- The broad protection area (also called source catchment protection zone) ensures the protection of raw water against chemical pollution (pollutants that are not or hardly biodegradable) and contributes to ensure the yield of the water catchment. It generally covers the rest of the RB of the water catchment and can be optional (France). Activities can also be regulated, even if the conditions are generally less stringent;

- In Sweden and the UK, reference to a fourth zone was also made, as optional and/or now merged with the other three zones.

As described for each zone, the zoning allows restricting potentially polluting activities to prevent pollution of the water bodies. In Finland and Sweden, in addition to this, a system of permits/development plans has been found to be used to further protect the areas. In Finland, the activities potentially harmful to groundwater are limited in areas important or suitable for water supply through the environmental permit decision, which may impose conditions and establish a supply buffer zone. Voluntary arrangements or plans to protect groundwater have also recently become customary for local authorities and waterworks. In Italy, the legislation considers safeguard areas, divided into absolute conservation and respect zones (these can be further divided into restricted and wider respect zones, according to the kind of withdrawal operations and to the vulnerability and pollution risk of the water resource considered). The absolute conservation zone roughly corresponds to the “immediate protection area” mentioned above and, according to the Italian legislation, has to have a radius of at least 10 m from the withdrawal point in the case of groundwater and, where possible, in the case of surface water. The respect zone is the area immediately surrounding the absolute conservation zone and corresponds to the “close protection area” mentioned above; it must have a radius of 200 m from the withdrawal point, unless otherwise specified by the local authorities. The wider respect zone corresponds to the “broad protection area” mentioned above and is optional. Underground transit time of water particles are often considered when adjusting these zones (e.g. in Romania, 20 days for the immediate protection area and 50 days for the close protection area).

In Sweden, in addition to the zoning, development plans in the protected zone are then subject to a number of conditions that may vary depending on the local situation, hydrogeological conditions, etc. The presence of a water protection zone means that the risks for water pollution need to be evaluated for any exploitation within the zone during the development planning step. Areas of national interest for water supply can be defined, but none has been designated so far.

In other countries, the system of three zones is not as clear, but protection zones are implemented (Denmark). By August 2011, a 25-meter spray protection zone was made compulsory in Denmark around all drinking water wells for public water utilities. Municipalities can decide on stricter measures where relevant.

Protection zones are specifically effective to control diffuse pollution, while permits and other measures (e.g. see below additional measures identified in Sweden and Finland) are more relevant for point-source pollution.
According to the Koiva RB management plan (Estonian Ministry of the Environment, 2010), the purpose of sanitary protection zones of water intakes is to prevent deterioration of the quality of used drinking water and to protect the water intake constructions. The width of a sanitary protection zone of groundwater intake depends on the level of protection of the used aquifer and the volume of abstracted water, and can be from 10 meters to 50 meters (exceptionally up to 200 m) from the water abstraction point. For example, the water intakes in the Koiva RB district do not have sanitary protection zones wider than 50 m. The majority of water intakes (80 bore wells) have a sanitary protection zone of 30 meters; five wells have a sanitary protection zone of 50 meters. A sanitary protection zone is not ensured in a few isolated cases (the border guard station of Vastse-Roosa).

In Bulgaria, areas for the abstraction of water for human consumption (sanitary protection zones) have been designated between 2001 and 2006. For sanitary protection zones around rivers, the zone I covers a portion of the river on a minimum distance of 500m above and 50m below, except for mountain rivers where the boundary is set at no more than 30 meters on both sides of the river. The boundaries of the zone II is determined depending on the degree of pollution, the purification self-capacity of the river, the type of pollutants and specific local conditions. The boundaries of zone III is set at no more than 25 000 m both upstream and on both sides of the river above the intake. In cases where there is another intake of drinking water upstream of the river, the boundaries of zone III is set to the border of zone I of the second intake. For sanitary protection zones around reservoirs and lakes, the zone I in the case of a dam includes water area of the dam to a distance of 1000m upstream from the intake and strip width of 50m from the boundary of the water body. In the case of lakes and coastline, the zone I covers 50 meters wide on all sides, measured at the highest water level. The boundaries of zone II are determined depending on the self-purification capacity of the reservoir or lake, and on the quantitative and qualitative characteristics of water flow in rivers and surface runoff from adjacent areas. The boundaries of zone III is defined as for sanitary protection zones around rivers, and include the catchment areas of the collection dam and flowing rivers in them. Along the lake or pond provides band width of 200 meters, which are designed anti-erosion (Bulgarian Minister of Environment and Water et al., 2000).

In Slovenia water protection areas are defined according to the Rules on criteria for the designation of a water protection zone (Uradni list Republike Slovenije, 2004). Drinking water protection areas are divided into three areas: the wide area with a minor water protection regime (VVO-III), the core area with a strict water protection regime (VVO-II) and the narrow area with the most rigorous water protection regime (VVO-I). The wide area corresponds to the whole catchment area of the intake and is intended to ensure the long-term safety of drinking water. The water protection regime aims at ensuring an acceptable risk of harm to the water body with radioactive materials or substances which are persistent or degrade very slowly. Core zone is the area which, according to natural conditions, provides a long enough residence time, a sufficient dilution and sufficient time for water filtration. The water protection regime aims at ensuring an acceptable risk of harm to the water body with pollutants which degrade slowly. The narrow area of the closest area to the intake, in which, according to the natural resources, incur little dilution of pollutants and quickly arrives at the infiltration point. The water protection regime aims at ensuring an acceptable risk of harm to the water body with regard to microorganisms and other pollutants. According to the project CC-WaterS (2012), in the capture area only the maintenance and renovation of facilities that serve the capture are allowed. In the narrowest area (VVO-I) use of fertilisers and pesticides is forbidden.
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Public water utility is obliged to pay reimbursements to owners of agricultural land in VVO-I. Paying of reimbursements started in 2010.

In Romania, the zones are called respectively Sanitary protection area with severe regime, Sanitary protection area with restriction regime and Hydrogeological protection perimeter and adjustments take into consideration the local, natural, and anthropic factors: the geomorphological, geological, tectonical, geotechnical and local hydrogeological area characteristics, the punctual and fuzzy sources of pollution, and other aspects in the area. In the case of spring catchments, a minimum of 50 meters upstream and 20 meters laterally to the catchment will be required for the sanitary protection area with severe regime, and the hydrological protection perimeter will be adjusted based on detailed analyses of the hydrogeological situation. In the case of wells exploiting confined aquifers, the sanitary protection area with severe regime coincides with that with restriction regime, and is defined, as a 10 meters radius circle. In that case the hydrogeological protection perimeter is defined for all catchments exploiting the same aquifer structure. Sanitary protection areas are established for constructions and plumbing connected to pumping stations, purification ones and water conduction (Radu et al. 2009).

- **Time dimension**

In France, protection areas must be designated around water catchments used for the production of drinking water, current and future. These protection areas are designed to protect water resources against pollution likely to make the water unsafe to drink (mostly occasional and accidental). Areas can be distinguished between areas where stricter targets are set to reduce the processing required for the production of drinking water (areas of current interest), and areas to be conserved for their use in the future for the production of drinking water (areas of future interest).

In the Netherlands, future areas are not mentioned in any of the four RBMP (Meuse, Rhine, Ems and Scheldt).

At this stage, Luxembourg has only designated temporary drinking water protection areas.

### 4.2.2 Measures taken for certain types of water bodies

- **Groundwater**

As seen above, the main policies are implemented to foster groundwater protection.

A guide for the designation of groundwater protection areas used for drinking water production has been published in Luxembourg in March 2010 (AGE, 2010). The guidance further explains the objectives and definition criteria for the three protection areas defined (see general section). Similarly in Belgium (Brussels region) the regulation covers groundwater. In Portugal, the three zones apply for groundwater protection. They are defined, based on lithology, hydrogeological characteristics and vulnerability, but also economic aspects (Rosario de Jesus, 2001).

The Italian legislation takes into consideration not only the protection of zones currently used for the production of drinking water from groundwater, but also those that will be used for this purpose in the future.

Lerner and Harris (2009) synthesise the land-use policy instruments which affect groundwater in the UK in the following table.
4.2.3 Measures taken by specific MS

The exact definitions of DWPA and activities allowed in each area differ amongst MS. In France, the areas are defined in the legislation. In Luxembourg, a guide further specifies how the areas should be delimited and what activities are allowed in each area for groundwater.

In Belgium (Brussels area), the regulation covers groundwater and defines the method, which is directly dependent on flow time. Flow times are also used for the designation in Sweden, UK and for the close area in Luxembourg.

The designation process differs across RBs. For example in France, in the Rhône Méditerranée Corse RB, the process involves two steps, with a pre-designation and a final designation, while in the Adour-Garonne RB, another rating is used (see Box 1).
Box 1: Designation process for DWPA in the Rhône Méditerranée Corse RB and in the Adour-Garonne RB

<table>
<thead>
<tr>
<th>Rhône Méditerranée Corse RB (Agence de l’eau Rhône Méditerranée Corse et al., 2010)</th>
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<tbody>
<tr>
<td>Areas of current interest are areas in which water resources are already heavily used and its alteration would pose immediate problems for the people who depend on it. The pre-designation is based on two criteria: the catchment serves more than 5 000 people (based on 150 litres/day/inhabitant) and a community depends on this catchment for more than 80% of its consumption. Catchments drawing more water than required to satisfy a population of 50 000 people (based on 150 litres/day/inhabitant) are automatically pre-designed, regardless of the second criterion.</td>
</tr>
<tr>
<td>Areas of future interest are areas in which the water resources are currently low or unsolicited but have strong potential. The pre-selection is based on four criteria: the potential of the alluvial aquifer, the land use, the water quality of the alluvial aquifer, and the intrinsic vulnerability of the resource. Each criterion is weighted according to its importance. The criteria “potentiality” and “land use”, predominant in case of new drilling, have a coefficient of 2, while the criteria “water quality” and “vulnerability” have a coefficient of 1. Four classes were defined for each criterion, with a rating between 0 and 3. Therefore, each area has an overall score ranging from 0 to 18. The rating 0 for a criterion leads to the immediate elimination of the area. The criterion that will probably be most affected by CC are “potential” and “water quality”.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Adour-Garonne RB (Agence de l’eau Adour Garonne et al., 2007)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The selection of DWPA in 2007 was based on four quantitative criteria, rated 1 or 0, for each water body. A rating of 1 is given if the water body provides more than 30% of the water withdrawn volume in a department (NB there are 101 departments in France) for the production of DW (surface and groundwater), if it is unique, if it has a residual potential, and if it will be usable in the future. Otherwise, each criterion is rated 0. Therefore, each water body has an overall rating between 1 and 4. Water bodies with a rating superior to 1 are pre-designated.</td>
</tr>
<tr>
<td>Areas of current interest and areas of future interest are distinguished thanks to a qualitative criterion: the 2015 “good status” objective of the EU Water Framework Directive. Pre-selected water bodies with a good status are designated as areas of current interest and the other are designated as areas of future interest.</td>
</tr>
</tbody>
</table>

In the Netherlands, the register of protection areas for the abstraction of human consumption water consists in two maps, one for surface water bodies (direct and via bank filtrates) and the other for groundwater bodies (public drinking water and food industry). (Ministerie van Verkeer en Waterstaat et al., 2009a, Ministerie van Verkeer en Waterstaat et al., 2009b, Ministerie van Verkeer en Waterstaat et al., 2009c, Ministerie van Verkeer en Waterstaat et al., 2009d).

Northern Europe

The Danish Nature Agency (NST) is presently mapping and identifying certain groundwater areas used for drinking water production where there is a need for extra protection measures. When such an area is identified, affected municipalities will be informed, and required to present a draft action plan for the area. Groundwater is also protected through Pesticide action plans, since soils are relatively densely cultivated.

In Lithuania, the areas are called sanitary protection zones and belts around wellfields and individual borewells are designated to protect groundwater sources against pollution, as well as to ensure the safety and quality of groundwater supplied to customers (three belts, as identified in the general section). The sanitary protection zones must be defined for water bodies with the same
Policy review

thresholds as defined in the WFD, i.e. wellfields supplying more than 10 m³ a day as an average or serving more than 50 persons (AAA & LGT, 2010d).

In Latvia, the territory was divided into 16 groundwater bodies (GWB), 11 of which are transboundary and 4 of which are located in the area of several RB districts. Most (14) of the GWBs are hydraulically related to surface water bodies – mainly to the rivers Venta, Gauja and Salaca. These are Devonian artesian waters or, in other words, confined groundwaters, which are the main source of centralised drinking water supply in Latvia. Overall, quantities available significantly exceed amounts of water abstracted. In order to protect these water resources, protection zones were established around the water intakes. In Riga, the centralised water supply system also uses water artificially recharged (into groundwater aquifers) from the lake Baltezers and water from the river Daugava. The Daugava RBMP defines drinking water abstraction sites as water sources where water withdrawal exceeds 10 m³/day, and stipulates that there are about 1,200 such sites in the districts. For these sites, “strict regime zones” and “chemical protection zones” are designated. In “strict regime protection zones”, any economic activity is prohibited, except those connected with water extraction. In “chemical protection zones”, an environmental impact assessment is required before starting any new activity. The designation of “bacteriological protection zones” is not needed for most abstraction sites because of a good protection of artesian groundwaters against bacteriological pollution. However, the Riga Water municipal enterprise has designated bacteriological zoning for the shallow groundwater abstraction sites at Balterzers, Rembergi and Zakumuiza (Latvian Ministry of the Environment, 2003). Overall, the Environment Ministry estimates that drinking water resources are well protected against potential pollution (VARAM, 2009).

North Western Europe

In Ireland, water sources which must be replaced or upgraded, or where operational practices should be improved are listed in a Remedial Action List (RAL). The criteria for this are failure to meet certain quality standards (IE EPA, 2011).

Abstractions in the UK are currently heavily regulated through Catchment Abstraction Management Strategies (CAMS) to prevent water stresses. The abstraction licenses delivered have been evolving with the awareness of a changing climate. They are now meant to be delivered on a risk assessment basis, they are limited in time (to allow for the review of abstraction in the light of changing pressures) and can only be renewed provided the abstraction:

- is environmentally sustainable – the CAMS process will identify unsustainable abstractions and devise a strategy for dealing with them;
- has a continued justification of need – the licence holder will need to demonstrate that they still have reasonable need for water, and whether the maximum authorised quantity is still justified; and
- is an efficient use of water – this means using the right quantity of water in the right place at the right time (abstractors are expected to use water in a responsible and efficient way, and to provide evidence of this when applying for a replacement licence).

Licences can also be traded (transfer of rights to abstract water from one person to another) to optimise the allocation of water resources (UK Environment Agency, 2010).
Continental Europe

In the Czech Republic, the Ministry of Agriculture is responsible for the monitoring of private water management companies which provide drinking water to households as well as the wastewater treatment plants and the companies that manage the sewage system. The Ministry of Agriculture has created a water information system, which provides an inventory of surface and groundwater sources used for drinking water as well as information on water levels in water courses and reservoirs, and on water quality in reservoirs\(^{37}\). All the data is processed, presented and stored in the public administration information system. In addition, a register of surface water quality has been developed (physical and chemical quality parameters are measured by RB administrations); the water quality is assessed according to five different categories defined by the Czech national standard CSN 75 7221\(^ {38}\). The Czech Act on Water\(^ {39}\) requires the protection of surface water, groundwater and water which is used or can be potentially used for drinking purposes and whose average abstraction rate is higher than 10,000 m\(^3\)/year. If specific circumstances apply, the water authority may determine protected zones for water resources with abstraction rates that are lower than 10,000 m\(^3\)/year. According to the Act on Water, two types of protection zones are defined:

- First degree protection zones – which serve to protect water resources in the collection area;
- Second degree protection zones – which are designated by the water authorities to protect the quality of the water resource.

The Act on Water also determines specific spatial characteristics of the protection zones (e.g. size and other characteristics related to the protected territory). Access to the first degree protection zones it is not allowed with the exception of the persons that abstract the water. In both zones, it is prohibited to carry out any activities which can threaten the water quality. In 2011, a national directive was adopted\(^ {40}\) to ensure consistency between activities carried out by regional authorities, the capital city of Prague, and the municipal authorities and boroughs in the capital city of Prague with regard to the provision of drinking water in emerency and crisis situations. The directive calls upon relevant authorities to maintain adequate water supplies for such situations and to ensure that adequate and operational equipment is in place. The types of emergency situations considered include situations that may be caused by CC (e.g. drought, deterioration of water quality by natural events, serious damage to infrastructure).

In Slovakia, a project was launched in 2009 on the security of drinking water supply\(^ {41}\) aims to develop guidelines for water companies to carry out risk assessments and to manage water systems.

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\(^{37}\) www.voda.gov.cz


including methods to audit water systems. The Plan for the Development of Public Water Supplies and Public Sewage Systems in the Slovak Republic calls for a re-evaluation of the quality of the groundwater reserves by taking into account the possible effects of CC.

In Bulgaria, the quantity of freshwater from surface water sources used in 2003 was 6.450 million m³, while the amount of used freshwater from groundwater sources was 467 million m³. The main consumers of freshwater are industry and agriculture. The share for drinking water consumption decreased twofold between 1999 and 2003, due to higher water prices and measures taken to decrease water losses in the water supply systems (GHK, 2006).

According to the Hungarian 5th National Communication to the UNFCCC (Hungary, 2009), the measures that need to be undertaken are as follows in the hydrology field:

- indicator and monitoring systems development and formulation, to follow CC impacts on hydrology and water management, impact assessment studies preparation;
- assessment of the real constraints and potential for adaptation with special regards to utilisable water reserves and flood control;
- development of economic water usage, higher involvement of local water assets and precipitation;
- repeated measuring and assessing of water restraint potentials and surface and under-surface water reserves;
- mandatory development of detailed CC related impact assessment for significant hydrological investments;
- reduction of non-climate related impacts on hydrological reserves (land use, urbanisation, settlement policy, wastewater).

4.3 Measures taken in transboundary basins

Several agreements are in place in the EU to address transboundary water issues, including actions from UNECE, international conventions – e.g. for the Rhine (Convention on the protection of the Rhine, signed in 1999), the Danube (Danube River Protection Convention, which entered into force in 1998), etc.

UNECE is very active in actions related to water and climate change and on transboundary actions in that field. It published a “Guidance on Water and Adaptation to Climate change” (UNECE, 2009) that was developed under the Convention’ Task Force on Water and Climate in 2007-2009 and adopted by the Meeting of the Parties in 2009. It provides step-by-step advice to decision makers and water managers on how to assess impacts of climate change on water quantity and quality, how to perform risk assessment (including health risk assessment), how to gauge vulnerability, and how to design and implement appropriate adaptation strategies. In 2010, pilot projects started on adaptation to climate change in transboundary basins, with the aim to collect good practices and lessons learnt based. In April 2012, a third workshop was organised on “water and adaptation to climate change in transboundary basins: Making adaptation work”, following two workshops in previous years on the same topic. The activities have now gained international recognition for
working on the specific and often neglected aspect of transboundary cooperation in adaptation which is now receiving more and more attention from the adaptation community.

The Convention on the protection of the Rhine has the following aims: sustainable development of the Rhine ecosystem, production of drinking water, improvement of sediment quality, flood prevention and protection and help restore the North Sea in coordination with other measures. It gives a framework for cooperation to riparian States, with regular reports from the Contracting Parties to the International Commission for the Protection of the Rhine. The convention does not refer to climate change, but the Commission is active in developing knowledge about this issue in the Rhine catchment (see website42).

Danube River Protection Convention also organises cooperation on transboundary water management. Its objectives are the sustainable and equitable water management, rational use of water, control of pollution, control floods and ice hazards, control accidents impacts and reduce pollution loads of the Black Sea. Similar to the Rhine Convention, climate change is not mentioned in the Danube Convention, but the International Commission for the Protection of the Danube River implements actions in that field, including a climate adaptation strategy43 and a study on Climate Change in the Danube Basin (Mauser et al., 2012).

The Tisza countries have a long history of cooperation including the agreement on the protection of the Tisza and its tributaries in 1986 and the establishment of the Tisza Forum to address transboundary issues in 2000. Actions include coordination and information exchange.

The Albufeira Convention (2000, then 2008) establishes transboundary agreements between Spain and Portugal to promote good water status along with a sustainable, equitable and rational use of water resources between the two countries44. The convention does not mention CC nor CC adaptation needs. The question whether this is satisfactory in a changing environment remains debated (Proença de Oliveira & Veiga da Cunha, 2010).

However, the report on the review of the European water scarcity and droughts policy (EC, 2012b) reports that in international basins, a major gap still exists in dealing with water quantity. It states that “only 5% of the screened international RBMPs include co-ordinated measures for the entire international RBD to deal with WS&D”.

4.4 Adaptation strategies

In several MS, strategies for adaptation to CC are implemented, and work at international level is also under way (e.g. OECD, UNEP). They however do not necessarily consider specifically impacts to drinking water. An example of country where water is considered, even if not as a central point, is Finland. The 2009 Evaluation of the Implementation of Finland’s National Strategy for Adaptation to CC suggested that “Town planning processes will be associated with a requirement to carry out

42 The following website from ICPDR provides information on CC in the Rhine catchment: www.iksr.org/index.php?id=342&L=3&ignoreMobile=1

43 For further information, please refer to: www.icpdr.org/main/activities-projects/climate-adaptation

44 5 RBs are shared between Portugal and Spain, the Douro, Tejo, Guadiana, Minho and Lima basins.
additional investigations on adaptation to CC in particularly vulnerable areas (flood risk areas, attention to the microclimate, terrain and soil, conduction of rainwater and surface waters, construction in shore areas)”. In Finland, the water resource management sector is considered as one of the most advanced in adapting to CC. In Denmark, a Task Force for CC adaptation is in place, with a portal informing citizens, industry and municipalities, partly containing information about drinking water protection. In Portugal, the National CC Adaptation Strategy (ENAAAC) was adopted in 2010. It established nine sectoral working groups, including one dedicated to water resources: ENAAC-RH, the goal of which is to reduce the vulnerability to CC of water resources systems and dependent activities and services (i.e. water planning and management, water services, agriculture and forests, energy production, ecosystems and biodiversity, coastal zones, tourism...). In Greece the Operational programme “Environment & Sustainable Development” for 2007-2013 includes as priority axis “Protecting and managing water resources”.

Sectoral adaptation is also in place. For example, the Finnish Ministry of Agriculture and Forestry, issued in 2011 an Action Plan for the Adaptation to CC, assessing security of supply (water included), sustainable competitiveness and risk management in the future for a number of sectors. The Action plan states that measures included in water management plans and flood risk management plans are reconciled so that they support each other.³

In the UK, CC challenges are largely integrated into the UK Environment Agency water strategies and plans (UK Environment Agency, 2010). The Water Resources Strategy for England and Wales promotes for example the increase in the resilience of supplies and critical infrastructure to reduce the impacts of CC (UK Environment Agency, 2009b). In particular, the strategies for the abstraction from surface water sources and groundwater sources for a range of uses, including agriculture, industry, power generation and public water supply have been evolving with the awareness of a changing climate (UK Environment Agency, 2010).

In Latvia, a national research programme on CC Impact on the Water Environment of Latvia (KALME)³ took place in 2006-2009, which aimed to investigate how CC may influence Latvian lakes, rivers, and the Baltic Sea coast and coastal waters, and to elaborate science-based proposals to adapt to and mitigate adverse impacts. It included 9 work packages: CC impact on runoff, nutrient flows, and regime of the Baltic Sea; CC impact on the nutrient run-off in drainage basins; CC impact on freshwater ecosystems and biological diversity; coastal zone processes; bio-geo-chemical processes and primary production in the Baltic Sea; CC impact on ecosystems and biological diversity of the Baltic Sea; adaptation of environmental and local policy to CC; programme management and public outreach; and runoff extremes caused by CC and their impact on territories under flood risk. However, little has been done to date in order to use the research results as part of the development of recommendations regarding mitigation and adaptation measures (Zilans, n.d.).

At international level, the OECD works on both the issue of climate change an that of water, and has specifically devoted work during the Cancun COP 16 on water and climate change⁴⁵ and in particular reports on policy frameworks for adaptation to CC in the Water sector are available. A dedicated portal is available on UNEP’s website investigating adaptation to CC⁴⁶.

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⁴⁵ See www.oecd.org/env/climatechange/waterandclimatechange.htm
⁴⁶ See www.unep.org/climatechange/adaptation/
Chapter 5: Adaptation measures

In brief:
Several adaptation measures can be implemented in the EU but need to be tailored to the specific needs of the local level, taking into account the socio-economic context, the water bodies, the water infrastructures, etc. Many measures that are beneficial for climate change adaptation also have other environmental benefits and could be prioritised. Several projects have collated existing measures thus forming a toolbox, and a decision-tree to help decision-makers choose the best measures may be a useful next step.

5.1 Adaptive capacity and adaptation responses

“Adaptive capacity” is the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC 2007). In this respect, it is a component of the concept of vulnerability. According to the IPCC third assessment report, factors that determine adaptive capacity to climate change include economic wealth, technology and infrastructure, information, knowledge and skills, institutions, equity and social capital. It is beyond the scope of the current study to consider how society’s adaptive capacity will change over time and what could be the consequent implications for vulnerability.

ADWICE rather identifies existing or potential “adaptation responses” to address impacts on drinking water resources. Regarding drinking water, the challenges of adaptation to CC are:

- to better understand the impacts of climate change on drinking water resources,
- to ensure sufficient supply of drinking water
- to secure the quality of drinking water supplies
- to minimise the impacts of adaptation measures on the environment and on socio-economic activities.

Adaptation can be implemented through the following key strategies:

- influence the direct and/or indirect drivers of the use and degradation of drinking water resources (e.g. demand, land use);
- decrease pressures on water resources (e.g. abstraction/supply, pollution);
- modify the state of water resources (e.g. increase water availability, water quality);
- anticipate impacts (e.g. droughts and floods, low water quality);
- cope with impacts (e.g. improve water treatment infrastructures).
Adaptation measures

Amongst these key strategies, multiple approaches can be distinguished, based on (adapted from Lemmen et al. 2008):

- intent: autonomous or planned adaptation
- timing (relative to climate impact): reactive, concurrent or anticipatory adaptation
- temporal scope: short-term or long-term adaptation
- spatial scope: localised or widespread adaptation, but also
- adaptation means: technological (e.g. deepening of existing boreholes); land-use (e.g. soil management); behavioural (e.g. altered groundwater use); managerial (e.g. altered abstraction practices), policy (e.g. groundwater abstraction licensing regulations).

These adaptation responses can then be combined and tailored to the needs of specific water bodies (groundwater, rivers, riverbanks, lakes and reservoirs, etc.) and/or specific challenges of CC (e.g. water management in urban areas, sea level rise).

Whatever the approach/combination of approaches chosen, a number of principles must be kept in mind:

- Adapting to climate change is not necessarily about inventing something new, since CC is likely to exacerbate existing “non-climate” pressures, which already require corrective/adaptive actions (e.g. water abstraction). For example, reducing non-climate pressures on groundwater resources through a reduction of abstraction could increase the resilience to climate change through maintained water levels. For example, according to Estonia’s Fifth National Communication (Estonian Ministry of the Environment & Estonian Environment Information Centre, 2009), the impacts of climate change on water management are relatively small in Estonia and there is no need to implement specific measures solely because of climate change. Factors such as the rising of sea level will be solved in connection with water management plans under WFD, regional planning and construction requirements.

- Adapting for climate variability/CC within the water resources sector is not about a single action; multiple approaches at different scales need to be embedded within an adaptive management framework. These approaches need to be integrated both horizontally (cross-sectoral harmonisation of policy and practice, for example between water and land including agriculture) and vertically (across the scales of governance involved in management, from the local upwards to the national) (Holman and Trawick, 2011);

- Adaptation is a dynamic process, with strategies and management decisions that require to be updated in light of changing conditions and increased understanding (IAH, 2006);

- Water resources vary in space and time. A systemic approach is required over water resources and over their life cycle, to make best use of water, which is not necessarily available in the quantities desired at the time or place it is needed. For example, it should be recognised that increased groundwater abstraction as a
Adaptation measures

short-term response to surface-water shortages may be unsustainable in areas expected to experience an increase in drought frequency, severity or duration (Green et al., 2011).

5.2 Toolbox: identification of existing and potential adaptation responses

A number of adaptations measures to prepare and face CC have been identified. There are classified in the support Excel spreadsheet. In this section, they follow the four challenges identified above.

5.2.1 Increasing the understanding of impacts of CC on drinking water resources and of effectiveness of adaptive responses

Risk assessments and monitoring are required in order to:

- build knowledge on the response of water resources to climatic and anthropogenic pressures and develop the ability to assess changes in availability (Mukherji and Shah, 2005);
- provide scientifically-grounded basis for management and adaptation (Mukherji and Shah, 2005);
- check the validity of modelling/scenarios through empirical data; and
- eventually monitor compliance (Lange & Donta, 2005).

Cross-disciplinary research, historical observations and modelling skills are needed to assess potential direct and indirect impacts of CC scenarios on drinking water resources. Direct factors of influence include e.g. increase in temperature, modification of precipitation patterns. Indirect factors relate for example to the impact of various socio-economic scenarios on water demand, in response to CC. The identification and mapping of risks and vulnerability of water bodies to e.g. sea-level rise, temperature increase, low flows, etc., allow informing water managers on the urgency and level of ambition in taking actions. This analysis can address existing and/or upcoming risks and highlight remarkable hotspots. The investigation of costs and effectiveness of adaptation measures allows carrying out the appropriate adaptation responses, with regard to the expected impacts of CC and environmental and socio-economic contexts.

Robust adaptation measures must be effective and cost-efficient, yet minimise side-effects, promote equity, and must be technically and socially feasible within the implementation time-scale (EC, 2009).

For example, in some cases floodplain restoration-based flood mitigation approaches can have lower investment costs than building grey infrastructures (dams and dikes) and can be considered as win-win solutions in achieving objectives of the Water Framework Directive. This must however be tested before being largely implemented. Pilot investments to demonstrate advantages and/or shortcomings of such an approach are highlighted in the Integrated Tisza River Basin Management Plan. This assessment allows developing risk-based water management plans (e.g. Catchment
Adaptation measures

Abstraction Management strategy) and building risk-based infrastructures, in the context of high uncertainties surrounding climate change.

Efficient tools are needed to monitor the impacts of CC and support knowledge gathering. ONERC (2011) suggests for example to implement a reference information network to monitor the impacts of CC on groundwater, to develop an observatory of low flows at national levels, and to monitor the development of water demand through a national water withdraw bank. Optimising existing monitoring networks to gather more accurate information on meteorology, hydrology/stream flows, water temperature and other water quality standards would also allow better adapting water use to available resources.

In order to select appropriate adaptation measures to be prepared for the impacts of CC in the Danube RB, the activities agree on several preparation measures. At first, the overall vulnerability to CC should be determined. Therefore existing monitoring networks should be enlarged by further stations or observed parameters, particularly in regard to CC. The observed data are supposed to be stored in homogenous data formats and then exchanged within the DRB. Based on these observations, information systems, forecasting and early warning systems should be implemented in different water related fields, e.g. floods, droughts or water quality. There is also a common agreement in the activities on the demand for further research to identify knowledge gaps and to reduce the uncertainty (which cannot be totally avoided). Education, trainings and information campaigns should be carried out to raise public awareness. This also includes capacity building and strengthening the exchange among institutions on local, regional, and transboundary levels (Mauser et al., 2012).

Lastly, improved communication and information sharing would allow strengthening the awareness and warning capacity about the status of aquatic environments and water availability. In this context, Early warning systems (EWS) could be further developed and generalised. Capacity building programmes could also be promoted to switch from “trial-and-error” approaches to training and exchange of expertise.

5.2.2 Ensuring sufficient supply

Adaptation responses to ensure sufficient supply can be considered from the demand-side or the supply-side. They are closely related to adaptation responses targeting water quality.

<table>
<thead>
<tr>
<th>Target</th>
<th>Adaptation measures</th>
</tr>
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<tbody>
<tr>
<td>Demand-side</td>
<td></td>
</tr>
<tr>
<td>Supply-side</td>
<td></td>
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<tr>
<td>Drivers</td>
<td>Monitoring demand</td>
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<td></td>
<td>Regulating demand:</td>
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<td></td>
<td>• Regulating consumption through restrictions (e.g. licensing)</td>
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<td></td>
<td>• Awareness raising</td>
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</tbody>
</table>

Table 14: Adaptation measures to ensure sufficient supply of drinking water
Adaptation measures

<table>
<thead>
<tr>
<th>Target</th>
<th>Adaptation measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand-side</td>
<td>Supply-side</td>
</tr>
<tr>
<td>• Pricing policies</td>
<td>• Promoting infiltration and retention: limiting soil sealing and compaction</td>
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<tr>
<td></td>
<td>• Diversifying sources of supply: use of alternative water sources; reuse; recycling</td>
</tr>
<tr>
<td>Pressure</td>
<td>• Increase water efficiency / Water savings</td>
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<td></td>
<td>• Increasing winter storage capacity</td>
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<td></td>
<td>• Increasing connectivity of infrastructures and boosting supply</td>
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<td></td>
<td>• Optimising and/or developing new abstraction infrastructures (New well construction; Optimisation of well operation)</td>
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<tr>
<td>State</td>
<td>• Riverbed cleaning to reduce clogging</td>
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<td>Impacts</td>
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5.2.2.1 Supply-side responses

Supply-side responses aim to increase the availability of water in order to ensure long-term supply of drinking water and cope with demand competition from other sectors (see Table 14).

Promotion of water infiltration and soil retention

Water infiltration and retention allows recharging groundwater bodies and keeping water available for plants\(^{47}\), in addition to limiting detrimental impacts on water quality linked to run-off and water erosion. Infiltration can be increased through:

- implementation of land use policies limiting soil sealing (ONERC, 2011), in particular in urban areas, and/or;
- implementation of agricultural practices limiting soil compaction (e.g. no tillage).

Preventive measures for ensuring the built environment is better adapted to increased precipitation can have indirect impacts on DW, both in terms of improved soil infiltration and short-term water retention on plots of land. Various measures are being implemented for example in Belgium to increase infiltration (limit on built-up areas, choice of permeable materials), especially in the

\(^{47}\) And therefore limiting irrigation needs and/or leaching.
Adaptation measures

context of flood prevention plans (Nationale Climate Commission, 2010). In Wallonia, it is notably recommended as a priority to impose regulations on construction materials which promote water infiltration in soils (Agence Wallonne de l’air et du climat, 2011).

- **Diversification of sources of supply**

The diversification of supply sources and their integration into combined systems allows responding best to situations of scarcity, by using every resource for the purposes that is more appropriate depending on its amount, regularity and reliability. Resources of different nature (e.g. surface and groundwater) indeed show significant differences in terms of variability and reliability.

In case of seasonal and/or permanent water shortages, the use of alternative water sources as well as water recycling and reuse to meet the water demand of socio-economic activities (agriculture, industry) can help ensuring sufficient supply of freshwater for drinking purposes. Potable or irrigation water can be obtained through waste water recycling, utilisation of brackish or sea water and rainwater harvesting (Lange & Donta, 2005), provided it is done with strict caution and monitored (ONERC, 2011). The introduction of alternative supply mechanisms comprises the construction and operation of desalination plants (Lange & Donta, 2005). Some sources consider that extensive desalination will be required to meet even the most basic freshwater needs of Eastern Mediterranean and Middle East countries in the 21st Century, to potentially manage CC impacts, despite the costly nature of this solution (Cyprus Institute, n.d.).

- **Increase in water storage capacity**

In a context of increased severity and duration of low flows, like in Ireland and the UK, ensuring that water supply sources and associated infrastructure (e.g. winter storage capacity) are sufficiently robust to meet future demands is a priority (Water UK, 2008; UK Environment Agency, 2005). In this respect, reservoirs are a possible option, which allow increasing storage and ensuring water supply throughout the year, therefore managing uncertainty. However, developing a new reservoir, or enlarging an existing one, is costly and usually controversial. Reservoirs have a large environmental footprint. They often involve large quantities of water being pumped into them at times of high flow, and consequently have a high ongoing energy requirement and a high carbon impact. Many reservoirs do not allow for an incremental approach to water resources planning and need to be considered alongside other supply and demand management options. As such, where reservoirs are promoted, it is important to ensure they are the most appropriate response to water resources pressures in the long term (in the context of a changing climate) and that effective water efficiency measures have been put in place first (UK Environment Agency, 2009b). ONERC (2011) also sees particular potential of reservoirs for the agricultural sector, but only after efficiency has been increased.

- **Increase in water infrastructures’ and/or water bodies’ connectivity**

Increasing connectivity of water bodies and water infrastructures allows buffering water level changes through the recharge/discharge of water bodies. It therefore improves the resilience of existing resources and provides additional security from extreme events (UK Environmental Agency, 2009). This is true in both the cases of groundwater (e.g. natural or artificial recharge) and surface water (e.g. water supplementation of lakes). For example, the water level of lake Balaton, in Hungary, was regulated through the opening of the Sió Canal to drain water surplus or to recharge...
Adaptation measures

the lake with other water sources to sustain the lake water level in case of higher evaporation than natural inflows.

- Optimisation and/or development of new abstraction infrastructures

An option to adapt to and meet an increased water demand is to optimise and/or develop new abstraction infrastructures, for example constructing new wells or improving their operation. This could also consist in replacing vertical abstraction points with horizontal/linear drains to face groundwater levels decrease. Developing new wells also allows coping with water quality issues, when existing wells are contaminated. This measure allows increasing water availability for people but does not ensure the sustainability of supply.

5.2.2.2 Demand-side responses

The following measures work directly or indirectly on DW availability, by regulating demand and/or increasing water efficiency (see Table 14).

- Monitoring demand and consumption

Monitoring consumption in general and installing individual meters in particular is necessary to identify trends and adjust consumption.

- Regulating demand

Demand and consumption can be regulated through several approaches, including:

- water allocation and restrictions
- pricing policies
- awareness raising

- Water-use restrictions and allocation strategies

Climate change adaptation will require the progressive reduction of water consumption and the reallocation of water availability to those uses that are deemed socially (and/or economically and/or environmentally) as more appropriate.

Water use restrictions, through licensing/permits and/or temporary bans, may be an efficient tool to regulate water consumption during seasonal water shortages and/or in geographic areas prone to water scarcity/drought. Already implemented in several countries (e.g. France, Finland, the Netherlands, UK), they could be increasingly necessary to anticipate and/or cope with CC impacts in the future, in particular where increases in water efficiency are insufficient.

The design and implementation of water use restrictions can be based on field records for all water abstractions for public and relevant industrial sites (Ministerie van Verkeer en Waterstaat et al., 2009-a, b, c, d) as well as monitoring/simulation data on water availability (e.g. groundwater level, surface water’s low flows). Differences in response time to the impacts of CC will have to be taken into account when implementing such restrictions. Indeed, as many aquifers have a large storage capacity and are potentially less sensitive to CC often responding more slowly and having a more substantial time lag to CC than surface water systems, there may be increasing pressure to use groundwater to reduce drought impacts (Dragoni & Sukhija, 2008).
Adaptation measures

In order to increase adaptive capacity, a proposal could be to give a time-limited status to all previously permanent abstraction licences and/or to adjust the volumes and abstraction periods to seasonal availability, in line with the principles developed in the UK. There, abstraction licences can be modified in relation to volume and abstraction period to adjust to seasonal water availability (UK Environmental Agency, 2009). The UK policy-makers also give the possibility to regulate water abstractions through compulsorily converting all permanent abstraction licences to time-limited status, in order to provide the flexibility to respond to CC (UK Environmental Agency, 2009, UK Environment Agency, 2010). In practice, drought orders to prevent irrigation abstraction might be increasingly used to protect available water resources for environmental uses and for public water supply. (UK Environment Agency, 2009b).

Revision to some of the altogether 220 regulation permits for lakes currently applicable in Finland is needed because of the upcoming changes in the timing of runoff and floods (Ministry of Agriculture and Forestry, 2011). Regulation of waters and diversion at power plants is a possible short-term action (Ministry of Agriculture and Forestry, 2011).

Linked to restrictions, allocation hierarchies are often used to decide which sectors have priority in water distribution. The hierarchy can be based on priority uses (DW), for instance to support sectors accounting for higher GDP generation and employment, but also water savings in water-intensive sectors. On the other hand, the principle of tradable quotas allows freely optimising the allocation of water amongst consumers (see e.g. Varela-Ortega et al, 2010, Mukherji and Shah, 2005). At this stage Spain is the only EU country that has implemented a trade system.

Developing sustainable abstraction management faces difficulties related to the identification and quantification of illegal abstraction, through illegal and/or unlicensed wells (Varela-Ortega et al., 2010; Mukherji and Shah, 2005). For RB shared between several MS, cross-border governance of water allocation may also need to be strengthened (e.g. identified by Agence Wallonne de l’air et du climat, 2011).

Water pricing and economic incentives

Various economic instruments can be implemented to work on water demand. Water pricing has an impact on the valuation of water and on cost-efficiency of measures (including reduced or increased payback times), and is advocated in many publications.

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49 For example, Bekesi et al. (2009) describe an adaptive Groundwater Level Response Management (GWLRM) methodology which uses groundwater storage depletion as a basis to restrict existing allocation limits in an Australian aquifer. The aim is to direct water allocation towards sustainable levels on the basis of measured trends. A GWLRM correction, equal or less to any calculated storage depletion, is applied to existing allocation limits as an interim tool towards the recovery of groundwater resources. Undesired declines in groundwater level, as might occur under CC, would result in a reduction in groundwater allocation limits, although Bekesi et al. (2009) do not indicate how these reductions might be distributed between abstractors or abstractor sectors.

50 The need to modify existing legislation to improve the preparedness for risks linked to water is recognised in Finland. Drought risks could be prevented by amending the Water Act to include provisions according to which the permits can be revised or new conditions can be imposed if drought has or can be expected to have significant harmful impacts on society which otherwise cannot be sufficiently reduced. Denmark on the opposite does not see a need for revising existing permits or regulations.

51 In adapting to CC and promoting water efficiency it is important to recognise that fixed distribution costs will remain fixed, thus water costs will not necessarily decrease with decreasing use. The Wallonia adaptation strategy for example
Adaptation measures

Subsidies can also be used to promote water savings (see Lange & Donta, 2005), through specific water tariffs or quotas. In this context, toxic subsidies, contributing to excessive water use directly or through the support of certain practices (e.g. certain cropping patterns), must be eliminated (Lange & Donta, 2005).

> Awareness-raising

Since consumer behaviour is an important part of water demand, awareness-raising has an important role to play to regulate water consumption. This may be done e.g. through the development of information campaigns to increase the water awareness of citizens and their perceived value of water (Ministerie van Verkeer en Waterstaat et al., 2009-a, b, c, d), through the installation of individual water meters, or through communicating knowledge through a public information portal (ONERC, 2011).

> Water savings and water efficiency

The WFD water hierarchy promotes water savings in all sectors and for all uses (e.g. ONERC, 2011) to prevent potential conflicts. Water savings imply either a reduction in demand and/or an increase in water efficiency. Water efficiency can be achieved through technological improvements (e.g. water-efficient devices, decision tools) and/or changes in practices (e.g. irrigation practices). Such measures can be implemented in various sectors, for example:

- in the water distribution and wastewater sectors, through leak detection and repair, dimensioning infrastructures taking into account CC;
- in the energy sector, through improved performance of existing and future power plants in terms of water withdrawal and consumption;
- in the construction sector, through use of water saving devices in new buildings, construction of water efficient buildings, promotion of water re-use, use of green infrastructures such as green roofs and renovation projects;
- in agriculture and forestry, through optimisation of irrigation (schedule, drip irrigation) as well as choice of low-water using crops and/or regulation of evapotranspiration, e.g. through optimised forest composition. For example, in Spain, the National strategy for the sustainability of irrigated areas plans to modernise around 145,000 ha of irrigated areas in Andalucía, aiming to save 383 million m$^3$ of water per year (Junta de Andalucia, 2010).

5.2.3 Secure the quality of drinking water

Measures targeting quality of drinking water can target different steps of the DPSI(R) framework. Table 15 identifies, for various adaptation measures, which steps are targeted.

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52 e.g. for DW by Ministerie van Verkeer en Waterstaat et al., 2009-a, b, c, d; Zachariadis (2010) and Lange & Donta (2005) discuss various implementation options
Adaptation measures

Table 15: Adaptation measures to secure the quality of drinking water

<table>
<thead>
<tr>
<th>Target</th>
<th>Adaptation measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drivers</td>
<td></td>
</tr>
<tr>
<td>Pressure</td>
<td>Source protection:</td>
</tr>
<tr>
<td></td>
<td>– Establishing protection perimeters, for surface and groundwater (land use zoning)</td>
</tr>
<tr>
<td></td>
<td>– Good agricultural practices in the catchment zone</td>
</tr>
<tr>
<td></td>
<td>– Industry risk management and requirements (e.g. incorporating climate change considerations into discharge licensing)</td>
</tr>
<tr>
<td></td>
<td>– Identification and remediation of contaminated soil areas</td>
</tr>
<tr>
<td></td>
<td>– Flood management</td>
</tr>
<tr>
<td></td>
<td>– Barriers to sea water intrusion in aquifers</td>
</tr>
<tr>
<td></td>
<td>--&gt; principles of Integrated planning and sound management (e.g. check building plans and other planning activities likely to have hydrological consequences).</td>
</tr>
<tr>
<td>State</td>
<td>Maintaining high water table level and minimum river flows</td>
</tr>
<tr>
<td>Impacts</td>
<td>Adaptation of water treatment processes</td>
</tr>
<tr>
<td></td>
<td>– Improving water treatment microbiological safety</td>
</tr>
<tr>
<td></td>
<td>– Ensure infrastructures’ treatment capacity</td>
</tr>
<tr>
<td></td>
<td>– Desalination</td>
</tr>
<tr>
<td></td>
<td>Construction of new abstraction wells</td>
</tr>
</tbody>
</table>

As highlighted in Table 15, measures to secure the quality of drinking water can be implemented on water:

- before abstraction, through water sources protection, maintenance of water levels, management of riverbeds;
- “during” abstraction, through the creation of new wells where water bodies are the least polluted;
- after abstraction through the adaptation of water treatment processes.

**Source protection**

CC adaptation responses in terms of source protection are not different from measures that are already implemented to cope with existing pressures on water quality. These measures could however be strengthened to cope with a possible exacerbation of these pressures in the context of a
Adaptation measures

classifying climate. Floods may increase washing of nutrients from soils, altered precipitation patterns will change the need for drainage and irrigation etc.

Source protection aims to reduce pressures on freshwater bodies so that the quality of water at the abstraction well/point meets quality standards and requires limited treatment. It mostly consists in establishing protection perimeters and restricting certain land uses on the catchment areas that can cause nutrient, hazardous substances and organic pollution. Afforestation of the catchment areas can be promoted, as well as best practices in the agricultural and industrial sectors, in order to prevent point source and diffuse pollutions. In the agricultural sector, adaptation options could include limits on the application of inorganic and organic nitrogen inputs, changes in crop types or land use, winter time plant cover, reduced tillage, well managed and sufficiently vegetated buffer zones along water courses, etc. (see e.g. Stuart et al. 2011, TEHO project results in Finland).

Measures related to flood management may also have significant benefits on water quality by avoiding run-off and water erosion. A range of adaptation responses are currently implemented, including the acquisition of temporary flood control structures for operational flood prevention cooperation between authorities as well as the reinforcement of grey infrastructures such as dikes and dams. The development of green infrastructures and restoration of natural or near-natural systems, such as floodplains, is increasingly promoted, for the multiple services provided in addition to flood control.

Source protection may also include developing barriers to sea water intrusion in aquifers and identifying and remediating contaminated sites.

Integrated planning and sound management are key principles to prevent decline in water quality (UK Environment Agency, 2005). For example, it is recommended to check building plans and other planning activities that might have hydrological consequences, e.g. in terms of run-off (e.g. in Flanders, Nationale Climate Commission, 2010).

Actions have already been taken by MS in this context, like Romania, which has developed the "Code of attitudes to climate change mitigation in agriculture", a publication that can be considered "European farmer’s Manual". The document includes recommendations for adapting agricultural technology and process-specific activities of all agricultural production to climate change, and examples of best practices that lead to emissions of greenhouse gases. At EU level, a handbook of

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53 The Danish Government’s Climate Change Adaptation Strategy for example states that there may be a ‘need for adaptation of existing regulation with a view to achieving environmental policy objectives’ and that ‘altered precipitation patterns will also change the need for drainage and irrigation’. In Belgium it is also recognised that adaptation measures to CC concerning nitrates may be needed in the future (Agence Wallonne de l’air et du climat, 2011).


55 The Danish RBMPs report that pollution of water bodies may also be related to polluting substances (nutrients, pesticides, hazardous chemicals) present in the soil from previous activities. The risk is that these substances are increasingly released to the aquatic environment with CC. RBMPs include the identification of these areas and possibly their remediation within certain land use areas, including those of interest for DW supply.

56 Procedure called “watertoets”, within the framework of the Coordination Commission Integrated Water Policy
ideas for administrations about integrating water issues in farm advisory services was developed in 2010.57

Maintaining high water table level and minimum river flows

The quantity of water is closely related to its quality through dilution factors. Maintaining high water table level and minimum river flows prevent from low chemical quality as well as salinisation (brackish river water). Connectivity between water bodies is currently considered by the Netherlands which evaluate e.g. how the release into low-flow rivers of water stored in water impoundments could improving water quality through dilution (e.g. of brackish water). For further information about adaptation responses, see section 5.2.2 on water availability.

Water treatment

Improving/developing water treatment processes/infrastructures allows anticipating or coping with a degradation of water quality at the abstraction point and/or with higher/ lower water flows in water treatment infrastructures. This can consist in:

- improving drinking water treatment microbiological safety;
- adapting water treatment capacity of infrastructures; and/or
- developing treatments to use alternative sources of water (e.g. desalination).

Box 2: Improving drinking water treatment microbiological safety

While the aim of Article 7(3) of the WFD is to reduce the level of purification treatment required in the production of DW, the possible need to adjust water treatment processes has been identified in most MS in order to comply with DW quality standards. Microbiological safety in the preparation of DW at waterworks ought to be increased, e.g. by reviewing the requirements concerning microbiological barriers in groundwater and waterworks, sampling and monitoring routines. Additional treatments for DW are however likely to be energy-intensive processes, potentially increasing greenhouse gas emissions (Water UK, 2008).

According to the project CC-WaterS (2012), comparing increase of water price because of groundwater treatment and reimbursement, it can be concluded that active groundwater protection by limitations of land use in the narrowest water protection zone (VVO-I) is more rational than unlimited land use that implies groundwater treatment (see Table 16).

Table 16: Comparison of costs for GW treatment and compensation

<table>
<thead>
<tr>
<th></th>
<th>Current price of water for standard use (€/m³)</th>
<th>Increase of price (€/m³)</th>
<th>New water price (€/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GW treatment</td>
<td>0,4963</td>
<td>0,1330</td>
<td>0,6293</td>
</tr>
<tr>
<td>Reimbursements for</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>limited agricultural</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>activities on VVO-I</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

57 See http://ec.europa.eu/environment/water/quality/good_practices.htm#handbook
Adaptation measures

- **Construction of new abstraction wells**

  Developing new wells allows coping with water quality issues, when existing wells are contaminated. This measure allows increasing water availability for people but does not allow ensuring the sustainability of supply.

5.2.4 **Minimising the impacts on the environment and socio-economic activities**

Integrated planning and sound management will be increasingly required to ensure sufficient supply of drinking water while limiting the impacts from adaptation measures. These measures may impact the environment (e.g. dams have negative impacts on biodiversity); and environmentally-friendly measures may have impacts on socio-economic activities (e.g. through restrictions of land uses and/or control of practices). In Wallonia, the adaptation strategy recommended to create a working group to improve the knowledge on the reduction of the availability of cooling water for power plants in summer. In this context, the design and adaptation of insurance schemes to anticipate impacts from extreme events, and possible water shortages (due to a lack of availability and/or quality) are investigated.

Adaptation responses seem to increasingly promote the safeguarding of ecosystem services compared to the development of grey infrastructures. Ecosystem services may reduce negative impacts from CC on drinking water resources, directly or indirectly. Measures that restore natural conditions of water systems are frequently considered beneficial for water quantity and quality. Increasing the connectivity between water bodies within a catchment enables, for example, natural dispersal processes to operate more effectively thus reducing pollutant concentrations. The re-meandering of streams raises the systems carrying capacity (additional water). The creation of riparian buffer zones improves water retention and water quality. Active floodplains provide protection from floods (Laaser et al 2009). These services may also benefit other uses than drinking water, through e.g. saving of water treatment costs, better water retention for agricultural purposes.

Beyond impacting water quality and quantity, ecosystem services also provide a range of environmental and socio-economic benefits that may offer synergies and win-win opportunities across sectors and activities (e.g. safeguarding of biodiversity; recreational purposes; etc.).

However, these measures also have drawbacks, in terms of difficulties to be implemented (e.g. restoration of wetlands may be difficult, or take a long time to be effective), reducing (short-term) economic development (e.g. is certain land-uses are banned in safeguard zones), forbidding certain uses (e.g. re-meandering does not allow navigation). The development of comprehensive risk-benefit assessments should be further promoted where trade-offs between services are unavoidable.

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58 In the Brussels Region (Belgium), the ‘blue network’ being implemented since 1999 is an integrated program for the purification and restoration of Brussels’ rivers and water bodies. It aims to restore the continuity of the hydrographic system and benefit from its ‘flood buffer’ function by recovering clean run-off water. This programme also contributes to the upgrading of rivers, ponds and wetlands in urban areas (National Climate Commission, 2010).
5.3 Tailoring sets of adaptation measures to the needs of water bodies

Section 5.2 highlighted a range of existing or potential adaptation measures, which present both advantages and shortcomings in various hydrological contexts. These measures must be combined and tailored to the needs of specific water bodies in order to adapt to climate change efficiently.

5.3.1 Surface water

The management of water levels in lakes, rivers and wetlands is frequently possible thanks to the normal and emergency water storage capacity as well as the highly interconnected nature of many European water systems. Apart from the obvious advantages for the environmental water quality, this measure influencing water levels (e.g. in rivers), can help to reduce pollution levels, avoiding to overcome relevant thresholds.

The implementation of the New Vásárhelyi Plan may provide considerable assistance to coping with the flood waves in the Tisza, the river most exposed to floods. The objective of this programme is to improve the flow conditions of flood waves, and to ensure diversion to the reservoirs and containment of the flood.

5.3.2 Groundwater

The classification of adaptation measures can be based on the different groundwater processes which they affect:

- Managing the recharge of groundwater e.g. Managed Aquifer Recharge (MAR), land use planning and land management to avoid activities or land uses which limit potential recharge (hard surfaces, afforestation) and to promote those which increase infiltration (e.g. good soil management, terracing, etc.);
- Managing groundwater storage e.g. conjunctive use of surface and groundwater to increase aquifer storage availability prior to recharge periods, MAR to maximise use of available storage capacity;
- Protecting groundwater quality e.g. managing coastal groundwater levels (through abstraction control and/or MAR), land use planning to avoid development of potentially polluting activities above vulnerable aquifers, etc.;
- Managing demand for groundwater – e.g. abstraction management and licensing controls, reducing losses in groundwater transport and inefficiencies in usage, water pricing;
- Managing the discharge of groundwater – e.g. avoiding the planting of high water use species such as short rotation willow in shallow groundwater areas.

However, whilst most of these technologies and strategies are well known and implemented in some countries, the effectiveness of these options to reduce the future vulnerability of water-
Adaptation measures

stressed areas, given the significant uncertainties in drought severity, frequency and duration, is uncertain.

Managed Aquifer Recharge (MAR) is a promising adaptation options for increasing water availability, whose use has rapidly increased in Australia, USA and Europe in recent years (Dillon et al., 2010). MAR is the purposeful recharge of water to aquifers for later recovery (or environmental benefit). MAR can be carried out using infiltration ponds in outcrop areas of unconfined aquifers or can be injected through boreholes into confined aquifers (known as Aquifer Storage and Recovery or ASR). The latter is often preferred for DW supplies in urban areas because of the protection against pollution afforded to the aquifer by the overlying aquitard. Dillon et al (2010) found that stormwater ASR could produce water supplies for less than half the cost of seawater desalination, whilst rural infiltration ponds were an order of magnitude cheaper than ASR systems. A common advantage of MAR is the use of local aquifers (including in urban areas) to capture locally produced water for subsequent local use, significantly reducing energy and infrastructure costs. Narasimhan (2010) reports on a system in the USA whereby MAR is used with conjunctive surface –groundwater management - artificial recharge structures are used to store underground surplus surface water during wet years. Groundwater extraction, which is normally restricted, is increased as needed during dry years to compensate for lower surface water flows. Hrkal et al. (2009) recognise the difficulties of adaptation within shallow aquifers in hard rocks, but suggest a combination of measures would help:

- Increasing the efficiency of groundwater abstraction through replacing vertical abstraction points (such as wells and boreholes) with horizontal/linear drains. These can be a simple yet efficient methods of withdrawing groundwater flowing within a shallow sub-surface zone in hard rocks, with the drain laid perpendicular to the groundwater flow;
- Increasing recharge from surface water courses, through decelerating streams that have previously been regulated by restoring meanders and improving the river/aquifer connection;
- Reducing evapotranspirative losses, particularly from forest, by selecting a forest composition which would produce the lowest evapotranspiration

Sea water rise could result in salt standards being exceeded. Oude Essink et al. (2010) consider a number of technical adaptation options to prevent or reduce the salinisation process in coastal areas:

- Freshwater injection barriers through injection or (deep-well) infiltration of fresh (purified sewage) water near the shoreline, though they note that this could create unwanted high groundwater heads;
- Extraction of saline and brackish groundwater, but this could lead to undesirably low groundwater heads and create problems with the disposal of the extracted groundwater without causing ecological impacts;

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59 An aquitard is a water-saturated sediment or rock whose permeability is so low it cannot transmit any useful amount of water, but does not prevent the flow of water to or from an adjacent aquifer.
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- Modifying pumping practice through reduction of withdrawal rates or adequate relocation of extraction wells;
- Land reclamation and creating a foreland where a fresh groundwater body may develop which could delay the inflow of saline groundwater; however, they report that this is ineffective, and actually causes an increased salt load to the connected surface water systems;
- Increase of (artificial) recharge in upland areas to enlarge the outflow of fresh groundwater through the coastal aquifer and to reduce the length of the salt water wedge; and
- Creation of physical barriers, such as sheet piles, clay trenches and injection of chemicals but the depth of these limits their applicability in deep aquifers.

5.3.3 River banks

There are a number of potential management options for RBF plants identified by Grischek et al. (2010), which, although not directly addressed at CC, provide adaptation potential (see Table 17 below). These include:

- Changing the land use in the catchment zone, to reduce contaminant concentrations within the groundwater component of abstracted RBF water; this includes catchment protection on the bank where the well field is located but also on the other river bank as groundwater flow can occur beneath the river
- Improvements in river water quality, to reduce contaminant concentrations within the river water
- Technical measures in the riverbed, for example river bed cleaning to reduce clogging if seasonal flood events are not able to erode the river bed and limit the clogging, or if enhanced clogging is induced by a CC-related requirement to increase water abstraction; recharge basins fed by river water is an alternative solution
- Optimisation of well operation, to maximise removal efficiency during the transport through the aquifer; this entails controlling the flow path length and travel time as well as the mixing of river and groundwater by the selection of the most suitable wells from a well field
- Building new wells to compensate for declines in production or to replace wells in order to tackle raw water quality problems related to unfavourable flow or mixing conditions between river and groundwater.
Adaptation measures

Table 17: Potential management actions for river bank filtration sites

<table>
<thead>
<tr>
<th>Management action</th>
<th>Responsible parties</th>
<th>Implications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimisation of well operation</td>
<td>Waterworks</td>
<td>Short-term; highly effective</td>
</tr>
<tr>
<td>New well construction (location, depth)</td>
<td>Waterworks</td>
<td>High capital cost</td>
</tr>
<tr>
<td>Technical measures in the river bed</td>
<td>Waterworks</td>
<td>Continuous measure; high operating costs</td>
</tr>
<tr>
<td>Improvements in river water quality</td>
<td>Environmental regulator, industry</td>
<td>Long-term measure</td>
</tr>
<tr>
<td>Changes in land use or management in the catchment zone</td>
<td>Waterworks, farmers</td>
<td>Long-term measure; ongoing costs</td>
</tr>
</tbody>
</table>

Source: after Grischek et al., 2010

5.4 Tailoring sets of adaptation measures to impacts

While the above sections classify adaptation measures in terms of their relevance for specific types of water bodies, further elements must be taken into account for tailoring the combination of measures implemented to the specific challenges posed by CC in a given area.

In order to help water managers choose the right combination of measures, a decision-tree could be developed, e.g. in the context of the CIS expert group on climate change and water. The decision-tree would include as branches for the selection at least the different aspects highlighted as important to understand the vulnerability of drinking water bodies to CC, i.e.:

- Regional impacts from CC (expected precipitation, temperature and sea level changes, leading to variations in drought, floods and other events),
- Types of water resources (surface water - flowing or standing, groundwater – confined or not, shallow or deep, hard rock or not, river bank filtration),
- Geographic and pedologic characteristics (soils, coastal area, mountains, etc.),
- Socio-economic characteristics (land-uses, state of competition for water, urban areas, etc.).

5.5 Main stakeholders implementing adaptation

Climate change has or will have significant impacts on a range of water services, in terms of quality and availability of water sources, infrastructure capacity and resilience, and water/wastewater treatment. Different stakeholders will be impacted in a variety of ways, and have different levers to implement adaptation measures.
5.5.1 EU and national decision-makers

At EU level, many research projects and service contracts have investigated different aspects of the impacts from CC on water resources, even if drinking water is generally not a specific focus, and a number of adaptation measures lists are available (from ClimWatAdapt, PREPARED, Carpivia, etc.). The Blueprint has recently underlined once more the need to adapt and to increase resilience of water bodies to CC. A Climate change adaptation strategy is also expected for Spring 2013, which should provide further guidance into these topics. While water issues and adaptation solutions are local matters, the role of the EU in sharing knowledge and best practices (e.g. through the CIS groups and best practices that can be taken out from the first RBMPs), as well as supporting the implementation of measures, including financially, is important.

At national level, many projects to investigate the national situation are also going on, with detailed information on the regional issues and what can/should be done about them. These projects are very useful to gather monitoring data and implement modelling at a relatively fine scale; thus highlighting the issues that the country is facing, and to find adequate solutions, taking into account the socio-economic context and national priorities. Similar to the EU level, best practices sharing and funding opportunities for river basin level actions can be decided at national level. In addition, the national level interacts with the Commission to highlight issues and needed support.

5.5.2 River basin managers

The WFD requires the setting up of a River Basin Authority as the main body in charge of coordinating actions at the level most relevant to understand water issues. The river basin managers are at the forefront of the decisions to be made with regards to understanding risks and vulnerability, and to implement mitigation and adaptation options, to increase resilience and reduce potential impacts. Water is a local and seasonal issue, and impacts will result from CC but also from many other factors (land-use, geography, topography, soil types, water demand, economic development, competition for water, etc.), which requires detailed understanding to finetune the actions.

The RBMPs include many actions that are taken by managers to reduce the impacts from floods, WS&D, and ensure sustainable management of water in each river basin. However, better assessment of their efficiency and effectiveness is required to learn lessons and increase the adequacy of proposed actions, including when analysing the conditions for transferring measures from one basin to another.

With regard to water management, a recent paper (Pahl-Wostl et al., 2012) concludes that polycentric governance is very important and effective, i.e. having many centres of decision-making, independent but coordinated. In the practical comparison of 29 river basins polycentric governance was found to adopt good governance principles including for public participation and stakeholder engagement, equitable and water management processes, water allocation and climate change adaptation policies.
5.5.3 Scientists

The body of scientific evidence investigating the impacts from CC on water bodies is high and increasing, although papers specifically investigating impacts on drinking water are rare. In the EU, many projects have been investigating impacts from CC on water, as identified in Table 18.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Project</th>
<th>Fund</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate Change scenarios</td>
<td>PRUDENCE</td>
<td>2001-2007, FP5</td>
</tr>
<tr>
<td></td>
<td>Prediction of Regional scenarios and Uncertainties for Defining European Climate change risks and Effects</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MICE</td>
<td>FP5</td>
</tr>
<tr>
<td></td>
<td>Modelling the Impacts of Climate Extremes</td>
<td></td>
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<tr>
<td></td>
<td>ENSEMBLES</td>
<td>2004-2009, FP6</td>
</tr>
<tr>
<td></td>
<td>Ensemble prediction system for CC based on the principal state-of-the art, high resolution, global and regional Earth System models developed in Europe</td>
<td></td>
</tr>
<tr>
<td>Climate Change impacts on the aquatic environment and water cycle.</td>
<td>EURO-LIMPACS</td>
<td>2004-2009, FP6</td>
</tr>
<tr>
<td></td>
<td>Impacts from Global Change on European Freshwater Ecosystems</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CIRCE</td>
<td>FP6</td>
</tr>
<tr>
<td></td>
<td>Climate change and Impacts Research: the Mediterranean Environment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SCENES</td>
<td>FP6</td>
</tr>
<tr>
<td></td>
<td>Water Scenarios for Europe and for neighbouring States</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WATCH</td>
<td>2007-2011, FP6</td>
</tr>
<tr>
<td></td>
<td>Hydrological, water resources and climate communities will analyse, quantify and predict the components of the current and future global water cycles and related resources states</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ACOWA</td>
<td>FP7</td>
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<td>Water availability and Security in Southern Europe and the Mediterranean</td>
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Scientists have an important role to play in terms of increasing our understanding of the impacts from CC on water bodies, but also integrating future changes in land-use and demand for water to increase our preparation to possible impacts. Research into the effectiveness of adaptation measures and the conditions in which they are most successful will be beneficial to all stakeholders that wish to implement such measures. Increasing exchanges between science and both policy-makers and decision-makers at all levels will ensure that latest scientific results are taken into account in policy-making/decision-making, that results are interpreted soundly, including taking

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<td>ClimWatAdapt</td>
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<td>Climate Adaptation – modelling water scenarios and sectoral impacts</td>
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<td>Climate change integrated assessment methodology for cross-sectoral adaptation and vulnerability in Europe</td>
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<td>Climate Water</td>
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<td>Study on European and international adaptation measures and strategies related to CC impacts and on how these are taken into account in water policies</td>
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<td>PREPARED</td>
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<td>Adaptation of water supply and sanitation systems to cope with climate change.</td>
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Adaptation measures

into account uncertainties and assumptions made, and that scientific research provides answers to questions from policy-makers/decision-makers.

5.5.4 Water utility companies and mineral water businesses

The water industry (including water utilities and mineral water businesses) is increasingly aware of related challenges and is a key actor impacted by CC. To provide an appropriate strategic response to climate change, water industry may develop two parallel responses:

- Strategies for climate change mitigation, including mitigation of CO2 equivalent emissions;
- Strategies for climate change adaptation.

In addition, water companies may implement actions voluntarily, as a way of securing their business, or to answer a regulatory requirement, as is done in the UK (see Box 3).

Box 3: UK water resource management plans

From 2007, all water companies in the UK have to prepare water resource management plans which look ahead 25 years and show projections of future demand for water, and how the companies aim to meet this demand. These plans aim to secure a long-term sustainable supply and demand balance for the supply of water.

These plans must namely address how the supply and demand forecasts have taken into account the implications of climate change. Based on the Water resources planning guideline, water companies must include clear information about:

- the vulnerability of its system to climate change;
- the impacts of climate change on the supply-demand balance;
- how it calculated these impacts and the confidence levels associated with them;
- what options have been driven by climate change alone and how resilient these options are to the effects of climate change, specifically in terms of sensitivity to a different climate change outcome to that planned for;
- any future modelling proposals to improve the assessments carried out.

Concrete guidance and methodology are further detailed in sections 3, 4 and 6 of the Water resources planning guideline.

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60 For example, all companies in England and Wales identified climate change as a key challenge in their recently published Strategic Direction Statements. [www.water.org.uk/home/policy/climate-change/adaptation-briefing](http://www.water.org.uk/home/policy/climate-change/adaptation-briefing)

Climate change is also mentioned as one of the biggest challenges on VEOLIA website: [http://www.veolia.com/veolia/ressources/documents/2/21872_RA_VEOLIA_2011_FR_72dpi.pdf](http://www.veolia.com/veolia/ressources/documents/2/21872_RA_VEOLIA_2011_FR_72dpi.pdf)


Adaptation measures

In addition, it was noted that water companies, when communicating about CC and water, stress the importance of taking mitigation actions to limit the impacts of water processes on CC, such as reducing the carbon emissions from water abstraction, treatment and distribution. There is less communication on water vulnerability and on measures implemented to safeguard water quality and quantity in the context of changing climate. For example EUREAU has a position paper on Climate change mitigation, but not on adaptation. Mitigation actions namely include:

- the reduction of the carbon footprint through the optimisation of processes (in terms of water production, packaging, transport, waste management), along with the development of consistent metrics for carbon and CO2 equivalent calculations and reporting. In this context, Evian (France) claims to have reduced its CO2 emissions by 40% between 2008 and 2011;

- implementation of compensation mechanisms such as the restoration of wetlands (e.g. Evian communicates about initiatives in Ramsar sites in Thailand, Argentina and Nepal or in mangroves in Senegal) and/or afforestation (e.g. Vittel’s website highlights an afforestation project in association with PurProject in Bolivia and Peru). Veolia Environment claims to limit the impact of its desalination plants on marine environment, through a careful selection of the location of the water intake and design of outlet tunnels.

Much less information is publicly available on how risks are assessed or whether vulnerability assessments are performed and how they are incorporated into adaptation actions carried out by water businesses. Yet, some water companies claim to be taking concrete steps which contribute more or less directly to climate change adaptation, either through the strengthening of existing measures or through specific actions. Adaptation measures include:

- better understanding of the impacts of climate change: in Australia, SA Water claims to develop partnerships with research institutes to better anticipate the impact of climate change on water resources and refine water quality models, in the UK Anglian Water is working with universities to increase its understanding of CC impacts (pers. comm.);

- source protection; through restricting land uses on protected areas (e.g. Buxton water in the UK) and/or promotion of best agricultural practices (e.g. Vittel in France);

- water resource planning: climate change must now be explicitly taken into account in water resource management plans in the UK. Such plans outline how each water company plans to ensure sustainable water supplies over the next 25 years (see Box 3 above);

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63 The position paper is accessible from: eureau.org/sites/eureau.org/files/documents/2010.06.18-PP_CC_Mitigation.pdf
64 www.evian.fr/decouvrir_evian/evian_et_l_environnement/
65 www.vittel.com/fr/index.htm#dvp_durable
66 www.veolia.com/en/
Adaptation measures

- increase in water efficiency, which is now widely recognised across the water industry as an important option. For example, Suez Environment⁶⁷ claims to optimise its distribution networks, through technical services such as leakage detection, improvements of networks “yields”, etc.;

- assessment of the susceptibility of key assets and infrastructures to extreme weather events and increase of their resilience to climate change: in this respect, Water UK, a federation of water industries, published in 2007 a reference tool to help companies better consider and adapt to climate change impacts on key assets and infrastructures⁶⁸ (see Box 4 below). This work complements the UKWIR work⁶⁹, which provides a framework for water industry’s research activities in the context of a changing climate;

- support developing countries facing water scarcity to adapt: some brands stated that they carry out development actions to address water scarcity issues in third countries, like Cisowianka⁷⁰ (Poland) in South Soudan;

- promotion of sustainable consumption patterns and awareness-raising, e.g. some brands like Perrier (France) claim to promote sustainable consumption patterns through education programmes, e.g. in the context of the WET project⁷¹.

The fact that companies promote better water resources strategies and planning, shows that anticipation seems increasingly promoted in the water industry sector, in particular to secure investments in the long-term. However in practice, it is likely that a number of water businesses still develop ad-hoc adaptation measures through trial-and-errors approaches in responses to the latest observed trends. In addition, contacts made during the ADWICE study showed that modelling is on-going and that companies are seeking to find investment solutions that are resilient to CC, including through scenario planning and about the resilience to catastrophic events, e.g. from CC.

⁶⁷ www.suez-environnement.fr/eau/enjeux/preserver-ressources-eau/
⁶⁹ “UKWIR: A Programme of Research for the UK Water Industry. See www.ukwir.com/ukwirlibrary/92560
⁷⁰ www.cisowianka.pl/
⁷¹ www.projectwet.org
Box 4: Adaptation toolbox by Water UK

Water UK proposes a toolbox for water companies, including a number of adaptation recommendations in the fields of water resources management, wastewater treatment, optimisation of water and wastewater networks, sludge management and site wide services (e.g. IT, electrical supplies, buildings, security). Because adaptation is an ongoing process, which requires continued or increased emphasis and action, the proposed options correspond to three levels of ambition: capabilities\(^72\), plans\(^73\) and actions\(^74\). Each option is accompanied by a note reflecting the level of urgency.

In order to secure the supply-demand balance, it is for example suggested, amongst other options:

- to develop catchment groundwater quantity and quality modeling tools for groundwater investment options and strategy (CAPABILITY);
- to identify the need for hydrological barriers, desalinization, alternative sources to face sea-level rise (PLAN);
- to investigate alternative sources and investigate relocation of the abstraction / build additional assets (ACTIONS).

\(^{72}\) ‘Capabilities’ involves building models and monitoring trends to understand changes, make predictions and test scenarios

\(^{73}\) ‘Plans’ refer to using models and data to try out alternative options, and finalise an adaptive plan. Where new options are to be considered, part of this plan is likely to need pilot scale trials.

\(^{74}\) ‘Actions ’ means implementing the plans. This may include ‘hard’ engineering and ‘soft’ measures too, such as demand management and stakeholder dialogue.
Identification of knowledge gaps and the most vulnerable areas in the previous chapters is used for identifying the main targeted areas of possible actions. Such actions should recognise that climate change is not the only factor impacting the drinking water resources and that integrated water management is required, adapting to the specific situation, and considering all possible uses of the water resources. In addition, different actions are suggested for decision-makers at different levels (EU, national, and local).

6.1 Issues at stake

Sufficient resources of water of potable quality is a key human need. The preservation of clean drinking water in a sufficient amount is a key objective of the EU freshwater policies and the Blueprint to Safeguard Europe’s Waters. Many pressures are threatening drinking water quality and quantity, including pollution (point source and diffuse), changing land-uses, high abstraction rates, and CC.

The resulting impacts from CC on water bodies do not only depend on the impacts of CC itself, but also depend on several other factors: the type of water body, its geographical and pedological situation and land-use and competition for water (that is itself impacted by CC). Figure 44 illustrates these impacts.

![Diagram illustrating the components of resulting impacts from CC on water bodies](image-url)
This study shows that the assessment of effects of CC on water resources is a relatively recent area of research, and even more recent with regard to drinking water which is still little investigated. CC impacts drinking water resources in a number of ways, either directly through effects on the water cycle (e.g. recharge of water bodies used for drinking water abstraction), or indirectly through subsequent land-use changes, water abstraction, leaching, etc. Therefore, there is an obvious need for more knowledge in order to mitigate the impacts on drinking water resources and adapt to climate change, and to better understand the between climate change and drinking water resources.

The study also underlines the following aspects:

- Climate change is not necessarily the main driver in drinking water vulnerability, important drivers of water uses are land-use, economic development, urbanisation, etc.
- Research investigating impacts from CC on drinking water resources is still scarce, with more focus put on water resources regardless of their use, and
- Understanding drinking water issues separated from other water issues is not necessarily relevant for decision-makers, who have to take decisions for water use in general, similarly understanding the impacts from CC in isolation from other drivers is not necessarily useful.

An important outcome of the ADWICE conference is that decision-makers cannot take decisions based on CC impacts alone. All activities using water have to be taken into account and the combined impacts from CC, land-use, pollution risks etc. should be considered, for effective measures to be taken. The propositions made in this chapter were developed in this spirit of managing potentially diverging priorities, highlighting trade-offs and synergies. In addition, it is important to recognise that there is no “one size fits all” solution. Water issues require rather toolboxes for decision-makers to identify possible measures and have enough supporting evidence to take informed decisions. In order to achieve this, further support to scientists is needed to enrich the evidence base.

### 6.2 Identification of vulnerable areas

Within this study, vulnerable areas have been identified at different scales through literature review, modelling, and case studies. In general, at the EU level, there is a North-East to South-West gradient of increasing vulnerability. However, the situation also depends very much on local conditions, as demonstrated through the literature review and the case studies. Depending on the type of water resource (see typology in section 3.4.1), the vulnerability to CC will be very different.
The main vulnerable areas are identified as:

- Mediterranean areas and other already arid areas, in which even small impacts on the water balance may result in high consequences,
- Islands, that rely on scarce natural water resources (e.g. Cyprus and Malta are the two countries in the EU that rely for a high percentage of their drinking water on desalination),
- Coastal areas, and in particular towns reliant on groundwater (which in addition are subject to high seasonal touristic pressures),
- Mountainous areas, in particular the Alps, are expected to suffer from lower snow cover which provides valuable natural water storage for later release,
- Intensive agricultural areas, that already pose risks in terms of abstraction and pollution, which are expected to be exacerbated by CC,
- Densely populated areas, in particular urban areas, that require large amounts of water and have important assets that can be lost because of extreme events,
- Closed lakes, temporary rivers, karstic and fractured hard rock aquifers, as well as shallow wells and boreholes, which are less resilient to CC by their very nature,
- Highly-modified environments, in which resilience and buffering capacity of the natural environment is lower.

These areas, while being more vulnerable, are also likely to be those where measures to mitigate and adapt to CC have already been locally implemented, and thus from where lessons can be learned. Encouraging dialogue between stakeholders is therefore one key measure to promote, while taking into account the situations in the various MS.

6.3 Draft research roadmap

Results of the present study stress the low amount of research papers that focus on the impact of climate change on drinking water resources. Several reasons may account for this, such as:

- research focuses on water resources in general because it is the primary output of models, rather than on the specific uses of these resources (e.g. drinking). Focusing on uses increases the complexity of modelling; and
- research on drinking water is focusing on other pressures than CC, which may be more “observable” on the field, such as Dissolved Organic Carbon and organic pollutants, etc.

There is a need to continue strengthening research in this specific area, in parallel to the development and implementation of concrete actions by policy-makers and other stakeholders (see Draft Action Plan for decision-makers). Opportunities exist through EU funding of research.

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No priorities are given to the elements in this list.
projects in the frame of FP7 research framework (and upcoming Horizon 2020), Interreg Programmes, European Innovation Partnerships (EIPs) as well as the future Programme for the Environment and Climate Action (LIFE).

Based on the study’s findings, this Research Roadmap aims to highlight key research areas to be promoted within the research community, across disciplines and spatial scales (from the local to the EU levels). Three key research areas have been identified:

- Understanding the influence of multi-stressor conditions on water resources in the context of a changing climate;
- Improving our understanding of impacts and vulnerability; and
- Assessing the costs and benefits of mitigation/adaptation options.

For each research area, suggestions regarding one or several of the following action types are specified:

- Identification and understanding of drivers, pressures and mechanisms leading to impacts and vulnerability;
- Development of relevant scenarios, integrating drivers from CC, hydrologic, socio-economic, land-use, etc.;
- Development of indicators and thresholds of impacts;
- Fine-tuning of methodologies to assess vulnerability;
- Improvement of modelling and downscaling to regional/local scale;
- Identification of technical solutions for mitigation/adaptation;
- Socio-economic assessments; and
- Governance.

Where possible, following indications will be given for each activity of a given research area:

- Why? What has been done so far? Why do we need to go further?
- What? What should be done?
- Who? Who could be in charge?
- How? Through what means?

**Research area 1: Understanding the influence of multi-stressor conditions on water resources in the context of a changing climate**

Water resources undergo multiple environmental and socio-economic pressures (e.g. pollution from agricultural and industrial activities; water abstraction during touristic season) that are expected to be exacerbated in the context of a changing climate. Linking CC to these pressures is required to better understand the interactions of climatic and socio-economic drivers (including land use change) and their relative influence on water resources. In particular, a key challenge is to understand how CC will impact water demand and which trade-offs in water uses are to be expected, in particular related to drinking purposes (Action R1.1).
Several climatic and socio-economic scenarios can be developed to describe possible futures and related impacts on water resources. It is necessary to ensure the consistency of the on-going or upcoming work from different research fields (CC, hydrology, land-use, socio-economic scenarios, etc.), through the promotion of multidisciplinarity. In particular, work in progress should be in line with the approach developed by IPCC in its upcoming fifth assessment report (AR5), which will put greater emphasis on assessing the socio-economic aspects of climate change and implications for sustainable development, notably through Shared Socioeconomic Reference Pathways and Shared Climate Policy Assumptions.

The development of scenarios must also take into account the fact that water resources are not only sensitive to mean climatic or socio-economic changes (e.g. mean temperature, mean precipitation, mean water abstraction) but also to changes in their variability (e.g. seasonal and/or geographical). Scenarios must reflect the possibility of repeated events and their likelihood of occurrence, which can influence the magnitude of impacts and the actions to be taken for adaptation (Action R1.2).

The robustness of the assessment of CC impacts on water resources and of the vulnerability of water bodies can be hindered by high uncertainties related to future climatic and socio-economic pressures. Several strategies can be envisioned to deal with these uncertainties and increase the robustness of decision-making, including:

- Focus on worst-case scenarios;
- Developing scenarios at a local scale to rely on observations and historical trends; and
- Assess the likelihood of certain scenarios, based on expert judgment or statistical analysis.

This type of research would be in line with the work of Working group II of IPCC AR5 on Impacts, Adaptation, and Vulnerability. It can be conducted e.g. in the context of FP7 projects. For example, the FP7 Work programme 2013 includes as one of its topics 'Water resources management under complex, multi-stressor conditions' (ENV.2013.6.2-1).

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<tr>
<th>What?</th>
<th>Action R1.1: Identifying pressures (in terms of land-use, pollution, abstraction etc.) put on water resources in the context of a changing climate</th>
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<tr>
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<td>Action R1.2: Further developing socio-economic scenarios of water demand and land use change in the context of climate change, including accounting for uncertainties and/or variability</td>
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| Who? | Coordination of research community across spatial scales and disciplines (in the fields of CC, hydrology, land use, social sciences and economy). |
|      | Working groups of IPCC AR5 |

| How? | Currently through FP7 framework and through Horizon 2020 framework from 2014. Cooperation of EU research community with working groups from IPCC AR5. Cooperation between several research fields. |
Research area 2: Improving our understanding of impacts and vulnerability of water resources to CC

CC is expected to have many impacts both on the quantity and the quality of water resources in the future, with differences in terms of geography (both because of direct impacts from CC, and indirect impacts on water use patterns), type of water resources, etc. The understanding of the effects of CC on drinking water resources has been improving but still need to be enhanced. In particular, there is a general paucity of studies regarding specific water resources such as groundwater and water from lake/river bank filtration, which have a high share in providing drinking water in the EU. There is also a need to better understand impacts from repeated events (e.g. if a water body is resilient to one dry summer, will it be resilient to two dry summers, and what is the likelihood that the two dry summers occur in a row). Further information need to be produced to fill these data gaps (Action R2.1).

The development of relevant indicators allows accounting for and communicating about the magnitude of impacts. Indicators of future water quality across Europe (for both surface water and groundwater) do not currently exist. There is a need to better understand the impacts of climate change on a whole range of water quality determinants including pesticides, emerging pollutants, cyanotoxins, etc., in particular to assess the impacts on chemical status. The Joint Research Centre of the European Commission (JRC) is currently modelling a baseline water quality based on diffuse source pollution as well as the water quality impacts of short-term agricultural policy change. European Environment Agency is also working on a range of indicators related to water quality, such as the concentrations of nutrients in freshwater and oxygen consuming substances in rivers. However, a longer-term perspective on overall future water quality (linked to both climate and socio-economic change) is still needed (Action R2.2). Impacts of climate change on the status of water bodies are closely linked to the availability of water for the aquatic ecosystems. There is also a further need to understand the impacts of climate change on aquatic ecology and Good Ecological status, which could inter alia occur through the notion of ecological flows. Indicators of water availability for the ecosystems (e.g. Water Exploitation Index) are being improved to better reflect actual impacts of water abstraction (e.g. consumption vs. abstraction). Given these ecological constraints, improved information is needed on socio-economic trade-offs resulting from future environmental allocation of water (Action R2.2).

In order to highlight the importance of the effects of CC in the various situation of the MS, it is necessary to determine what changes/impacts are considered unsustainable and detrimental. This requires an agreement on threshold values for each indicator of impact, which are often subjective and subject to high uncertainty. Of the indicators used within the ADWICE vulnerability assessment, only one (WEI76) has widely agreed thresholds but the relevance of this indicator is debated and the indicator is currently being improved (Action R2.3).

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76 Water Exploitation Index. The shortcomings of this indicator are discussed in the report. A WEI+ indicator is currently developed to better account for the water returned to the environment after abstraction (in particular from power plants).
A number of research projects aim to assess the vulnerability of water resources related to main societal and economic drivers. In particular, the FP6 project WATCH\textsuperscript{77} and the FP7 project ClimWatAdapt\textsuperscript{78} provided modelling results taking into account various climatic and socio-economic scenarios. Based on existing approaches, a vulnerability assessment methodology has been worked out in the ADWICE study that provided regional vulnerability maps. However, the set of indicators on which this methodology relies remains incomplete and the way of aggregating the results into a single vulnerability message could be refined in the future (Action R2.4).

Based on scenarios of impacts and vulnerability assessment methodologies, models allow predicting the vulnerability of water resources to climate change. Because water vulnerability models are often developed based on global CC scenarios, the results are often too coarse and impractical for decision-makers. In addition, the choice of GCM impacts results and is not an easy choice. Water management is mostly decided and implemented at the regional/local (river basin) scale and global data on CC do not allow considering the high regional variability of CC impacts and specificities due to water resource types. In the ADWICE study, case studies were investigated to analyse at a finer scale the effect of CC on specific types of water bodies. Yet, downscaling of global modelling could be used more systematically to take into account regional/local variability of climatic conditions and be able to fine-tune the understanding of regional/local water bodies vulnerabilities based on the impacts of land cover, water demand, soil properties, etc. Downscaling the assessment of water vulnerability must allow providing concrete tools to decision-makers for the design/selection of appropriate mitigation/adaptation measures (Action R2.5).

So far, the specificities of various water bodies are not reflected in modelling exercises. The modelling of surface water/groundwater relationships in the context of a changing climate is especially missing to understand how these interactions may influence the scale and time lag of impacts. There is a need for improved integrated modelling of water resource systems that better reflect surface water–groundwater interactions (Action R2.5).

Lastly, communicating uncertainties and reducing uncertainties from current CC modelling is important, to convey what the certainty for decision-making is (Action R2.6).

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<th>Action R2.1: Filling data gaps</th>
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<td>Action R2.2: Developing indicators of impacts of CC, in particular on aquatic ecology and Good status as well as water availability</td>
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\textsuperscript{77} WATCH brought together the hydrological, water resources and climate communities to analyse, quantified and predicted the components of the current and future global water cycles and related water resources states; evaluated their uncertainties and clarified the overall vulnerability of global water resources related to the main societal and economic sectors. www.eu-watch.org/Research-Work

\textsuperscript{78} FP7 project ClimWatAdapt. www.climwatadapt.eu

ClimWatAdapt simulate and analyse in-depth climate change induced changes to water quantity and quality in the EU-27 Member States based on SCENES scenarios.
### Research area 3: Improving water management and developing efficient mitigation/adaptation options

The adaptation measures available in the EU are numerous but must be tailored to the specific needs of the local level, taking into account the socio-economic context, the water bodies, the water infrastructures, etc. Appropriate mitigation/adaptation options should rely on best practices developed in Member States as well as technological improvements and innovations. In particular, efforts should be put on enhancing groundwater recharge through Managed Aquifer Recharge (MAR) or natural retention and making better conjunctive use of surface water and groundwater (Action R3.1.). Many measures may be in synergy with other goals of environmental policies and should be prioritised to optimise environmental and cost benefits in particular contexts. In this respect, the prototype of the hydro-economic model built by the Joint Research Centre to underpin the Impact Assessment of the Blueprint could help assess the costs and benefits of the Member States’ programmes of measures and other tools at national and/or river basin level. This may also require the development of better valuation methods for green infrastructures with multiple benefits in terms of ecosystem services provided (Action R3.2.).

The 2012 Strategic Implementation Plan of the European Innovation Partnership Water programme stresses the gaps between, among others, sectorial policies, institutions, regional levels, stakeholder groups, and different planning horizons. It also highlights that the fragmentation of institutions and responsibilities in the water sector results in institutional barriers, a low profile on the political agenda and a lack of public awareness and private involvement. Better understanding the shortcomings of water governance and enhancing governance processes are necessary to meet the challenges of integrated and transboundary water management (Action R3.3).

These issues can be addressed through several research frameworks, including FP7 and Horizon 2020, LIFE/LIFE+ which highlights the importance of identification of efficient
mitigation/adaptation measures\textsuperscript{79}, Interreg IV programmes which promote transnational and interregional cooperation\textsuperscript{80} and were already successful in the field of governance, as well as EIP Water partnerships which carry great potential in the implementation of pilot/demonstration measures, through involvement of different types of stakeholders.

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<th>What?</th>
<th>Action R3.1: developing effective mitigation/adaptation options based on new technologies/innovation</th>
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<td>Action R3.2: carrying out socio-economic assessment of demand and supply-side management options as well as infrastructures (green infrastructures vs. grey infrastructures)</td>
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<td>Action R3.3: improving governance</td>
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| Who? | Action R3.1: experts, in collaboration with stakeholders on the field |
|      | Action R3.2: JRC to continue its work, possibly with the collaboration of national research institutes. |
|      | Action R3.3: Water Task Force in the EIP Water, as suggested in the Strategic Implementation Plan. JRC to continue its work on transboundary basins such as Danube. |

| How? | LIFE projects (identification of efficient mitigation/adaptation measures) |
|      | FP7/Horizon 2020 |
|      | EIP Water partnerships (governance, implementation of pilot measures and/or decision-supporting tools) |
|      | Interreg programmes (e.g. Interreg IV B, on transnational cooperation or C on interregional cooperation) |

### 6.4 Draft action plan for decision-makers

It is important for decision-makers to identify measures that:

- are relevant to address the specific issues in the local situation (in terms of hydrology, geography, topology, and socio-economy),
- consider different pressures on drinking water resources (e.g. pollution by different types of pollutants, soil sealing).

Where possible, win-win situations, no-regret measures and measures that increase resilience to the CC impacts, including catastrophic events, should be favoured.

There is an evident need for a toolbox of possible measures, highlighting their advantages and drawbacks, including situations in which they are most relevant, instead of generic one-fits all

\textsuperscript{79} E.g. water project 'ENSAT - Enhancement of Soil Aquifer Treatment' (LIFE08 ENV/E/000117)

\textsuperscript{80} E.g. Interreg IV B program project CC-WaterS on the impact of CC on water supplies
recommendations. In addition, the scale at which the actions are implemented is very important, therefore decision-makers at three different levels are targeted in the recommendations below.

6.4.1 At EU level

There are many EU projects which are trying to assess the impact of CC on water bodies, and identifying mitigation and adaptation measures, from different points of view (e.g. focussing on measures adapted to urban areas, or specific regions). These projects are performed either internally, e.g. by the JRC, or financed through FP7 or LIFE+ funds. More local and applied projects are also supported by regional development funds, etc.

Understanding of impacts and vulnerability at EU level is important to:

- target support, by prioritising more risk-prone regions and developing the solidarity between MS,
- identify regions that encounter similar challenges (e.g. droughts, in a context of high touristic pressure in the summer), so that best practices are shared and lessons learned, and
- continue to support research in these areas (see draft research roadmap).

Action D1.1: Better implementation of water policies and link with other environmental policies (including Climate change)

The EU has already implemented several policies regarding water, and regarding CC, and further developments about CC are expected in the near future, with an EU Climate Change Adaptation Strategy expected in Spring 2013. The current EU water policies framework (see policy review in section 4.1) does not explicitly mention CC related issues, with the exception of the Floods Directive. However, the step-wise and cyclical approach of the Water Framework Directive, and in particular the regular update of the RBMP allow to implement adaptive management, as the status in each RB will be updated, and through the lessons learned on effectiveness by implementing measures in previous rounds. The second RBMPs are also expected to take into account and respond to CC challenges more robustly, through climate-proofing of measures. In addition, the recently published Blueprint to Safeguard Europe’s waters considers the challenge of CC and offers a range of actions to improve the implementation of existing water policies.

In terms of long-term planning, best practices may be learned from the UK process which now requires water managers to have a 25 year planning horizon.

Lastly, the requirement of good ecological status from the WFD, and the current discussion about ecological flows, raise the need for clear allocation and decision rules. If CC results in less water being available, how will allocation rules evolve and should decisions be taken to ban abstractions, at the expense of certain uses, in particular drinking water? Some guidance and criteria may be useful to open the discussion of this sensitive issue.
| **What?** | Ensure that CC is taken into account in decision-making frameworks at all levels, in particular through climate-proofing of measures. Seek longer term planning from MS or from stakeholders involved in water management (e.g. in the RBMP), that inherently obliges them to take into account CC. Open a discussion about the need for allocation and decision rules for achieving good ecological status and ecological flows |
| **Who?** | European Commission DG ENV and CIS groups, e.g. through the peer-review mechanism of RBMP advocated in the Blueprint for climate-proofing of measures. European Commission DG ENV, by proposing an amendment of information to report in the RBMP, or asking for voluntary submission of long-term plans. European Commission DG ENV, with the CIS groups |
| **When?** | In the context of the peer-review mechanism advocated in the Blueprint, the action could be performed in the short term. The requirement for long-term planning, if not voluntary, will require time and agreement by the EU institutions, a similar issue will arise for the need for allocation and decision rules, but the discussion can be opened in the short term. |

**Action D1.2: Disseminate information about the impacts of climate change on drinking water resources in the EU**

In order to understand and adapt to the impacts of CC in Europe, it will be important to share information on climate scenarios and climate impacts. The EEA has recently launched the European Climate Adaptation Platform (CLIMATE-ADAPT - climate-adapt.eea.europa.eu) that aims to support Europe in adapting to CC. Such an initiative is important, and provides useful information including by sector and specifically for water management.

| **What?** | Support the development of the CLIMATE-ADAPT platform, with regular updates (this may require the development of a reporting form or template, to harmonise the data reported) Disseminate awareness of the portal, for its effective use by all stakeholders |
| **Who?** | EEA and European Commission to regularly update the platform, using both top-down information (i.e. projects commissioned by and funded at EU level) and contributions by national and local stakeholders Dissemination by all parties involved in CC adaptation |
| **When?** | Continuous updates and dissemination |

**Action D1.3: Support and guide decision-making at finer scales, through robust frameworks**
Water is a local issue. As identified in this report and in line with many previous publications, the adaptation measures available at the local level are many, and existing inventories constitute a useful toolbox for decision-makers to choose from. This, however, also means that careful selection is required, and that measures are adapted to the local situation to achieve their means in an effective and efficient way. To reach this goal, the EU could support the development of a decision-tree tool. Such decision-tree could be based on parameters that take into account the situation in each RB and identify possible adaptation and mitigation measures. The outputs of the tool should include information about the synergies and trade-offs between the possible measures (e.g. one measures may exclude the implementation of another measure, due to spatial or other constraints) or between environmental objectives (e.g. a given measure may have benefits for both water retention and carbon storage, and/or include a trade-off with agricultural yields).

In the Blueprint, several actions are identified that involve the drafting of CIS guidance, which could also benefit the protection of drinking water resources. For example, the implementation of natural water retention measures may increase the resilience to the impacts of CC, or reduce the vulnerability to CC, and the CIS guidance on trading schemes and cost-benefit assessments may also help decision-making on such issues, by prioritising measures that provide multiple ecosystem services that were unaccounted for or undervalued in the past. The work of the CIS on the science-policy interface as indicated in the Blueprint should also take into account the interface at different scales, from the EU level to the local level.

<table>
<thead>
<tr>
<th>What?</th>
<th>Develop a decision-tree tool to help local decision-makers to select and adapt adaptation measures for their local situation. As identified in the scientific roadmap, modelling at finer scales is a priority and a robust science-policy framework is needed so that scientists address issues relevant to decision-makers, with information flowing both ways.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Who?</td>
<td>European Commission DG ENV, through or with the help of the CIS. The implication of DG CLIMA and the teams drafting the EU Adaptation strategy would be beneficial.</td>
</tr>
<tr>
<td>When?</td>
<td>Relevant information on adaptation measures are available and were compiled already, this action could thus be performed in a relatively short timeframe.</td>
</tr>
</tbody>
</table>

**Action D1.4: Support and guide decision-making at a fine scale, through exchange of experiences**

Many MS already have concrete experiences of implementing adaptation measures, including information on what was successful and what had unexpected impacts, and lessons learned from these experiences to share with other MS, especially those MS that are already under stress from pressures that are expected to be exacerbated by CC (e.g. Mediterranean MS). In addition, the various stakeholders involved in water management and their representatives at EU level (industry federations, NGOs) also have thorough knowledge of barriers to implementation and levers for reducing these barriers.
<table>
<thead>
<tr>
<th>What?</th>
<th>Include in a decision-tree about adaptation measures and/or on the CLIMATE-ADAPT portal, or in a designated document, lessons learned from past experiences of implementing measures in the MS.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Who?</td>
<td>European Commission DG ENV, based on collaborative work through the CIS working groups, or census of measures reported in the RBMPs.</td>
</tr>
<tr>
<td>When?</td>
<td>Relevant information could be gathered through the CIS and RBMP contacts, and compiled in the short term.</td>
</tr>
</tbody>
</table>

**Action D1.5: Reinforce the implementation of measures to protect water that will also decrease vulnerability of water bodies to CC**

In many cases, the impact from CC will not result in new impacts, but will exacerbate current pressures. Therefore, the strengthening of measures that are currently available but either insufficiently implemented, or that would benefit from stronger enforcement, may also be beneficial to reduce the impacts that CC is expected to have on water bodies. For example, the Blueprint identified the need to extend nitrate vulnerable zones and reinforce action programmes, add cross-compliance requirements in the CAP linked to the Sustainable Use of Pesticides Directive, etc. As mentioned in the literature review, many of these pressures are expected to increase under CC. For example, CC will be responsible for new conditions that may benefit certain pest species, leading to the increased use of pesticides. In combination, less rain from CC will reduce the dilution of pesticides in water bodies, resulting in higher pollution. The introduction of such requirement in the CAP may lead to a lower impact from pesticides.

<table>
<thead>
<tr>
<th>What?</th>
<th>Strengthen measures that protect water bodies with benefits for CC adaptation, such as:</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>- measures to protect water bodies from nutrient (nitrates, phosphates, etc.) and pesticides pollution;</td>
</tr>
<tr>
<td></td>
<td>- measures to protect water bodies from industrial pollutions (through the EQSD and IED)</td>
</tr>
<tr>
<td>Who?</td>
<td>European Commission DG ENV, in collaboration with relevant units and DGs</td>
</tr>
<tr>
<td>When?</td>
<td>Within the framework of actions of the Blueprint</td>
</tr>
</tbody>
</table>

### 6.4.2 At national level

The national level is important as it sets orientations that are relevant at a finer scale than the EU level, including identifying measures to be taken in areas most at risk. National decision-makers can also provide support to regions, and decide and implement national policies. In certain MS, the national authorities may act as a coordinator (e.g. in decentralised States) and in other (mostly small countries) they have a more hands-on role, with few differences across regions. The actions identified above for the EU, or below for the RB level, will be also relevant at national level and are not repeated here.
Measures that are most relevant to be implemented at national level are presented below.

**Action D2.1: Requirement for long-term planning of water resources use**

As indicated in Action D1.1, some long-term planning can be required at national level, as for example is required from all water companies in the UK, with a 25 years planning. This implicitly makes companies take account of CC in their planning. This could also be applied to other water managers if relevant, such as the authorities responsible for granting abstraction permits, etc.

<table>
<thead>
<tr>
<th>What?</th>
<th>Require companies to plan taking account of CC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Who?</td>
<td>National government</td>
</tr>
<tr>
<td>When?</td>
<td>Short to medium-term</td>
</tr>
</tbody>
</table>

**Action D2.2: Report practices to the EU level, to update information and share lessons learned**

As indicated in action D1.2, a platform is in place at EU level to share experiences. In order to ensure that these experiences do not remain a repository of top-down, EU commissioned and EU funded projects, it is important that MS contribute to the inventory of actions.

<table>
<thead>
<tr>
<th>What?</th>
<th>Report MS practices at the EU level, including contextual information and lessons learned, so that others can benefit from positive and negative results</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Disseminate information about the existence of the platform, to be used at national and local levels</td>
</tr>
<tr>
<td>Who?</td>
<td>National authorities, who implement actions, and with the help of local stakeholders implementing actions where relevant</td>
</tr>
<tr>
<td></td>
<td>All for dissemination actions</td>
</tr>
<tr>
<td>When?</td>
<td>Continuous updates and dissemination</td>
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</table>

**6.4.3 At River Basin level**

Water is a local issue, and the river basins were identified in the WFD as the relevant scale to address water issues. While CC is a global phenomenon, it also has localised impacts, that will be different across the EU. The RB level is thus an important level for action, which can also benefit from the attentive supervision at the national/EU levels. This support could ensure that objectives are achieved and develop information exchange and best practices sharing that would not be accessible at RB level.

This project showed that a large amount of actions are already taken at RB level to protect water bodies from a range of impacts, including CC. A number of EU projects have catalogued the measures available to stakeholders to be implemented to mitigate or adapt to the impacts of CC and this study has selected those most relevant to CC, also identifying which stakeholders are most relevant to implement them. The classification aims to clarify the situation in which they...
are most relevant, as well as identifying synergies and trade-offs to be considered when they are implemented.

**Action D3.1: Improve the diagnostic**

A thorough and detailed understanding of the issues at RB level is needed to adopt relevant actions and adapt them to the situation, including:

- Identification of pressures, in particular from CC on DW bodies and from combined CC and other pressures, and
- Identification of risk and vulnerability to CC (monitoring / modelling), especially of water resources used for drinking water abstraction.

Where this identification is reported in the RBMP, this could allow better information exchange across EU regions, as the information can be collated at EU level.

| What? | Peer-review the RBMP to identify good and less advanced methodologies for identification of impacts, risks and vulnerability  
Disseminate good practices and lessons learned  
Guide local stakeholders in how they can implement methodologies and organise the assessments  
Involve local experts in the local assessments, build capacity at local level, build cooperation between stakeholders (from both public and private sectors) to share and exchange data |
| --- | --- |
| Who? | European Commission, DG ENV to collate information from the local level and help disseminate it  
Local stakeholders through cooperation |
| When? | Short to medium term |

**Action D3.2: Design of policies, measures and their impact assessment**

Local policies should be designed taking into account the local situation and assessing their impacts at local level. Assessing effects at the local level is important as it allows to take into account more precisely the local context than with national or EU policies, and to adapt effectively to the impact of CC. In order to apply good practices, some measures can be taken to ensure their efficiency and limit unintended harmful effects, including:

| What? | Climate proofing of policies and measures proposed for dealing with water issues (assessing whether CC will have an impact on these measures), and  
Cost-benefit analysis of the measures, including when deciding between green and grey infrastructure developments. |
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Who?</td>
<td>River Basin managers and stakeholders, local authorities</td>
</tr>
<tr>
<td>When?</td>
<td>Continuously when implementing measures and policies</td>
</tr>
</tbody>
</table>
Action D3.3: Communication

The EU level has the strong advantage of allowing to disseminate information from the local level and from very different regions of the EU to be used by other stakeholders. However, such dissemination is dependent upon local stakeholders providing information about their situation and experience. In addition, the communication between stakeholders within a river basin may allow sharing information collected by different stakeholders to help take informed decisions, take into account various challenges from the stakeholders, and their constraints, into decision-making at local level.

<table>
<thead>
<tr>
<th>What?</th>
<th>Promote dialogue and exchange of information by providing information about own actions, and seeking information from other regions, including:</th>
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<tbody>
<tr>
<td></td>
<td>Regions in which the impacts from CC are similar, but also,</td>
</tr>
<tr>
<td></td>
<td>Vulnerable regions that have already implemented measures, and can help identify lessons learned and best practices, and</td>
</tr>
<tr>
<td></td>
<td>Regions that are different in terms of the climate, but are relying on similar sources of water for abstraction (e.g. groundwater), or have similar types of water bodies (e.g. strong reliance on snow melt, many temporary rivers), etc.</td>
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<tr>
<td></td>
<td>Promote dialogue between the different stakeholders within the RB, to exchange information about the vulnerability of the water bodies, the scenarios tested by the stakeholders, and common solutions that could be taken.</td>
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</table>

| Who? | Local stakeholders, including private and public stakeholders from different backgrounds that use or abstract water (e.g. water managers, water industries, water treatment industries, land-owners, farmers, beverages industry) |

| When? | Continuously when implementing measures and policies |

6.4.4 Actions at local and city level

In addition to these levels, specificities may arise for e.g. cities, in which local stakeholders may have to develop their own strategy with regard to specific challenges (e.g. how to sustain water supply in densely inhabited areas in drought periods). The RB scale may then be too wide for the specific challenges and require more detailed data gathering and assessment, as well as different types of solutions.

In addition, many solutions advocated for a more efficient use of water resources more generally will reduce the vulnerability of drinking water resources, as they may reduce the competition for water, such as water re-use, water efficient products, water efficient buildings etc. (see the Blueprint to safeguard Europe’s water recommendations and the Water scarcity and droughts policy review).
| **What?** | Deal with ad-hoc issues arising from certain local situations, e.g. draft a drought management plan at city level  
Implement actions to increase water efficiency |
| **Who?** | City authorities, with the help of relevant stakeholders  
All stakeholders |
| **When?** | Ad-hoc timing |
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