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Impacts of climate change on water resources – adaption strategies for Europe

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Der vorliegende Forschungsbericht liefert eine Synthese des wissenschaftlichen Sachstandes zu Klimawandel in Europa und dessen Auswirkungen auf Wasserressourcen und das Auftreten von Extremereignissen wie Hochwasser und Dürreperioden. Beobachtete und für die Zukunft projizierte Änderungen werden auf regionaler Ebene im Detail analysiert. Aus dem wissenschaftlichen Sachstand werden die Herausforderungen abgeleitet, die sich aus diesen Änderungen für Europäische Gesellschaften ergeben, und es werden Optionen für die Anpassung vorgestellt und in den Kontext Europäischer Politikgestaltung eingeordnet.</td></tr>
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16. Abstract The present research study provides a synthesis of scientific evidence on climate change impacts on water resources in Europe. Observed and projected changes at regional level are analysed in detail. Challenges for European societies that result from these changes in water resources are derived, and options for adaptation are compiled in order to provide support to policy-makers in developing adaptation strategies.		
17. Keywords Climate change, Europe, water resources, water scarcity, floods, droughts, adaptation, water resources management, water supply and sanitation, agriculture, electricity, inland waterway transport, tourism		

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Executive Summary

The objectives of the present research study were twofold: first, to provide a synthesis of the state of the art of research on climate change impacts on water resources and the occurrence of extreme events (floods, droughts and heatwaves) in Europe. Observed and projected changes at regional level are analysed in detail. The second objective was to analyse the challenges for European societies that result from these changes in water resources, to compile options for adaptation, and to provide support to policy-makers in developing adaptation strategies. This report presents the results of a research project carried out by Ecologic and the Potsdam-Institute for Climate Impact Research on behalf of the German Federal Environment Agency.

Climate change and its impacts on water resources in Europe

Over the course of the past 100 years, global climate has been changing, thus impacting on temperature, precipitation and radiation budgets and generally altering the regional water balance in many parts of Europe. However, due to the variation in local circulation patterns and orography, trends may differ from region to region.

Overall, the studies project that climate change is going to continue and may even accelerate in the future, despite differences in the underlying assumptions regarding economic development (scenario storylines) and model uncertainty. Again, regional differences will play an important role.

Depending on sector and region affected, the impacts of climate change on the water sector in Europe can be severe and should be taken into account when developing management strategies to guarantee sustainability of water resources.

Observed Trends

Temperature in Europe has risen between 0.8 to 0.95°C over the last century. Precipitation in northern Europe increased about 10 to 40%, while the Mediterranean experienced a decrease by about 20% in some areas. More extreme precipitation events have been observed, and the average amount of rainfall per wet winter day increases even in areas where the annual precipitation sum decreases. Heat waves have become more frequent, especially in central and southern Europe.

There is evidence that the observed changes in climate have been accompanied by changes in water resources and extreme events. River discharge in northern and eastern Europe was already observed to increase, while southern Europe has experienced decreases in runoff. In the transition zone, namely central Europe, river runoff seems to be stable. Most stations in central Europe, southern Scandinavia and Great Britain show an increase in long dry spells during summer, while the same pattern is observed in southern Europe for the winter period. Glaciers in eight out of nine European glacier regions are currently melting. Over the last two centuries, sea levels of the Baltic Sea have increased significantly, while the Mediterranean has shown a more complex development: depending on water circulation patterns

increases in some and decreases in other areas. Studies in Finland and Switzerland show a decrease of the period when lakes are covered by ice.

Model projections

Global climate models project a further increase in temperature in Europe of 1 to 5,5ºC by the end of 21st century, with regional and interseasonal differences in the degree of warming. A general increase in precipitation in winter is expected over most of Europe (except southern Mediterranean regions); a general decrease in precipitation in summer is projected in southern, western and central Europe. Extreme daily precipitation will continue to increase, as well as heatwaves and intense precipitation events. In central and southern Europe drought risk is likely to increase.

Predictions of the effects of climate change on runoff regime and river discharge are still uncertain to some extent. The general trend is towards an increase in winter runoff and decrease in spring runoff at high latitudes. Changes in seasonal runoff dynamics will be caused by the effects of warming on snow accumulation and snow melt processes. As a result, peak flows could occur up to two months earlier than at present, and the occurrence of peak runoff and floods could shift from spring to winter. In general, the frequency and intensity of floods are projected to increase, though floods caused by snowmelt are expected to decrease.

Modelling studies also suggest that under higher CO_2 concentrations an increase in the frequency of droughts and heatwaves can be expected in the future. Most studies on water supply and demand conclude that annual water availability would generally increase in northern and north-western Europe and decrease in southern and south-eastern Europe. Temperature rise and changing precipitation patterns are expected to exacerbate the already acute water shortage problem in southern and south-eastern European regions.

According to the IPCC, the sea level rise expected for Europe is between 13 and 68 cm by 2050 due to thermal expansion only, although there are some regional differences. Estimates show that flooding caused by a 1m rise in sea level would affect about 13 million people in five European countries.

The latest research results on the regional impacts of climate change on water resources and extreme events are presented in Table 4. Six case studies from representative regions in Europe further illustrate the regional impacts of climate change in greater detail. The results show that in the near future (2020) particularly southern and south-eastern Europe will face increased water shortage and drought conditions in summer. By 2030, Spain might already experience a decrease in water resources in several main river basins by 4-14%, and by the year 2080, 14 to 38% of the Mediterranean population could be living in catchments with increased water stress. The length of drought periods could also be changing. In Greece, the return-period of a 100-year drought might decrease to 10-40 years by the end of the century. At the same time, central European countries like Hungary might also become affected by decreases in summer precipitation with the respective consequences for ecosystems and agriculture. In eastern (winter) and northern (winter and spring) Europe increasing flood risks could be seen as the largest threats. With climate change having the potential to alter the temporal occurrence of floods, this could affect dam security in Sweden. However, it should be noted in this context that the spatial resolution of the driving climate model constitutes an important factor in determining future flood risks on the catchment scale. For this reason, mainly regional studies were used in the present analysis. For western Europe, both more frequent flood events in winter and drought periods (or heat days) in summer are expected. While Germany might have to face more floods in the Rhine basin in particular in winter, reductions in average river discharges might be experienced for the summer months. In the eastern parts of the country, the Elbe basin, reductions in water availability and thus water quality might have to be expected. In mountainous regions, particularly in the Alps, the loss of snow and ice might increase and is very likely to accelerate. Due to these altered snow-melt dynamics, the role of the Alps as a freshwater reservoir during the dry summer months might be declining in the future. Coastal areas will experience the impacts of sea level rise resulting in more frequent and intense flooding events.

Adaptation challenges and options

Whether changes in climate, water balance or flood risk are damaging to human societies depends on their sensitivity and vulnerability to these changes. Analyses of the vulnerability of European societies and of individual sectors to water-related climate change impacts were carried out, and the results suggest that adaptation measures should be taken. In addition to water resources management at river basin level and the water supply and sanitation sector, which will be faced with the challenge to secure water supply, waste water management, flood protection, allocation of water etc. under changing climatic conditions, other economic sectors will also be affected by changes in hydrology. For instance, irrigation agriculture in the Mediterranean will suffer from exacerbated water scarcity, while agriculture in northern European regions might in some cases benefit from increasing temperatures and precipitation. Sectors such as electricity, inland waterway transport and tourism are also highly dependent on water resources and thus vulnerable to changes.

This report presents the vulnerability to climate change impacts for individual sectors and an overview of possible adaptation measures at operational level. Potential interactions between measures taken by different sectors are taken into account. In a further step, the framework conditions set by European policies are analysed with a focus on their relevance for adaptation. Individual sectoral policies are discussed as well as overarching environmental policy programmes, financial instruments and research programmes.

A large number of options for adaptation is available, and some measures are already being implemented in the European Union, albeit usually in the form of individual projects. Only few Member States have developed comprehensive adaptation strategies in response to climate change impacts to date. However, relevant policy processes at European level are beginning to take climate change impacts into account and explore ways to incorporate adaptation issues into future planning and activities. The EU is called upon to further develop and promote adaptation in a process of mutual exchange among Member States. Some building blocks and key issues for the development of adaptation have been identified as essential results of this project.

- **Adaptation should be based on integrated and flexible water management**, in order to take account of remaining scientific uncertainties, of the interplay between different pressures on water resources and of the potential interaction between measures taken in different sectors. Priority should be given to no-regret and win-win solutions that will deliver benefits under different climate scenarios. It should also be ensured that adaptation responses do not create additional pressures on water resources. Potential interactions with efforts to mitigate climate change should be considered.

- **Existing tools provided by European and national policy and legislation should be used.** In particular, climate change impacts and adaptation concerns should be included in the Programmes of Measures and the River Basin Management Plans to be drawn up as part of the implementation of the Water Framework Directive.
- **Better integration and co-ordination between sectors is needed**. Water management will not be able to cope with all impacts from climate change alone. Other sectors depending on water resources, such as agriculture, electricity, inland waterway transport and tourism, need to contribute to adaptation efforts. Sufficient co-ordination is key to ensure consistency between measures, to avoid conflicts and make use of synergies.
- **Increasing water efficiency as key element of adaptation.** In many regions, adaptation to climate change will be closely linked with adaptation to water scarcity. Measures that reduce water consumption and increase efficiency will be essential elements of adaptation strateiges and should be promoted in all sectors. Economic instruments may be useful tools to encourage efficient use and allocation of water and support necessary behavioural changes.
- **Adaptation of water management is closely related to land use planning.** Spatial and land use planning can contribute to adaptation, for instance through reducing the vulnerability to flooding or through improving the capacity of soils to store water and improving local water balance. Changes in land management may be an important supplementary tool to cost-intensive investments in physical flood control structures.
- **Information and participation are necessary to support adaptation.** Improved information and awareness of climate change impacts, the necessity to adapt, and potential adaptation measures are important in order to create support for the implementation of measures and reach agreement between different stakeholders.
- **Funding and financial instruments can be used to support adaptation.** The funding resources of its cohesion policy can be used to support and steer adaptation efforts in the Member States and by individual actors. Cohesion funding might tackle regional disparities with regard to climate change impacts or adaptive capacity, and support can be granted for building or upgrading infrastructure.
- **Knowledge gaps remain, and further research is needed.** In order to improve the information basis on which decisions about adaptation measures and strategies are taken, further scientific investigation is needed for instance with regard to regional climate change impacts, the vulnerability of individual sectors, and the costs, benefits and effectiveness of adaptation measures.

1 Introduction

1.1 Background and objectives

The global mean surface temperature has been continually increasing over the past decades, and most scientists today agree that we are witnessing a change in the global climate largely caused by anthropogenic emissions of greenhouse gases (IPCC 2007). Due to the complexity of the earth system and the manifold processes influencing and influenced by the climate, multiple impacts along different causal chain are to be expected as a result of warming.

Impacts on water resources are among the main concerns in Europe. Several recent studies highlight the challenges that result from changes in water availability and water quality, from sea level rise, from shifts in precipitation patterns and in the snow regime and from an increase in the frequency or intensity of floods and droughts (EEA, 2004; IPCC, 2001&2007; Schröter et al., 2005; Eisenreich, 2005; EEA, 2005b; EEA, 2007).

Since the current warming of the climate is to a large extent caused by the human-driven increase in the atmospheric greenhouse gas concentrations, the evolution of the global emissions will significantly influence the magnitude of future climate change. Therefore in order to mitigate climate change and to prevent disastrous impacts, the reduction of greenhouse gas emissions should be the primary political goal. The declared aim of the European Union is to limit the temperature rise to 2 degrees above pre-industrial levels, an aim that has to be translated into policy measures and emission reduction targets (European Commission, 2005a).

However, efforts are also necessary to cope with the changes in climate and associated impacts on water resources that are already happening or that are to be expected even if emission reduction strategies are successful. Adaptation to climate change effects has long been an important issue for developing countries, but is gaining relevance also on the European political agenda. In September 2006, the European Commission (DG Research, DG Environment, and Joint Research Centre) organised a workshop in Brussels which discussed climate change impacts on the water cycle and promoted dialogue between scientists and policy-makers.[1] In February 2007, the German EU presidency hosted an international symposium titled “Time to Adapt - Climate Change and the European Water Dimension“ in Berlin. The symposium, which was supported by the European Commission, provided a platform for representatives from governments, science and research, stakeholder groups and non-governmental organisations to discuss the likely impacts of climate change on water management and water dependent sectors, as well as options for adaptation. A set of key messages and conclusions represents the principal outcome of the conference.[2] The European Commission launched a Green Paper on Climate Change and Adaptation in June 2007. In the context of the Common Implementation Process of

1 http://ec.europa.eu/research/environment/newsanddoc/other_pubs_en.htm.

2 A number of background documents, presentations and the conclusions are available from the conference website at http://www.climate-water-adaptation-berlin2007.org/.

the Water Framework Directive, a working group was set up in 2007 that will explore potential adaptation strategies in the context of the European water policy.

The first objective of the present study is a synthesis of the state of the art of climate change research in Europe: historical trends and projections for the future of climate and water resources related components, including an evaluation of research on regional climate impacts. A comprehensive overview is provided of what is currently known about possible climate change in Europe, and how it would affect water resources and the occurrence of extreme events (floods, droughts and heatwaves) on the continent in the 21st century. The second objective was to analyse the challenges for European societies that result from these changes in water resources, to compile options for adaptation, and to provide support to policy-makers in developing adaptation strategies. This report presents the results of a review carried out by Ecologic and the Potsdam-Institute for Climate Impact Research on behalf of the German Federal Environment Agency. Research done in the context of this project is closely related to the above-mentioned February 2007 conference "Time to Adapt". Research results provided background material for the conference, and conference results were considered in the drafting of this final report.

1.2 Structure and scope of the report

This report presents the results of the project "Impacts of climate change on water resources – adaptation strategies for Europe". The first part of the report (chapters 3 and 4) presents an evaluation and summary of state-of-the-art scientific knowledge on climate change impacts on water resources in Europe, which provides the basis for the compilation and discussion of adaptation options in the second part (chapters 5 - 7).

A brief introduction to the methodology, concepts and definitions applied is given in section 2. In the following subsections of chapter 3, observed past trends and projections for the future in the European climate are presented first (section 3.1), and impacts of these changes in climate on water resources, extreme events and coastal systems are discussed subsequently (section 3.2). Furthermore, the potential dramatic changes that might result from abrupt climate change, and the nature and likelihood of such changes, are touched upon (section 3.3). The findings on water-related sensitivities to climate change are summarised for the major European regions and for several time horizons in section 3.4, providing an overview of symptomatic impacts and a basis for developing appropriate adaptation measures. While section 3 summarizes the results at the European scale, section 4 gives more insight to the region-specific pattern of climate change in Europe and the resulting impacts on water resources by means of case studies representing the most important subregions in Europe: the Mediterranian, Westeurope, Skandinavia, central Europe and Eastern Europe.

Section 5 discusses the impacts of climate-driven changes in water resources and extreme events for European societies, with subchapters for five focus sectors (see below). The following chapter 6 presents approaches to adaptation. The first subchapter (6.1) introduces measures and options for implementing adaptation on the ground, again grouped by sector. Section 7 looks at adaptation from a policy perspective. It introduces the relevant legislation and policies at the European level that constitute the common framework for mitigation and adaptation efforts in the Member

States, and explores the scope for integrating adaptation to water-related climate change effects into these policies.

Section 8 finally draws conclusions and presents recommendations for future action on adaptation.

Focus sectors

The discussion of challenges resulting from changes in water resources for European societies and of possible adaptation measures and strategies focuses on five economic sectors:

1. Water management (water resources management and water supply and sanitation services)
2. Agriculture,
3. Energy/electricity,
4. Inland waterway transport,
5. Tourism.

This approach is motivated by the idea that water management alone will not be able to deliver full adaptation, but that the success of adaptation efforts will depend on the contribution of other sectors which heavily rely on and influence water resources.[3]

It is also in line with modern integrated water management approaches (IWRM) which seek to find a balance of the water needs of different users and to involve all relevant actors and stakeholders in decision-making about water allocation and management. River basin management as required by the European Water Framework Directive identifies the maintenance of a functioning ecosystem and the ecological and chemical protection of surface water and groundwater bodies as its main goals. The protection of water resources and the long-term sustainability of water use in a given river basin is in the interest of all stakeholders alike, since all human activities rely to some extent on the availability of water in sufficient quantity and quality.

The five key sectors that were chosen for this study are particularly relevant in terms of their vulnerability to water-related climate change impacts, their economic importance, and their potential to contribute to adaptation efforts. For each of these sectors, challenges resulting from climate-driven changes in water resources are discussed individually (chapter 5), adaptation measures are presented (chapter 6), and relevant policy areas are analysed (chapter 7). The water management sector is subdivided into two different areas: the overarching issues of water resources management (WRM) on the one hand, and the actual delivery of water supply and sanitation services (WSS).

It has to be noted that other sectors and areas such as forestry, built environment, human health, and biodiversity will also be impacted on by climate change, and will also have to be considered in adaptation strategies. Some of these issues are touched upon in the present study where appropriate. However, in-depth discussions of challenges and adaptation measures for these sectors should be placed in a more

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[3] The selection of the focus sectors was approved by an expert workshop which took place in April 2006 at the German Federal Ministry for the Environment.

general context, and not in the framework of ***water-related*** climate change impacts only. Comprehensive analyses and discussions can be found in recent relevant publications for instance by the European Environment Agency and the Intergovernmental Panel on Climate Change (e.g. EEA 2005b, IPCC 2007, IPCC 2001).

Since the final objective of the study is to present elements of potential adaptation strategies that integrate different sectors, the individual sector analyses pay particular attention to potential conflicts and synergies with adaptation efforts in other sectors. These linkages and relationships between the sectors are summarised in section 7.4.

2 Methodology and approach

Information sources

This study is based on an evaluation of scientific literature and policy documents, on a questionnaire survey, and on 15 interviews conducted with experts and stakeholders.

A questionnaire was designed jointly by Ecologic, the Potsdam-Institute and the European Environment Agency (EEA) and distributed on behalf of the German Federal Ministry for the Environment and the EEA to the National Focal Points and the Pilot River Basins. In total 26 responses were received and evaluated (November 2006). The questionnaire results also provided input to the EEA report “Climate change and water adaptation issues” (EEA 2007).

The aim of the survey was to collect information on the degree of awareness concerning the issue of climate change impacts on water resources in Europe; to assess the vulnerability to climate change in Europe; and to compile potential adaptation measures and strategies as well as information on implementation experiences. Respondents also provided an assessment of the effects of climate-driven changes in water resources on key sectors, and of the implications for their societies in general. The main results of the questionnaire survey are included in this report as separate chapters or boxes. The full evaluation report is available for download at http://climate-water-adaptation-berlin2007.org/.

Definitions

For the identification of climate change impacts and possible adaptation strategies, the concept of **vulnerability** plays a key role. This concept, as widely used in adaptation research (see for instance IPCC 2001, Schröter et al. 2005, Turner et al. 2003), denotes the degree to which a system will be affected by adverse effects of climate change, which in turn depends on three different factors. Firstly, on the character, magnitude, and rate of climate variation to which a system is exposed (**exposure**), secondly, on the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli (**sensitivity**), and thirdly on the ability of a system to adjust to climate change, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (**adaptive capacity**).

Impact matrix

The analysis will be carried out by covering three main problem fields:

(1) climate change as such (observations and scenarios),

(2) impact of climate change on water balance components and water supply, and

(3) impacts of climate change on extreme events (floods, droughts and heatwaves).

The three problem fields will be investigated and discussed in relation to the European scale and for its major geographical subregions to give a general picture and impression about the regional differences. The major changes in water resources will be highlighted for Europe and its regions taking the results of the Symposium held in Berlin 12-14 February 2007 into account. The Berlin Symposium and also this report highlight the importance of water resources availability for major sectors, such water supply and satitation, agriculture, energy, water transport and tourism. It is also the core idea of the Integrated Water Resources Management (IWRM).

The **impact matrix** is provided for four time frames (see Table 4), which are relevant for adaptation measures and are the base of most climate change and water resources related impact studies: present day situation, 2020, 2050 and 2080 with main focus on 2020 and 2050 and an outlook for 2080 when feasible. This is done by condensing the results described in Section 3.1 and 3.2 and by means of case studies representing the most important subregions in Europe: the Mediterranian, West Europe, Scandinavia, central Europe and East Europe (Section 4).

The impact matrix forms a comprehensive summary, including the key vulnerability of water resources and water related sectors across Europe and its regions and indicate main challenges to cope with climate related changes of water resources and to develop adaptation strategies.

While section 3 summarizes the results at the European scale, section 4 gives more insight to the region-specific pattern of climate change in Europe and the resulting impacts on water resources by means of case studies representing the most important subregions in Europe: the Mediterranian, Western Europe, Skandinavia, central Europe and Eastern Europe.

3 Climate change and its impact on water resources

3.1 Trends in climate and climate scenarios for Europe and its regions

The climate of the earth has always been characterised by variability and changes. However the extent and the rate of climate change observed over the last decades exceeds all changes in the last thousands of years (IPCC, 2001). According to the Intergovernmental Panel of Climate Change (IPCC, 2001) (IPCC, 2007), there is a strong evidence that the observed climate warming is attributable to human activities, mainly to emissions of greenhouse gases and change in land use patterns. The crucial scientific challenge nowadays is to investigate how pronounced climate change will be in future, which climate variables are most sensitive, what impacts on water resources availability and extreme events are to be expected, how the climate will change at the regional level, whether mitigation of climate change is possible, and how the society can adapt to possible changes.

The following sections will give a summary of the already observed changes in Europe from the beginning of 20th century up to now (Section 3.2.1) and a synthesis of the possible climate change in future based on model simulations (Section 3.2.2).

3.1.1 Observed trends in climatic components

Summary

The most important climatic drivers for the water cycle are temperature and precipitation, and, to a lesser extent, solar radiation. While temperature shows a relatively constant and consistent increasing trend over Europe, trends in radiation and especially precipitation are much more site specific, although some general patterns are apparent (EEA, 2004):

- The observed annual mean **temperature** in Europe shows an increase of approximately 0.8 °C (IPCC, 2001) to 0.95 °C (EEA, 2004) over the last century. The seasonal increase in winter temperature is more pronounced than the one in the summer.
- The observed change in precipitation shows a more heterogeneous pattern. The observed annual precipitation over northern Europe has increased by between 10 and 40 % in the last century while parts of the the Mediterranean basin has experienced up to a 20 % reduction in annual precipitation. There is an increasing trend in mean precipitation per wet winter-day in Europe, also in regions where the total precipitation amounts decrease. Generally, more extreme precipitation events are observed.
- New research results indicate a strong connection between the North Atlandic Ocellation (NAO) and European climate especially with winter precipitation and frequency of extreme rainfall events (IPCC, 2007).
- There is evidence of changes in **climatic zones** due to global climate change in

Europe, especially during the last 30 years. This results subsequently in changes of regional temperature and precipitation regimes.

- An increase in the occurrence of **heatwaves** is already recorded, and a shift of the statistical distribution towards warmer temperatures (Schär et al. 2004).

Temperature

Temperatures have been recorded in Europe starting in the 17th century. Especially during the last two decades of the 20th century, a strong increase in temperature can be observed (IPCC, 2007). According to IPCC, 2007, eleven of the last twelve years (1995 -2006) rank among the 12 warmest years in the instrumental record of global surface temperature (since 1850). The updated 100-year linear trend (1906–2005) of 0.74 [0.56 to 0.92]°C is therefore larger than the corresponding trend for 1901-2000 given in the Third Assessment Report (TAR) of 0.6 [0.4 to 0.8]°C (IPCC, 2001), and the linear warming trend over the last 50 years (0.13 [0.10 to 0.16]°C per decade) is nearly twice that for the last 100 years.

The change in temperature is generally more pronounced in higher latitudes, and the air temperature over the European continent has warmed more than the global average, with a 0.8 °C to 0.95 °C increase since 1900. Another overall pattern is that winter temperature in Europe has increased more than temperature in summer (see Figure 1 a and b). Important are the regional characteristics of temperature change: the warming has been greatest in Northwest Russia, northern Scandinavia and western Mediterranean. Other parts of Europe, especially central Europe and the eastern Mediterranean coast, show lower increases in temperature or even some decreases (Southeast Germany, Northeast Italy, Macedonia and northern Greece, see Figure 1c).

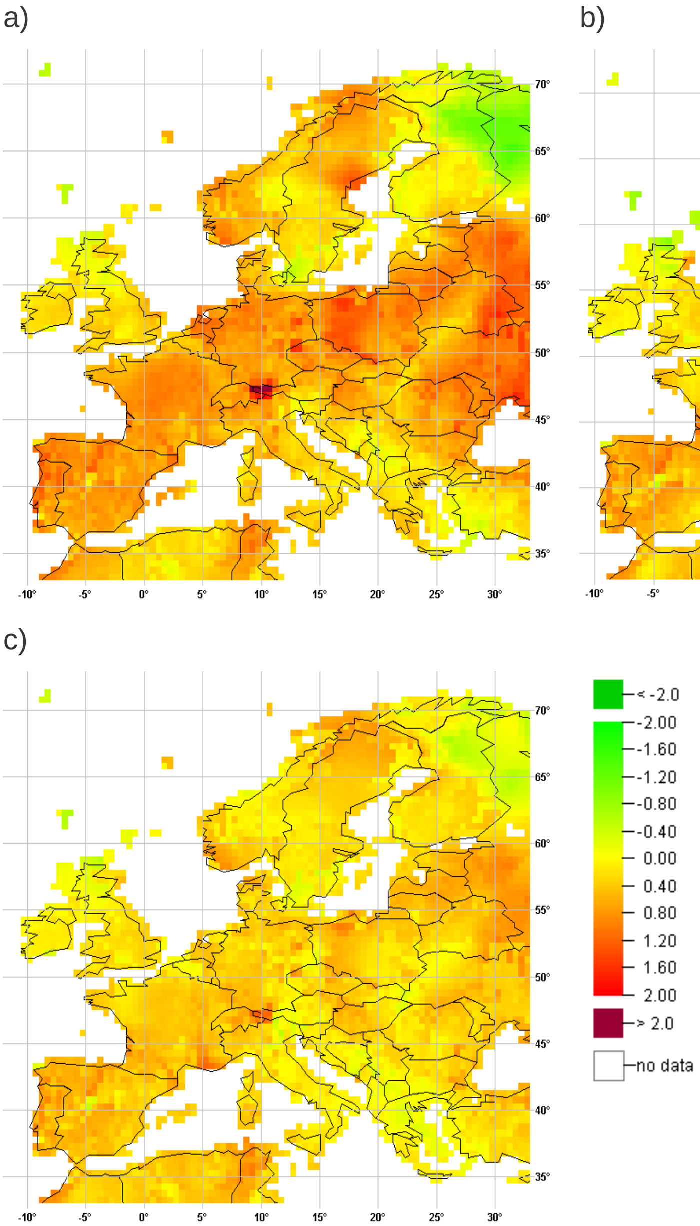

Figure 1 The observed trend in temperature over the last century (difference mean annual values 1975/2004 and 1931/1960) for the a) winter and b) summer season, and c) annual averages (This reference period was chosen instead of 1901/1930, because many time series do not cover the first decades of the 20th century. Source: PIK Global Climate Dataset, 2007).

Precipitation

More heterogeneous than the trends in temperature are the precipitation trends over Europe, because precipitation depends more on regional circulation patterns and local orography. A general pattern is that following the law of Clausius-Clapeyron saturated moisture content is a non-linear function of temperature. The observed higher temperatures stimulate the global hydrological cycle (more evapotranspiration leads to more water vapour in the atmosphere and to more precipitation). Consequantly, The average atmospheric water vapour content has increased since at least the 1980s over land and ocean as well as in the upper troposphere (IPCC, 2007). The increase is broadly consistent with the extra water vapour that warmer air can hold. However, large areas in the Mediterranean region and in central and eastern Europe experienced a decrease in precipitation over the last century.

The observed precipitation trends for the period from 1900 to 2000 show a contrasting picture between increase in northern Europe by 10–40 %, and decrease in southern Europe with up to 20 % less precipitation, especially in the winter season (IPCC, 2001; Klein Tank et al., 2002). Observations show that west-wind circulation patterns become more frequent, and precipitation in luff (west) of mountain ranges increases, while it decreases in lee (east) of the mountain ranges.

The seasonal precipitation pattern shows more pronounced trends across the European continent than the average annual changes (Figure 2a and b). In the winter season, especially, southern and eastern Europe became drier, while many parts of Northwest Europe became wetter (Figure 2a). The changes in winter precipitation can partly be linked to specific weather conditions, such as stronger western winds over northern Europe, bringing more clouds. Increases in the duration of high pressure areas in central Europe are responsible for the observed decreases in summer precipitation in the UK, eastern and western Europe and south of Scandinavia (Figure 2b).

Temperature and precipitation extremes

Due to global warming, widespread changes in extreme temperatures have been observed over the last 50 years. Cold days, cold nights and frost have become less frequent, while hot days, hot nights, and heat waves have become more frequent (IPCC, 2007). In Europe, the number of cold and frost days has decreased in most parts of Europe over the past 100 years, whereas the number of days with temperatures above 25 °C (summer days) and of heatwaves (a heatwave is an extended time interval of abnormally and uncomfortably hot weather lasting from several days to several weeks) has increased (EEA, 2004), especially in western and southern parts of the continent. Even more pronounced is the decrease in the number of frost days, due to a more significant warming in winter than in summer (Jones et al., 1999; Klein Tank et al., 2002). Important is that the tendency towards milder winters in Europe over the last decades is partly caused by stronger westerly circulation in winters, which is consistent with a positive phase of the North Atlantic Oscillation (NAO)[4] (Hurrell and Van Loon, 1997).

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[4] The North Atlantic Oscillation (NAO) is a phenomenon associated with winter fluctuations in temperature, rainfall and storminess over much of Europe. When the NAO is ‘positive’, westerly winds are stronger or more persistent. As a result, northern Europe tends to be warmer and wetter than average and southern Europe colder and drier. When the NAO is ‘negative’, westerly winds are weaker or less persistent. This causes northern Europe to become colder and drier and southern Europe to become warmer and wetter than average (MetOffice, 2006).

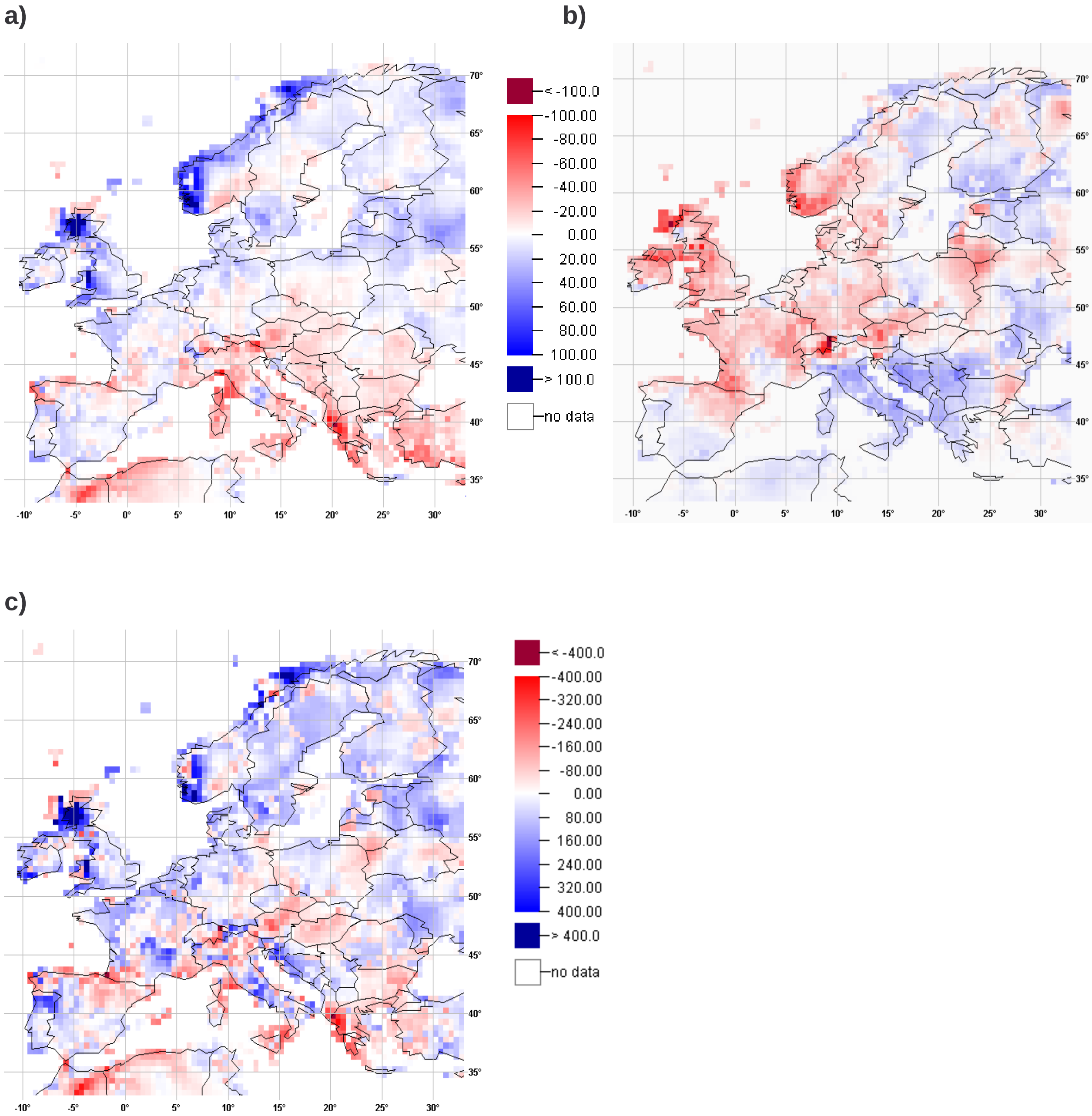


Figure 2 The observed trend in precipitation over the last century (difference mean annual values 1975/2004 and 1931/1960) for a) winter and b) summer season (seasonal sums in mm), and c) annual averages (annual sums in mm). (This reference period was chosen instead of 1901/1930, because many time series do not cover the first decades of the 20th century). Source: PIK Global Climate Dataset, 2007.

Many regions in southern Europe experienced a significant decrease of very wet days, defined as days with precipitation > 20 mm, over the last decades, whereas the number of wet days with precipitation > 1 mm increased in central and northern Europe (EEA, 2004; Klein Tank et al., 2002). The frequency of heavy precipitation events has increased over most land areas, consistent with warming and observed increases of atmospheric water vapour (IPCC, 2007). Observations also show that in many regions, the trend in precipitation extremes is more pronounced than the trend in average precipitation. An increase has been observed in the number of very wet days in central and northern Europe, whereas a decrease has been observed in parts of southern Europe (EEA, 2004). If changes in temporal precipitation trends are assessed, results by the STARDEX project show that for the last 40 years, winter heavy rainfall extremes increased in central Europe, the UK and Scandinavia, and summer heavy rainfall extremes increased across northern Scandinavia, south-western Europe and north-western Russia (Goodess, 2005).

3.1.2 Climate scenarios and anticipated future trends

Summary

Projected warming in the 21st century shows scenario-independent geographical patterns similar to those observed over the past several decades. Warming is expected to be greatest over land and at most high northern latitudes, and least over the southern Ocean and parts of the North Atlantic ocean (IPCC, 2007).

Although there is uncertainty about the extent of future climate change due to the difficulty in predicting future socio-economic development (scenario uncertainty) and due to unsatisfactory model resolution and mathematical description of all global circulation processes (model uncertainty, especially for precipitation), some important trends are relatively certain (EEA, 2004, IPCC, 2007):

- The **warming** across Europe in all seasons is in a range of 1 – 4 °C (B2 scenario) and 2.5 – 5.5 °C (B2 scenario) by 2071-2100. For Europe, a basic analysis for four regional climate model simulations was performed by Raisanen et al., (2004) under the framework of EU project PRUDENCE. In northern Europe all four simulations indicate a larger warming in winter than in summer. In southern and central Europe, the winter-summer contrast in warming is reversed from that in the North. (IPCC, 2007)
- Due to the results of the ACACIA project (Parry, 2000), the trend towards increasing precipitation in northern Europe would continue at a rate of 1 to 2 % per decade, both for winter and summer. Central Europe is in the transition zone between increase in the north and decrease in the south, and the projected changes are small or ambiguous.
- A general increase in **precipitation in winter** is expected over most of Europe (except southern Mediterranean regions) (Giorgi et al., 2004). A general decrease in **precipitation in summer** is projected in southern, western and central Europe up to Scandinavia. Extreme daily precipitation will even increase in most of those areas where the mean annual precipitation decreases (Raisanen et al., 2004). Precipitation changes for intermediate seasons (spring and autumn) are less pronounced than for winter and summer (Giorgi et al., 2004).

It is projected that heavy precipitation events will increase over many areas of Europe, and that summer dryness and **headwaves** will become more frequent throughout Europe. Especially in central and southern Europe, risk of drought is likely to increase.

Where do climate scenarios come from?

The scenario storylines used in this report and in almost every climate study have been defined by the IPCC (see Table 1). According to the terminology of the IPCC (IPCC, 2001), scenarios are images of the future, or alternative futures. They are neither predictions nor forecasts. Rather, each scenario is one alternative image of how the future might unfold. Some systems, those that are well understood and for which sufficient information is available, can be modelled with some certainty, as is frequently the case in the physical sciences. However, many physical and social systems are poorly understood, and information on the relevant variables is so incomplete that they can be appreciated only through intuition and are best communicated by images and stories. Prediction is not possible in such cases.

Table 1 The Emissions Scenarios of the Special Report on Emissions Scenarios (SRES) (IPCC, 2001; Nakicenovic and Swart, 2000).

Scenario	Description
A1	The A1 storyline and scenario family describes a future **world of very rapid economic growth**, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income.
A2	The A2 storyline and scenario family describes **a very heterogeneous and regionally oriented** world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than in other storylines.
B1	The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on **global solutions to economic, social and environmental sustainability**, including improved equity, but without additional climate initiatives.
B2	The B2 storyline and scenario family describes a world in which the emphasis is on **local solutions to economic, social and environmental sustainability**. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the A1 and B1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

When discussing future climate change it is important to understand that there cannot be any prediction of the future. Scenarios are rather projections into the future under the assumption that society behaves in a certain way. As a result, climate change varies from scenario to scenario, and is associated with ***scenario uncertainty***.

The second important source of uncertainty is a not fully adequate understanding and/or reproduction of atmospheric circulation processes in **Global Circulation Models** (GCM) (***model uncertainty***). Although using the same or similar basic physical equations, different GCMs produce results which may vary for certain scenarios. Important is also the spatial scale of GCMs (the grid size for which calculations are performed), which is between 1.5 and 2.5 degrees. This is why for climate change impact assessments at the large European scale usually climate scenarios resulting from GCMs are used, while for regional scale impact assessment usually results of **Regional Climate Models** (RCMs) are taken.

RCMs are using the results of GCMs as boundary conditions, but they reflect better local topographical and coastline features influencing climate and local physical processes (relevant especially for precipitation and for the summer period, e.g. convective processes in the atmosphere). Hence, when available and tested for plausibility, RCMs climate scenarios should be considered for regional to river basin scale impact assessments.

For temperature, GCMs and RCMs behave similarly, except that GCMs exhibit a larger spread. The differences between GCM and RCM precipitation responses for some regions are significant. The spread of precipitation during summer period is larger for RCMs than for GCMs. For both, however, in terms of precipitation, the bias is twice as large as the response to climate change, when observed climate is used as a cross validation.

Temperature

The scenarios indicate that a **warming** across Europe in all seasons in a range of 1 – 4 °C (B2 scenario) and 2.5 – 5.5 °C (A2 scenario) by 2071-2100. Over northern and eastern Europe, the warming is stronger in winter (December to Ferbraury), and the reverse happens over western and southern Europe with stronger increases in summer (June - August) (IPCC, 2007). The EU target of limiting global temperature increase to no more than 2.0 °C above pre-industrial levels is likely to be exceeded around 2050 (EEA, 2004). The range of uncertainty mainly is the result of the different storylines of demographic, technological and economic development leading to different emissions scenarios as shown in Table 1.

The possible changes in temperature under scenario conditions across Europe have been investigated in the PRUDENCE project (Jacob et al. 2007). Figure 3 illustrates the projected change in temperature until 2100 as a result of a set of different RCMs. Important is that the relative spatial pattern projected by each climate model remains the same over one emission scenario (A2), and only the size of the anomaly varies between the models. A general pattern is that except Scandinavia, the increase of temperature is the highest during summer and lower during winter. Scandinavia shows a general increase in temperature by about 3-5 °C. The highest uncertainty exists for eastern Europe, especially during summer.

Within Europe, the warming is estimated to be less pronounced along the Atlantic coastline (British Islands).

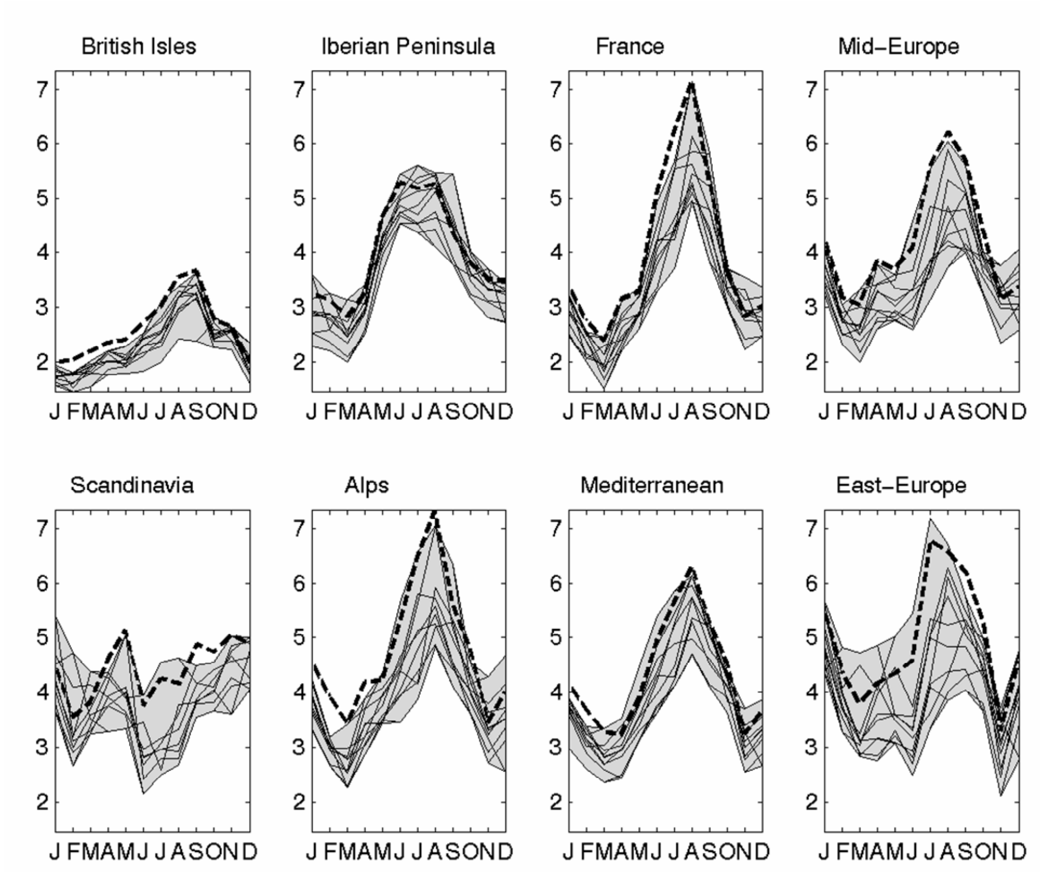


Figure 3 Monthly changes in temperature for different regions in Europe simulated by an ensemble of different RCMs in the project PRUDENCE (Jacob et al. 2007). Shown is the signal in 2m-Temperature, 2071-2100 minus 1961-1990 for the A2 SRES scenario. The thick black line indicates the result of the driving GCM for the region.

Precipitation

Raisanen et al. (2004) give the change in precipitation applying two GCMs to scenario A2 and B2. Across all scenario simulations, the results agree on a general increase in winter precipitation in northern and central Europe and on a general decrease in summer precipitation in central and southern Europe, a bit smaller in central Scandinavia. Over all, there is an annual increase in northern and an annual decrease in southern Eutope. Increased Atlantic cyclonic activity could lead to stronger precipitation (up to 15-30 %) in winter over western, central and northern Europe, and in response to anticyclic cricluation to reduced precipitation in winter over southern Mediterranean regions (Giorgi et al., 2004). In summer, a blocking situation caused by enhanced anticyclonic circulation over the Northeastern Atlantic could lead to decreases in precipitation (up to 30-45 %) over western and central Europe and the Mediterranean.

Despite of precipitation increases, the amount of snow and area covered by snow are expected to decline due to warming. The precipitation reduction in southern Europe is expected to have severe effects, e.g. more frequent droughts, with considerable impacts on crop production and availability of water resources. Figure 4 illustrates the projected seasonal change in precipitation under scenario conditions until 2100 as a result of the same RCMs as in Figure 3 (Jacob et al. 2007). As for temperature, the overall pattern of change is similar for different RCMs for the same emission scenario (A2), although the spatial heterogeneity is larger than for temperature. A general picture is that the summer precipitation all over Europe, except Scandinavia, decreases, while in most cases winter precipitation icreases. However, the winter increase in precipitation is small in the Mediterannean and cannot compensate the decrease in summer. The highest uncertainties in simulated precipitation trends exist again for East Europe.

Summarizing, uncertainty in projections of future precipitation is larger in comparison with temperature. This applies particularly to regional precipitation patterns and seasonal distribution of precipitation, which show a considerable range of projections. Nevertheless, it should be stated that scientific confidence in the ability of climate models to estimate future precipitation is steadily increasing (IPCC 2007).

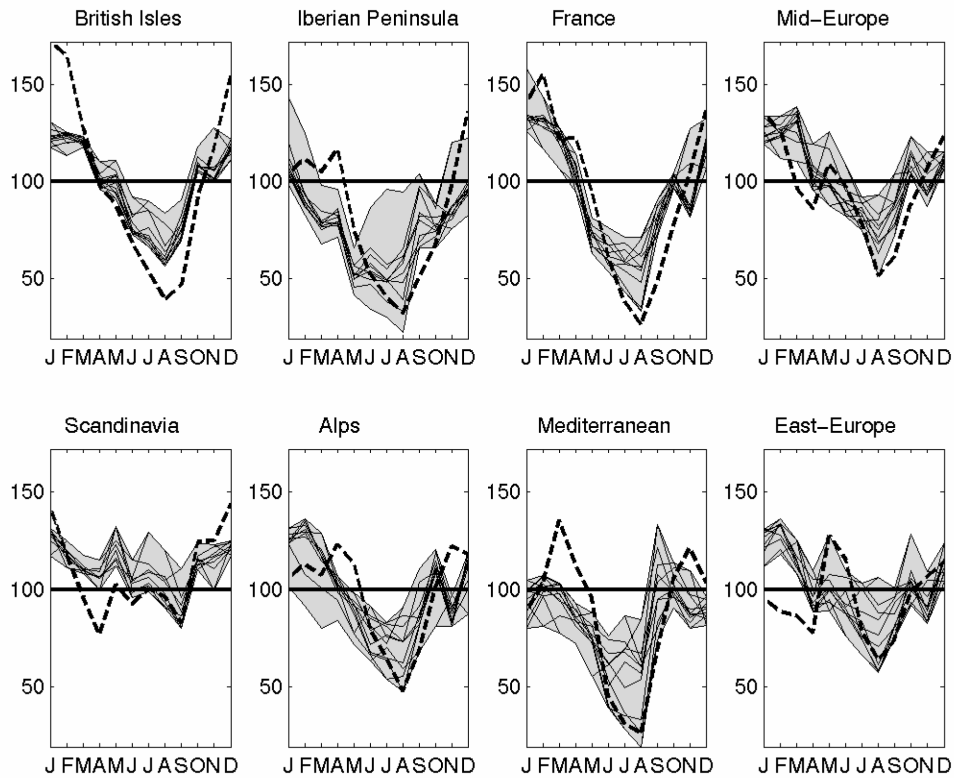


Figure 4 Monthly changes in precipitation for different regions in Europe simulated by an ensemble of different RCMs in the project PRUDENCE (Jacob et al. 2007). Shown is the difference 2071-2100 minus 1961-1990 for the A2 SRES scenario. The thick black line indicates the result of the driving GCM for the region.

Temperature and precipitation extremes

According to IPCC (2007), yearly maximum temperature is expected to increase much more in southern and central than in northern Europe. Following Luterbach et al. 2004, cold winters, which occurred on average once every 10 years in the period from 1961 to 1990, are likely to become rare in Europe and will almost entirely disappear by 2080. In contrast, by 2080 nearly every summer in many parts of Europe is projected to be hotter than the 10 % hottest summers in the current climate. Under high emission scenarios every second summer in Europe will be as hot or even hotter than 2003 by the end of the 21st century (Luterbacher et al., 2004). In southern Europe, these changes are projected to occur even earlier (e.g. in Spain by the 2020s) (Parry, 2000).

It is very likely that heavy precipitation events will increase over many areas of the globe, and it is likely that summer dryness will rise over most mid-latitude continental interiors (IPCC, 2007). Works of Giorgi ***et al.***, 2004 and Räisänen ***et al.***, 2004 agree that the intensity of daily precipitation events will predominantly increase, even in regions where the mean annual precipitation will decrease (Christensen & Christensen, 2003, Kundzewicz ***et al.***, 2005), leading to more extreme precipitation events. The number of wet days will decrease according to Giorgi ***et al.*** (2004), which would lead to longer dry periods except in the winter of west and central Europe. Increase of the number of days with intense precipitation has been projected in Europe (Kundzewicz ***et al.***, 2005).

Palmer & Räisänen (2002) analyzed the modelled differences between the control run with 20th century levels of carbon dioxide and an ensemble with transient increase in CO_2 and calculated around the time of CO_2 doubling (61-80 years from present). They found a considerable increase of the risk of a very wet winter in Europe and a very wet monsoon season in Asian monsoon region. The modelling results indicate that the probability of total boreal winter precipitation exceeding two standard deviations above normal will considerably increase over large areas of Europe. For example, an over five-fold increase is projected over parts of British Isles and much of the Baltic Sea basin, and even over seven-fold increase for parts of Russia.

3.2 Climate change impacts on water resources for Europe and its regions

3.2.1 Observed trends in water resources and extreme events

Summary

- **River discharge** decreased considerably in some southern European river basins and increased in some rivers of eastern Europe. In central Europe, no significant trends were observed.
- Over the observation period between 1975 and 2001 the annual number of **flood events** in Europe clearly increased.
- Based on the results of trend analysis for the last 40 years, **long dry periods** in summer showed an increase in most stations in central Europe, the UK and southern Scandinavia, and long dry periods in winter increased in southern Europe.
- **Glaciers** in eight out of the nine European glacier regions are in retreat.
- During the last two centuries, the **level** of the Baltic Sea has risen significantly,

but in the Mediterranean Sea a more complex phenomena has been observed: from an increasing trend at some gauges to a decreasing trend in others.

- A long-term trend towards shorter **duration of ice cover** has been reported for lakes in Finland and Switzerland.

Annual river discharge

Annual river discharge, as well as precipitation, varies widely across the European continent, reflecting different climate conditions and topography. Discharge levels follow amounts of regional precipitation and range from very high on Britain's west coast, in western parts of Norway, and in Iceland to very low in parts of Spain, Sicily, Turkey and southern Ukraine. In semi-arid and arid regions the annual discharge volume is mainly determined by precipitation in the upper parts of a basin. The uncertainties in the measurements of annual river discharge are relatively low (Jasper et al., 2004), because data availability is good and processes are well understood.

The observed trends in annual river discharge over the twentieth century show different patterns in river basins across Europe (Figure 5). It is very likely that the observed changes are mainly due to changes in precipitation, although river discharge is also affected by various anthropogenic factors such as river engineering measures and land use change. River discharge decreased considerably in many southern European river basins such as the Loire (France), the Jucar and Guadalquivir (both in Spain), and the Adige (Italy) (EEA, 2004). In contrast, increases in river discharge occurred in some rivers of eastern Europe (e.g. the Danube tributaries). In central Europe, no significant trends were observed (e.g. the Rhine and the Elbe). Fresh water input to the Baltic Sea did not change substantially between 1920 and 1990 (Winsor et al., 2001).

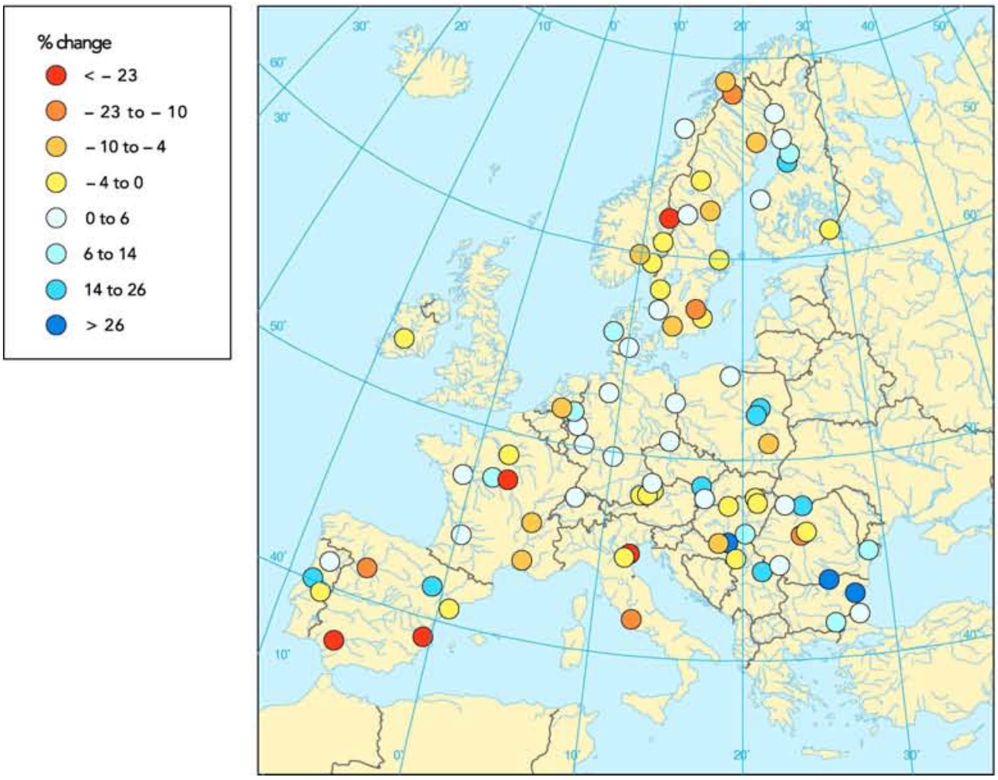


Figure 5 Changes of the mean annual river discharges over the twentieth century (EEA, 2004; permission for reproduction obtained).

A study of trends in annual maximum daily river discharge was performed recently using 70 time series for European gauges from 1961 to 2000 (Kundzewicz et al., 2005). The period was divided into two twenty-year subperiods. It was found that the overall maxima occurred more frequently in the later subperiod 1981-2000 (46 times) than in the earlier subperiod 1961-1980 (24 times). Figure 6 presents the direction of changes in annual maximum daily river discharge for 70 stations in Europe. Some gauges show significant positive or negative trends in annual maximum flow, while for most of the gauges trends are not statistically significant.

In a national-scale study for 61 stations in Sweden, Lindstrom et al. (2004) found a substantial increase in annual discharge and flood magnitude, but they were not exceptional in the context of high flows observed earlier.

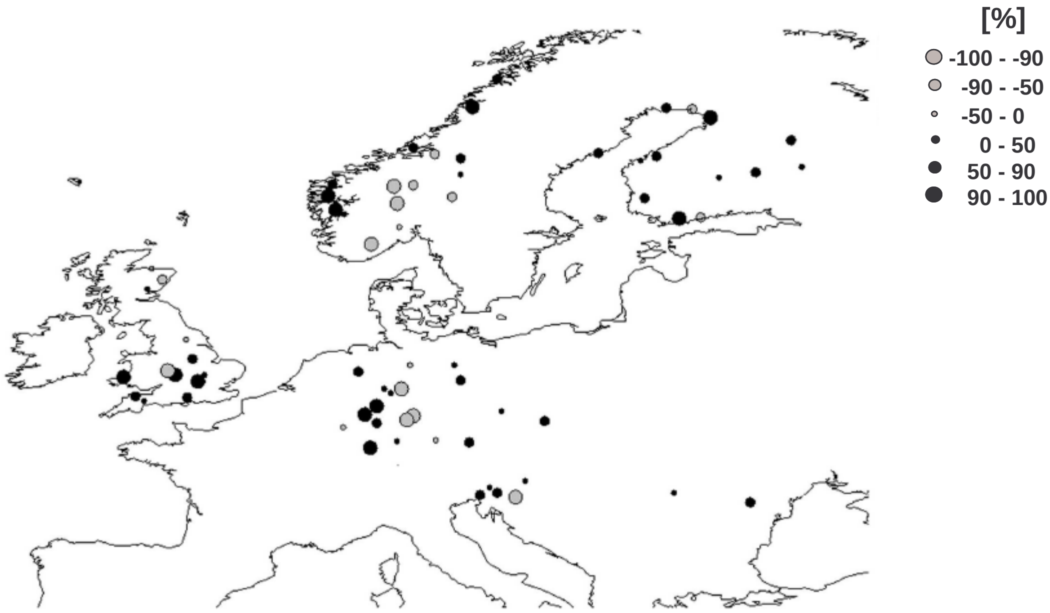


Figure 6 Significant changes in annual maximum flow of European rivers: shown are the directions and significance of changes (Kundzewicz et al., 2005). Directions of change are indicated by colour of the dots, with black referring to positive and grey to negative changes. Significance of change is shown through size of the dots, with the numbers representing the respective significance levels of the observed changes. Only values above 90% and lower -90 % can be seen as significant: -100 – -90% means significant decrease, and 90 – 100% significant increase. Permission for reproduction obtained.

Floods

The number of great flood disasters worldwide has grown considerably over recent decades: six cases in the 1950s, seven in the 1960s, eight in the 1970s, 18 in the 1980s, and 26 in the 1990s (Berz, 2001; Kundzewicz and Schellnhuber, 2004).

Milly et al. (2002) examined historical time series on the occurrence of hundred-year floods in large-scale river basins around the world, and then used climate models to evaluate whether the observed behaviour was related to the greenhouse effect or not. They found a higher frequency of hundred-year floods in the second half of the records compared to the first half. The trend found in hundred-year flood occurrence over the 20th century was rather small: 1.99 x 10^{-4} events per year, which means one extra hundred-year flood every 5,000 years. This trend was identified in climate model runs with 20th century conditions. Nevertheless, it was shown that this trend will continue, and perhaps even grow in the future.

The same tendency is observed in Europe. Over the period between 1975 and 2001, 238 flood events were recorded in Europe, and the annual number of flood events clearly increased (EEA, 2004). Extreme floods occurred during the last decade in Germany, Austria, the Czech Republic, Hungary and Poland. However, this tendency in the occurrence of extreme events can not be attributed to the impacts of climate change alone and results from a concurrent combination of changes in climatic conditions and land-use patterns. The flood damage recorded in the European continent in 2002 was higher than in any single year before (Kundzewicz and Schellnhuber, 2004).

The World Water Council (WWC, 2003) reported that economic losses caused by weather and flood related catastrophes worldwide had increased ten-fold over the past 50 years. The WWC ascribes this development partially to the results of rapid climate change, causing more intense rainy seasons, stronger storms, shifts in rainfall and rising sea levels. However, the question to which extent such an increase in flood damages can specifically be linked to climatic forcing rather than increased vulnerability and land use change is very complex and requires further investigations.

Droughts

According to the results of the trend analysis performed by the STARDEX project (Goodess, 2005) for the last 40 years, long dry periods in summer showed an increase in most stations in central Europe, the UK and southern Scandinavia, and long dry periods in winter increased in southern Europe. It was also found in this project that ***partly*** the observed changes in extremes (heavy rainfall, floods, droughts and heatwaves) can be explained by changes in large-scale atmospheric circulation.

The heatwave of 2003 affected France, Spain, Portugal, Germany, Italy, Switzerland, Austria, England and eastern European countries. The temperatures in summer 2003 in Germany were on average about 3.4°C higher than in the period 1961-1990, corresponding to a recurrence period of 450 years (Demuth, 2005). However, Schär et al. (2004) claim that the extremely hot summer of 2003 statistically cannot be attributed to a warming of climate alone. They suggest that along with the increase in mean temperature, an increase in the variability of temperatures might be happening.

Glaciers and snow cover

Glaciers are considered as key indicators for the early detection of global greenhouse gas related warming trends (IPCC, 2001). According to data from the World Glacier Monitoring Centre, glaciers in eight out of the nine European glacier regions are in retreat (see Figure 7), which is consistent with the globally observed trend. From 1850 to 1980, glaciers in the European Alps lost approximately one third of their area and one half of their mass (EEA, 2004). During the melting process, there is an increase in the number of hazardous events such as falling ice and landslides. Alongside, the annual snow cover in the northern hemisphere has decreased by about 10 % since 1966 (EEA, 2004).

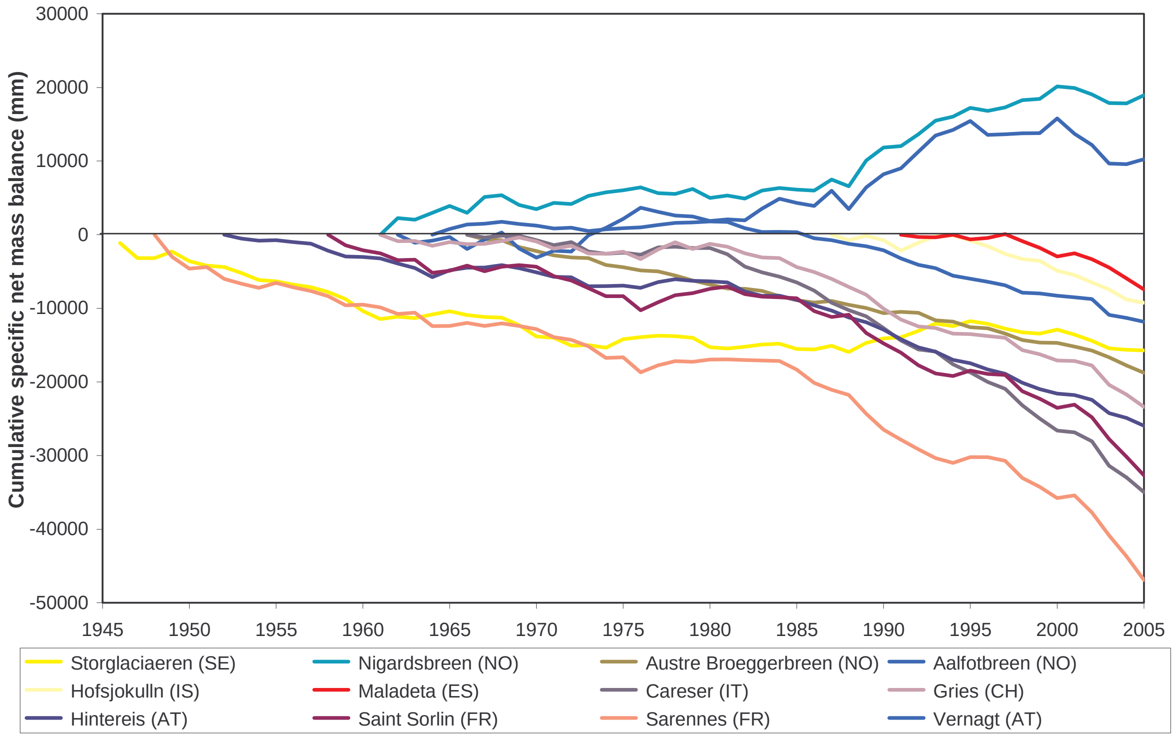


Figure 7 Change in cumulative specific net mass balance of glaciers from all European glacier regions between 1946 and 2005. Source: World Glacier Monitoring Centre, 2007.

Sea level rise

During the last 2 centuries, the level of the Baltic Sea has increased significantly with a clear shift in the rate of change at the end of the 19th century from 1.8 cm/century to 9.9 cm/century (Omstedt et al., 2004). This is correlated with a decrease in the probability of ice occurrence, particularly in the southern Baltic, and a tendency for shorter ice periods (Jevrejeva et al., 2004). In the Mediterranean Sea a more complex phenomenon is observed: from an increasing trend at some gauges to a decreasing trend in others. Recent data indicate a rapid rising of sea level, up to 20 mm·yr^{-1} in the eastern Mediterranean observed in field measurements as well as by satellite altimetry (Cazenave et al., 2001; Jevrejeva et al., 2004; Tsimplis and Rixen, 2002). However, it is still not clear whether the sudden rise in sea level since the mid of 1990's represents a long-term trend or an inter-annual or decadal fluctuation.

Lakes

A long-term trend towards shorter **duration of ice cover** has been reported for lakes in Finland and Switzerland (Kuusisto, 1987; Livingstone, 1997; Palecki and Barry, 1986). The trend to an earlier ice melting increases the ice-free period and lake temperatures in spring (Blenckner et al., 2002). There are some records of a progressive reduction in ice cover at Loch Leven in Scotland and Windermere in the English Lake District (George et al., 2000). In future only a few lakes in the more mountainous areas of the Atlantic Region will freeze every year, though even here the duration of ice-cover will be reduced. Historical observations from a high alpine lake in Switzerland indicate that the date of ice break-up occurred 12 days earlier in 1990s than 150 years ago (Eisenreich, 2005). As a result of reduced ice duration, effects of UV radiation became more pronounced in some high alpine lakes in the last century (Psenner and Schmidt, 1992).

Long-term measurements in the English Lake District and in Sweden demonstrate that the winter **temperature of the lakes** has increased by at least 0.6 ^{o}C over the last fifty years (George et al., 2000; Weyhenmeyer, 2001).

Melting of glaciers and loss of soil permafrost in catchments of high alpine and subarctic lakes as a result of climate warming causes dramatic changes in **chemistry and biota** of these lakes. For example, a temperature increase by two degrees that melted the permafrost in the Lake Schwarzensee, a remote high alpine lake in Austria, resulted in doubling of conductivity and silica, increased productivity, and notable increase in pH (Psenner and Schmidt, 1992). In the study of Eisenreich (2005) it was concluded that the increase in water residence time was the main factor causing strong internal eutrophication in Swedish lakes, illustrating the potential sensitivity to climate change of lakes with a long water residence time.

3.2.2 Impacts on water balance components

Changes in climate parameters (mainly temperature and precipitation) will cause changes in water balance components. Major target components considered in this report are evapotranspiration, river discharge and groundwater recharge. These components mainly determine the availability of water resources. Also, a brief examination of possible climate impacts on glaciers, snow cover and on lake systems is included.

To assess the impacts of climate change on water balance components, a coupling of atmospheric and hydrological models is required. For this purpose, GCM outputs regarding changes in climatic parameters such as temperature and precipitation are used as inputs for the hydrological models. However, one of the main problems is the scale difference between the climate and hydrological systems. Whilst GCMs have a quite coarse spatial resolution (i.e. grid sizes of about one hundred kilometers), hydrological models require much finer detail (i.e. a spatial resolution of one kilometer as a maximum). The two main techniques to overcome this problem are the use of statistical methods or RCMs (IPCC 2007).

Summary:

- Generally, **evapotranspiration** increases due to climate change. In areas with sufficient available moisture (e.g. regions in northern Europe), increase in temperature would lead to increases in evapotranspiration.
- Predictions of the effect of climate change **on runoff and river discharge** are uncertain. The general trend is towards an increasing of winter runoff and decreasing of spring runoff at high latitudes. In central Europe, winter runoff could increase, and summer runoff decrease, while the annual runoff most probably will remain practically unchanged. Some studies indicate a decrease in annual average runoff in south-eastern Europe.
- Several river basin case studies indicate possible climate-induced **changes in the timing of runoff** resulting from the effects of rising temperatures on snow cover dynamics, which would enhance winter runoff, reduce summer runoff, and shift monthly peak flows by up to two months earlier than at present. The occurrence of peak runoff and flood risk could move from spring to winter.
- Most studies on water supply and demand conclude that annual **water availability** would generally increase in northern and north-western Europe and decrease in southern and south-eastern Europe. Temperature rise and changing precipitation patterns are expected to exacerbate the already acute water shortage problem in southern and south-eastern European regions.

Evapotranspiration

Evapotranspiration is defined as the release of water vapour from the earth's surface (soil and surface waters) to atmosphere by evaporation and plant transpiration. Generally, evapotranspiration increases due to climate warming. Evapotranspiration is influenced mainly by the availability of energy (solar radiation) and water, as well as by air temperature, air humidity, wind speed, vegetation and soil characteristics. It is well established that as temperature rises, the energy available for evaporation increases and the atmospheric demand for water from land and surface waters increases as well. Furthermore, a warmer atmosphere can hold more water. Evapotranspiration is driven by the availability of energy, but actual evapotranspiration rates are constrained by the actual water availability. Higher temperature will lead to an increase in potential evapotranspiration, but could result in lower actual evapotranspiration if water availability decreases.

In areas with sufficient available moisture (northern Europe) an increase in temperature will lead to an increase in evaporation and evapotranspiration. By contrast, in southern Europe (e.g. the Mediterranean region) a reduction in water availability during the summer season will lead to a reduction in total evapotranspiration despite a temperature driven increase in evaporative demand. According to estimates of Arnell (1996) for several catchments in the UK, the rate of actual evaporation would increase by a smaller percentage than the atmospheric demand for evaporation, with the greatest difference in the driest catchments, where water limitation is larger.

River discharge

River discharge consists of a portion of precipitation that is not evaporated, transpired or stored by soils. Changes in annual river discharge are projected to vary significantly across Europe under climate change, related to regional environmental settings and local changes in precipitation and temperature. Predictions of climate change effects on river discharge are quite uncertain and the predictions of different models using different climate scenarios are variable. Studies providing projections of annual runoff changes for northern Europe have been done by Werrity (2002) and for central and south-eastern Europe by a number of authors (Alcamo et al., 2005; Chang et al., 2002; Estrela et al., 2005; Etchevers et al., 2002; Menzel and Bürger, 2002; Santos et al., 2002). The uncertainties are mainly caused by uncertainties in the projections of changes in precipitation. Here the use of Regional Climate Models is of advantage.

As a general trend demonstrated by many modelling studies, runoff in higher-latitude areas with increased precipitation most likely will increase in winter and decrease in spring due to the fact that less precipitation will fall as snow in winter and less snow melting will occur in spring. In mild temperature climates, annual runoff would remain practically unchanged, but will exhibit a more dynamic seasonal cycle. Summer flow in river basins with considerable groundwater contribution will change due to changes in precipitation during the groundwater recharge period in winter. In arid and semi-arid Mediterranean areas changes in precipitation will be translated into runoff changes, while the latter will be considerably higher in percentage.

Projected changes in river discharge mainly depend on changes in precipitation, and the relationship is non-linear. Figure 8 demonstrates exemplarily the projected changes in average annual river discharge in Europe compared to today's levels and discrepancies between projections of change based on two GCMs. By 2020 most of Europe expects only small changes in runoff (-5 to +5 %), while the Mediterranean region and eastern Europe may expect decreases up to 25 %. Northern Europe may expect increases in river discharge up to 25 %. For some areas two models ECHAM4 and HadCM3 project changes in different directions (e.g. Portugal, Spain, UK). For 2070s signals of changes are more explicit with river discharge decreasing by more than 25 % in southern and south-eastern Europe, and increasing by more than 25 % in most parts of northern and north-eastern Europe (Figure 8). Consequently, stress on water resources may continue to grow significantly in southern Europe.

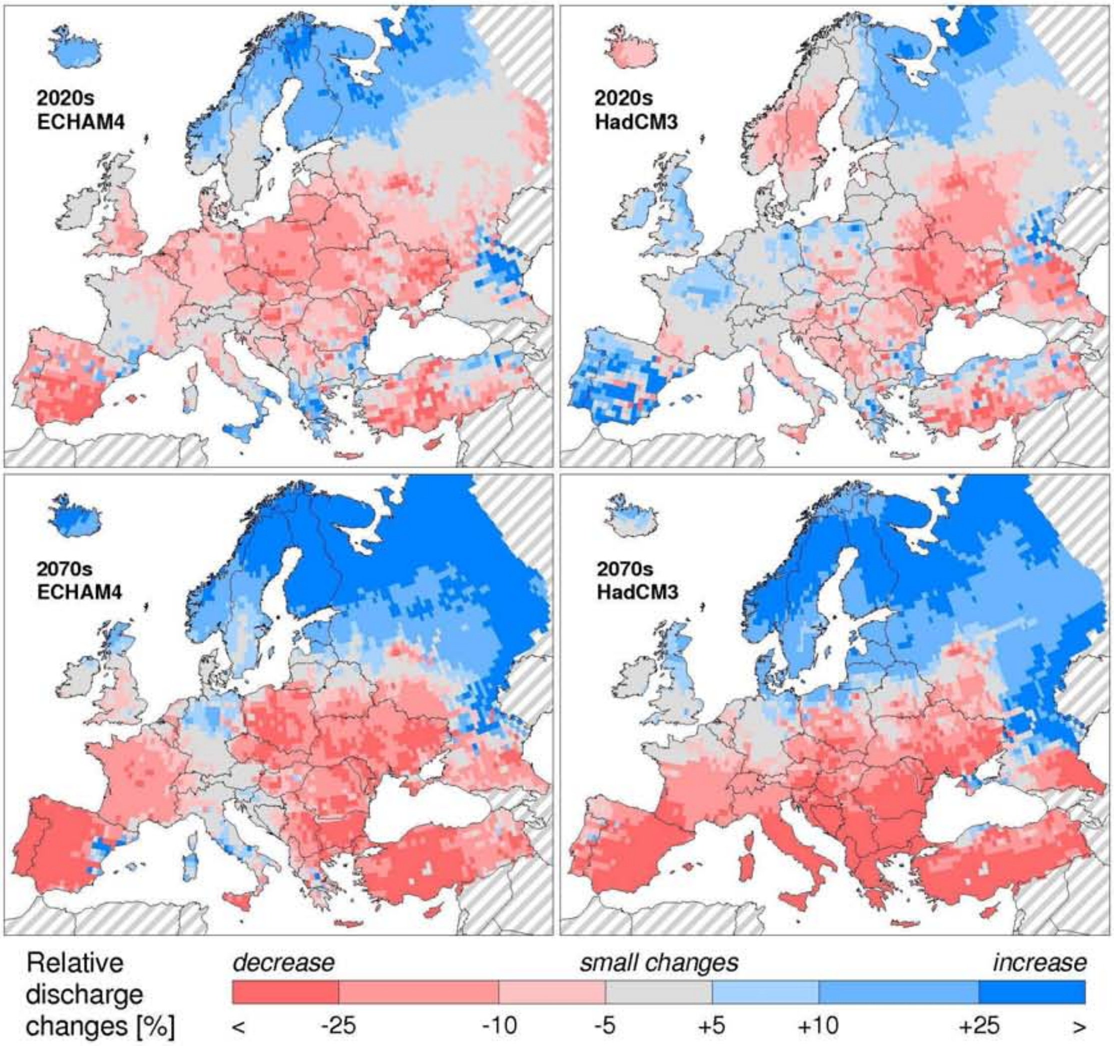


Figure 8 Change in river basin discharge under climate change. Depicted are relative changes of annual average river basin discharge between the climate normal period (1961-90) and two future time slices (2020s) and (2070s). Computations from WaterGAP 2.1 model (Alcamo ***et al.***, 2003; Döll, 2002) with climate scenarios based on the IS92a scenario as computed by the ECHAM4 and HadCM3 global climate models, and with a reference water use scenario (Lehner et al. 2006).

Some other studies (e.g. Arnell, 2004a) indicate a decrease in annual average runoff of 20-30 % by the 2050s and of 40-50 % by the 2075s in south-eastern Europe. Here, annual rainfall and river discharge have already begun to decrease in the past few decades (Hulme et al., 1999). Projected percentage changes in annual river discharge are often more pronounced than changes in precipitation due to non-linearity.

Changes in runoff regime and seasonality are also expected to occur under climate change. By 2020 an increase in winter runoff and decrease in summer runoff can be stated. Summer runoff in southern Europe may decrease by up to 50 % by 2050 and up to 80 % by 2080 (EEA, 2005b). A similar trend is also expected for the Rhine (Middelkoop et al., 2001), the Volga (Oltchev et al., 2002) and Slovakian rivers (Szolgay et al., 2004). For central Europe a decrease of summer flow by up to 50 %

(Eckhardt and Ulbrich, 2003) in particular in the Alps after the melting of its glaciers (Schneeberger et al., 2003) is likely. Changing precipitation and temperature in alpine and mountain regions together with changes in snow cover and precipitation type (rain instead of snow) may cause a shift in the flow regime. For the Swiss Alps Zierl and Bugmann (2005) state that summer discharge of Alpine catchments will significantly decrease, winter floods will become more frequent and that the snow line will rise. Arnell and Reynard (1996) modelled river discharge in the UK under various climate scenarios and found that discharge would increase in winter under all scenarios. Many models predict higher changes in monthly flow than in annual flow (shift in seasonality) (Eisenreich, 2005).

Groundwater recharge

Already relatively small changes in precipitation amounts in conjunction with temperature rise may notably impact groundwater recharge, potentially leading to a reduction in recharge (Eitzinger et al., 2003). Rising temperature induces longer vegetation growth periods. This leads to increasing evapotranspiration, which continues later in the autumn season leading to delayed and lower groundwater recharge. Also the end of the recharge period would come earlier in spring. This would be most evident in south-eastern Europe. Cooper et al. (1995) found that the effects of various climate scenarios on groundwater recharge depend on the aquifer type, and that scenarios incorporating higher evapotranspiration resulted in the highest change in hydrological regime of aquifers.

For instance, Arnell (2003a) found that average annual groundwater recharge in the UK is expected to fall by 5 to 15 %. Hattermann et al. (2007) reported an average decrease in groundwater discharge for the Elbe basin (Germany) of 22 % by 2055 with up to 75 % decrease in some parts of the basin. Eckhardt and Ulbrich (2003) found a decrease of groundwater recharge in the Dill catchment (Germany) of up to 50 % by 2070 – 2100. Kruger et al. (2001) estimated a reduction of groundwater recharge by 15 to 30 % until 2050 for central European river basins.

Generally, the coupling of effects of both climate change and anthropogenic activities could be even more important for groundwater. Aquifers usually recharge very slowly, and the current level of water abstraction may appear to be not sustainable under future climate conditions, especially in some southern European regions, where aquifers are already overexploited and falling groundwater levels are already observed (Eisenreich, 2005). Other possible negative consequences of falling groundwater levels are a loss of wetlands and, in case of aquifers in coastal zones, salt water intrusion.

Water resources availability

Above stated changes in water balance components under climate change translate to changes in water resources availability. Apart from possible climate change impacts on the water cycle, other pressures (mainly in domestic, industrial, and agricultural water demand) control the availability of water resources in Europe. Information on the combined impacts of climate change and human water withdrawals can be found in studies by Döll (2005) and Lehner et al. (2001), indicating increasing pressure on water resources in most of eastern Europe, southern Europe and parts of central Europe by 2070s compared to situation in the 1990ies (Henrichs and Alcamo, 2002).

Schröter et al. (2004, 2005) investigated changes in water stress status of European river basins by 2080 considering climate change and population growth for Europe. Water stressed basins are defined as having less than 1700 m^3 water per capita and year. Simulations were carried out for four emission scenarios (A1f, A2, B1, B2) with respective population sizes and based on four GCMs (HadCM3, CGCM2, CSIRO2 and PCM) for A2 emission scenario compared to the hypothetical case of no climate change.

Table 2 Number of people (millions) living in European watersheds with less than 1700 m^3 per capita per year, by socio-economic storyline (A1f, A2, B1, B2), assuming no climate change and climate change calculated by four GCMs (HadCM3, CGCM2, CSIRO2, PCM) in the years 2025, 2055 and 2085. The change in number of people (millions) due to climate change is shown as well (Schröter et al., 2004).

	millions						Change (millions)			
	total population	no climate change	HadCM3	CGCM2	CSIRO2	PCM	HadCM3	CGCM2	CSIRO2	PCM
2025										
A1f	633.0	357.5	356.2				-1.3			
A2	646.4	365.6	364.2	364.2	364.2	364.2	-1.4	-1.4	-1.4	-1.4
B1	633.0	357.5	360.8				3.2			
B2	609.4	342.0	346.3				4.3			
2055										
A1f	610.5	286.0	350.8				64.8			
A2	656.1	331.0	376.7	379.6	374.5	375.7	45.7	48.7	43.5	44.8
B1	610.5	286.0	352.9				67.0			
B2	565.9	250.7	287.7				36.9			
2085										
A1f	570.1	249.0	324.6				75.6			
A2	716.3	437.4	465.5	461.4	449.0	444.9	28.1	24.0	11.6	7.5
B1	570.1	249.0	298.8				49.8			
B2	557.2	246.4	297.0				50.6			

A large proportion of Europe's population already lives in watersheds with less than 1700 m^3 $capita^{-1}$ $year^{-1}$ (estimated as the water stress threshold), and beyond the 2020s climate change would increase the number of people living under this threshold level (Table 2). Until 2025 climate change has no severe impacts on the number of people living under water stress situations (Table 2), but for 2055 and 2085 the amount of people under water stress considerably increases.

Increases in water stress are projected for southern Europe especially the Iberian Peninsula and Italy for all cases and partly for central Europe (Schröter et. al., 2005). The authors stated that population growth and climate change by 2080 would increase the number of people living in water-stressed watersheds, and water deficiency would be exacerbated for many already stressed areas, particularly in southern Europe.

Glaciers and snow cover

Most of European glaciers, especially in the Alps, experienced a retreat and loss of glaciers ice mass. It is very likely that the glacier retreat will continue. By 2050, about 75 % of the glaciers in the Swiss Alps are likely to disappear (EEA, 2004). Northern hemisphere snow cover extent is projected to decrease further during the 21st century. Under a warmer climate, snow cover will diminish substantially. At least three consequences can be expected: (1) summer discharge of Alpine catchments will significantly decrease, (2) winter floods will become more frequent, and (3) the snow line (defined as the altitude above which snow becomes a seasonal or permanent feature) will rise (Schröter et al., 2004). Snow cover is highly sensitive to changes in temperature. Simulations indicate that the elevation of a reliable snow cover will rise between 200 m and 400 m, i.e. from about 1300 m a.s.l. today to 1500-1700 m a.s.l. at the end of the 21st century (Schröter et al., 2004). The projected increase in winter precipitation can partly compensate for the temperature-related rise of the snow line, but it cannot prevent the upward shift. Sensitivity studies for five Alpine catchments have shown that per degree Celsius of warming elevation of reliable snow cover moves upward by approximately 150 m (Schröter et al., 2004). The simulated development of snow line altitude is shown exemplarily for two alpine catchments in Figure 9.

Lakes

According to the report by the European Commission's Joint Research Centre (Eisenreich, 2005), the response of lakes to climate change is most coherent for physical parameters: there is a high probability for increase of lake temperature, shorter ice-cover duration, and stronger thermal stratification. Freshwater systems in the arctic, subarctic, and alpine regions are particularly sensitive to climate change, and most climate change scenarios indicate that the highest and most rapid temperature increase will occur in these regions (Arctic Council, 2004; McCarthy et al., 2001).

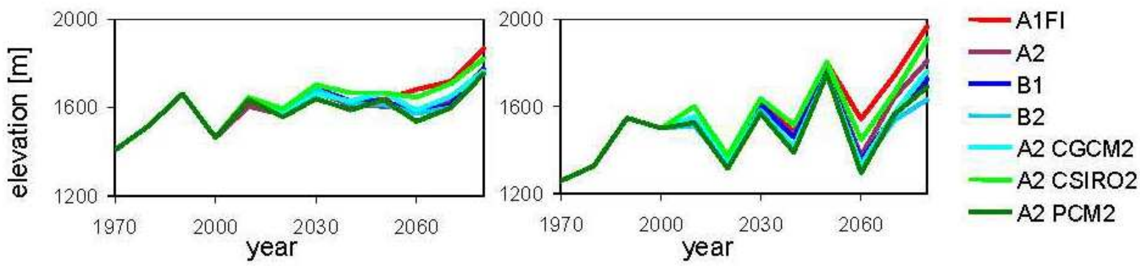


Figure 9 Elevation of snow line (elevation above which the snow cover is reliable) as projected for seven future climate scenarios. The left chart shows the Alptal catchment, the right chart shows the Verzacsa-Lavertezzo catchment (Schröter et al., 2004).

The most visible changes will occur in lakes, which previously were permanently ice-covered and now will become temporarily ice-free (Psenner, 2003), and also in lakes which will totally loose their winter ice-cover. Expected changes in cycling of nutrients and chemical regime of lakes (e.g. eutrophication rate) are less coherent and strongly depend on local conditions and the current lake type. However, even small shifts in climate parameters may have dramatic effects on biota and biodiversity, especially in extreme habitats where species are living at the limit of their capabilities. In regions with higher precipitation and hence higher runoff the pollution loads from catchments (diffuse source pollution) to the lakes will be increased under assumption of unchanged land management, and vice versa (Krysanova et al., 2005a).

3.2.3 Impacts on extreme events (floods and droughts)

According to the Clausius-Clapeyron law, the atmosphere’s water holding capacity increases with temperature, and hence the potential for more intense precipitation increases. Higher and more intense precipitation has already been observed globally, and this trend is expected to increase in the future world under global warming. This is a sufficient condition for flood hazard to increase (Kundzewicz and Schellnhuber, 2004). Besides, there are other, non-climatic factors escalating flood hazard. Changes in land-use patterns can also intensify the impacts of extreme precipitation events. For example, deforestation, urbanisation and the elimination of floodplains and wetlands alter the water storage capacity of soils and thus influence runoff patterns (Kundzewicz and Schellnhuber, 2004). Settlements and infrastructure in flood prone areas and in coastal zones also potentially increase flood losses. However, assessing changes in flood hazard, it is difficult to disentangle the climatic component in hydrological extremes from strong natural variability and human-induced environmental changes. Projections of extreme events and their consequences for future climate are therefore highly uncertain.

Summary

- **Temperature variability** increases strongly in the future, with maximum changes in central and eastern Europe.
- Episodes of intense precipitation will most likely increase in frequency and consequently **risk of floods** will increase.
- Considerable increase of the risk of very wet winters in Europe over large areas of Europe is expected. **Risk of late autumn and winter floods** (caused by rain) is increasing, but less snowmelt floods in Europe are expected.
- Model results suggest that under enhanced greenhouse-gas concentrations, summer temperatures are likely to increase by over 4°C on average by 2070-2100, with a corresponding increase in the frequency of **droughts and severe heat waves**.
- In general, increases **in frequency and intensity of droughts and floods** are projected by many modelling studies, which could cause significant financial and human losses throughout Europe.

Risk of extreme events shown by models

Under the scenario of CO_2 doubling, climate models are converging towards an intensification of the hydrologic cycle with an increase in precipitation intensity, up to 1 % per decade in the 20th century over the northern mid- and high latitudes, whereas other areas in southern mid-latitudes will be experiencing drier conditions (IPCC, 2001). The results of climate models have shown that the risk of extreme precipitation and flooding would increase in the future (Milly et al., 2002; Palmer and Räisänen, 2002). It is also recognised that changes in the hydrologic cycle would emerge as extreme events in time, either floods or droughts at specific periods of the year.

Palmer and Raisanen (2002) analysed differences between the control model run with 20th century levels of CO_2 and an ensemble with transient increase in CO_2 around the time when CO_2 will be doubled (about 61-80 years from present). They found a considerable increase of the risk of a very wet winter in Europe. Their results indicate that the probability of total winter precipitation in the boreal zone to exceed two standard deviations above normal will increase by a factor of five to seven over large areas in Europe (e.g. in Scotland, Ireland, parts of Russia, and much of the Baltic Sea basin area).

Climate change may also change the timing and magnitude of both high flows (Reynard et al., 2001) and low flows (Arnell, 1999). The occurrence of greatest flood risk could move from spring to winter (Ludwig et al., 2004), and be enhanced by the expansion of impermeable surfaces due to urbanisation (De Roo et al., 2003).

Figure 10 (De Roo, personal communication) presents the change in 100-year return level between the control and scenario periods based on the HIRHAM climate run at 12 km driven by the A2 emission scenario for European rivers with an upstream area larger than 1000 km^2. Over most areas of northern Europe, the 100-year discharge level will decrease, in spite of an increase in the average runoff. This will be mainly due to higher temperatures causing a shorter snow season and less snow accumulation. A similar trend can be seen in some rivers draining from the Alps and the Carpathian Mountains. Elsewhere in Europe, the 100-year discharge is mainly projected to increase, even in areas where the climate is getting much drier on average, like in Spain and southern France. This implies that in many rivers in Europe extreme discharge levels may become more frequent and/or more intense. In some major river basins like the Rhone, Rhine, Elbe and the Upper Danube, the probability of a 100-year flood almost doubles, or, in other words, the return period of such extreme flood events decreases from 100 to about 40-60 years.

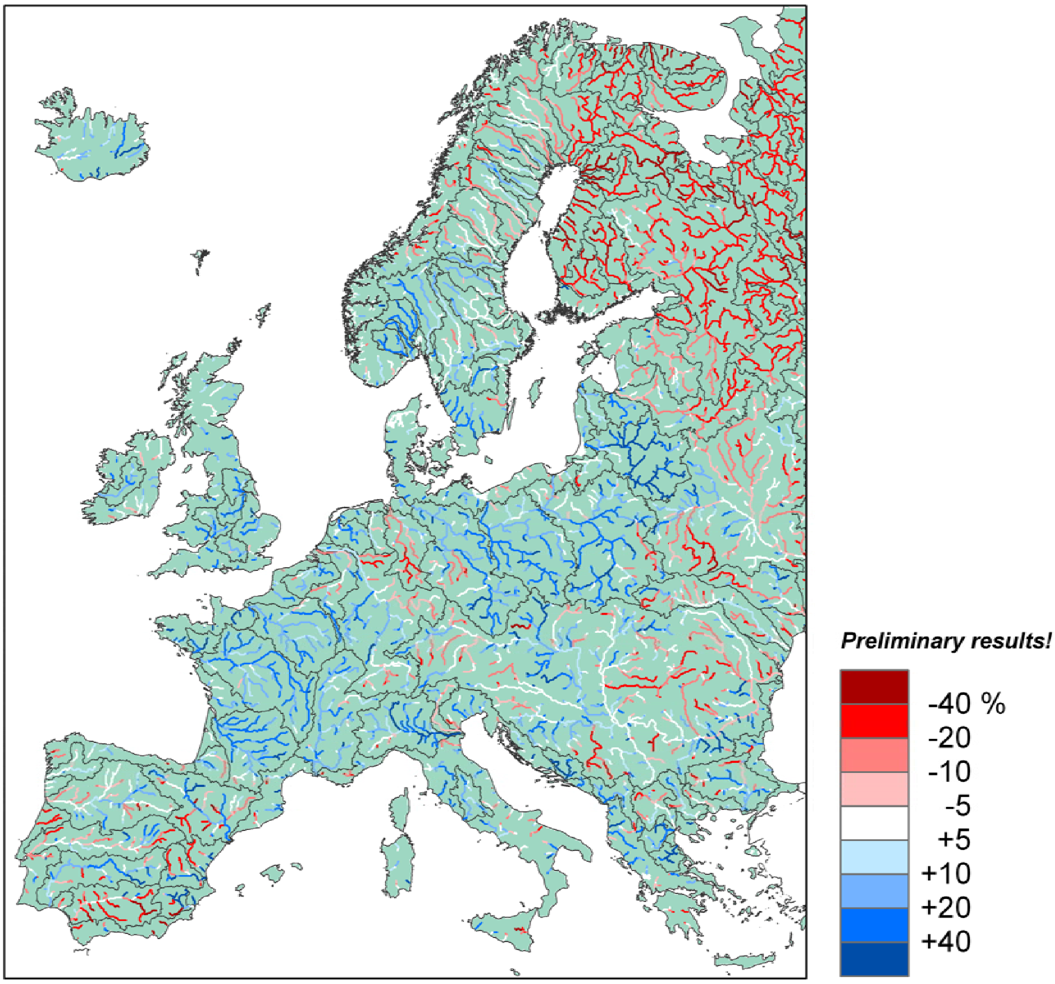


Figure 10 Change in 100-year return level between the control and scenario periods under A2 emission scenario for European rivers with an upstream area larger than 1000 km^2 (based on HIRHAM climate run at 12 km. Source: European Commission, DG Joint Research Centre).

The latest climate impact studies suggest significant summer drying across many parts of Europe, particularly in the Mediterranean basin with more hot days and heatwaves becoming very likely (Goodess, 2005; IPCC, 2001; Lehner et al., 2005). Model simulations indicate that low flows in central European mountain watersheds may be reduced by up to 50 % (Eckhardt and Ulbrich, 2003; Szolgay et al., 2004). A climate change impact study by (Arnell, 1999) has projected that droughts are likely to increase in frequency and intensity across most of western Europe under a range of climate scenarios. The study of Lehner et al. (2005) show changes in recurrence of 100-year droughts for the 2020s and 2070s using ECHAM4 and HadCM3 climate models and Baseline-A water use scenario (Figure 11). One can see higher risk of projected droughts in southern Europe and parts of central Europe, with an increasing tendency by 2070.

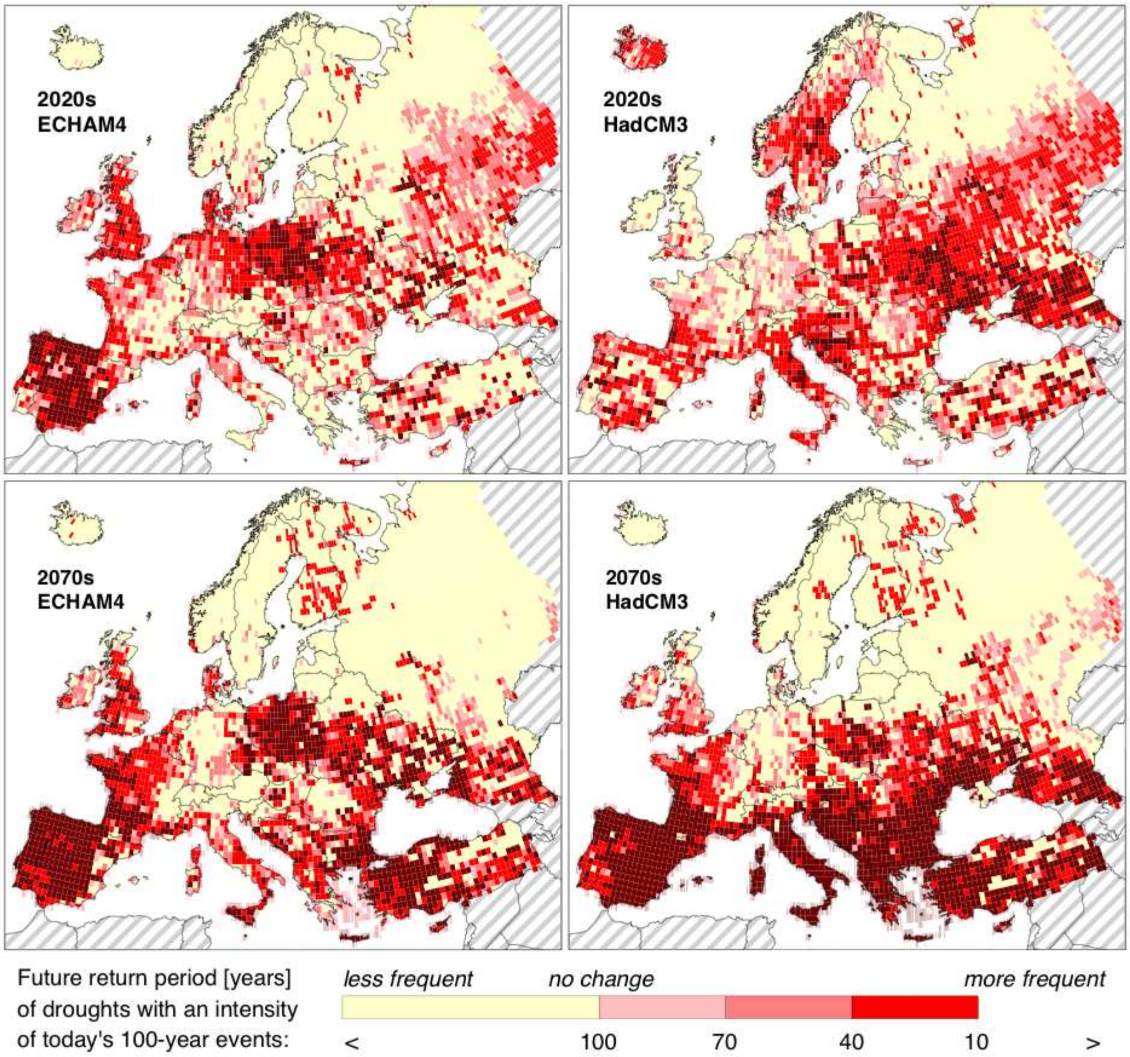


Figure 11 Changes in 100-year return-levels of river discharge in recurrence of 100-year droughts for the 2020s and 2070s using ECHAM4 and HadCM3 climate models and Baseline-A water use scenario (source: Lehner et al. 2005).

The results of this and other studies lead to an assertion that over the next 100 years Europe is likely to experience more frequent meteorological drought conditions, especially in the southern regions. These events might manifest themselves either as short but extreme single season droughts (such as the hot summer of 2003) or longer-term, multi-seasonal droughts, and they might be either local or more widespread in nature.

Simulations by Schär et al. (2004) suggest that every second summer in Europe by the end of this century would be as hot and dry as the summer of 2003. According to them, "***the European summer climate might experience a profound increase in year-to-year variability in response to greenhouse forcing. Such an increase might be able to explain the unusual European summer of 2003, and would strongly affect the incidence of heatwaves and droughts in the future."***

Statements: global and European scale

The World Water Council (2003) stated that ***"the expected climatic change during the 21st century will further intensify the hydrological cycle, with rainy seasons becoming shorter and more intense in some regions, while droughts in other areas will become longer in duration, which could endanger population and crops and lead to drops in food production globally. The risk of more frequent, and possibly more brutal, storms and extreme weather events will increase".***

The Third Assessment Report (TAR) on Climate Change (IPCC, 2001) states that "***it is very likely (a 90-99 % probability) that precipitation has increased by 0.5 to 1.0 % per decade in the 20th century over most mid and high latitudes of the northern Hemisphere continents***" and that "***it is likely (a 66-90 % probability) that there has been a 2-4 % increase in the frequency of heavy precipitation events in the mid- and high latitudes of the northern Hemisphere over the latter half of the 20th century***". As a consequence, it has been concluded (IPCC, 2001) that: "***flood magnitude and frequency are likely (a 66-90 % probability) to increase in most regions, and low flows are likely to decrease in many regions***." Vellinga and Van Verseveld (2000) conclude that ***"as concentrations of greenhouse gases in the atmosphere continue to rise, it is likely that there will be an increase in the intensity of rainstorms, river floods, droughts, and other extreme weather events."***

The European Environmental Agency (EEA, 2004) stated that climate change is likely to increase the frequency of extreme flood events in Europe, in particular the frequency of flash floods, which have the highest risk of fatality. The frequency and intensity of flood events will be closely related to future changes in the patterns of precipitation and river discharge. As a consequence of increased precipitation intensities in many European regions, peak runoff is subject to increase, leading to increased occurrence of flood events. It is foreseen that episodes of intense precipitation will grow in frequency, especially in winter, thus increasing the risk of flooding. In addition, the winter precipitation will fall more often as rain, as a result of higher temperatures. This will lead to immediate runoff and higher risk of flooding (IPCC, 2001). Schnur et al. (2002) state that "***changes in extreme climate, such as hot spells, droughts or floods, potentially have a much greater impact on society than changes in mean climate, such as summertime temperature averaged over several decades***".

Uncertainty, knowledge gaps and unresolved problems in flood research

The high uncertainty associated with future trends in CO_2 emisssions, climate model results, and impact assessment using climate scenarios and hydrological models should be clearly recognised. Due to complexity and nonlinearity in the interactions between climate and the water cycle, acting at various spatial and temporal scales, some unexpected impacts could happen and some statements about impacts will be corrected in future.

Schnur et al. (2002) stated that today's climate models are not reliable at predicting extreme climate events in local areas, such as flooding in a given river basin, because they are limited in their resolution to a coarse grid size of about 200 or 100 kilometres. For more precise projections at the river basin scale, climate change simulations would need a much higher resolution of tens of kilometres or lower, but this will not be available for quite some time. However, even the higher resolution of climate models will not reduce uncertainty in model predictions of extreme events to zero due to other sources of uncertainty, in particular, uncertainty related to GCM performance in simulating precipitation.

Until these high-resolution climate change simulations are available, downscaling methods need to be applied to produce the proper spatial resolution needed for extreme events modelling. Downscaling methods available are Regional Climate Models (using the GCM's as boundary conditions), statistical downscaling methods and stochastic downscaling. No clear consensus exists on which methodology is more reliable. Some authors, e.g. Arnell (1999) advise not to use downscaling at all.

Hydrologists have not yet been able to distinguish the influence of climate change on flooding in relation to other anthropogenic interferences or in relation to the natural variability of the area-specific meteorological conditions. For such analysis the further development of process-oriented hydrological models coupled with meteorological and hydraulic simulation tools is necessary (Bronstert, 2003).

3.2.4 Impacts on coastal systems

Summary:

- Global warming is responsible for a **rise in sea level** of 1-2 mm/yr with a subsequent increase in coastal erosion, flooding, salinisation of estuaries and land aquifers. The rate of sea-level rise due to thermal expansion only already amounts to 0.20 – 0.37 m for 1990 – 2090 (globally). The magnitude of sea-level rise is expected to be geographically non-uniform.
- An intensification of the hydrological cycle has impacts on the **water and salinity budget** of coastal systems, coastal shape and productivity (eutrophication) leading to loss of habitats.
- The response of coastal systems to climate forces **varies regionally** and is tightly coupled to human activities on land emphasising the importance of downscaling models and statistics for proper assessment.

Temperature increase alone already causes a **rise in sea-level** due to thermal expansion. Additionally, mass loss of glaciers, ice caps and runoff from thawing of permafrost contribute to sea level rise (IPCC, 2001). Like glacier retreat, sea level rise is an important indicator of climate change. Main consequences resulting from sea level rise are flooding (storm surges) of coastal areas, coastal erosion, the loss of flat coastal regions, enforced landward intrusion of salt water and endangered coastal ecosystems and wetlands.

The projected sea level rise for Europe is between 13 and 68 cm by 2050 due to thermal expansion only (IPCC, 2001). Regional values can be 50 % higher or lower (Eisenreich, 2005). The projections of sea level rise between 1990 and 2100 indicate that rates could be 2.2 to 4.4 times higher than the rate in the twentieth century. Furthermore, sea level is projected to continue rising for centuries.

However, recent "non-conservative" studies indicate that some non-linear processes and feedbacks may enhance melting of polar glaciers very significantly and cause sea level rise of several meters over one century (e.g. (Hansen, 2003), see also Section 3.3 below). In case such pessimistic projections would be realised, sea level rise might become the most important climate change related problem on the Earth. Already today some densely populated areas in Europe (especially in the Netherlands, United Kingdom, Germany and Italy) are located below or a few metres above sea level. These areas could enlarge under climate change induced sea level rise.

Beside inundation of coastal zones, other important biogeophysical impacts caused by sea level rise are anticipated: (1) increasing probability and frequency of storm surges (Lowe et al., 2001), (2) accelerated coastal erosion (Stive, 2004; Zhang et al., 2004), (3) impacts on groundwater bodies like rise in groundwater level (Barlow, 2003) and salt water intrusion and (4) impacts on the biological system (loss of wetland areas, (Nicholls, 2004), changes in light and temperature conditions leading to physiological stress for organisms and changes in the functions of coastal ecosystems). Generally, coastal areas most threatened by climate change are deltas, low-lying coastal plains, islands and barrier islands, beaches, coastal wetlands, and estuaries (Beniston et al., 1998; Nicholls and Klein, 2004).

About 9 % of all European coastal zones (defined as a 10 km strip, lying below a 5 m elevation, see Figure 12, can be potentially affected by climate change. Member States concerned are the Netherlands, Belgium, Germany, Romania, Poland and Denmark (EEA, 2005b). Flooding due to one meter rise in sea level would affect 13 million people in five European countries. The highest potential impact would be on the Netherlands, whereas Poland and Estonia would feel the least impact.

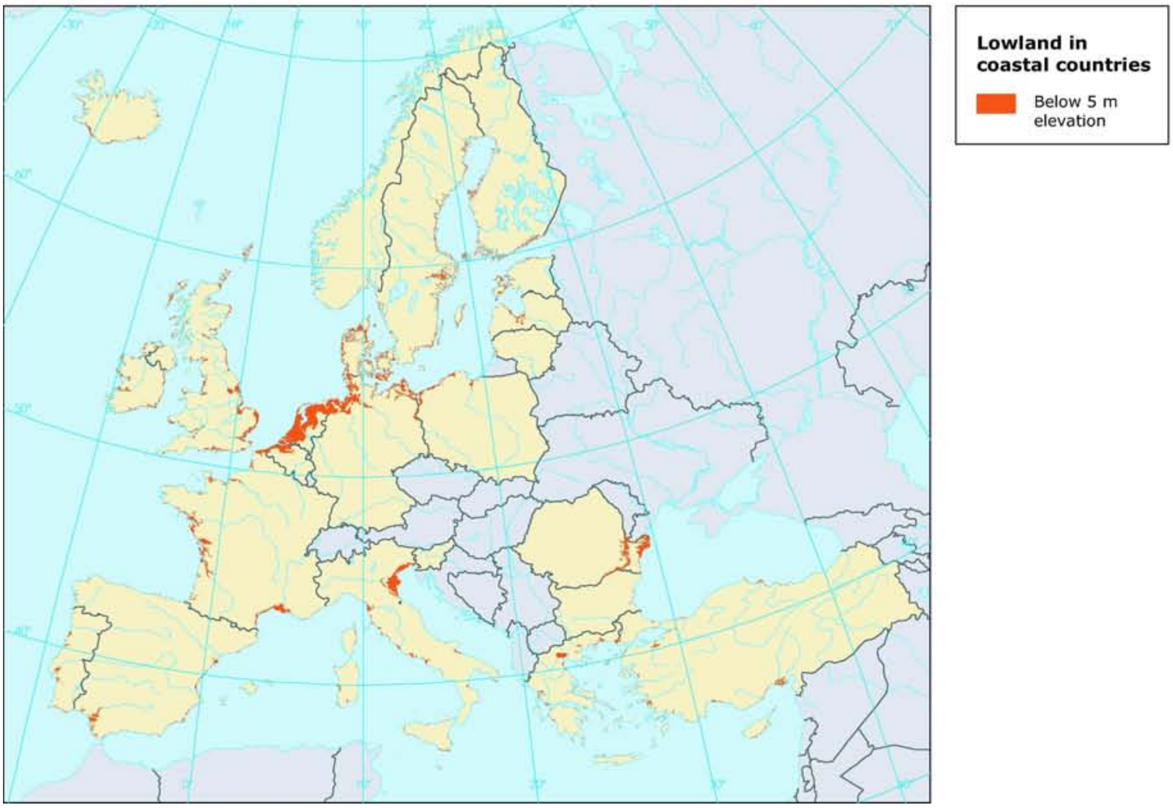


Figure 12 Coastal lowlands (elevation below 5 meters) in Europe (EEA member countries) (EEA, 2005b; permission for reproduction obtained).

3.3 Likelihood of abrupt climate change and possible impacts

Historical data suggest that climate in some regions has changed very rapidly. During the last decade research of the potential mechanisms of abrupt climate change has been done, but there are no quantitative scenarios comparable to those for ‘usual’ climate warming published yet. However, the public awareness has been raised globally after the film ***The Day After Tomorrow*** shown in 2004. Recently the Report on ‘Vulnerability to abrupt climate change in Europe’ was published by Tyndall Centre for Climate Change Research (Arnell et al., 2005) based on published studies on mechanisms of abrupt change (Alley et al., 2003; NRC, 2003), some model simulations and expert judgement. Our overview will follow main findings described in this Report.

Summary

- **Three variants** of abrupt climate change are in principle possible: 1) a collapse of the thermohaline circulation in the North Atlantic, 2) an accelerated climate change, and 3) the rapid sea level rise that could result from disintegration of the West Antarctic Ice Sheet.
- **The likelihood** of these extreme impacts occurring is ***highly uncertain and probably very low.***
- **Major expected** impacts depend on variants and could affect agriculture, human

health, physical infrastructure and ecosystems, availability of water resources, coastal infrastructure including many European cities.

3.3.1 Mechanisms of abrupt climate change

According to recent research results, three variants of abrupt climate change are in principle possible:

1) a collapse of the thermohaline circulation in the North Atlantic, resulting in a cooling across Europe;
2) an accelerated climate change, caused by additional, usually not accounted-for feedbacks like the release of greenhouse gases from permafrost and the oceans during climate warming; and
3) the rapid sea level rise that could result from disintegration of the West Antarctic Ice Sheet.

The thermohaline circulation can be imagined as a pump, bringing warm water across the North Atlantic towards the European continent. The pump is driven by cooling of this warm salty water, becoming more dense, and then sinking to flow southwards at depth. Large inputs of freshwater into the North Atlantic may prevent further sinking and basically create a collapse by switching off the transport of warm water across the Atlantic. Freshwater could come from increased precipitation over the Arctic Ocean, increased runoff from rivers draining into the Arctic, and/or accelerated melt of the Greenland ice sheet. Model simulations show that as a result temperatures across Europe could fall by up to 3^{o}C during a decade (Vellinga and Wood, 2002). Several studies have sought to identify critical thresholds for the collapse of the thermohaline circulation in the North Atlantic, e.g. (Rahmstorf and Ganopolski, 1999). However, the likelihood of the collapse during 21st century is very uncertain: firstly, it is not clear how close the circulation is to a threshold, and secondly, it is not clear how much extra freshwater is likely to arrive into the North Atlantic.

The accelerated climate change can be caused by additional feedbacks in the climate system. It is well known that the climate system is characterised by a large number of feedbacks, most of which are incorporated into climate models. However, some of the feedbacks are not well understood or adequately included in models, and some of them have the potential to produce substantially higher increases in temperature than currently simulated by GCMs. For example, higher temperatures may lead to an increased release of methane from wetlands in high latitudes, and higher temperatures at the sea bed may lead to the release of methane currently stored as methane hydrates (Ehhalt, 2001). Recent research also suggests that higher temperatures would increase the rate of carbon release from soils (Knorr et al., 2005).

The West Antarctic Ice Sheet is grounded below sea level (as opposite to the Greenland Ice Sheet grounded above sea level), and thus potentially unstable. If the ice shelves surrounding the ice sheet were weakened by melting from above or below, it is possible that melting and discharge of ice would increase substantially. Other mechanisms, which may trigger “rapid” deglaciation, include rapid acceleration of ice streams within the West Antarctic Ice Sheet. The complete collapse of the West Antarctic Ice Sheet would raise sea levels by around 5 m globally, but the rates of sea level rise during collapse are unlikely to exceed 1 m/century. The complete disintegration of the Greenland Ice Sheet would raise sea levels by 7 m, and this freshwater would contribute to weakening of the thermohaline circulation. This effect is rather unrealistic for the 21st century but is possible over the next 1000 years.

3.3.2 Likelihood of abrupt climate change

One of the major questions is the likelihood of possible abrupt change occurring, for which there are no scientifically robust estimates. The likelihood of these extreme impacts occurring is ***highly uncertain*** and ***probably very low*** (Arnell et al., 2005). Taking into account the high uncertainty associated with abrupt climate change, the most urgent and effective action now is to monitor – in the oceans, atmosphere and ice sheets - for the onset of abrupt change.

The study of Arnell et al. (2005) conducted a survey of expert opinions in order to provide some estimates of the likelihood of abrupt climate change. Difficulties in identifying a large sample of appropriate experts, and unwillingness of some experts to make subjective estimates of risk, meant that the final sample sizes were small. Estimates of the likelihood of thermohaline circulation collapse or accelerated climate change varied significantly between experts, over several orders of magnitude: most experts believed the risk of either to be very low (well under 1 %), but a minority assessed the risk as considerably greater. For more details see (Arnell et al., 2005).

3.3.3 Expected impacts

A rapid or abrupt climate change would (by definition) alter the mean climates substantially, and have significant effects on the frequency of extreme events (tropical cyclones, hurricanes, prolonged droughts and intensive floods).

The estimation of possible impacts of abrupt climate change in the study by (Arnell et al., 2005) was based on expert interpretation of published and “grey” literature on the implications of gradual climate change, supplemented by a number of computer simulations investigating changes in river discharge, crop suitability and energy requirements across Europe under the thermohaline circulation collapse and accelerated feedback scenarios. The expert judgement was provided by the project team, with input from some sectoral experts and climate change impact researchers. Table 3 summarises the key implications (shown in order of their significance) of the three abrupt climate change scenarios for Europe.

Summary of impacts

The collapse of the thermohaline circulation: major expected impacts are on agriculture, human health, physical infrastructure and ecosystems. The economic and cultural centre of gravity of Europe would move southwards.

The accelerated climate change: major impacts also on availability of water resources, agriculture, human health, physical infrastructure and ecosystems. The economic and cultural centre of gravity of Europe would move northwards.

The rapid sea level rise would threaten coastal infrastructure and inundate large parts of many European cities, and would highly increase coastal flood losses. The economic and cultural centre of gravity of Europe would move inland.

Table 3 Major implications of abrupt climate change in Europe shown in order of their significance (from Arnell et al., 2005).

Collapse of the thermohaline circulation
• Major reductions in crop production, with consequent impacts on food prices, access to food, and rural economies • Increases in cold-related deaths and illnesses • Movement of populations to southern Europe, and shift in centre of economic gravity • Major changes in temperate and Mediterranean ecosystems and the services they provide (food, recreation, biodiversity, forest products) • Disruption to winter travel opportunities and increased icing of northern ports and seas • Requirement to refurbish infrastructure, especially in western Europe, towards Scandinavian standards • Reductions in runoff and water availability in southern Europe, and major increase in snowmelt flooding in western Europe
Accelerated climate change
• Major reductions in crop production, with consequent impacts on food prices, access to food, and rural economies • Increase in summer heat-related mortality and illnesses, and increased risk of transmission of disease • Major reductions in water availability in southern and western Europe, coupled with large increases in demand for water, particularly for irrigation • Major changes in boreal and Mediterranean ecosystems and the services they provide • Requirement to refurbish infrastructure, especially in western and northern Europe • Reduction in ice cover in northern ports and seas
Rapid sea level rise
• Inundation of parts of coastal cities (including London, Hamburg, Venice, Amsterdam and Rotterdam), coastal wetlands and deltas • Inundation of coastal facilities, including ports and power stations • Very substantial increase in coastal flood damages and requirement for major investment in coastal flood defences • Major threat to viability of the financial services industry, particularly insurance • Relocation of economic activity away from coastal cities

3.4 Identification of key challenges and water related sensitivities

For major European regions and four time horizons water related sensitivities to climate change are summarised in a preliminary form in Table 4. There, five European regions, namely (1) southern Europe (Spain, Portugal, Italy, Greece and southern France), (2) northern Europe (Norway, Sweden and Finland), (3) western Europe (United Kingdom, Ireland, northern France, Germany, Belgium, Netherlands, Luxembourg, Switzerland, Denmark), (4) eastern Europe (Poland, Baltic states, Czech Republic, Slovakia, Hungary, Slovenia, Austria) and (5) South-eastern Europe (Serbia, Croatia, Bosnia, Albania, Bulgaria, Romania, Macedonia) are distinguished. For each region observed changes alongside with three time horizons 2020, 2050 and 2080 are considered. Information is provided for climatic components (temperature, precipitation and seasonal properties), water resources sensitivity and expected change of the occurrence and intensity of extreme events.

This integrative table includes relevant information from the previous sections delivering a base to characterise "syndromes" posing a major threat to this region and requiring the development of appropriate adaptation measures. These syndromes should integrate the striking challenges for Europe and its regions in terms of climate change induced alterations of water resources.

As can be drawn from the table, certain aspects are difficult to address with confidence when considering broad regions in Europe and available results of climate and hydrological models. For example, the possible development of flood risk has to be addressed at the local or at the river basin scale. This is why the following sections deal with climate change and climate change impacts on hydrology for six target areas in form of case studies. Thereby, the aim is to cover the main regions in Europe using literature dealing with regionally explicit impacts on water resources and extreme events.

Temperature trends, both observed and anticipated for the future, are more explicit, and provide more evidence. For precipitation changes, more regional environmental settings are included to reduce the uncertainty incorporated. When possible, results based on scenarios from Regional Climate Models are considered.

In respect to increasing water stress and occurrence of drought and heatwaves, regional scale information is an asset, but tendencies are already foreseeable. Especially southern Europe and south-eastern Europe will suffer from water shortage and increased summer drought already in the near future (by 2020). For eastern Europe (winter) and northern Europe (winter and spring) flood risks may be assigned as the major threat (or syndrome). Projections for western Europe have higher variability, showing both more floods in winter and more droughts (respectively, heat days) in summer. Mountainous regions, especially the Alps, will and already undergo loss of snow and ice mass, with a high certainty to continue in future with accelerated rates. Hence, important water resources are diminishing, risk of disasters related to mass movements are increasing, and higher risk of late winter floods can be stated. Although floods related to ice jams in rivers are expected to decrease.

Finally, it can be stated that considering the various sources for uncertainty, there is an astonishing degree of certainty about some future climate changes, which are consistent over all scenario simulations and GCM results. These are:

- The CO_2 concentration of the atmosphere will increase even under scenario conditions where the CO_2 emissions would decrease over the second half of the 21^{st} century.
- This will lead to an increase of the global temperature, which will be more pronounced at higher latitudes.

- o The temperature increase will stimulate evapotranspiration and result in an intensification of the water cycle.
- o It is likely that the trend to increasing global precipitation will continue.
- o Some case studies indicated climate-induced changes in the timing of runoff. These result from impacts of rising temperatures on snow cover dynamics. The change in flow regime can result in new flood types in certain regions.
- o Most studies on water supply and demand conclude that the general trend is that annual water availability would increase in northern and north-western Europe and decrease in southern and south-eastern Europe.
- o Global warming is responsible for a rise in sea level of 1-2 mm/yr with a subsequent increase in coastal erosion, flooding, salinisation of estuaries and land aquifers.

Generally, the following statements can be deduced about water resources in Europe and regional impacts of climate change:

(1) Water resources in Europe: Temperature rise and changing precipitation patterns are expected to exacerbate the already acute water shortage problem in southern and south-eastern regions. An increase in frequency and intensity of droughts and floods is projected by model studies (EEA, 2005b), which could cause significant loss of human lives and financial losses throughout Europe.

(2) Most sensitive regions: South-eastern Europe, the Mediterranean, Alpine and central European regions can be identified as most sensitive to climate change, because considerable adverse impacts (see Table 4) are projected to occur on natural and human systems that are already under pressure from changes in land use. As an example, between 14 and 38 % (dependent on IPCC-SRES storyline scenario) of the Mediterranean population will be living in watersheds with increased water stress by 2080.

(3) Benefiting regions: Northern and some western regions of Europe, on the other hand, may experience beneficial impacts, particularly within agriculture, for some period of time.

(4) Mountains and sub-arctic areas: Impacts of temperature rise on snow cover, snow line, glaciers and permafrost are leading most likely to adverse impacts. An increased risk of natural hazards (floods, mass movements), and loss of plant species and habitats may be expected. Mountainous regions, like the Alps, are particularly sensitive to climate change and are already suffering from higher than average increases in temperature.

(5) Coastal zones: Climate change could have profound impacts on coastal zones due to sea level rise and changes in frequency and/or intensity of storms. This would result in threats to ecosystems, infrastructure and settlements and the tourism industry. Habitats and coastal ecosystems on the Baltic, Mediterranean and Black Seas in particular are at high risk. It is projected that the Mediterranean and Baltic coasts will experience considerable loss of wetlands.

Table 4 Overview of water related sensitivities to climate change for broad regions in Europe.

regions	components	observed changes / trends	2020 **	2050 **	2080 **
Western and Central Europe (UK, Ireland, northern France, Germany, Belgium, Netherlands, Luxembourg, Switzerland, Denmark)	Temperature*	- 0.4 to 1.6 °C, av. + 0.53			+ 1.4 to + 5.5 °C
	Precipitation*	- 36 to + 26 mm, av. + 1 mm			- 20 to + 30 %, highly uncertain
	Climate seasonality	Temp: winter ↑ Precip: winter ↑	Temp. winter + 1.2 to + 2.0 °C, summer: + 1.2 to + 1.9 °C,	Temp. winter + 2.4 to + 4.0 °C, summer: + 1.9 to + 3.5 °C,	Temp. winter + 3.6 to + 5.7 °C, summer: + 2.6 to + 4.9 °C, Precip. Winter +16 to + 26 %, summer: - 9 to - 25 %
	Water resources	Runoff +/- 5 %		Runoff: winter ↑, summer ↓; +/- 10 %	+/- 10 %, partly water stress
	Floods / droughts		←	Flood risk winter ↑ Regionally summer drought ↑	→
	Syndrome		←	high variability, summer droughts and winter floods, partly water stress situation	→
Eastern Europe (Poland, Baltic states, Czech Republic, Slovakia,Hungary, Slovenia, Austria)	Temperature*	- 0.4 to + 1.4 °C, av. + 0.48 °C			+ 1.6 to + 5.5 °C
	Precipitation*	- 16 to + 8.3 mm, av. - 1 mm			- 15 to + 30 %, highly uncertain
	Climate seasonality	Temp: winter & spring ↑ summer & fall ↓ Precip: summer ↑	Temp. winter + 1.9 to + 2.2 °C, summer: + 1.2 to + 1.4 °C,	Temp. winter + 3.6 to + 4.9 °C, summer: + 1.9 to + 2.4 °C, Precip. winter: + 7 to + 18 %	Temp. winter+ 5.8 to + 6.3 °C, summer: + 3 to + 3.6 °C, Precip. Winter: + 8 to + 28 %, summer + 14 to + 27 %, highly uncertain
	Water resources	Runoff - 10 to +25 %	runoff and recharge ↓, shift to winter max. runoff from spring	Runoff +/- 10 %	+ 5 to - 20 %
	Floods		←	winter flood risk ↑	→
	Syndrome			winter floods***	
South-eastern Europe (Serbia, Croatia, Bosnia, Albania, Bulgaria,Romania, Macedonia)	Temperature*	- 0.35 to + 1.1 °C, av. + 0.27 °C, high regional variability			+ 1.5 to + 7 °C
	Precipitation*	- 6.6 to + 7.2 mm, av. 0.18 mm			+ 10 to - 30 %, highly uncertain
	Climate seasonality	Temp: fall ↓ winter ↑ Precip: winter strong ↓	Temp. winter + 1.5 to + 2.1 °C, summer: + 1.9 to + 2.3 °C	Temp. winter + 2.9 to + 3.9 °C, summer: + 3.1 to + 4.3 °C, Precip. summer: - 7 to – 34 %	Temp. winter: + 5.8 to 6.3 °C, summer: + 5.6 to + 6.8 °C, Precip. winter: - 9 to - 15 %, summer: - 26 % to – 52 %, highly uncertain
	Water resources	Runoff -10 to + 25 %		runoff and recharge ↓ + 5 % to – 15 %	- 10 % to - 25 %
	Floods			winter floods risk ↑	
	Drought	summer drought ↑	←	summer drought ↑	→
	Syndrome		←	summer drought***	→

regions	components	observed changes / trends	2020 **	2050 **	2080 **
Southern Europe (Spain, Portugal, Italy, Greece, southern France)	Temperature*	- 0.44 to + 1.17 °C, av. + 0.38 °C			+ 1.5 to + 5.5 °C
	Precipitation*	- 13.2 to + 25 mm, av. - 0.3 mm			- 50 to - 5 %, highly uncertain
	Climate seasonality	Temp: winter & fall ↑ Precip: winter fall ↓	Temp. winter: + 1.4 to + 1.8 °C, summer: + 2.1 to + 2.9 °C	Temp. winter: + 2.6 to + 3.4 °C, summer: + 4.4 to + 5.5 °C	Temp. winter: + 4.0 to + 5.3 °C, summer: + 6.1 to + 7.6 °C
	Water resources	Runoff 0 to - 20% ↓		Runoff -25 % to – 10 %	Runoff < - 25 % Severe water stress
	Floods		winter flood risk ↑	winter flood risk ↑	winter flood risk ↑
	Drought	Summer drought increase	summer drought	summer drought	summer drought
	Syndrome		←	Water scarcity / summer droughts	→
Northern Europe (Norway, Sweden, Finland)	Temperature*	- 0.34 to + 1.72°C, av. + 0.56 °C			+ 1.5 to + 8.5 °C
	Precipitation*	- 12.5 to 21.7 mm, av. + 3.35 mm			- 10 to + 45 %, highly uncertain
	Climate seasonality	Precip: summer ↓ winter ↑	Temp. winter + 1.7 to + 2.6 °C, summer: + 1 to + 1.2 °C, Precip: winter: + 8 to + 15 %	Temp. winter + 3.2 to + 5.0 °C, summer: + 1.8 to + 2.3 °C, Precip: winter: + 17 to + 25 %	Temp. winter + 5.0 to + 7.6 °C, summer: + 2.8 to + 3.6 °C, Precip: winter: + 11 to + 38 %, summer: + 8 to + 14 %
	Water resources	Runoff + 15 to -20 %		Runoff 0 to + 10 %	Runoff + 5 to + 25 %
	Floods		Flood risk winter / spring ↑	Flood risk winter / spring ↑	Flood risk winter / spring ↑
	Drought				
	Syndrome		←	Winter & spring flood risk	→

* Observed values: PIK Climate dataset: mean average temperature (°C) calculated as difference between average temperature for the period 1971 to 2003 minus average temperature period 1901 to 1930. Same for precipitation (mm).

** Temperature, precipitation and Seasonality, water resources as difference or percentage change to the 1990ies based on A2 SRES storyline assumptions. Main Source: (Alcamo and Döll, 2001; Carter et al., 2000; Lehner et al., 2005; Lehner et al., 2001; Parry, 2000).

*** Syndromes can not be broadly assigned to this spatial aggregation, further, spatial more detailed consideration at the country, river basin scale are necessary.

3.5 Awareness of impacts in Europe

The questionnaire survey carried out as part of the present research project asked European countries to provide an assessment of their own vulnerability to climate change and the specific impacts they expect on their water resources. Responses to the questionnaire revealed that awareness of climate change impacts is generally high, that European countries expect significant changes in water resources and hydrology as a consequence of climate change, and that recipients are well informed about the results of up-to-date scientific research.

Sensitivity of water resources to climate change

Most respondents classified water resources in their countries as sensitive to climate change impacts. Countries with extensive coastal and mountainous zones were more likely to describe them as very sensitive. Interestingly, urban areas were deemed less sensitive than others, with only the four island countries UK, Ireland, Cyprus, and Malta describing these as very sensitive, and one deeming them not sensitive (Switzerland). According to the predictions of most climate models, countries in southern Europe expect to be more vulnerable to the impacts of climate change on water resources. This is reflected in the overwhelming number of areas judged as very sensitive by the southern respondents.

Expected changes

Recipients were also asked to provide information based on their predictions of changes to specific elements of the water system, namely precipitation, recharge, flooding, drought and sea level rise. Many respondents gave very detailed responses, which differentiated between regions, individual river basins, time scale of impacts, and seasonal impacts. The information provided in response to this question shows that respondents are highly familiar with scientific evidence (case studies, climate model scenarios, regional studies). Many countries make a distinction between summer and winter conditions, and between the predicted effects of climate change in different regions. A summary of observations is presented in Table 5.

Table 5 Quantification of expected changes in water resources.

Water variable	Expected changes
Increase in precipitation	The highest increases were predicted by north-western and Scandinavian countries (up to 30%), with more modest predictions from Alpine countries (generally 10-20%) and yet lower estimates from southern states (5-10%). The majority stated that these increases were based on winter precipitation, and a number specified that western or north-western regions would receive the most of this increased precipitation.
Decrease in precipitation	There was a greater variety of predictions as to the rate of decreased precipitation. Most often predictions fall within the range of 15-25%. Most results pertain to summer conditions, with an emphasis on southern and eastern regions. Northern

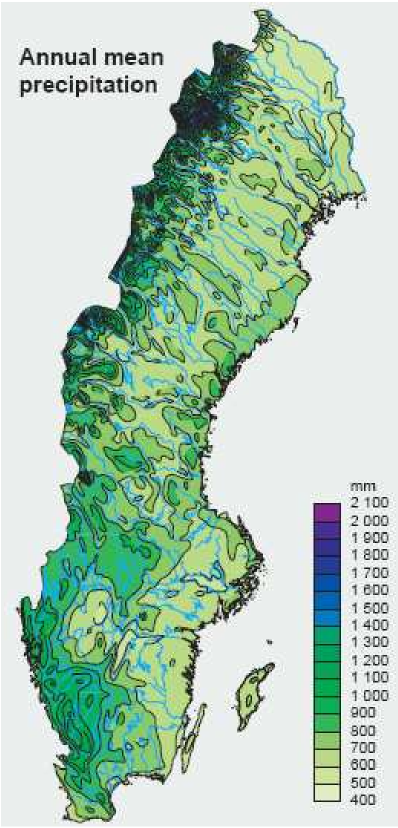
Water variable	Expected changes
	as well as southern countries expect to experience significant decreases in precipitation.
Increase in runoff	The mode estimate was 10-25%; responses were usually based on winter conditions.
Decrease in runoff	Many countries gave very similar figures for decreased as for increased run-off, referring to winter and summer conditions respectively, and often highlighting a north-western/ south-eastern regional variability. Some countries expect large changes (up to 50% decrease).
Increase in groundwater recharge	Most predictions fall between 5 and 15%, again pertaining mostly to winter conditions. Southern states do not expect noteworthy increases, but most northern and western countries do.
Decrease of groundwater recharge	Recipients expect greater changes in reduced groundwater recharge in summer than from increased recharge in winter, according to the questionnaire. Although the accuracy of responses appears to vary, values ranging from 5 to 50% (and even 65%) were given.
Increase in flood frequency	All those who supplied information here expect significant increases in flood frequency, with most responses being between 5 and 20% (some higher), though a few countries noted the difficulty of giving a predicted rate of increase, simply noting that increases were expected.
Decrease in flood frequency	Very few countries attempted to provide values for decreased flood frequency, but a number of mountainous countries made the connection between decreased snowmelt and floods (spring and summer).
Increase in drought frequency	Most countries signalled their prediction that droughts will increase in frequency; the mode response was 20%, but some countries expect very strong increases (up to 100%). Some indicated a regional variation within their country, with southern and south-eastern regions expected to suffer the worst. Some countries preferred to express their predictions in terms of the increased frequency of 1 in 100 year floods (down to 1 in 60, or even 1 in 20 –The Netherlands), or in the number of heatwave days (up by 20 –France).
Decrease in drought frequency	The only countries that predict a decrease in drought frequency are in Scandinavia, who specify the north-western peripheries as the likely areas to be affected.
Sea level rise	All countries with coastline expect sea-level rise, at least along some parts of their shoreline; predictions range from 0-100cm in the century, with a rate range of 2-30 mm a year (France).
Sea level decline	Two Scandinavian countries (Sweden and Finland) expect land upheaval to bring net decline in sea-level (0-60 cm) along portions of their coast.

4 Climate change and water resources: regional assessment

4.1 Case Study 1: Northern Europe: Sweden

Sweden's geography is characterised by a multitude of lakes, rivers and streams, covering a total area of 39,000 square kilometres (UNFCCC - Sweden, 2005). Like in several other Scandinavian countries, most of the major water reservoirs are used for hydropower production (EEA, 1999). The majority of large rivers in the northern parts of Sweden is thus regulated and river flow is largely determined by the demand of energy production (Lindström and Bergström, 2000). With climate change having the potential to alter the spatial and seasonal distribution of water resources, the secure supply of electricity through this renewable energy source could become disrupted in the future. It is thus of major interest for Swedish society to project and prepare for such an uncertain future and major research initiatives have already aimed at modelling the potential climatic and hydrological changes.

a)



b)

Figure 13 Map of a) Sweden (Source: CIA World Factbook, 2007) and b) precipitation distribution during the time period 1961-1990 (Source: UNFCCC - Sweden, 2001).

The present climate in Sweden is temperate and moist, with precipitation occurring throughout the year. Along the coasts in the south (see Figure 13a), the climate can be described as warm-temperate, while in the rest of the country a cool-temperate climate dominates. Mean temperatures in July are around 14-16°C along the entire coast, decreasing by 0.6°C with each 100 metres of altitude (UNFCCC - Sweden, 2005).

Although southern and northern Sweden exhibit similar temperatures in the middle of summer, the season length varies markedly. In the most southern parts, summer – defined as the period of time when the mean diurnal temperature > 10°C – extends for almost 2 months longer compared to the most northern ones. The reverse trend is true for the winter season, which lasts about half a year in the north and only a few weeks in the south. Temperatures in January in the north range between -9 and -17°C, further in the south between -3 to -8°C (UNFCCC - Sweden, 2001).

Across most parts of Sweden, mean annual precipitation is around 600-800mm (see Figure 13b), and can reach 1500-2000mm in mountainous areas in the north. Most precipitation falls during the months of July to November. Despite being a rare problem, drought conditions have been occurring in the southern parts of Sweden in the past. Precipitation during the winter months often falls as snow and in northern Sweden, snow cover can last for more than 150 days a year (UNFCCC - Sweden, 2001).

Approximately half of the annual runoff occurs as intense spring floods during the months of May to July. In the south, where the winters are milder, the mean runoff in winter is almost double that in summer. For the whole of Sweden, mean annual runoff during 1961-1990 has been estimated at 415 mm/year (Lindström and Bergström, 2004 and references therein).

Reservoirs along the course of the regulated rivers usually store the spring and summer floods. When the reservoirs are full in summer and autumn, flow levels in the rivers return to almost natural conditions. Any excess water accumulating in the reservoirs during these seasons is discharged through spillways to avoid exceeding prescribed water levels. The regulation of rivers in Sweden has thus changed the occurrence of floods. While those in spring have become less frequent and intense, summer and autumn floods can still reach discharge peaks as if the rivers were unregulated or even exceed previous levels. This is partly due to the fact that the natural storage capacities of lakes are usually lost when they are converted into regulation reservoirs (Lindström and Bergström, 2000).

4.1.1 Observations

4.1.1.1 Trends in climatic parameters

Mean annual temperatures in Sweden have been rising over the past century. Differences between the period 1901-1990 and 1991-2002 were +0.7°C (Lindström and Alexandersson, 2004); when the time frames 1961-1990 and 1991-2000 are compared, mean annual temperature increased by 0.76°C (Räisänen and Alexandersson, 2003). Between the latter periods, winter has shown the highest warming trend with 1.97°C while those in summer and autumn were the lowest, with 0.21 and 0.18°C, respectively. However, is should be noted that in Sweden, the last century has already exhibited such warm periods before, namely during the decade

1931-1940 which was almost as warm as the years 1991-2000. And changes in temperature and precipitation between the years 1901-1930 and the period 1931-1940 were even higher (Räisänen and Alexandersson, 2003).

Mean annual precipitation during the decade 1991-2000 has been increasing by 6.1% compared to the time frame 1961-1990. Except during autumn, when rainfall decreased by 3.6%, precipitation during winter, spring and summer showed increases of around 10% (Räisänen and Alexandersson, 2003).

4.1.1.2 Temperature and precipitation extremes

Specific investigations regarding changes in the occurrence or magnitude of extreme climatic events appear to be quite rare for Sweden. However, some studies are available which aimed to assess such trends for the Nordic countries as whole. Tuomenvirta ***et al.*** (2000), for example, performed an analysis of the development of temperature extremes in the Fenno-Scandia region during the period 1950-1995. In this region, which includes Norway, Denmark, Sweden, and Finland, statistically significant linear trends in spring warming were observed, mainly due to the significant increase in daily minimum temperature during the months of March-April. As a result, the diurnal temperature range has been decreasing. These changes were mainly ascribed to a strengthening of the North Atlantic Oscillation (NAO).

The STARDEX study has analysed changes in European temperature and precipitation extremes for the time frames 1958-2000. Without any specific data available for Sweden, the observed trends in precipitation for the whole of Scandinavia are presented instead. For the summer months, an increase in the longest dry period, i.e. the maximum number of consecutive dry days, has been observed for southern Scandinavia, while in northern Scandinavia, the magnitudes of heavy rainfall events has been rising. During the winter months, heavy rainfall extremes have been rising across the whole of Scandinavia (Goodess, 2005).

4.1.1.3 Water resources and hydrological extremes

Lindström and Bergström (2004) have investigated the associated trends in runoff over the past century. Although the last two decades of the 20th century were very wet, with runoff anomalies of +8% compared to the mean of 1901-2002, levels during the 1920s were almost as high. The 1970s on the other hand were the driest decade with an anomaly of -9%. Overall, an increasing but non-significant trend in annual runoff (+5%) over the course of the last century was identified. It should be noted again that this trend was not unique for the 20th century, as runoff records from the 19th century point towards even higher runoff, despite the prevailing temperatures being lower. Hence, it is the occurrence of higher temperatures combined with higher runoff which is so characteristic for the developments in recent years. With regard to the spatial distribution, significant increases in runoff between 1941 and 2000 occurred mainly in the northern and south-western parts of the country. The observed increases in the north resulted essentially from higher spring flood volumes (Lindström and Bergström, 2004). This was corroborated by findings showing that winter and spring flows in northern and south-western Sweden have been increasing significantly between 1941 and 2000. For the summer, tendencies towards reduced streamflow levels for central Sweden were observed (Hisdal ***et al.***, 2004).

Between 1970 and 2002, summer and autumn floods increased markedly. However, it should be noted again that the floods occurring during the 1920s were of equal magnitude. Due to the potential underestimation of flood peaks and frequencies at the beginning of the last century, it remains difficult to establish significant trends in the occurrence of floods (Lindström and Bergström, 2004). Furthermore, the influence of the regulated river system on flood development should not be ignored. Lindström & Bergström (2000) have thus argued previously that higher flood frequencies could instead represent a "return to more normal conditions for the first time since 1970, which is about when the hydropower system was developed to its present state". However, with regard to the timing of annual maximum flood peaks, a clear trend can be identified. Many stations in Sweden have been showing an earlier occurrence of maximum snowmelt floods between 1941 and 2000 (Hisdal ***et al.***, 2004).

4.1.2 Projections

4.1.2.1 Trends in climatic parameters

Temperature

The Swedish Regional Climate Modelling Programme (SWECLIM) was set up to develop regional climate change simulations for Sweden and the Nordic Region (Rummukainen ***et al.***, 2004). The regional climate models (RCMs) RCA1 and RCAO by the Rossby Centre were used to obtain projections for the time frame 2071-2100. Input for the boundary conditions of RCA1 was obtained from downscaled information of the general circulation models (GCMs) HadCM2 and ECHAM4/OPYC3 (Rummukainen ***et al.***, 2001) under the business-as-usual (BaU) scenario. Simulations of the RCAO model were based on input of the HadAM3H and ECHAM4/OPYC3 GCMs using the A2 and B2 SRES emission scenarios (Andreasson et al., 2004; Nakicenovic et al., 2000).

According to the results of RCA1 and RCAO, mean annual temperature in Sweden is projected to increase between 2.5 and 4.5°C by the 2080s compared to the years 1961-1990 (Andreasson ***et al.***, 2004). The rise in temperature is expected to be greatest during the winter months, increasing between 2.8 and 5.5°C by the end of the century. As a result, temperature zones would move northwards and the vegetation period would extend by 1-2 months throughout the country, in the far south even up to three months (UNFCCC - Sweden, 2005).

Bergström ***et al.*** (2001) modelled the potential changes in temperature for a range of river basins representing different climatic zones across the country (see Figure 14). For the most northern one, the Suorva basin, the projected increase in temperature was around 3.4°C, for the southernmost one, the Torsebro basin, temperature is expected to rise by 2.8°C.

Figure 14 Location of river basins which were investigated in the SWECLIM study with regard to future climatic and hydrological changes (Map modified after Bergström ***et al.*** (2001)).

Precipitation

According to the modelling results by SWECLIM, precipitation over Sweden is projected to increase between 7 to 23% by the end of the century (Andreasson ***et al.***, 2004). The increases in precipitation are expected to be largest in winter, while the south could experience reduced rainfall levels during summer (UNFCCC - Sweden, 2005). For the six river basins that were assessed with the RCA model in the SWECLIM study, very detailed results are available. By the end of the century, precipitation in January in the northern basins Suorva and Kultsjön is anticipated to rise between 24 and 39%. For Blankaström in the south, decreases of around 2% and for Torsebro, increases of 1-2% are projected. For the month of July, however, differences between the modelling results are quite large depending on which GCM drove the regional model. Whereas simulations derived from HadCM2 project increases of 11 and 9% for Suorva and Kultsjön, respectively, results of ECHAM4/OPYC3 anticipate decreases of 2 and 17%, respectively, by the end of the century. The same applies to the southern basins, Blankaström and Torsebro, for which simulations based on HadCM2 project increases (6%) and based on ECHAM4/OPYC3 reductions (14-19%) in precipitation (Bergström ***et al.***, 2001).

4.1.2.2 Trends in variability and climatic extremes

In Sweden, the daily temperature range is expected to decrease in winter, thus reducing the difference between mild and cold winter days. Essentially, this change would be caused by a pronounced reduction of cold extremes. During summer, the exact opposite trend could be experienced, with a disproportionate increase in warm extremes occurring (UNFCCC - Sweden, 2005). Results of the MICE project indicate that, by the end of the century, the number of consecutive summer days with maximum temperature >25°C could increase by more than 40 under the A2 scenario (compared to 1961-1990 average) (MICE, 2004).

With regard to precipitation, an increase in the frequency and magnitude of extreme events is projected, even during seasons when overall rainfall is expected to decrease (e.g. during summer in southern Sweden). In northern Sweden, the number of intense rainfall days is projected to increase by more than 5 by the end of the century in the A2 scenario (MICE, 2004). Consequently, this indicates a trend towards a more extreme climate where both high and low precipitation extremes are anticipated to become more common (UNFCCC - Sweden, 2005).

4.1.2.3 Water resources and hydrological extremes

Runoff

In the present climate, water resources in Sweden are generally of sufficient quality and availability to provide drinking water and guarantee a reliable supply of hydropower. However, dry years in the south have previously affected water quality and were also noticeable in hydropower production (UNFCCC - Sweden, 2005). Increases in precipitation in the north, on the other hand, have the potential to alter the occurrence and magnitude of floods. The SWECLIM study has thus placed great emphasis on assessing the impacts of climate change on water resources and investigating the potential changes in runoff in great detail. Results for the end of the century indicate that mean annual runoff in Sweden could increase between 5 to 24% (Andreasson ***et al.***, 2004).

The greatest increases in annual runoff volumes are anticipated to occur in the mountainous regions in north-western Sweden, reaching values up to +40% (Andréasson ***et al.***, 2004). For the Suorva and Kultsjön river basins (see Figure 14), runoff under the RCA model and BaU scenario is projected to increase between 23-30% and 11-23%, respectively, by the end of the century (Bergström ***et al.***, 2001). Furthermore, a shift in the runoff regime towards decreasing spring and increasing autumn and winter flows is expected (Gardelin, 2004). Results from multi-model ensemble simulations highlight similar developments for the most important river for hydropower production in the Nordic countries: the Luleälven, which flows south-east from the Scandinavian Mountains to the north-western part of the Bothnian Bay. For this catchment, an overall increase in river flow is projected, with spring peak flows occurring about 1 month earlier by the end of the century compared to the present climate (Carlsson ***et al.***, 2005).

In the south, summer runoff is expected to decrease markedly while winter runoff could still increase (Andréasson ***et al.***, 2004). However, total runoff from the three largest lakes in southern Sweden, Vättern, Mälaren and Vänern, is projected to show pronounced reductions (Andreasson ***et al.***, 2004). Most scenarios for south-eastern Sweden also point towards distinct decreases in annual runoff volumes. The river basins Blankaström and Torsebro (see Figure 14), for example, could be subjected to runoff reductions between 10-41% and 11-26%, respectively (Bergström ***et al.***, 2001). As south-eastern Sweden is already experiencing water shortages during summer under the present climatic conditions, this problem could intensify in the future (Andréasson ***et al.***, 2004). It is interesting to note in this context, that the spatial distribution of the modelled future changes in river flows is comparable to the observed changes, showing trends towards less river discharge into the Baltic Sea in the southeast accompanied by increases in the north (Graham, 2004).

For central Sweden, results of the runoff simulations for the river basins Torpshammar and Höljes are largely dependent on the type of GCM driving the RCA1 model. For the BaU scenario, the HadCM2 model projects increases in mean annual runoff between 5-41% for the Torpshammar basin, while the ECHAM4/OPYC3 simulations deliver changes between -19 and +14%. For the Höljes basin, results are a bit clearer and most simulations point towards increases in runoff (up to 40%) (Andreasson ***et al.***, 2004). To investigate the sensitivity of the hydrological system to climate change, Xu (2000) examined the response of a study region in central Sweden to a range of hypothetical climate change scenarios (ΔT = 1 to 4°C; ΔP = -20 to +20%). It was found that all scenarios resulted in major reductions in snow accumulation and significant increases in winter flows in the study region close to Stockholm. Furthermore, most scenarios pointed towards a decrease in spring and summer runoff (Xu, 2000).

Glaciers

Assuming a doubling of CO_2 concentrations by the 2050s, Schneeberger ***et al.*** (2001) have assessed the potential impacts of rising temperature and changes in precipitation patterns on the Storglaciären glacier in northern Sweden. According to the scenario conditions, increased precipitation (14%) between October and April would lead to an increase in snow accumulation during winter. However, this would be largely compensated by higher ablation rates during the melt season, thus leading to a retreat of the glacier terminus by 300m. Furthermore, the Storglaciären would also experience a loss of 30% of its present ice mass (Schneeberger ***et al.***, 2001).

Extremes

In general, it is difficult to assess the flooding probability in regulated rivers (Bronstert ***et al.***, 2000), but some attempts have been made to investigate the development of floods in a changing climate. Until present, spring floods were the largest floods in most northern river basins in Sweden (Bronstert ***et al.***, 2000). In the future, however, altered snow dynamics could cause spring flood peaks to decrease across most of the country, and the return period of a present day 100-year flood is projected to increase markedly under a BaU scenario (Andreasson ***et al.***, 2004). Only for the northernmost regions, like in the Suorva basin, no changes in the magnitude and frequency of spring floods are anticipated by the end of the century, as snow accumulation in these areas might not be particularly affected by the future climatic changes (Gardelin ***et al.***, 2002).

For the autumn season, on the other hand, an increased frequency of high flow events is expected. In the northern river basins Suorva and Kultsjön, for example, large increases (up to 56%) in the magnitude of the 100-year flood could occur by the 2080s and its return period could become reduced to 5 years. For the more central river basins Torpshammar and Höljes, some simulations of the RCA model and the BaU scenario project even increases in the magnitude of the 100-year flood of up to 92% (Andreasson ***et al.***, 2004).

Impacts on hydropower

The expected increase in runoff volumes in northern Sweden indicates that the hydropower production potential in these areas could be increasing in the future. Results from ensemble studies for the Luleälven river show that its hydropower potential could indeed grow on average by 34% by the 2080s (Carlsson ***et al.***, 2005). However, with flood magnitudes and frequencies in northern Sweden projected to rise accordingly, flood problems would be intensifying in a region which supplies many of the large hydropower reservoirs and delivers most of the Swedish hydroelectricity (Andréasson ***et al.***, 2004). With a comprehensive survey assessing the effects of climate change on the development of extreme water flows currently lacking (UNFCCC - Sweden, 2005), their impact on hydropower production potential remains quite uncertain.

Impacts on water supply and water quality

In areas where flows are expected to increase, there is a greater risk for diffuse pollution from agricultural sites. According to modelling results performed under the SWECLIM project for the Rönneå river, the problem of eutrophication could thus increase in the future. The consequence could be higher riverine nitrogen concentrations, increasing annual nitrogen loads in the Rönneå to more than 30% by the 2080s. However, it should be noted that these consequences also apply to scenarios which project reductions in future water discharge. Although annual nitrogen loads would be comparatively smaller under such low flow conditions, riverine concentrations would be higher in comparison (Arheimer ***et al.***, 2005).

For lake systems, most climate change scenarios of the SWECLIM study point towards increases in the mean concentration of several biogeochemical variables. In Lake Ringsjön in southern Sweden, the higher nitrogen and phosphorus availability would lead to increased algal production, with cyanobacteria, zooplankton and detritus concentrations increasing as a response (Arheimer ***et al.***, 2005). For Lake Erken in eastern Sweden, climate change is projected to result in similar changes (Blenckner ***et al.***, 2002).

Despite the fact that these results are based on potentially occurring climate scenarios, observations have already confirmed such developments for the present. An example would be the autumn of the year 2000, when high flow rates led to an increased influx of humic substances into several lakes, causing large problems for water treatment plants in the Stockholm area (UNFCCC - Sweden, 2005). Moreover, the impacts of a changing climate on lake systems were also investigated in the European CLIME project. As the timing of ice breakup strongly influences the timing of numerous physical, chemical and biological processes, climate change has the potential to alter the diversity of these ecosystems (Weyhenmeyer ***et al.***, 2004). In Lake Erken, for example, warmer temperatures were found to reduce ice thickness and snow cover duration, thus favouring early phytoplankton growth under the ice. In addition, higher water temperatures increased remineralisation rates of organic matter and release rates of nutrients from the sediments to the water column. In combination with the successive deepening of the thermocline, this has led to a second peak in phytoplankton growth in autumn (Pettersson ***et al.***, 2003). As these alterations can equally prolong the growth of cyanobacteria and toxic species, altered odour and tastes, plus the presence of toxic algae and harmful substance could present the largest threats to water quality in the future (UNFCCC - Sweden, 2005).

4.1.2.4 Changes in sea level

Sea levels in the Baltic Sea will obviously be affected by the rise in global sea levels. However, the global projections for the anticipated rise of 9-88cm (Church ***et al.***, 2001) have to be considered in connection with local effects, such as vertical land movements and wind-driven effects. In Sweden, land uplift has been prevailing since the last glacial period, occurring at a maximum rate of 9.0mm/year in the Bay of Bothnia (Ekman and Mäkinen, 1996). Assuming a rise of 9 and 88cm, modelling results with the GCMs HadAM3H and ECHAM4/OPYC3 under the A2 and B2 scenarios indicate that winter sea levels in Stockholm could be changing between -48 to +46cm by the end of the century (Meier ***et al.***, 2004). It is thus important to note the importance of regional effects on the relative sea level rise.

4.1.3 Summary and conclusions

With about half of Sweden’s electricity being produced by hydropower, the impacts of climate change on this important resource have frequently being discussed (Bergström ***et al.***, 2003). In particular, since the last two decades of the 20th century showed increases in runoff of +8% (Lindström and Bergström, 2004) which have led to an unusually high production of hydropower (Bergström ***et al.***, 2003). The Swedish Regional Climate Modelling Programme (SWECLIM) was thus set up to investigate the impacts of climate change on hydrology in Sweden.

By the end of the century, temperatures are projected to rise between 2.5 and 4.5°C compared to the 1961-1990 mean, and precipitation could increase between 7 and 23% (Andreasson ***et al.***, 2004). With regard to the latter, changes in the regional distribution are quite pronounced, with winter precipitation in the northern river basins expected to rise between 24 and 39%, while catchments in the southern parts of the country might experience only slight increases (1-2%). In summer, precipitation in the south could even decrease up to 19% (Bergström ***et al.***, 2001). According to the projected changes in precipitation, mean annual runoff is expected to increase between 5 to 24% by the end of the century. In continuation of the already observed trends, runoff in north-western Sweden might show particularly pronounced increases (+40%) (Andreasson ***et al.***, 2004). This would be accompanied by a shift in the runoff regime towards decreasing spring flows and increasing autumn and winter flows (Gardelin, 2004). In river basins in the south-eastern parts of Sweden, runoff reductions as high as 41% (e.g. in the Blankaström catchment) could occur by the end of the century (Bergström ***et al.***, 2001).

The projected shift in the occurrence of floods from spring to other seasons of the year could have critical impacts on the reservoirs and dams in regulated rivers. As reservoirs in spring are often low and thus represent a good buffer for floods, this capacity is lost during autumn and winter when the reservoirs are full (Bergström ***et al.***, 2003). Although climate change could have beneficial effects on hydropower production in general, by generating a higher supply of water over the year, floods and resulting dam accidents can still threaten the electric power supply (UNFCCC - Sweden, 2005). To prepare for the potential impacts of climate change, it seems important to investigate the occurrence of climatic extremes in more detail, thus allowing a better inference on trends in hydrological extremes.

4.2 Case study 2: Western Europe: United Kingdom

Asked about English weather, most people will presumably think of rain. This notion, however, does only partly reflect climatic realities in the United Kingdom (UK), as some areas have faced prolonged drought conditions in recent years. Beginning with the exceptionally dry year of 2003 and continued by the dry and mild winter of 2004/5, a severe drought period has been prevailing in the UK until September 2006 (Met Office, 2007). Especially affected by this climatic drought were regions in the southeast of England, where population density and water demand are high (DEFRA, 2006). In the Thames Valley, for example, annual water availability per capita is well below that of countries such as Spain or Portugal (Water UK, 2006) and with just 266m^3 per capita per year, ranges within the same category as Israel (Environment Agency, 2006; WRI, 2005).

Then again, as might be expected, excess water is also posing problems. Since small changes in average conditions can potentially lead to larger and more significant shifts, the impacts of climate change on river flows are particularly relevant (Boorman and Sefton, 1997). To obtain a better understanding of the impacts of climate change on society and the natural environment, the UK government has initiated a range of research programmes, such as the UK Climate Impacts Programme (UKCIP) or the Foresight Flood and Coastal Defence Project. While UKCIP aims to study the likely impacts of climate change in regional detail, the Foresight project investigated how flood risks in the UK might change within the next 100 years. A common theme to both research initiatives is their aim to deliver a sound scientific base, which can be used by governments, organisations or private businesses alike to prepare for the impacts of climate change.

At present, climatic conditions in the United Kingdom are of a temperate, maritime type, characterised by moderate temperatures and rainfall throughout most of the year. The climate is best described according to the UK's regional boundaries, namely southern and northern England, Wales, Scotland and Northern Ireland. Southern England experiences the mildest climate with mean summer temperatures (JJA; 1971-2000) around 16.5°C whilst the rest of the country only reaches summer averages of around 10°C. In winter (DJF; 1971-2000), the picture changes slightly with south-west and south-east England, and the lowland areas on the west coast and in Northern Ireland experiencing the highest mean temperatures around 5°C. Scotland, northern England and the mountainous areas in Wales show the lowest mean values around 0°C (Met Office, 2006).

Average annual precipitation in the UK for the time period 1971-2000 was 1125mm/year. According to Price (1998), water resources in the UK are best assessed along a north-south divide (see Figure 15). The area south-east of this line is densely populated, has a high water demand for public, commercial and agricultural use, and is characterised by low annual rainfall. The annual rainfall amount in this area is around 750mm/year (1971-2000), reaching levels as low as 605mm/year in East Anglia (Met Office, 2006). North-west of the line, the country is less densely populated, has a lower water demand and experiences higher rainfall (Price, 1998). Mean annual precipitation levels (1971-2000) in northern England are around 950mm/year, in Northern Ireland 1100mm/year, and reach up to 1500mm/year in Wales and Scotland (Met Office, 2006).

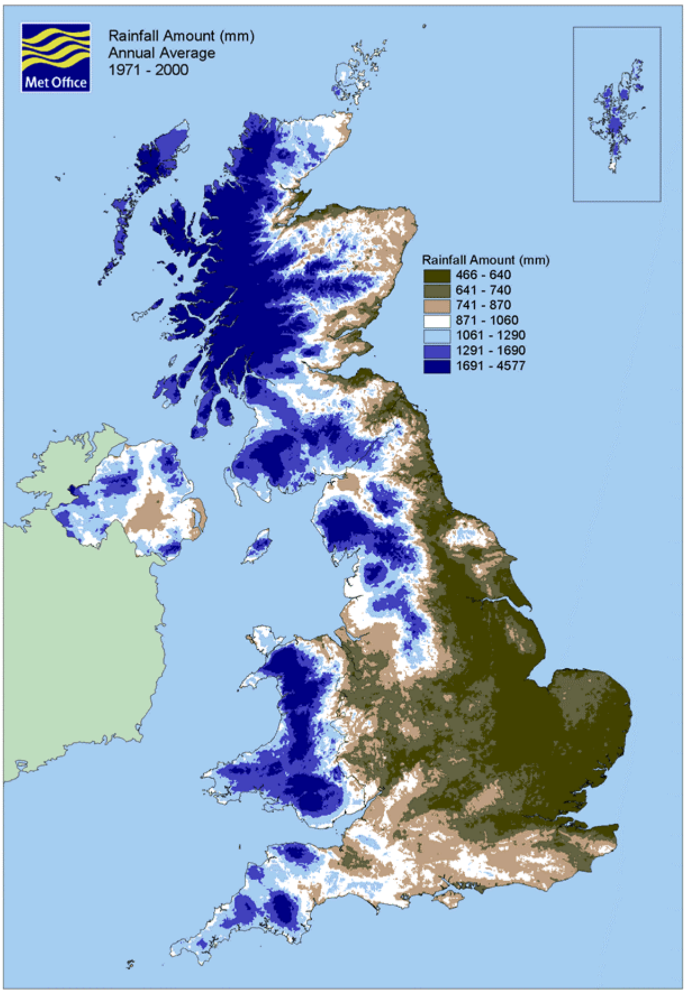


Figure 15 Annual average rainfall amount in the United Kingdom during the period 1971-2000 (Met Office, 2006).

4.2.1 Observations

4.2.1.1 Trends in climatic parameters

Over the last century, changes in the British climate have already been observed. The average annual temperature in central England has risen around 1°C and the 1990s were identified as the warmest decade since records began (see Figure 16a). At the same time, the thermal growing season of plants has lengthened by about 1 month since 1900, summer heatwaves have become more frequent and the number of frosts and winter cold spells has decreased (Hulme ***et al.***, 2002).

As expected, this rise in temperature has been accompanied by changes in precipitation patterns. Total winter precipitation in the UK has increased since 1961, in the northwest of up to 80%, both due to an increase in the number of wet days and a marked rise (60%) in precipitation amount per wet day. Total summer precipitation, on the other hand, has since decreased almost everywhere (see Figure 16b). Apart from western Scotland, south Wales and Northern Ireland, these reductions reached between 10-40%, caused by the reverse trend of less wet days and less precipitation (40%) per wet day (Osborn and Hulme, 2002).

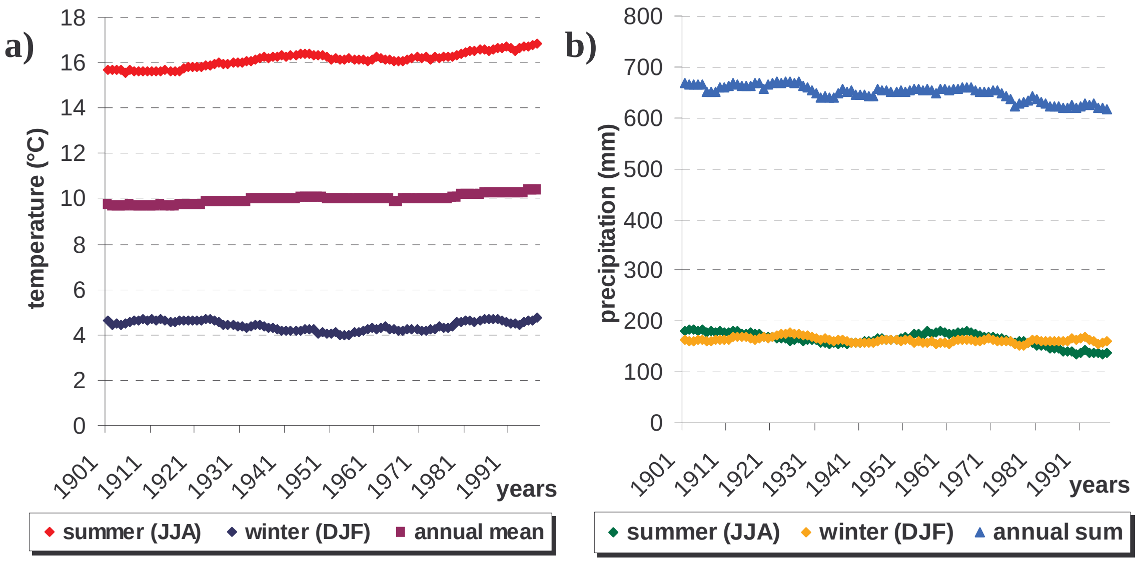


Figure 16 Observed data from meteorological station in Oxford. Shown are 30-year means of a) temperature and b) seasonal and annual precipitation sums. Data provided by MetOffice, UK.

4.2.1.2 Temperature and precipitation extremes

A warmer climate ultimately influences daily temperature extremes. Since the 1960s, “very hot” days in central England were observed to occur more often and several particularly warm summers have been experienced. Prolonged periods of extreme temperatures have also shown a trend: coldwaves became less frequent during the last century while the occurrence of heatwaves has increased.

Compared to 50 years ago, a larger proportion of precipitation is now falling on heavy rainfall days (Hulme ***et al.***, 2002) and the intensity of short-duration winter rainfall has increased. Changes in the frequency of heavy precipitation events (>15mm) have followed the same pattern as changes in total precipitation: increases in winter and decreases in summer. Over the time period 1961-1995 (compared to the 1961-1990 baseline mean), the probability for the occurrence of such extreme events in winter has risen by more than 100% at several stations in the country, while in summer, it declined between 40 and 80% (Osborn and Hulme, 2002).

In addition to those seasonal changes in precipitation patterns, shifts in the regional distribution have also been observed. Fowler et al. (2003) found that between 1961 and 2000 significant but regionally varying changes in extreme rainfall had occurred. The authors show that the frequency of prolonged heavy rainfall events (5-10 day duration) increased in northern and western regions of the UK, particularly in eastern Scotland. In the south of the UK, the annual maxima of 5 and 10 day precipitation events have been decreasing during the 1990s.

However, it should be noted that extremes in precipitation can also be the lack of it: rainfall drought. Since November 2004, periods of low precipitation have been prevailing in the south-eastern region of England. Mainly due to two consecutive dry winters, groundwater levels in this region have become depleted (Environment Agency, 2006).

4.2.1.3 Water resources and hydrological extremes

In the UK, groundwater provides about a third of drinking water supplies and many rural communities depend on this water resource. Aquifer characteristics, rainfall and water abstraction amounts largely determine groundwater levels. In general, groundwater levels become recharged during winter rainfall when evaporation levels and water consumption by plants are low. As indicated above, dry winters have thus a particular impact on recharge rates, even more so than dry summers (Environment Agency, 2006). Several UK aquifers have consequently shown below average water levels following the low rainfall winters of 1992, 1996 and 1997, but became replenished during the wet years of 2000/2001 (Environment Agency, 2006).

With this upward trend in rainfall extremes in winter, flood risks are expected to rise accordingly. The UK has already experienced serious flooding in April 1998 and in the winter terms of 2000 – 2003. In January 2003, some rivers in southern England even reached the highest flows since the snow-melt floods of March 1947 (DEFRA, 2006). In Scotland, Werritty (2002) has observed an increase in high flow frequency during the period 1970-1996, which has been accompanied by a reduction in low flows (expressed as Q95) since 1990. Although Prudhomme et al. (2003) have recently confirmed an increase in the frequency and magnitude of high flows in UK rivers in the last 30-50 years, it currently remains difficult to distinguish these trends from natural climatic variability.

4.2.1.4 Sea level rise

For an island nation like the United Kingdom the sea has always played a prominent role. While in the past seafarers have conquered the world oceans, today holiday makers are conquering beaches and sea-side resorts for recreational purposes. But the encounters between man and sea are not always positive. Storm surges and coastal erosion threaten homes and livelihoods, and in the future such problems are likely to be aggravated by the impacts of sea level rise. While sea level rise does not only entail the loss of land due to permanent inundation, other equally severe consequences are expected. One of them is the increased risk of destructive floods reaching further inland. Another would be the threat posed to the UK's water resources. Rising sea levels might cause the salinisation of coastal aquifers and freshwater bodies, whilst floods could have negative effects on water quality.

Mean global sea levels have been rising at a rate of 1.5mm/year during the last century (Church ***et al.***, 2001). Around the UK though, these changes in sea levels have been modified by natural landmass movements. Such vertical land movements can be caused by the continuing readjustment of land since the last deglaciation period, tectonic activity or localised sediment consolidation due to groundwater abstractions (Lowe and Gregory, 2005). In the UK, the first effect is dominant and as a result, southern Britain is currently sinking relative to the sea and the northern part of the island is rising (Hulme ***et al.***, 2002). But the impacts of climate induced sea level changes are still discernible. With adjustments for natural land movements made, mean sea levels around the UK were found to have risen at a rate of around 1mm/year during the course of the last century and are now about 10cm higher than in 1900 (Hulme ***et al.***, 2002; UNFCCC - UK, 2006).

4.2.2 Projections

4.2.2.1 Trends in climatic parameters

Most projections about the impacts of climate change in the UK are based on scenarios developed within the UK Climate Impacts Programme (UKCIP) and were generated with the Hadley Centre regional climate model HadRM3. The UKCIP scenarios correspond to four different IPCC emission paths, namely the low (B1), medium-low (B2), medium-high (A2) and high (A1FI) scenarios (Nakicenovic ***et al.***, 2000). The latest scenario set was developed in 2002, accordingly named UKCIP02, and projects region-dependent increases in annual average temperature between 0.5° and 1.0° C by the 2020s. If the medium-high emission path is followed, this temperature change could reach up to 2.5°C by the 2050s in south England. Summer warming will be greater in the south-east than in the north-west of the UK and warming in summer and autumn will be more pronounced than in winter and spring (Hulme ***et al.***, 2002).

Projections about the changes in precipitation patterns follow a similar trend. Winter precipitation is expected to show a higher degree of increase in the south-east (up to +15% by the 2020s, up to +25% by the 2050s) than the north-west. Summer and autumn precipitation show the reverse gradient over most of the UK, with the south-east experiencing higher reductions (up to -20% by the 2020s, up to -40% by the 2050s) than the north-west. Due to the overall increase in temperature, significant decreases in snowfall are anticipated (Hulme ***et al.***, 2002; UNFCCC - UK, 2006), in Wales the reductions could be as large as 28% (Pilling and Jones, 2002).

It is worth mentioning at this point, that the projections of the previous set of UKCIP scenarios (UKCIP98) are differing in some points from those of UKCIP02. While the former have anticipated the occurrence of drier summers for only southern England and Wales, the latter are now projecting this trend for the whole of Britain. In addition, UKCIP02 arrives at slightly higher warming rates, due to the assumption of a higher climate sensitivity and the included effect of decreasing sulphate aerosol concentrations on climate (Hulme ***et al.***, 2002).

4.2.2.2 Temperature and precipitation extremes

As a consequence of higher mean temperatures, the frequency of hot summer days is expected to rise and that of very cold winters to decrease. According to the medium-high and high emission UKCIP scenarios, more than 20 extra “extremely” warm summer days (i.e., the 90th percentile days) will be occurring by the 2080s, apart from Scotland with between 10 to 15 extra days. During winter, the largest increases in additional warm days will occur along the south coast of England. Typical mild winter days usually experienced in this region will occur more frequently in the rest of the country (Hulme ***et al.***, 2002).

In the same way as more temperature extremes are expected in a warmer climate, so are extremes in precipitation. An analysis with the regional climate model HadRM2 by Jones and Reid (2001) has already pointed towards such developments in the future, as the authors found increased totals of heavy precipitation events for a given return period by the 2080s, particularly in south-east England, south Wales and western Scotland. A further study by Ekström et al (2005) for the same time frame using the newer HadRM3H model was able to confirm such trends. The authors showed that the magnitude of 5-10 day extreme precipitation events for given return periods could be increasing by 10% across most of the UK (except central and eastern England) and up to 20% in Scotland. The magnitudes of shorter duration events (1-2 days) were also found to increase by 10% across most of the UK (except central, eastern and north-eastern England). It is important to note that in a comparison of their HadRM3H and HadRM2 modelling results, Ekström et al. (2005) found the latter to project markedly higher changes in magnitudes, sometimes even with a different regional distribution.

As the strongest rainfall events are more likely to occur outside the summer season and not equally throughout the year, changes in the winter season could be particularly pronounced. Southern and south-eastern England, for example, is expected to experience more heavy precipitation in winter by the end of the century (Goodess, 2005; Jones and Reid, 2001). For the summer season, extremes in the opposite direction are expected. Very dry conditions, like in 1995 and 2003 (DEFRA, 2006), could appear more frequently during the summer months (UNFCCC - UK, 2006).

4.2.2.3 Water resources

The impact of climate change on groundwater resources remains difficult to assess. On the one hand, warmer and drier summers and autumns – as projected for the south-east of the UK – can lead to higher soil moisture deficits, which ultimately shorten the recharge season in winter. On the other hand, this could be compensated by the expected increases in winter rainfall. However, groundwater levels are best recharged during extended periods of steady rain and the contribution of heavy rainfall events in winter might be of limited value for an effective recharge (UK Groundwater Forum, 1998). In a study with the CCIRG scenarios, Arnell (1996) found that the reduced recharge season would outweigh the effects of higher winter precipitation and that groundwater recharge, especially in southern Britain, may decrease. Still, under the newer UKCIP02 scenarios, which project lower mean annual and summer rainfall throughout the UK in contrast to the CCIRG scenarios, reduced groundwater recharge might also be experienced in other regions.

A comprehensive assessment of the impacts of climate change on river flows and water resources under the UKCIP02 scenarios was carried out by Arnell (2004b). As might have been expected, the enhanced seasonality in future rainfall patterns seems to leave its mark on the seasonal distribution of runoff. Although annual runoff still shows decreases of 15% for the east of England by the 2020s, little change is seen in the north and west of the UK. However, when analysing seasonal and monthly runoff the expected pattern becomes apparent. During winter, runoff is projected to decrease in the east and increase in the north and west of the UK, where mean winter flows also show a modest rise. Summer runoff is expected to decrease between 15-20 % across all of the UK, with mean summer flows turning out about 30% lower compared to the baseline period 1961-1990. Low flows, measured as Q95, are to decrease by approximately 25%, with the largest relative reductions likely to occur in the south and east of England. For the 2050s, the same patterns but with more pronounced changes are expected (Arnell, 2004b).

Additional regional modelling results have confirmed such developments for a catchment in mid-Wales for the 2080s where changes in the mean annual values of precipitation, potential evapotranspiration and discharge have remained relatively small (Pilling and Jones, 2002). However, the analysis of seasonal changes has revealed distinct trends: reductions in summer flows around 17% and autumn flows of around 12%. Additional confirmation of an increase in seasonality was also found for mean monthly flows, with discharge from December to April increasing and from May to November decreasing, reaching flow reductions in August as high as 28%.

One of the problems is determining the effects of natural multi-decadal variability in the context of climate change. Arnell et al. (2003b) have thus assessed changes in mean monthly flows and low flows in six British catchments with the UKCIP98 scenarios. The results indicate that human induced climate change has a different seasonal effect on flows than natural multi-decadal variability and shows distinctive hydrological signals: the already familiar pattern of increases in winter and decreases in summer. The authors show that by the 2050s, the climate change signal becomes most apparent in northern upland catchments in winter and in southern lowland catchments in summer. However, when the effects of natural climatic variability and anthropogenic climate change are combined, the ranges in possible future low flows and monthly and seasonal streamflows increase substantially. This finding is consequently of particular importance for water management, as uncertainty about the future development of water resources availability increases even further (Arnell, 2003b).

The anticipated changes in summer and winter rainfall entail obvious challenges for water resources management. While higher winter precipitation increases the risk of flooding, lower summer rainfall intensifies the pressure on water availability. And the projected trends in river flows seem to indicate such developments for the future: high and low flow events in the Upper-Wye catchment in Wales (Pilling and Jones, 2002), the Thames (Diaz-Nieto and Wilby, 2005; Wilby and Harris, 2006) and a number of other UK catchments (Arnell and Reynard, 1996) are expected to become more extreme.

4.2.2.4 Changes in hydrological extremes

Although most regions in the UK are expected to experience an overall decrease in annual rainfall of up to 10% by the 2050s (Hulme ***et al.***, 2002), some catchments will still be faced by an increase in the occurrence floods at the same time (Kay ***et al.***, 2006). Results from the Foresight project even point to substantial increases in flood risks in all of England and Wales by the 2080s (Office of Science and Technology, 2004). In the past, many floods in the UK, like the one in autumn 2000, were caused by long duration, extreme rainfalls events. Future increases in the magnitude of such rainfall events, as projected for Scotland and parts of England, could thus obtain a particular significance (Ekström ***et al.***, 2005).

In fact, eight catchments, mainly in the northern part of the UK, are anticipated to show substantial increases in flood frequencies of a given return period by the 2080s, as results of the HadRM3H model under the A2 scenario have shown (Kay ***et al.***, 2006). The same trend is expected for the river Thames and the river Severn, indicated by studies with the HadCM2 model for the 2050s. In these catchments, the rate at which daily discharges are currently exceeded will rise markedly, and the magnitude of flood events with a 50-year return period could increase by 16% and 20%, respectively. It is worth mentioning that, in contrast, more frequent floods would be less affected by the assumed climatic changes, since the magnitudes of 5-year events would increase by only 11% and 15% in the Thames and Severn, respectively (Reynard ***et al.***, 2001).

These projections about increasing flood magnitudes and frequencies do not just apply to large catchments like the Thames or Severn as smaller river basins are likely to undergo similar changes. Using a range of global circulation models and scenarios, Prudhomme et al. (2003) analysed responses in the Greta, Rea, Beult, Wye and Halladale catchments to future climatic changes. With the largest responses observed for catchments in northern England and Scotland, these small river basins also showed an increase in the severity and frequency of flood events.

Although most of the results presented here seem to point towards increased flood frequencies and magnitudes under enhanced greenhouse conditions, Kay et al. (2006) have found that not all UK catchments are exhibiting such similar trends. In the south and east of England, some could be experiencing lower flood frequencies in the future, despite the projections of future increases in winter average and extreme rainfall. Depending on flood generation processes, the reason for such phenomena could be the high soil moisture deficits developed over summer and autumn in these areas, which need to be replenished before flooding can occur.

To assess the vulnerability of UK water resources to droughts, Fowler et al. (2003) used the UKCIP98 medium-high climate change scenario for the periods 2021-2050 and 2051-2080. Due to the anticipated higher potential evapotranspiration rates, decreasing summer rainfall levels and a higher climatic variability, the authors found that the magnitude and duration of droughts in the Yorkshire region was to increase in the future. For the Thames estuary, Diaz-Nieto and Wilby (2005) have projected an increased risk of extreme low flows in response to the expected changes in precipitation patterns and potential evapotranspiration under the A2 and B2 scenarios. Similar developments were also confirmed in the MICE project which assessed trends in extreme events using the HadRM3 model and the A2 scenario. For southern Britain, the mean number of hot (≥30°C) and dry (≤0.1mm day^{-1}) days is projected to increase between 10 and 15 days in the future (2070-2099) under the A2 scenario (MICE, 2004).

4.2.2.5 Changes in sea level

The global average sea level rise has been projected to reach between 9 and 88cm by the end of the century (Church ***et al.***, 2001). At the regional scale, however, global projections are of little value and the relative rise in sea level becomes important, which accounts for the local phenomena of vertical land movements: for the British Isles this means rising in the north and sinking in the south. Depending on scenario, sea levels in the 2080s in western Scotland could thus be between 2cm lower or 58cm higher than current levels. And the largest increases are consequently anticipated for the south-eastern parts of England, particularly London, where sea levels could be between 26 to 86cm higher than today (Hulme ***et al.***, 2002).

The largest problem of future sea level rise is expected in connection with the occurrence of extreme weather events such as storm surges. In the past, floods resulting from this combination of high tides, waves and storms have often caused large damages and sometimes even cost lives. In conditions of higher sea levels, such extremes are likely to occur more often. Studies with the HadRM3H model have been performed, which accounted for future changes in atmospheric storminess, higher mean sea levels and vertical land movements. The largest increases in the relative surge height of a 50-year event will occur along the south-eastern coast of England, although heights would be increasing around all of the UK. Ultimately, this means that the return periods of extreme events could drop by more than an order of magnitude at some locations in the future (Lowe and Gregory, 2005). Such projections were also confirmed by the UKCIP02 modelling results with the medium-high emission scenario. Water levels along the UK’s east coast with a current 2% probability of occurring in a given year could have an annual occurrence probability of 33% by the 2080s (Hulme ***et al.***, 2002).

4.2.3 Summary and conclusions

In this assessment, the impacts of climate change on water resources in the United Kingdom have been investigated. Although it still proves difficult to assign absolute values to the projected changes, most studies presented here paint a fairly clear and congruent picture. Temperatures across the UK will continue to rise in the future and with them the variability of water resources availability.

Most of the observed and projected changes are occurring along the north-south divide described by Price (1998), which separates the country into a north-western part that experiences higher rainfall, and a south-eastern part, where precipitation levels are generally lower. As a consequence of the projected future changes, these regional differences could become even more distinct in the future with winter precipitation in the north-west increasing and summer rainfall in the south-east decreasing (Hulme ***et al.***, 2002). At the same time, south-eastern England and Scotland could experience more frequent and intense precipitation extremes, especially in winter (Ekström ***et al.***, 2005; Jones and Reid, 2001). In summer, on the other hand, hotter and drier conditions aiding in the development of droughts could occur in the south (MICE, 2004). The impacts of such variable precipitation patterns on groundwater levels are difficult to determine and current estimates point towards an overall reduction in groundwater recharge for most of the UK. Both high and low flows are projected to become more extreme in several UK catchments, and flood frequencies and magnitudes are expected to rise accordingly (Prudhomme ***et al.***, 2003; Reynard ***et al.***, 2001). These could be aggravated by the anticipated rises in sea level, which would also negatively impact on storm surge heights (Lowe and Gregory, 2005).

Due to the number of government-led initiatives, climate change and the assessment of its impacts have obtained a high priority in the United Kingdom. Research results thus show a quite advanced state of knowledge and understanding about the potential impacts on water resources. Particularly with respect to assessing future flood risks, a lot of work has been undertaken and knowledge gaps, such as the preparation of flood risk maps, are currently being filled. Results from the Foresight report, for example, come to the conclusion that more effective land use management could help to reduce flood risks in most of their scenarios. As this option is of little benefit in a worst case scenario, more stringent measures such as the greater use of flood defences or even the abandonment of the threatened area are discussed. This shows that decision makers in the UK are already presented with the whole suite of available options, despite the fact that some of these might initially face harsh resistance.

In his work, Arnell (2003b) had shown that by the 2050s the climate change signal will become larger than natural multi-decadal variability and that the combination of both effects will lead to a substantial increase in the range of possible future streamflows. Considering that the frequency of extreme events, i.e. floods and droughts, is projected to rise, while the whole of the UK will be experiencing an overall decrease in precipitation levels, the need to prepare and adapt to such future possibilities is apparent. The approach taken by the UK government thus serves as a good example how an early discussion about the impacts of climate change enables and furthers the discussion about subsequent adaptation options.

4.3 Case study 3: Central Europe: Germany

Although climate change is generally associated with mainly negative impacts, Germany is thought to belong to those few temperate middle European countries which could initially benefit from the anticipated changes in temperature and precipitation patterns. However, while the overall idea of warmer and drier summers or expanding winegrowing regions might be rather pleasant, realities at the regional and local scale could look quite different. Particularly important in the context of rising temperatures is of course the availability of water. Agriculture could, for example, only benefit from higher temperatures if these are coupled to an adequate supply of water during the growing season. To assess the potential impacts of climate change in a suitable manner, studies at the regional and seasonal scale are thus needed to identify the respective trends for the different regions of Germany.

German climate is shaped by both marine and continental influences with regional variations depending on its altitude and distance from the sea. The country's average annual temperature is +9°C and the prevailing winds are westerly. While precipitation occurs in all seasons, it is still marked by large regional and seasonal differences. In the lowlands of northern Germany, annual rainfall reaches levels between 500 (continental) to 800 mm (maritime). Upland areas receive between 700-1500 mm of rain $year^{-1}$ and the Alps over 2000 mm $year^{-1}$ (UNFCCC - Germany, 2002).

Studies investigating changes of large-scale precipitation characteristics have shown that the development of annual precipitation totals in Germany exhibits a distinct pattern: an increasing trend in the western part and reductions over large areas in eastern and south-eastern Germany (Menzel ***et al.***, 2006). Particularly for the eastern part of Germany, such trends could become critical in the future. The region is already characterised by an almost semi-arid climate and exhibits, due to high demands in urbanised areas, a very low water availability. In the Elbe catchment, water availability is around $680m^3$ per capita and year - the second lowest when compared to the 15 largest river basins in Europe (Stanners and Bourdeau, 1995). With climate change having the potential to alter the length and severity of dry periods, the current situation could intensify in the future (Lahmer ***et al.***, 2001).

To investigate the contrasting impacts of climate change on the different regions in Germany, the Rhine drainage area in the west of the country and the Elbe river basin in the east are investigated in more detail (see Figure 17).

As it stretches from the Swiss Alps to the North Sea, the Rhine Basin covers altitudes between 0 and 4275m above sea level and displays large contrasts in its physiography. In the Alpine region, precipitation can be around 2000mm per year, with annual rainfall levels decreasing to 1100 to 570 mm further downstream in the German part. Overall, the hydrological regime of the Rhine is mainly determined by the spatio-temporal distributions of rainfall and patterns of snow storage and snow melt in the Alps and the German and French Middle Mountain ranges. Maximum runoff from the Alpine region

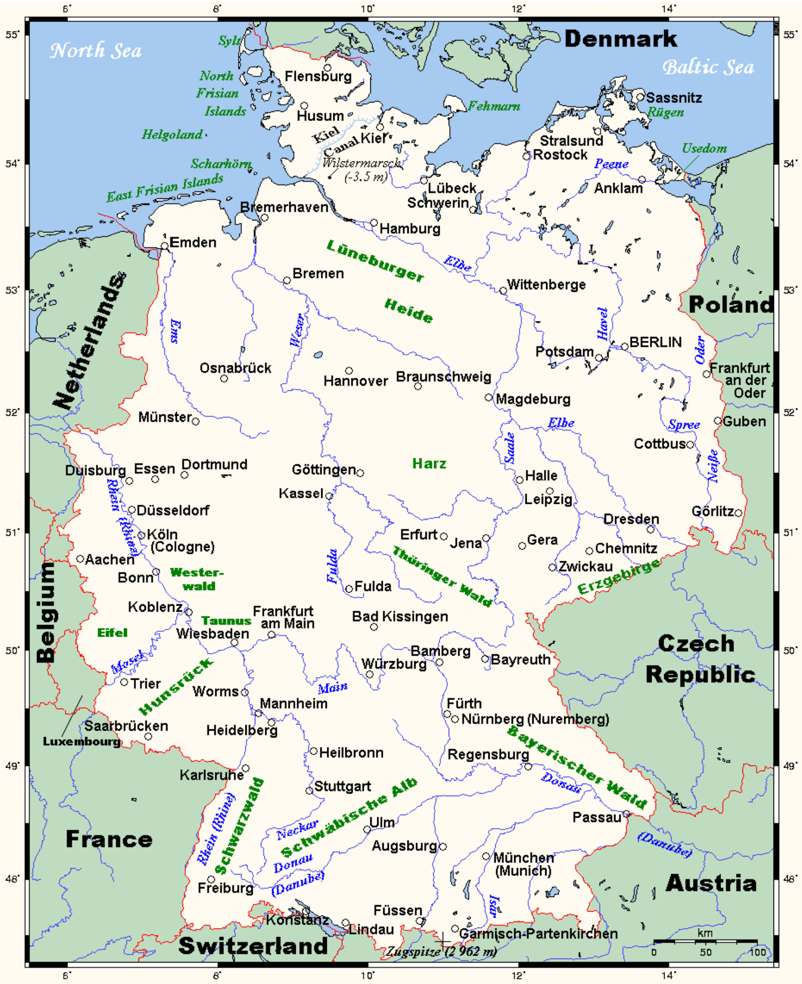


Figure 17 Map showing the major rivers in Germany (Source: http://upload.wikimedia.org/wikipedia/commons/d/df/Germanymap2.png).

occurs during summer, with the Alpine border lakes having a buffering effect on discharges. Downstream of Basel, the Rhine is increasingly dominated by a pluvial regime and downstream of the Mosel confluence, high flows occur more and more during the winter season.

Mean annual discharge at its outflow into the North Sea is around 2490 $m^3 s^{-1}$. Due to the different meteorological and physiographical conditions prevailing in the basin, flooding events are usually of regional character. In the Upper Rhine, the development of floods is generally linked to snowmelt processes in the Alpine regions and thus occurs in the spring season. In the Middle and especially the Lower Rhine, floods mainly occur during winter (see review of Pfister ***et al.***, 2004).

The Elbe river basin drains a major part of northern and north-eastern Germany and river discharges are characterised by spring and winter high water periods (Krysanova et al., 2005a; Lahmer et al., 2001). Due to the lack of high mountain regions in the upstream areas of the Elbe, buffer storages of glacial snow to alleviate the occurrence of floods or low flows are lacking. Water resources in the catchment are thus mainly dependent on current precipitation levels. The long-term mean is 660 mm per year

(Krysanova et al., 2005a), although in some regions these values can even be less than 500mm per year (Gerstengarbe ***et al.***, 2003; Lahmer ***et al.***, 2001).

4.3.1 Observations

4.3.1.1 Trends in climatic parameters

Temperature

During the course of the 20th century, a temperature increase of 0.6-1.0°C was observed and the 1990s were found to have been the warmest decade of the century (DWD, 2004; Jonas ***et al.***, 2005; UNFCCC - Germany, 2002). Still, this temperature rise was not a linear trend, and warm periods like in the 1940s occurred interspersed with phases of colder temperatures like the 1960s. Since the 1970s, however, a continuous and rapid warming trend has been prevailing which has lasted until today. With regard to the regional and seasonal distribution of warming trends, differences are quite large. During the 1990s, for example, the rise in temperatures has been particularly pronounced in the southern and south-western parts of Germany and during the winter season. The overall rise in temperatures is thus mainly attributed to higher minimum temperatures rather than higher maximum temperatures (Wulfmeyer and Henning-Müller, 2006).

Results of the climate study KLIWA for the federal states of Baden-Württemberg and Bavaria (see Figure 18) show an annual temperature increase of 0.5-1.2°C for the time period 1931-2000.

Figure 18 Map of Germany with the different federal states.

In these southern German states, mean temperatures in August were found to have risen between 0.7 and 1.7°C, and in December between 1.8 and 2.7°C (KLIWA, 2003). Winter temperatures in the south-western areas were found to show a particularly marked increase and data from a meteorological station in Stuttgart revealed that the number of frost days ($T_{min} \leq 0$°C) has decreased by 2.2 per decade since 1878, and that of ice days ($T_{max} \leq 0$°C) by 1.2 per decade (Wulfmeyer and Henning-Müller, 2006).

Observations from a study for the federal state of Brandenburg (see Figure 18) have shown increases in mean annual temperature by about 1°C during the time frame 1961-1998, with increases in winter (1.6°C) being again more pronounced than in summer (0.6°C) (Gerstengarbe ***et al.***, 2003). These changes are very similar for the Elbe catchment, with an observed (1951-1999) temperature rise of 0.8°C in summer and 1.4°C in winter (Wechsung ***et al.***, 2004).

Precipitation

Over the course of the last century, precipitation in Germany was found to have increased, particularly in the western parts in winter and spring. If the time frame 1901-2000 is analysed, the relative trend in winter precipitation (expressed as percentage of the mean) was 19%, during the time period 1971-2000, however, this increased to 34% (Jonas ***et al.***, 2005; Zebisch ***et al.***, 2005). Trends in summer rainfall, in comparison, have been rather small across the whole country (±10%) (Jonas ***et al.***, 2005).

In Bavaria and Baden-Württemberg, annual sums during the time period 1931-1997 changed only slightly. An analysis of seasonal trends, however, shows a redistribution in seasonal rainfall patterns: marked increases for spring and winter and reductions in summer. In spring and winter, these changes were combined with higher rainfall frequencies (KLIWA, 2003). In addition, data from a meteorological station in Stuttgart (see Figure 17) have pointed towards a shift to more extreme precipitation events, particularly during the winter months. Between the years 1878-2002, the contribution of winter precipitation to the annual sums was around 17% and rose to 18.5% during the years 1971-2002 (Wulfmeyer and Henning-Müller, 2006).

Interesting in this context are the observed changes in snow cover duration. Since the 1950s, reductions of 30-40% in Bavaria and Baden-Württemberg for altitudes below 300m were detected; at altitudes of 300-800m, these reductions were in the order of 10-20%. Above 800m, however, where temperatures are sufficiently low, the observed increases in precipitation have sometimes even contributed to extending snow cover duration (KLIWA, 2003).

In the Rhine Basin downstream of Cologne (see Figure 17), a comparison of the mean monthly precipitation of the climatic periods 1931-1960 and 1961-1990 revealed a slight increase in annual precipitation (2.5%). This was combined with changes in seasonal precipitation patterns, i.e. decreases in summer and autumn (Jun – Oct) and over-proportional increases during winter and spring (Nov – Dec and Feb – May) (Disse and Engel, 2001; Goodess, 2005). In addition to the observed increases in winter precipitation, the intensity of these events has also been observed to increase, rising the flooding probability for the Middle and the Lower Rhine and the Meuse (Pfister ***et al.***, 2004).

In Brandenburg, precipitation for the summer and winter half year during the period 1961-1998 has not shown any significant changes: reductions in summer reached 12.8mm, increases in winter 10.4mm (Gerstengarbe ***et al.***, 2003). More pronounced trends were observed in the Elbe basin where summer rainfall decreased 46mm and winter precipitation rose 50mm during the years 1951-2000 (Wechsung, 2006).

4.3.1.2 Temperature and precipitation extremes

Temperature

When recent developments of temperature extremes in Europe are discussed, the infamous summer of 2003 is always mentioned. With a mean summer temperature of 21.8°C, five standard deviations higher than the long-term mean value of 16.9°C (1878-2002), it proves difficult to assign such an event entirely to natural variability (Wulfmeyer and Henning-Müller, 2006). After all, this summer was shown to be the hottest year in Germany since observations began and the probability for such a summer occurring has risen twenty-fold over the course of the 20th century (Schönwiese ***et al.***, 2003; Zebisch ***et al.***, 2005).

In general, a clear trend in the occurrence of hot days (temperature > 30°C) can be observed. During the last century and especially over the last 20 years, the frequency of hot days during the months of July and August has increased markedly throughout Germany. However, several data analyses covering the last century (1901-2000) have shown that the overall variability has not been changing markedly, but rather the mean values of monthly and seasonal temperatures. This way, the probability for the occurrence of particularly warm months especially in winter has risen noticeably, while the frequency of cold days has decreased. The trend to hotter summers has been rising accordingly (Jonas ***et al.***, 2005).

In the Rhine Basin, similar developments have been observed. Between 1958 and 2001, extreme daily minimum and maximum temperatures have increased, with the minima showing larger changes than the maxima (Hundecha and Bardossy, 2005).

Precipitation

In addition to its extreme temperatures, the year 2003 has also been particularly dry, with a persistent dry spell prevailing between February and August (Zebisch ***et al.***, 2005). Jonas ***et al.*** (2005) have analysed the occurrence of such dry spells (consecutive days with precipitation ≤1mm) in Germany during the years 1951-2000. They observed that in many areas in Bavaria, northern and north-western Germany the trend in the number of dry spells of at least 7 days length increased, while that of dry spells of at least 11-days length decreased. Across Germany, a negative trend with regard to the occurrence of dry spells of maximum length was detected.

The occurrence of events with excess precipitation, on the other hand, was observed to increase. Over the course of the last century, the frequency and magnitude of days with extreme rainfall has risen markedly, with trends in the winter half year being more pronounced than in the summer half year (Grieser and Beck, 2002). Such changes were also observed by other authors who equally emphasised the strong seasonal differences. For the winter months, they detected a trend towards higher monthly and seasonal sums as well as an increased variability, ultimately leading to a marked increase of extremely high precipitation sums during this season. In summer, variability was found to decrease, which meant that extremely high monthly and seasonal precipitation sums were observed less frequent (Jonas ***et al.***, 2005).

In southern Germany, analyses of precipitation data have identified trends towards higher precipitation events at several climate stations. This means, that the probability of exceeding the 95th percentile has increased and that of falling under the 5th percentile has decreased (Trömel and Schönwiese, 2007). Especially in the winter season, the frequency of extreme precipitation events has risen by 30-35% during the period 1931-2000 (KLIWA, 2003).

In western Germany, a trend towards more extreme events has been observed (Jonas ***et al.***, 2005; Trömel and Schönwiese, 2007). During the winter months, both an increase in the probability of exceeding the 95th percentile and of falling under the 5th percentile was detected (Trömel and Schönwiese, 2007). Regarding daily precipitation, the same tendency towards more extremes is identified (Jonas ***et al.***, 2005). Similar trends are also observed for the Rhine Basin when the data of the years 1958-2000 are analysed. During this time, the frequency and intensity of extreme precipitation was found to increase, again particularly in the winter season but also during the transition months. This could explain the frequent flooding events occurring in the Rhine Basin during winter (Hundecha and Bardossy, 2005). Between 1900 and 2000, the peak discharges of winter floods near Cologne were observed to show an upward trend and rain data indicated a significant increase in flood-producing precipitation (Pinter ***et al.***, 2006). Overall, extreme events during the second part of the last century were found to exhibit an increased contribution to annual precipitation totals (Hundecha and Bardossy, 2005).

In eastern Germany, a trend towards a less extreme climate has been observed (Jonas ***et al.***, 2005; Trömel and Schönwiese, 2007). In the winter months, this is characterised by a higher probability of relatively low precipitation events, in summer and autumn, by decreases in the probability of both very high (> 95th percentile) and very low (< 5th percentile) events (Trömel and Schönwiese, 2007).

4.3.1.3 Hydrological extremes

Floods constitute one of the main natural hazards in Germany and have repeatedly caused major damages in the past. The 100-year floods in the Rhine Basin in winter 1993/1994 and 1995, and in the Oder Basin in summer 1997, or the 1000-year flood in the Danube and Elbe Basins in August 2002 count towards the most important and destructive flooding events in recent history. Floods across the larger catchments are generally caused by long-lasting advective rainfall, either with or without the contribution from snow melt. Extreme precipitation events of convective rainfall are usually responsible for small-scale flooding events with a high potential for damages (Zebisch ***et al.***, 2005).

The increased occurrence of floods especially in south-western Germany is often brought in connection with the higher frequency of extreme precipitation events in winter in these regions. Results of the KLIWA study have shown that during the last 30 years annual and seasonal discharge maxima have been exhibiting increasing trends. The frequency of winter high flows in the southern areas of Baden-Württemberg and at some stations in Bavaria was also found to have risen. No marked changes with respect to mean annual discharges were observed though (KLIWA, 2003). In the Elbe catchment, the variability of average annual discharge was found to have increased in the second half of the 20th century, rising from 184m^3 s^{-1} (1900-1950) to 202m^3 s^{-1} (1951-2002) (Krysanova ***et al.***, 2006).

During summer, certain large scale circulation patterns, such as the Vb atmospheric circulation type, are discussed as the potential causes for the increased occurrence of flooding events in Germany and central Europe (Kundzewicz et al., 2005). In addition, the effects of land use changes on flood development may not be neglected. In the Rhine Basin, a fifth of its former riparian zones are remaining today, and in the Elbe Basin, the area of flood plains has even shrunk to 15% of its original size. The use of heavy machinery in agriculture has further led to a solidification of the soils and reduced their infiltration properties, thus improving conditions for the occurrence of floods. With regard to these trends in flood development, anthropogenic influences are currently thought to outweigh the impacts of climate change (Zebisch et al., 2005).

4.3.2 Projections

4.3.2.1 Trends in climatic parameters

For projections of future changes in the climatic parameters temperature and precipitation for the whole of Germany, the results from two major modelling studies will be presented. On the one hand, the outcomes from a statistical downscaling exercise as performed in the ATEAM project (Schröter ***et al.***, 2004) and discussed by Zebisch ***et al.*** (2005), results from the dynamical regional climate model REMO (UBA and MPI, 2006), and the statistical model STAR which was used in the KLIWA and GLOWA-Elbe study (Wechsung, 2005). In the ATEAM project, output from the four GCMs HadCM3, PCM, CSIRO2 and CGCM2 and four different SRES scenarios A1, A2, B1 and B2 (Nakicenovic ***et al.***, 2000) were used to obtain projections for Europe at a grid size of 16x16 km and for the time slices 2020, 2050 and 2080. Zebisch ***et al.*** (2005) have aggregated these results for the German scale and have presented scenario projections of the HadCM3 model for all four emission scenarios and of all four GCMs for the A2 scenario. Results of the REMO model deliver projections of potential future climate changes under the B1, A1B, and B2 scenario (Nakicenovic ***et al.***, 2000) at a resolution of 10x10 km up to the year 2100.

Temperature

All ATEAM climate scenarios have shown a pronounced warming trend in Germany, with increases in mean annual temperatures of 1.6 to 3.8°C by the 2080s. With regard to the regional distribution, many scenarios have highlighted particular warming tendencies in the south-western parts of the country, some also for areas in eastern Germany. Despite the observed trends of a more pronounced warming during the winter season, climate scenarios in the ATEAM project have not reproduced such developments for the future (Zebisch ***et al.***, 2005). According to the REMO model, mean annual temperature could rise between 2.5 and 3.5°C by the year 2100. The southern and south-eastern parts of Germany are projected to experience the highest warming, particularly in winter. Winter temperature in these regions under the A1B scenario could be up to 4°C higher than during the period 1961-1990 (UBA and MPI, 2006).

Results of the KLIWA modelling study for the time frame 2021-2050, for which the regional climate model REMO and the statistical methods of Enke and Werner and Gerstengarbe were compared (Weber, 2004), have projected temperature increases under the B2 scenario for Bavaria and Baden-Württemberg of 1.2-1.7°C for the summer half year (Mai-Oct) and 1.0-2.0°C for the winter half year (Nov-Apr) (KLIWA, 2005, 2005).

To investigate future temperatures in the Rhine Basin, Middelkoop ***et al.*** (2001) have used the IS92a scenario and the global climate models UKHI and XCCC. For the 2050s, the authors project a temperature rise of 1-2°C which is more pronounced for the winter than the summer season. By the end of the century, temperatures in this catchment could rise between 1.6 and 4.8°C. Using the IS95a scenario and an expanded downscaling technique (EDS) with the EHAM4/OPYC3 and HadCM3 GCMs, Menzel ***et al.*** (2006) arrive at the lower end of the projected temperature range with 1.6 to 2.6°C. Shabalova ***et al.*** (2003) on the other hand, obtained the far higher value of 4.8°C by applying the IS92a scenario with the RCM HadRM2.

For the Elbe catchment, the impacts of a global temperature rise of 1.5°C, corresponding to a "business as usual scenario", and a 3°C increase, equivalent to an extreme scenario, were assessed. For the 2050s, the projected range obtained from the transient and equilibrium simulations with the global climate model ECHAMT21 was between 1.4 and 3.1°C (Krysanova et al., 2005a). Projections by the REMO model for the time frame 2020-2049 and the B2 scenario have shown a temperature rise of 1°C , with the winter months exhibiting higher warming trends than the summer (Jacob and Gerstengarbe, 2005).

Precipitation

In the ATEAM study, mean annual precipitation has only shown slight changes, which could remain below ±10% up to the year 2080. Larger changes become apparent when the seasonal distribution is analysed, with increases in winter precipitation projected for all climate scenarios. These increases are particularly pronounced in southern Germany, especially according to the HadCM3 model (Zebisch ***et al.***, 2005). The REMO model also projects for winter precipitation to rise all over Germany. Especially in the mountainous areas in the south and south-west, precipitation by the 2080s could be up to a third higher compared to the period 1961-1990 (UBA and MPI, 2006). Such trends have also been identified in the KLIWA study, where winter precipitation is anticipated to rise by up to 35% especially in the south-western parts (KLIWA, 2005).

Summer rainfall in the ATEAM study decreased in most scenarios, supporting the trend of an overall shift towards more winter precipitation. The projected decreases occur primarily in the south-western regions in the Rhineland and central parts of eastern Germany (Zebisch ***et al.***, 2005). Results of the REMO model confirm the projected decreases in summer precipitation for the southern, south-western and eastern areas of Germany, but also for the northern and coastal regions. By 2100, rainfall could decrease in these regions by up to 30% under the A1B scenario (UBA and MPI, 2006). Up to the 2050s, the KLIWA study has indicated only minor changes in summer precipitation of between -10% and +5%, with the highest reductions anticipated for the south-eastern parts of the country (KLIWA, 2005, 2005). However, it should be kept in mind that the KLIWA modelling exercise was carried out for the "more environmentally friendly" B2 scenario.

In the Rhine Basin, mean annual precipitation is projected to rise but the changes anticipated for the end of the century show large variations. Depending on GCM used, precipitation could increase between 4.8% (Shabalova ***et al.***, 2003) and 18-45% (Menzel ***et al.***, 2006). However, analyses of the regional and seasonal distribution give a better idea of the potential changes under the IS92a scenario. Summers in the 2080s are projected to experience decreases in rainfall and results by the HadRM2 model point towards reductions of 12% which could even reach 29% in the Alpine region (Shabalova ***et al.***, 2003). For the 2050s, the changes are less extreme and the UKHI and XCCC models show decreases in central Germany of around 2% and of approximately 4% in the Alps (Middelkoop ***et al.***, 2001). In winter, precipitation is anticipated to increase. During this season however, projections for the 2050s by the UKHI and XCCC models are more pronounced than for the 2080s by the HadRM2 model. Whereas the former expect winter precipitation to rise by around 9% in the Alps and around 14% in the lowlands (Middelkoop ***et al.***, 2001) the latter gives overall increases of around 6% (Shabalova ***et al.***, 2003). Other modelling exercises have confirmed these trends towards higher winter precipitation in the Rhine Basin and highlighted the simultaneous increase in flooding probability for the entire catchment (see review of Pfister ***et al.***, 2004). Furthermore, as higher temperatures cause a larger amount of precipitation to fall as rain rather than snow, the Rhine would shift from a combined rain-snow fed river to an entirely rain-fed river (CHR, 1997; Middelkoop and Kwadijk, 2001). In the Upper Rhine, this would move the occurrence of flooding events from spring and summer to winter (see review of Pfister ***et al.***, 2004).

For the eastern part of Germany, studies have repeatedly pointed towards a future situation in which precipitation levels could be markedly reduced. In Brandenburg, an assumed temperature increase of 1.4°C could lead to a decrease in mean annual precipitation sums which might drop to less than 450mm by the 2050s (Gerstengarbe ***et al.***, 2003). In the Elbe catchment, this temperature rise of 1.4°C was found to result in precipitation reductions of between 15.9 and 17% that occurred particularly pronounced in the central and southern parts of the basin (Wechsung, 2005). Studies of the GLOWA-Elbe project, using the STAR and Neuro-Fuzzy models, have also detected pronounced changes for each degree of temperature rise in the Elbe catchment. In summer, this reduction in precipitation would reach levels of 14 and 36mm, and in winter of 39 and 19mm for the Star and Neuro-Fuzzy models, respectively (Wechsung, 2005).

4.3.2.2 Temperature and precipitation extremes

In southern Germany, the KLIWA study has identified a tendency towards more extreme temperature and precipitation events up to the year 2050. However, these developments are strongly related to the seasons. In summer, the number of heat days (>30°C) is projected to double while that of frost days (Tmax < 0°C) in winter could be reduced by half (KLIWA, 2005a, 2005b). Results of the STARDEX study for the A2 and B2 scenarios project significant increases in temperature extremes for the German Rhine basin by the end of the century. These increases are expected to be particularly severe during summer and are accompanied by a higher year-to-year variability (Goodess, 2005).

The number of days with high precipitation (>25mm) is anticipated to increase in winter in Baden-Württemberg and at the climate station in Freudenstadt, for example, the number of such days during the months of December to February could double (KLIWA, 2005a, 2005b). In the Rhine basin, the magnitude and frequency of heavy winter precipitation events is also projected to rise, with the greatest 5-day winter rainfall anticipated to increase by up to 50% under the A2 scenario (Goodess, 2005). The annual number of low precipitation days (<1mm) and drought periods (11 or more consecutive days with precipitation <1mm) is projected to decrease in Baden-Württemberg in the future. At the same time, the duration of drought periods is not expected to increase either (KLIWA, 2005a).

4.3.2.3 Water resources and hydrological extremes

With runoff closely linked to precipitation, the small annual changes in precipitation as projected by the scenarios in the ATEAM study do not translate into large changes in mean annual runoff and stay below 10% until the 2080s. An analysis of the regional distribution reveals a different picture though, and especially scenarios based on the HadCM3 model show a tendency towards decreases in the north and north-east and increases in the south. However, the climate model CSIRO delivers results with the exact opposite trends. Regarding changes in the seasonal distribution, results of the ATEAM study are less ambiguous. Due to the higher evapotranspiration rates in summer and the shift in precipitation from summer to winter, most models project an overall reduction in runoff of up to 43% for the months June to August (Zebisch ***et al.***, 2005).

Shabalova ***et al.*** (2003) and Middelkoop ***et al.*** (2001) have both used the RhineFlow water balance model to estimate changes in river discharges for the 2080s and 2050s, respectively. For the end of the century, winter discharges throughout the Rhine area are projected to increase, with up to 37% in the alpine region. This could be due to the expected increase in winter precipitation, but also because less precipitation will fall as snow and winter discharges might increase accordingly. In summer, river discharges are projected to decrease by up to 31% in the lowlands and 35% in the Alps, with reductions in the Alpine region reaching values of 50% in August. These changes would correspond to the expected decreases in summer precipitation and the temperature induced increases in actual evapotranspiration (Shabalova ***et al.***, 2003). For the 2050s, Middelkoop ***et al.*** (2001) obtain similar results with the projected changes showing higher winter and lower summer flows. Compared to the results for the entire Rhine basin, the Alps are again expected to experience the most pronounced changes, i.e. the largest increases in winter followed by the largest reductions in summer. Interesting in this context are the anticipated shifts in the hydrological regime within the Rhine basin: in the upper alpine region, intra-annual differences between low winter and high summer flow might decrease or could even be inverted, while the existing summer-winter differences in the lowlands are amplified. To enable an easier comparison of the modelling results of the different authors, they are presented in Table 6.

Assuming a temperature rise of 1.4°C by the 2050s, the Brandenburg study showed that the anticipated reductions in precipitation could, in combination with the higher evaporation rates, lead to drastic decreases in groundwater levels in summer. Groundwater recharge could become reduced by up to 42% and runoff may decrease by 24% compared to the present day values (Gerstengarbe ***et al.***, 2003). Using statistical downscaling techniques and the process based eco-hydrological model SWIM, Hattermann (2005) and Krysanova ***et al.*** (2005a; 2005b) further assessed the potential impacts on hydrological flows.

Table 6 Projected changes in temperature, precipitation and river discharge for double CO_2 scenarios with the respective time frames indicated. Actual river discharge values were converted and are expressed as percent changes (%) to allow easier comparison between results of different authors.

River Catchment	Year	Temperature Mean (°C)	Precipitation Annual Mean (%)	River Discharge (%)	Reference
Rhine	2080s	1.6 – 2.6	↑ (18 – 45)		Menzel ***et al.*** (2006)
	2080s	4.8	↑ (4)	↑ (winter, Alps: 37) ↓ (summer: 31 – 35)	Shabalova ***et al.*** (2003)
	2050s	1 – 2	↑ (1.8 Alps – 11 lowlands)	↑ (winter, Alps) ↓ (summer, Alps)	Middelkoop ***et al.*** (2001)
Elbe	2050s	1.4 – 3.1	↓ (15.9)		Hattermann (2005) Krysanova ***et al.*** (2005a)
	2050s	1.4	↓ (17)	↓ (high flows: 25, low flows: 72)	Krysanova ***et al.*** (2005b)

According to the simulation results based on the ECHAM4/OPYC3 model, runoff and groundwater recharge show a decreasing trend in the future with the latter exhibiting a reduction by 37% on average. River flow is decreasing accordingly, with maximum values of 410 m^3 s^{-1} compared to > 550 m^3 s^{-1} in the reference period (1960 – 1990), and minimum flows of 50 m^3 s^{-1} compared to 180 m^3 s^{-1} (Krysanova et al., 2005a). Results based on the ECHAMT21 model indicate similar trends, with runoff and groundwater both decreasing as a response to the assumed temperature increase of 1.5 and 3°C. Groundwater recharge is shown to react particularly sensitive to the anticipated climate changes, experiencing potential reductions of 30.7 to 51.5% by 2050 (Krysanova et al., 2005a; Hattermann et al. 2007).

Results for the subcatchments of the Elbe such as the Mulde and the Stepenitz indicate similar developments. In the Mulde in the German part of the Elbe basin, projections by the HBV-D model for the time frame 2061-2090 show a decrease in mean monthly discharges under the IS95a scenario, especially during winter. This could be partially caused by the projected changes in snow accumulation and snow melt processes (Menzel and Bürger, 2002). In the Stepenitz, where the assumed temperature rises of 1.5 and 3°C could lead to decreases in annual precipitation of 7.3 and 6.4% respectively, basin discharge shows large changes. Compared to the reference state (1951-1990), the expected reductions are between 23.1 and 27.2% for the two climate scenarios, respectively (Lahmer ***et al.***, 2001).

Extreme events

Despite the varying projections regarding the future development of precipitation patterns in Germany, most studies point towards decreases in summer and increases in winter precipitation (KLIWA, 2005, 2005; Middelkoop et al., 2001; Shabalova et al., 2003; UBA and MPI, 2006). This could result in a higher risk of winter or early spring flooding, especially in the south-western parts of the country where these changes are expected to occur particularly pronounced. For the Rhine Basin, the ATEAM study has consequently pointed towards a shift of maximum monthly discharge from Mai and June in the 1990s (gauge at Kaub) to March in the 2050s (Zebisch ***et al.***, 2005), and the International Commission for the Hydrology of the Rhine Basin concluded that the frequency and magnitude of peak discharges was to increase in winter (CHR, 1997). However, due to the different geographical conditions prevailing in the Rhine Basin, it remains difficult to determine a specific season that will show a higher occurrence of flooding in the future. Also, because the spatial and temporal precipitation patterns of each of the Rhine’s tributaries strongly influence individual flooding events (Disse and Engel, 2001). To assess the impacts of climate change on flooding characteristics in several subbasins of the Rhine, Menzel ***et al.*** (2006) have used the ECHAM4/OPYC3 and HadCM3 model under the IS95a scenario. Results of the former model showed that in the Lahn, Main, Mosel and Neckar a clear increase in mean flood discharge for the years 2061-2090 could occur. Projections by the HadCM3 model, however, stayed within the limits of natural variability for most subbasins, highlighting that the uncertainty about future flood discharge in the Rhine remains quite high.

In the eastern part of Germany, the situation regarding the development of floods could be rather different. For this region, annual, summer and winter precipitation is projected to decrease (UBA and MPI, 2006; Wechsung, 2005) and with it river discharge and runoff (Hattermann 2005; Krysanova et al., 2005a; Krysanova et al., 2005b; Lahmer et al., 2001; Menzel and Bürger, 2002). And with rivers less likely to freeze in a warmer climate, the risk of winter ice jams which often led to flooding events in the Elbe Basin could thus be reduced accordingly (Bronstert, 1996). Flood probability analyses of the Stepenitz river basin have also confirmed that the risk for extreme floods is not expected to rise in response to climate change (Lahmer ***et al.***, 2001). Still, catchments in more mountainous regions such as the Selke in Saxony-Anhalt could still be experiencing an increased risk of early spring floods due to altered snow melt and precipitation patterns (Bronstert ***et al.***, 2002).

4.3.3 Summary and conclusions

Over the course of the last century, Germany has already experienced the signs of a changing climate. With the impacts expected to be very different in the south-western and eastern parts of the country, the observed and projected changes for the Rhine and the Elbe Basin were investigated in more detail.

The observed temperature rise was found to have occurred particularly pronounced in the southern and south-western parts of Germany and increases in winter temperatures were higher than those in summer. With regard to precipitation, increasing trends particularly for winter and spring were observed. This supports the overall shift in precipitation patterns, with reductions in summer being compensated by increases in winter (Disse and Engel, 2001; Goodess, 2005; Jonas ***et al.***, 2005; Wechsung, 2006; Zebisch ***et al.***, 2005). For the 2050s, the projected temperature increases for the Rhine basin are between 1 to 2°C (Middelkoop ***et al.***, 2001) and around 1°C in the Elbe catchment (Jacob and Gerstengarbe, 2005). The trend of a more pronounced warming in winter than summer is expected to be continued (UBA and MPI, 2006; Zebisch ***et al.***, 2005). Changes in seasonal precipitation patterns could be quite pronounced, with the winter months anticipated to show large increases (UBA and MPI, 2006; Zebisch ***et al.***, 2005) especially in the south-western regions (KLIWA, 2005; UBA and MPI, 2006). Summer rainfall is projected to decrease, particularly in the south-western, southern and eastern parts of Germany (UBA and MPI, 2006; Zebisch ***et al.***, 2005). In the Rhine Basin, the same trend of increasing winter and decreasing summer precipitation is expected to occur with the Alpine region showing the most pronounced changes (Menzel ***et al.***, 2006; Shabalova ***et al.***, 2003). This will affect river discharge and runoff and the risk of winter flooding is expected to rise accordingly (CHR, 1997; Zebisch ***et al.***, 2005). In the Elbe basin, high, low and monthly flows are anticipated to respond to the decreases in annual precipitation (16.5% on average (Wechsung, 2005)) and show marked reductions, with the corresponding changes in groundwater recharge being particularly pronounced (Krysanova et al., 2005a; Krysanova et al., 2005b; Lahmer et al., 2001; Menzel and Bürger, 2002).

Overall, the main impacts of climate change on water resources in the Rhine and Elbe Basins could be concluded as the following. In the south-western and western parts of the country, increases in extreme precipitation events could cause winter flood risks to rise, while decreases in summer rainfall could entail serious reductions in river discharges. In combination with the altered snow accumulation and snow melt dynamics, the role of the Alps as a freshwater reservoir during spring and summer could be declining in the future. This could have serious consequences during years with low precipitation levels in these particular seasons. In eastern Germany, a reduction in annual and seasonal precipitation could worsen the current situation of low water availability and might impact on water quality. This is not only of relevance for the agricultural sector which could experience water shortages during the growing season, but also for the functioning of important ecosystems which are often of touristic interest. Water shortages could thus lead to conflicts between, for example, water management and nature conservation efforts (Gerstengarbe ***et al.***, 2003).

4.4 Case Study 4: Eastern Europe: Hungary

Hungary's most important natural resources are its fertile soils and arable land, making it largely dependent on favourable climatic conditions. Global warming causing changes in temperature and precipitation patterns could thus have serious consequences for this central European country. The Great Plain, for example, the largest agricultural area in Hungary, has often experienced severe precipitation shortages in the last few decades. If such developments were to continue in the future, agricultural productivity would become increasingly threatened (Pongrácz ***et al.***, 2003). Considering the large share of agricultural production in the total output of Hungarian economy, climate change in this direction has thus the potential to lead to “harmful economical and societal impacts” (Domonkos, 2003).

Located in the Carpathian basin, Hungary is surrounded by the Carpathian Mountains in the north and east and by the Alps in the west. It is a low-lying country, with more than 70% of its area being flatland rising less than 200 metres above sea level (UNFCCC - Hungary, 2005). The Great Plain, extending east of the Danube to the Tisza river and beyond (see Figure 19), covers more than half of its territory. Together with the Little Plain in the north-west and Transdanubia to the west of the Danube, this region is very important for agricultural production. In total, about 63% of the country is agricultural land, of which a little less than 50% are used for growing crops. The rest serve as orchards, vineyards and grassland (UNFCCC - Hungary, 2005).

Figure 19 Topographic map of Hungary
(Source: http://en.wikipedia.org/wiki/Image:Hungary_topographic_map.jpg).

The climate in Hungary is temperate and shaped by continental, oceanic and Mediterranean influences. Mean annual temperatures range between 9 and 11°C. The coldest parts of the country are located in the mountain region in the north, while the warmest areas are situated in the south and in the Danube river basin south of Budapest (see Figure 19). The hottest month of the year is July with monthly mean temperatures of 20-22°C, and the mean number of hot days per year varies between 15 and 30. January is the coldest month with a monthly average of 1-4°C, and the mean number of winter days (Tmax ≤ 0°C) is around 25 to 40. The average length of time without frost is between 180 to 220 days (UNFCCC - Hungary, 1994).

Water requirements in Hungary are just about covered by annual precipitation, which is around 600mm/year. The distribution of precipitation is largely governed by the distance from the Atlantic Ocean and height above sea level, increasing about 35mm per 100m altitude (Bálint ***et al.***, 2004; UNFCCC - Hungary, 2005). Areas in the south-east of the country thus belong to the semi-arid and sub-humid climatic belts (UNFCCC - Hungary, 1994). The Great Plain is the driest part with annual precipitation levels between 450 and 600mm/year and a tendency for the occurrence of droughts. The south-western parts of the country are the most humid region, with mean annual precipitation of about 800mm. With regard to the seasonal distribution, winter has less precipitation than summer (Domonkos, 2003; UNFCCC - Hungary, 2005).

4.4.1 Observations

4.4.1.1 Trends in climatic parameters

Temperature

Following the global trends, mean annual temperature in Hungary has been increasing over the course of the last century. When the time frames 1900-1949 and 1950-1989 are compared, temperature increased by only 0.2°C (Molnar and Mika, 1997). An analysis of the developments of the entire 20th century, however, shows a warming trend of 0.77°C (UNFCCC - Hungary, 2005). While winter and spring exhibit warming trends similar to the annual average, temperature increases in summer are the most pronounced (around 1°C) and those in autumn constitute the smallest (0.4-0.5 °C). Over the last few years, the number of hot days has risen and that of frost days (Tmin ≤ 0°C) decreased. Regions in the eastern and north-western parts of the country have shown the strongest warming trend (UNFCCC - Hungary, 2005).

Precipitation

A further comparison of the time periods 1900-1949 and 1950-1989 showed that annual precipitation decreased during the second period: by 10-15mm in the Hungarian Great Plain and 40-60mm in other parts of the country (Molnar and Mika, 1997). The strongest reduction was found for the autumn season, showing a decrease of 17mm for the month of October. For the summer months, no reductions were observed but rather an increase (approx. 10mm) for the month of June.

Assessments of several climate stations in Hungary for the time period 1900-1990 have detected a decrease in the annual precipitation of 9.2 mm/decade (Kertesz and Mika, 1999). Such decreasing trends during the 20th century were also confirmed by other authors (Domonkos, 2003, and references therein). An analysis of annual precipitation totals from lowland stations of the period 1901-1998 showed a mean systematic decrease of 7.7–11.0 mm/decade, with the largest reductions occurring in the west. As a consequence, mean annual precipitation at the end of the 20th century was between 15 to 20% lower than at the beginning of the century (Domonkos, 2003). This decreasing trend was observed for all seasons but was found most pronounced for the transition months of March-April and September-October. This means that in spring, precipitation sums reach only about 75% of the values occurring at the beginning of the 20th century. Decreases in autumn and winter were less pronounced, with reductions of around 12-14%. Contrary to the previous results by Molnar ***et al.*** (1997), the summer months May-August showed virtually no systematic changes (Domonkos, 2003; UNFCCC - Hungary, 2005).

When precipitation trends in the second part of the 20th century are analysed, the observed changes are slightly different. During this period, rainfall in September increased markedly. Precipitation totals of the winter 4-month period November to February, on the other hand, exhibited large reductions of around 100mm, and these decreasing trends were found significant for all stations across the country (Domonkos, 2003). These results are also corroborated by analyses of Kertesz & Mika (1999). The authors found that precipitation in the winter half-year (October-March) decreased, except in a few areas in western Hungary, during two independent periods after 1981 (1981-1990 and 1991-1995) compared to the reference period 1951-1980. The summer half-year also showed a pronounced reduction in precipitation throughout most of the country, with the south-western parts exhibiting the largest decreases of 25-30%.

As a great proportion of Hungary's winter precipitation is caused by the Mediterranean or quasi-Mediterranean cyclonic activity, such trends in decreasing winter precipitation were also observed in several other Mediterranean countries. However, these developments can not be explained by climate change alone and a large part of the observed changes in European winter climate could result from the positive phase of the North Atlantic Oscillation (NAO) Index (Domonkos, 2003), causing colder and drier winters in southern Europe (Met Office, 2006).

Temperature and precipitation extremes

When the annual cycles of climatic data of the last 100 years in Hungary are examined, the largest temperature extremes seem to occur in winter (December to March) and the largest precipitation extremes in summer (May-August) (Bartholy ***et al.***, 2004). With regard to the changes of temperature means and extremes over the course of the last century, slight positive decadal trends can be observed; however, warming at the end of the last century is almost as pronounced as during the 1941-1954 period (Bartholy ***et al.***, 2003).

The minima of large precipitation events have shown their lowest values during the years 1971-1994 (Bartholy ***et al.***, 2003). Approximately at the same time, between 1975 and the beginning of the 1990s, the frequency of summer drought events in Hungary has almost doubled and was often accompanied by the occurrence of hot spells. However, drought frequency also increased during the rest of the year, especially in the winter months when large reductions in winter precipitation were observed (Domonkos, 2003). Analyses of heavy precipitation over the course of the last century did not deliver any significant trends. During the time period 1901-1990, the 30 year averages were compared regarding the occurrence of precipitation events above the 30mm/day threshold. It was found that during 1931-1960, the frequency of such events was slightly higher than during 1901-1930 or 1961-1990 (Schirok-Kriston, 1994). Regarding developments of heavy precipitation events during the second half of the 20th century, only one month of the year showed a clear increasing trend: September. Especially since 1995, after which a few years with extremely high values occurred (Domonkos, 2003). With the frequency of summer droughts, on the one hand, and heavy precipitation events in September, on the other, increasing, Domonkos suggested that this could indicate a shift of the Hungarian summer climate towards more Mediterranean conditions, where warm and dry summers are followed by rather wet early autumns (2003).

4.4.1.2 Climatological droughts and water resources

Droughts are a common phenomenon in the Hungarian climate. However, due to their frequent occurrence in the 1980s and 1990s and the significant damage they can cause to the agricultural sector, this topic has received considerable attention in the past (Szinell ***et al.***, 1998). To assess possible changes in the occurrence and persistence of droughts in Hungary, Szinell ***et al.*** (1998) examined the Palmer Drought Severity Index (PDSI) for the period 1881-1995. They detected a significant decrease of the PDSI for the majority of meteorological stations, indicating a year-round drying tendency for most of the country. For the months of May, October and November, these drying trends were particularly pronounced. An assessment of the drought patterns showed that particularly moderate droughts tended to occur more frequently in the north and east while in the south-western parts of the country almost no changes were observed. In the Szarvas area in the Great Plain, for example, results indicated a drying trend, accompanied by more frequent moderate and severe drought events in recent years. In addition, a tendency to form dry spells during the same season in consecutive years was detected for the months of June to October. Overall, it might be interesting to note that more droughts, especially the moderate and severe ones, happened towards the end of the time series investigated (Szinell ***et al.***, 1998).

Aridification processes were also studied in more detail for the Great Plain region. The term aridification is defined by Kertesz ***et al.*** (1999) as conditions of an increasingly semi-arid character which are induced over a longer period of time by “a rise in mean annual temperature, involving a rise in potential evaporation”, and by “decreasing annual precipitation, leading to water deficit”. For the Great Plain area, where groundwater levels were observed to have fallen 2-4m between 1965 and 1995, reduced infiltration of water into the soils and decreased groundwater recharge were seen as the most serious aspects of aridification (Kertesz ***et al.***, 1999; Kertesz and Mika, 1999).

For the Tisza catchment, PDSI analyses revealed variations in soil moisture during the growing season for the period 1901-1999. Significant drying trends were observed for the month of April at three of the five stations investigated. Negative but non-significant trends, however, indicating drying tendencies over the course of the last century, were observed for all stations and months investigated (April, June, August and October). While significant wet periods occurred only in the first part of the last century (1910-1940), marked dry periods took place in the second half, confirming an overall drying trend in Eastern Hungary (Makra ***et al.***, 2005).

Instead of the PDSI, the Standardized Precipitation Index (SPI) is an alternative method to investigate changes in water supply. According to the results obtained by the SPI, drying in Hungary over the course of the last century has mainly occurred in late spring-early summer and in late autumn. As both of these periods are important for agriculture, the first for sprouting and germination, the second for repleting soil moisture levels, continued drying trends during these times of the year could have critical consequences for agricultural productivity (UNFCCC - Hungary, 2005).

4.4.2 Projections

4.4.2.1 Trends in climatic parameters

Temperature

In an attempt to assess future changes in temperature at the regional scale, the output of 16 different GCMs for the SRES scenarios A1, A2, B1, B2 (Nakicenovic ***et al.***, 2000) was combined to produce and compare climate scenarios for the years 2050 and 2100. The projected increases in temperature vary, depending on model and scenario, between 0.8 and 2.8°C for the year 2050, and 1.3 and 5.2°C for the year 2100. While the largest increases are projected by the CCSR-NIES model under the A2 scenario, the lowest changes result from use of the ECHAM1 model under the B2 scenario. Regarding the seasonal distribution, the highest rises in temperature are expected in the winter and summer months, with winter exhibiting the largest uncertainties in the projections (Bartholy ***et al.***, 2003).

Precipitation

Just like for temperature, Bartholy ***et al.*** (2003) also investigated possible future changes in precipitation patterns in their ensemble modelling study and most models point towards increases in annual precipitation amounts over the course of this century. By 2050, 13 out of 16 models project changes between -1% and +7%, and between -3% and +14% by 2100. However, it should also be noted that some models project decreases as low as 7% by 2050 and 14% by 2100. With respect to seasonal changes, precipitation is expected to increase during winter and spring, while it may decrease in summer and autumn (Bartholy ***et al.***, 2003).

To assess the sensitivity of the climatic system to increasing CO_2 concentrations, Bartholy ***et al.*** (1995; 2003) have investigated the response of precipitation patterns in two areas in the Carpathian Basin to doubled CO_2 conditions. For the Lake Balaton watershed, results of modelling studies with the ECHAM GCM point towards distinct changes. During the summer period, both the frequency and amount of precipitation on wet days is projected to show substantial reductions. In winter, however, the projected changes are slightly more variable: while the frequency of precipitation events is anticipated to decrease across the whole catchment, the daily precipitation amount could decrease in the northern part while it might increase in the south (Bartholy ***et al.***, 1995). Overall, the reduction in summer rainfall compared to the second half of the 20th century could be as large as 25-35%, whereas winter precipitation might become reduced by only 0-10% (Bartholy ***et al.***, 2003). In the Great Plain area, the precipitation frequency under doubled CO_2 conditions is also projected to decrease at all stations, and the mean precipitation amount per wet day shows again seasonal and regional differences. In the eastern parts of the Great Plain (Szeged, Debrecen), for example, daily rainfall amounts in summer are projected to decrease up to 10%, while in the western parts (Budapest, Kalocsa, Kecskemet) their magnitudes might increase up to 5%. In the winter months, the reductions in daily rainfall amounts range between 5 to 15% (Bartholy ***et al.***, 2003).

4.4.2.2 Water resources and hydrological extremes

The sensitivity of the hydrological system to future climatic changes was studied by Novaky (1991) for 37 small watersheds in Hungary. Assuming an increase in temperature of 0.5°C and a 30mm decrease in mean annual precipitation, some catchments responded with reductions in long-term annual runoff of 20-30%. At the same time though, higher temperatures would cause snowmelt to occur earlier in the season and thus cause peak discharges of winter flood waves to increase significantly, for example up to 15-30% in the Danube at the Nagymaros gauge (Gauzer and Starosolszky, 1996).

With the Great Plain constituting an area that might respond particularly sensitive to future climatic changes, global warming effects on the small and shallow Csatlói oxbow, located on the floodplain of the Tisza river, were examined with an empirical stochastic model under the B1 scenario (Hunyady ***et al.***, 2005). Over the course of this century, the frequency of extremely low water levels in this lake is projected to increase, while the monthly minimum water levels may decrease. As a result, extreme drought events may lead to a temporarily drying-up of the oxbows (Hunyady ***et al.***, 2005). Minima, averages and maxima of the lowest water levels also showed decreasing tendencies. Between 1990 and 2100, minimum values during the month of August could become reduced by 29cm, averages by 11cm and maximum values by 31cm between 1990 and 2100 (UNFCCC - Hungary, 2005, and references therein).

In the future, especially small lakes could be affected by the expected increases in evaporation. The surface area of several smaller lakes could decrease significantly, eventually leading to a drying up of a number of the lakes in the Great Hungarian Plain. Further problems resulting from a decrease in water circulation could be higher saline concentration and eutrophication levels of the lakes. Ultimately, such developments would intensify the loss of wetland habitats, with negative consequences not only for biodiversity but also the economy (UNFCCC - Hungary, 2005).

Due to the repeated occurrence of droughts in Hungary in the past, which strongly affected agriculture and forestry, research has aimed to assess if climate change was a likely explanation for these phenomena. Investigations have shown that an average temperature increase of 1.5% combined with a decrease in mean precipitation of 15% would cause a rise of the drought index by 30% (drought index not specified – see EEA, 2007). This would have significant impacts on the agricultural areas exposed to drought, especially since the ecological balance of saline pasturelands responds very sensitive to climatic changes. In addition, even a moderate rise in temperature could increase the probability of forest and bush fires significantly (EEA, 2007).

4.4.3 Summary and conclusions

Similar to the global trend, temperature in Hungary has been increasing over the course of the last century. At the same time, annual precipitation decreased, showing the largest reductions for the transition months of March-April and September-October. Analyses of the second part of the 20th century show slightly different trends, with the major reductions observed for the months of November to February (Domonkos, 2003). Changes in the PDSI during the last century have pointed towards a year-round drying trend for most of the country, with trends in May, October and November being particularly pronounced. In addition, moderate and severe droughts were found to occur more frequently towards the end of the period investigated (Szinell ***et al.***, 1998).

The regional projections for temperature increase in Hungary vary between 1.3 and 5.2°C by the year 2100. Contrasting to the previously observed drying trend, most climate scenarios project annual precipitation to increase in the future. However, analyses of the seasonal distribution show that such increases may only occur in winter and spring, while summer and autumn rainfall could still decrease (Bartholy ***et al.***, 2003). Sensitivity analyses for doubled CO_2 conditions have highlighted the effect of seasonal and regional differences. In the Great Plain, for example, accompanied by an overall decrease in precipitation frequency, daily rainfall amounts in summer are projected to decrease up to 10% in the eastern parts, while in the western parts their magnitudes might increase up to 5% (Bartholy ***et al.***, 2003). Especially the numerous oxbow lakes could be affected by these changes, and modelling results show a higher frequency of extremely low water levels in these lakes. As a result of extreme drought conditions, some of the small and shallow oxbows might even temporarily dry up. This could have serious consequences for these ecosystems, some of which are also protected under the Ramsar Convention on Wetlands. They fulfil important ecological functions such as providing spawning, rearing, feeding and resting grounds for aquatic organisms or maintaining biodiversity by acting as aquatic species "banks". Recurring dry periods in recent years have already highlighted the potential impacts of a changing climate on these important habitats, causing eutrophication and a reduction of their size (Ramsar Convention Secretariat, 2006).

In addition to theses wetland areas, agriculture and forestry in Hungary also suffer under the recurrent drought conditions. This could become even more critical in the future if the drying trends persist during the growing season in summer, as is projected for Lake Balaton and some regions in the Great Plain under doubled CO_2 conditions (Bartholy ***et al.***, 1995; Bartholy ***et al.***, 2003). To prepare for such developments, the Hungarian government has already initiated several research campaigns to investigate the impacts of climate change on agriculture, forestry and water resources and to improve the understanding of drought occurrence. Joining of the United Nations Convention to Combat Desertification and Drought (UNCCD) has put further pressure on the country to develop suitable measures to minimise the damages of droughts in the future. The latest aim is to establish in cooperation with several ministries, the Hungarian Academy of Sciences and other institutions a National Drought Commission, representing all organisations concerned with drought mitigation (UNFCCC - Hungary, 2002). If Hungary's plan of drawing up a National Drought Mitigation Strategy is realised soon, the country should be in a stronger position to prepare for some of the future challenges of climate change.

4.5 Case study 5: South-western Europe: Spain

Throughout most of Europe, Spain is mainly famous for its sun-drenched coastline and sandy beaches. But this perception overlooks the large climatic and geographic variability that is prevalent in this southern European country. Located between two large water and land masses, the Mediterranean and the Atlantic, Africa and Europe, the Spanish Peninsula combines the influences of three different climatic types, i.e. oceanic, continental and Mediterranean. Featuring in addition a complex orography, these diverse natural realities combine to give a variable climate that is characterised by large temporal and spatial differences in temperature and precipitation patterns (UNFCCC - Spain, 2001).

In the north, the climate is described as temperate. The Mediterranean regions and inland Andalusia (see Figure 20) are characterised by dry summers and mild winters and in the central areas of the peninsula, the climate is more continental, exhibiting dry summers and cold winters. Very mild winters followed by very hot summers are typical for the Canary Islands and the coastal areas of Murcia and Almeria, which experience a dry climate with very little rainfall (UNFCCC - Spain, 2001).

As indicated above, spatial differences of annual mean temperatures can be immense and sometimes exceed 18°C on mainland Spain. In mountain regions, such as the Pyrenees in the north or the Sierra Nevada in the south, annual means can be below 2°C, while the plateaus exhibit temperatures between 10-14°C. In coastal areas in the southern Mediterranean, the Balearic Islands and the south Atlantic, annual averages are even higher and vary between 16 and 20°C (Moreno ***et al.***, 2005).

Mean annual precipitation sums show large regional differences and range from 150mm in the southeast to over 2500mm in the mountainous regions in the north. Seasonal rainfall patterns are also quite pronounced, and winter and spring exhibit the highest precipitation frequency. Summer, in contrast, has the lowest number of days with rainfall. Overall, the following spatial and temporal rainfall patterns can be established for peninsular Spain: 1) the higher the altitude, the higher the frequency of rainfall in summer; and 2) the mean annual number of rainfall days decreases from north to south and from west to east (Moreno ***et al.***, 2005).

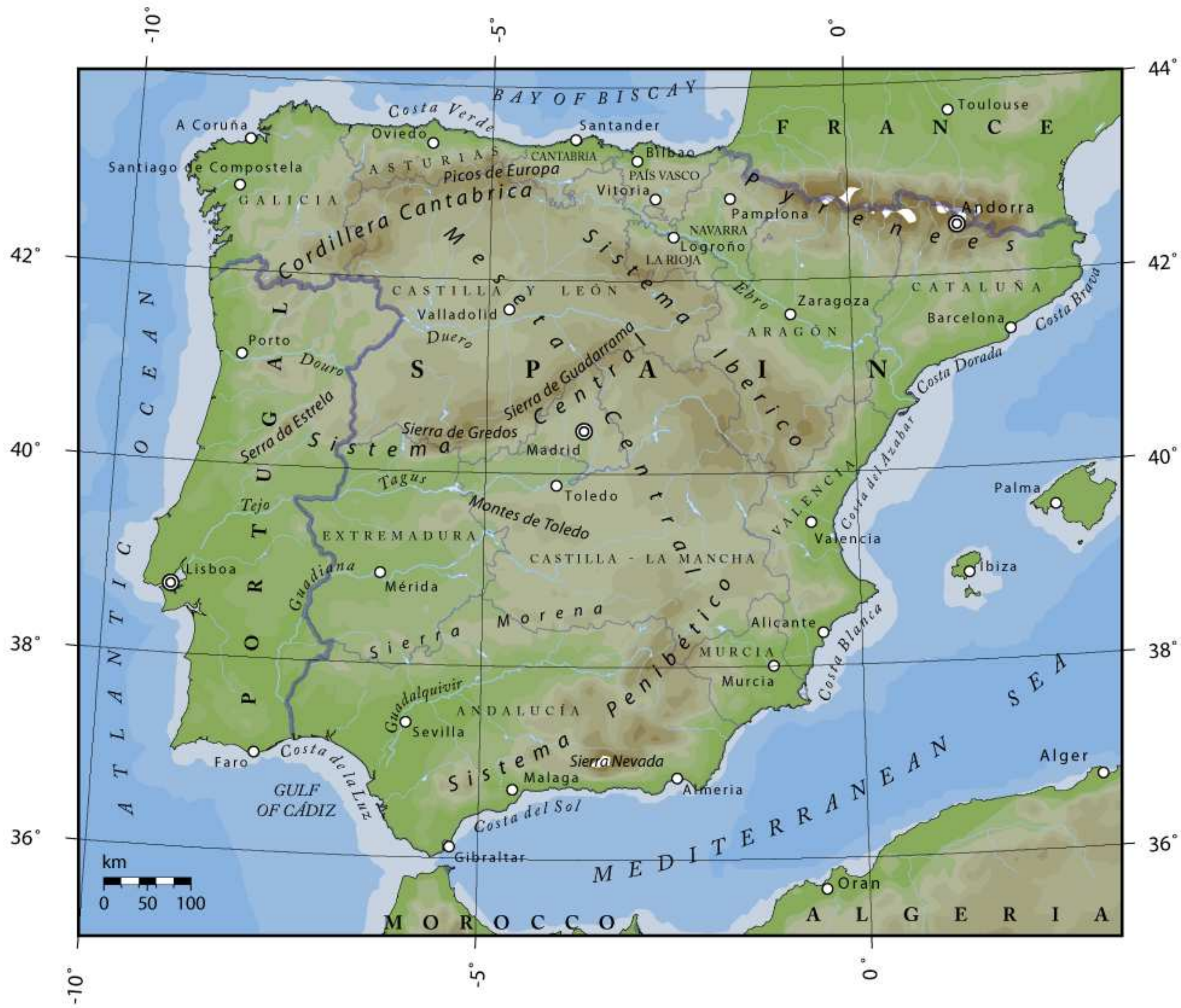


Figure 20 Map of the Iberian Peninsula showing mainland Spain and Balearic Islands (Source: http://upload.wikimedia.org/wikipedia/commons/5/58/Spain.png).

In addition to the high spatial and temporal variability, interannual climatic variability in Spain is also high. This is mainly due to atmospheric circulation patterns in the Northern hemisphere, such as the North Atlantic Oscillation (NAO) (Moreno ***et al.***, 2005), which have a large influence on winter temperatures and precipitation patterns in Europe (Met Office, 2006). Central and southern Spain is largely influenced by the Atlantic and the NAO. In coastal regions in the north and west, the impact of the NAO diminishes and along the south-eastern Mediterranean coast, Mediterranean influences dominate (Goodess and P.D., 2002).

Drought periods, whose occurrence is not only associated with dry summer periods, constitute a serious problem, particularly in southern Spain. In the years 1951-1990, dry periods of the 0.1mm/day threshold have lasted over 4 months in Andalusia, Extremadura and Castilla la Mancha, and extended to over 5 months in Malaga, Almeria and Huelva (Moreno ***et al.***, 2005). Irrigation is the largest user of water resources at present (EEA, 2000) and can account for more than 60% of overall water use (EEA, 2005f). With a water withdrawal ratio greater than 20%, Spain is already being considered as water stressed (EEA, 2003), although there are large regional differences with regard to water availability between the north and south of the country (EEA, 2005f). With aridity being one of the expected impacts of climate change, the current problems of groundwater over-abstractions, desertification and salinisation could intensify in the future.

4.5.1 Observations

4.5.1.1 Trends in climatic parameters

Temperature

Results of the European Climate Assessment (ECA) have shown that mean annual temperatures in Spain – like in most European countries – have been increasing at a rate of 0.3°C per decade during the period 1976-1999. This is in contrast to the previous period 1946-1975, during which a cooling trend has been observed at most Spanish meteorological stations (Klein Tank ***et al.***, 2002).

The annual number of cold (10^{th} percentile) and frost (<0°C) days has been decreasing during the period 1946-1999 in the Spanish Peninsula, while that of summer (>25°C) and warm (90^{th} percentile) days has been increasing. Changes in the occurrence of cold and warm days were particularly pronounced (Klein Tank ***et al.***, 2002). Overall, however, the warming trend has been mainly detected in winter (Moreno ***et al.***, 2005).

Precipitation

With few exceptions, annual precipitation amount has not been showing any significant trends in Spain and Catalonia including the Penedes-Anoia region during the course of the last century (Klein Tank ***et al.***, 2002; Martinez ***et al.***, in press; Ramos and Martinez-Casanovas, 2006). For the annual number of wet days, contrasting results have been obtained. Some authors did not find a significant trend over the course of the last century across Spain (Klein Tank ***et al.***, 2002); others have detected several significant negative local trends for all precipitation classes, especially the highest ones, in Catalonia (Martinez ***et al.***, in press). Although this latter finding is theoretically of particular importance, as the number of very wet days contributes substantially to annual rainfall amounts and hence recharge of soil and groundwater, other studies could not confirm this observation for this region (Lana ***et al.***, 2003). However, when the trends in number of wet days are analysed at the seasonal level, significant differences can be identified. In the Penedes-Anoia region in Catalonia, positive trends of the number of wet days in winter and summer were found, whilst negative trends were observed for autumn and spring (Ramos and Martinez-Casanovas, 2006).

In contrast to the secular trends over the course of the last century, annual rainfall during the second half of the 20^{th} century has shown a decreasing tendency, particularly in the south and interior of the Iberian Peninsula, in the coastal Mediterranean region and in the Canary Isles (Esteban-Parra ***et al.***, 1998; Garcia-Herrera ***et al.***, 2003; Millan ***et al.***, 2005; Moreno ***et al.***, 2005 and references therein). Romero ***et al.*** (1998) have confirmed such a drying trend especially in central and western Andalucia and western Catalonia since the mid 1980s. For some ***coastal*** regions in the north (Esteban-Parra ***et al.***, 1998) and in the Valencia region (Millan ***et al.***, 2005) increases in precipitation have been observed. Most authors agree that these changes were partially caused by variations in the large scale circulation patterns over Western Europe and the North Atlantic (Esteban-Parra ***et al.***, 1998; Millan ***et al.***, 2005; Moreno ***et al.***, 2005).

A study of the Mediterranean coastal region for the time period 1964-1993 has shown that seasonality in southern and north-eastern areas was increasing, resulting in higher precipitation amounts in Andalucia and Catalonia in autumn (Sumner ***et al.***, 2001). In the Valencia region, autumn rainfall was found to decrease during a similar time period, while winter rainfall in coastal areas was also increasing, highlighting the strong effects of local factors on seasonal rainfall trends (Gonzalez Hidalgo ***et al.***, 2001).

Overall, no clear trend with regard to interannual variability of precipitation could be confirmed, although there appears to be a tendency towards an increasing trend during the second part of the 20th century (Gonzalez Hidalgo ***et al.***, 2001; Moreno ***et al.***, 2005 and references therein).

4.5.1.2 Temperature and precipitation extremes

When assessing changes in climatic parameters, special focus is always given to the development of temperature and precipitation extremes, since small changes of the mean can be accompanied by relatively large changes in the extremes. For example, an analysis of the seasonal precipitation record (1821-2000) of the San Fernando area in south-western Spain has revealed, that the relationship between changes in the mean and standard deviation, and the probability of extreme events was non-linear (Rodrigo, 2002). The assumption that a warmer climate with higher evaporation rates could lead to large changes in the occurrence of extreme precipitation events thus seems justified. For Spain, however, studies have so far not been able to provide unambiguous evidence to support this hypothesis and instead often show opposing trends.

In Barcelona in Catalonia and in the coastal areas of Valencia, more high precipitation events were found to occur during the second half of the 20th century (Burgueno ***et al.***, 2004; Millan ***et al.***, 2005). In the Penedes-Anoia region in Catalonia, the increased intensity of winter, summer and autumn rainfall events during the period 1923-2002 meant that extreme events have contributed a larger fraction to annual total rainfall amounts (Ramos and Martinez-Casanovas, 2006). The same trend was identified for the Valencia region during the second half of the 20th century, where extreme events have been increasing their contribution to annual rainfall, despite the fact that annual rainfall was decreasing (Gonzalez Hidalgo ***et al.***, 2003). During the same time frame, the frequency and magnitude of the most intense events has been decreasing in the Canary Isles (Garcia-Herrera ***et al.***, 2003), and two stations in mainland Spain, Madrid and Tortosa, have shown that the contribution of very wet days to the annual precipitation amount had been decreasing significantly (Klein Tank ***et al.***, 2002). This trend for less days with intensive rainfall has been confirmed for most areas of the Iberian peninsula, mainly for the autumn and winter seasons, except the south-eastern part where a tendency towards more-intensive rain days was observed (Goodess and P.D., 2002).

As can be seen, it is currently difficult to identify general trends across the whole area of Spain, as even neighbouring meteorological stations have repeatedly displayed large differences. Trends appear therefore quite site specific. However, the probability that increases in extreme precipitation events would negatively impact on water availability is high. Increased runoff would lower water supply for crops and accelerate erosion processes (Ramos and Martinez-Casanovas, 2006). Even more problematic is the development, that the higher number of extreme rainfall events is becoming separated by longer dry periods, as for example in the Penedes-Anoia region (Ramos and Martinez-Casanovas, 2006). This is in line with observations showing that in general extreme events of both kinds, i.e. very little (0-4 mm/day) and intense (64 mm/day) precipitation, increased significantly in Spain in the second half of the 20th century (Alpert ***et al.***, 2002).

And prolonged dry periods could ultimately be one of the main problems that Spain is facing in the coming decades. Between 1951 and 2000, the trend of drought in the Valencia region, expressed by evolution of the Standardised Precipitation Index (Guttman 1999), was found to increase significantly in the mid to northern areas, while the developments in the rest of the region were more varied (Vicente-Serrano et al., 2004). In Catalonia, Serra et al. (2006) found that the annual and seasonal (winter) number of dry spells was showing a significant decrease for the 5 and 10mm/day thresholds, probably due to changes in the cyclonic tracks over the eastern Atlantic and Western Europe. On the other hand, the mean length of dry spells with a threshold level of 0.1mm/day was found to increase in both the summer and winter half-year seasons. Such developments seem to link with observations indicating that the risk of wildfires in coastal eastern Spain has been increasing between 1941 and 1994, both due to higher mean daily temperatures and decreases in the minima of daily relative humidity (Pinol et al., 1998). However, as Vicente-Serrano et al. (2004) pointed out, the development of droughts appears highly dependent on local factors and shows “extreme spatial variability”. Great care should thus be taken, when outputs of global climate models are used to infer drought developments in the Mediterranean.

4.5.1.3 Water resources

Throughout most of Spain, water resources are usually replenished during the coldest months of the year, as these provide the highest precipitation levels combined with the lowest temperatures and thus evaporation rates. During the summer months, most water in the ground is taken up by plants and no significant recharge or runoff takes place (Moreno ***et al.***, 2005). One of the main problems is the great demand for water during periods when resources are lowest, and agriculture in particular contributes to this problem: of the 110.000 hm^3 (cubic hectometres) annual discharge over Spain, agricultural use requires about 24.000 hm^3 during the summer months despite the fact that Spanish rivers only discharge about 10.000 hm^3 during this season (Moreno ***et al.***, 2005). Excess irrigation in combination with high demands by tourism can cause over-abstraction of groundwater supplies. This can lead to saltwater intrusions in coastal freshwater aquifers and several areas in Spain are already affected (EEA, 2003).

In southern and central Spain, mean annual river runoff is estimated around 25mm per km (EEA, 2003) and studies have shown that discharges in several main rivers have been decreasing during the second half (e.g. Ebro, Tagus) and over the course (e.g. Jucar and Guadalquivir) of the 20th century (EEA, 2004; Moreno ***et al.***, 2005 and references therein). In north-eastern Spain, annual potential evapotranspiration during the period 1941-1990 was estimated to have increased 13mm/decade, corresponding to the increases in temperature of 0.1°C/decade. With no significant changes in annual rainfall observed for this region, annual water deficits have therefore intensified (Pinol ***et al.***, 1998).

4.5.2 Projections

4.5.2.1 Trends in climatic parameters

The ECCE Project has been carried out to assess the possible impacts of climate change in Spain. For this purpose, several modelling experiments with a range of global models (HadCM3, CCGM, CSIRO, NIES2, ECHAM4 and GFDL) and a regional climate model (PROMES) were performed (Moreno ***et al.***, 2005). Using the IPCC SRES scenarios A2 and B2 (Nakicenovic ***et al.***, 2000) several time frames (2010-2040, 2040-2070 and 2070-2100) were investigated. Here, mainly the results of the regional climate model (RCM) will be presented as this case study aims to focus on the potential changes at the regional scale. However, future trends provided by the global circulation models (GCMs) will also be introduced briefly.

Temperature

Projections obtained by both the GCMs and the RCM show temperatures to increase over the course of this century. Overall, the warming trend in summer is more pronounced than in winter, and more intense in inland areas than in coastal zones. Average results of the six GCMs project temperatures to increase by between 1.8-2°C every 30 years in the summer months (JJA) and between 1.1-1.2°C in the winter months (DJF), with the higher values corresponding to results of the A2 scenario (Moreno ***et al.***, 2005).

Simulations with the regional model PROMES were only performed for the time frame 2070-2100. By that time, temperatures inland of the Spanish peninsula are projected to increase up to 5-7°C in summer and 3-4°C in winter, with the B2 scenario providing the lower range of values. With regard to the spatial distribution, coastal areas, the Balearic and the Canary Isles are anticipated to experience lower temperature increases than inland regions. In these areas, summer and winter temperatures are projected to remain around 2°C lower, in the Canary Isles in summer even 3°C.

Precipitation

As expected, the uniform trend of an overall increase in temperature is not repeated regarding projections of future precipitation changes. Large differences between the GCMs exist for the centre of Spain, although almost all point towards reductions in seasonal rainfall, most prominent in spring (MAM) and summer, compared to the baseline period 1960-1990. For the scenario A2, this decrease is also becoming progressively more pronounced throughout the century.

With PROMES, future possible changes can be assessed in more detail. For the winter months, both scenarios show slight increases in the northwest (15-45mm) and decreases in the southwest (15-45mm) in mainland Spain. Similar trends, but with increases in the north-eastern instead of north-western region, are anticipated for the autumn season (SON). In spring and summer, precipitation across the Spanish peninsula is decreasing, with pronounced reductions in the northern coastal and mountainous regions during the summer season (45-180mm). Overall, changes projected under the A2 scenario have a greater magnitude than under the B2 scenario. For the Canary Isles, changes in total precipitation are insignificant for all seasons (Moreno ***et al.***, 2005).

A further study with downscaled results of the ECHAM4 GCM under the scenario A (IPCC, 1992) was able to resolve even more detailed changes for the 2080s in Mediterranean Spain (Sumner ***et al.***, 2003). Contrasting to expectations, some regions in this area are even projected to experience increased annual precipitation totals (up to 14%), such as Almeria, Murcia and Valencia. Coinciding with results of the PROMES study though are projections regarding the anticipated decreases in precipitation totals (6 to 14%) in Andalucia or the mountainous parts of Catalonia.

These developments could have serious impacts on agricultural production and modelling studies have shown that wheat yields in the southern parts of the country could be seriously affected by climatic changes (Iglesias ***et al.***, 2000). Assuming an increase in CO_2 equivalents of 1% per year up to the 2050s, results of the global models HadCM2 and CCCM indicated that water-limited yields in these regions could experience reductions of up to 30%. It is worth adding though, that crop yields in the northern and western regions were found to be positively affected by the assumed climate change scenarios.

4.5.2.2 Temperature and precipitation extremes

With regard to temperature extremes, calculated as the 90th percentile $T_{max}90$, the PROMES model projects the largest increases to occur in summer and spring in the inland regions, reaching temperatures up to 7°C higher in the 2080s compared to the baseline period 1961-1990. In winter, the projected maxima stay lower with values below 5°C (Moreno ***et al.***, 2005). These projections are in line with the anticipated developments across Europe, where the occurrence of summer heat waves might become a more frequent phenomenon in the future (Beniston, 2004; Schär ***et al.***, 2004). The frequency of extreme cold days on the other hand is projected to decrease (Moreno ***et al.***, 2005).

For the northern areas of Spain, reductions in precipitation totals in the 2080s could be accompanied by decreases in the number of intense precipitation events. Modelling experiments with the regional model HadRM3H and the A2 and B2 scenarios have projected the number of rainfall days with precipitation ≥ 10mm and 20mm to decrease markedly, although uncertainties in these predictions are reasonably high with around ± 50% for the B2 scenario. In addition to this reduced rainfall intensity in the north of the country, the southern Iberian peninsula is anticipated to experience prolonged drought periods (Holt and Palutikof, 2004).

Due to an intensification of the positive NAO index, hydrological variability could be increasing in the future. Despite the fact that this might reduce the frequency of flood occurrence, the intensity of floods might still rise. Especially in inland basins and basins in the Mediterranean, this greater variability in precipitation patterns might lead to a greater variability in the occurrence of floods and flash floods (Moreno ***et al.***, 2005).

4.5.2.3 Water resources

Results of the modelling studies with PROMES have revealed that, due to lower water supply, actual evapotranspiration under both scenarios will be showing pronounced decreases in summer and autumn by the end of the century. The largest decreases are occurring during summer in the southern half of the Spanish mainland, with values in the A2 scenario of up to 60% and below 40% in autumn. In the B2 scenario, the decreases are more moderate, with approximately 40% and 20% in summer and autumn, respectively. Both scenarios show slight evapotranspiration increases in the northern part during these seasons. Trends in spring are again similar for both scenarios, with slight reductions in the south and increases in the north. During winter, the whole of the mainland will be experiencing around 20% higher surface evapotranspiration, reaching even 40% in some areas. For the Balearic and Canary Isles, no significant changes are observed (Moreno ***et al.***, 2005).

According to the results of the GCMs, summer rainfall levels in Spain could be decreasing by up to 40mm. Considering the fact that the summer months are usually not contributing to the recharge of water resources, increasing temperatures or decreases in rainfall during this season might thus not induce a pronounced effect. Important in this context though is the possibly higher water deficit due to increased irrigation rates – this will have to be counterbalanced in seasons when water generation is actually taking place (Moreno ***et al.***, 2005).

In order to assess the impacts of a changing climate on water resources, the ECCE project (Moreno ***et al.***, 2005) has aggregated the results of previous studies by the Spanish Environment Ministry (MIMAM, 2000). For the 2030s, two possible development paths are shown, 1) a temperature increase of 1°C and 2) a temperature increase of 1°C combined with a reduction in mean annual precipitation of 5%. For the 2060s, a scenario with a temperature increase of 2.5°C combined with an 8% decrease in mean annual rainfall is described.

Results from the analysis by MIMAM using a regional distributed model show that water resources in the catchments of the Guadiana, Canarias Segura, Jucar, Guadalquivir, Sur and Baleares would be most seriously affected. According to the climate scenarios 1 and 2 for the 2030s, mean reductions in total water yields in these rivers could be between 4-14%. For the 2060s, the projected reduction in water resources could reach 17% in mainland Spain, accompanied by an increased interannual variability (Moreno ***et al.***, 2005). In a country which is highly dependent on hydropower for its energy generation, such reductions in river discharge could become very problematic.

Furthermore, reduced water levels will also affect water quality. To investigate the impacts of climate change on streamwater chemistry, Avila ***et al.*** (1996) have studied a small catchment in the Montseny mountains in Catalonia. They found that the assumed increase in temperature (+4°C) and reduction in precipitation (-10%) could have a marked effect with the concentrations of calcium and alkalinity shown to increase sharply.

4.5.2.4 Changes in sea level

Spain has a coastline of about 9000km and a third of this length is covered by beaches. Sea level rise will threaten the existence of this important tourist attraction and thus impact on the country's most important industry. At present, a large number of beaches is already retreating due to the impacts of erosion and a popular strategy to counteract these losses is the artificial addition of sand (UNFCCC - Spain, 2001).

For each centimetre of sea level rise, about $3m^3$ sand are required for a linear meter of beach to be maintained. At present, there is no general agreement on the scale of future sea level rise but a value of 0.09 to 0.88 m until 2100 is being discussed (Church ***et al.***, 2001). This gives a central value of 0.48 m and equates to a rate of approximately 5mm/year until the end of the century. A sea level rise of this rate would thus require sand additions of $1.5m^3$/year/m, adding up to 4.5 million m^3 of sand to maintain the 3000km beaches. It is needless to point out that such strategies could not be continued for all beaches ***ad infinitum***, and other options, adjusted for the prevailing situation at each site, have to be considered. For example, the artificial maintenance of a beach would only represent a suitable measure, if the area of interest was adjacent to high and stable land. Should this not be the case, the beach could collapse and flood the land behind it, with potentially damaging consequences (UNFCCC - Spain, 2001). Another problem is that of confined beaches as they lack the capacity to migrate further inland. Losses of important beach areas, especially along the Cantabrian coast, are anticipated as a consequence (Moreno ***et al.***, 2005).

However, in addition to loss the of beach areas, other economically important sites could be affected. In the Ebro and Llobregat deltas, the Manga del Mar Menor and the Doñana coast, the flooding of coastal lowlands could occur (Moreno ***et al.***, 2005). Then there are the more indirect effects of sea level rise, such as the proceeding salinisation of coastal aquifers or estuaries with potentially serious consequences for ecosystems and local residents. Here, urbanised and agriculturally important areas such as Valencia and Castellon could be particularly affected (UNFCCC - Spain, 2001).

To prepare for the impacts of sea level rise, the Spanish Environment Ministry has initiated the development of the so called "Model for aiding coastal management" which includes the "Flooding Atlas of the Coastline". With these, flooding levels for the coastline of the Spanish mainland can be estimated which helps to assess the potential impacts of further sea level rise.

4.5.3 Summary and conclusions

Mean annual temperature in Spain has been rising at a rate of 0.3°C per decade since the mid-seventies, with the warming trend being most pronounced in winter (Moreno ***et al.***, 2005). During the second half of the last century, precipitation in the south of the Iberian Peninsula, coastal Mediterranean regions and in the Canary Isles has been decreasing (Esteban-Parra ***et al.***, 1998; Garcia-Herrera ***et al.***, 2003; Millan ***et al.***, 2005; Moreno ***et al.***, 2005 and references therein; Romero ***et al.***, 1998) while some coastal regions in the north (Esteban-Parra ***et al.***, 1998) and in the Valencia region (Millan ***et al.***, 2005) have experienced increased rainfall. At the same time, very small and very intense precipitation events were both found to have increased significantly across Spain (Alpert ***et al.***, 2002). With regard to dry spells and droughts, studies seem to point towards an increase in their frequency, duration and intensity (Serra ***et al.***, 2006; Vicente-Serrano ***et al.***, 2004). The changes in precipitation patterns have already shown their impacts on water resources and discharges in several main rivers have been decreasing during the second half (e.g. Ebro, Tagus) and over the course (e.g. Jucar and Guadalquivir) of the 20th century (EEA, 2004; Moreno ***et al.***, 2005 and references therein).

In the future, the warming trend in summer is projected to be more pronounced than in winter and more intense in the inland regions than in coastal zones. By the end of the century, the central and southern regions could experience precipitation reductions in autumn and winter, while the northern areas could see increases in precipitation. For spring and summer, rainfall is anticipated to decrease all over Spain, especially in the northern and inland areas. Already by the 2030s, water resources in several main rivers basins (Guadiana, Canarias Segura, Jucar, Guadalquivir, Sur and Baleares) could become seriously affected and show reductions between 4-14% (Moreno ***et al.***, 2005). With irrigation water amounts projected to increase for all regions, these developments could have serious consequences for agricultural production (Iglesias ***et al.***, 2000).

Overall it can be said, that when assessing the future impacts of climate change in Spain, particular attention must be paid to the regional differences. In Catalonia, for example, projections regarding future precipitation patterns can show large variations, depending on whether coastal or more inland regions are described. Furthermore, the impacts of altered precipitation patterns on water resources have to be studied in more detail and Moreno ***et al.*** (2005) have highlighted the importance of further model development to improve the understanding of resource generation and to support adequate catchment management. Especially groundwater represents an important natural resource in Spain and agriculture is largely dependent on it. However, reduced water resources availability will not only affect agriculture but a whole range of other important sectors such as energy, human health and tourism. In addition to the thorough investigation of past temperature and precipitation trends, the focus should now be directed towards a more detailed assessment of the future impacts of climate change on water.

4.6 Case Study 6: South-eastern Europe: Greece

The Greek landscape, with its nearly 3000 islands and a coastline of more than 18.000km length (EEA, 2006), is strongly influenced by the sea. Around 25% of the country, mainly the coastal plains, is lowland and only a small region in the northwest is further than 80km away from the sea. At the same time, Greece is one of the most mountainous countries in Europe. About two thirds of its land mass is covered by mountains (see Figure 21), with the highest, the Pindus range, being located in the country's centre (UNFCCC - Greece, 2006).

Greece has a Mediterranean climate, with the southern regions experiencing generally higher temperatures than the north. Greek summers are hot and dry with a mean temperature of 28°C in Athens and the southern parts of the country. The winters in the southern lowlands and the islands are mild and wet, while being cold with strong snowfall in the mountainous regions in central and northern Greece. The average winter temperature in Athens and the south is around 11°C (UNFCCC - Greece, 2006).

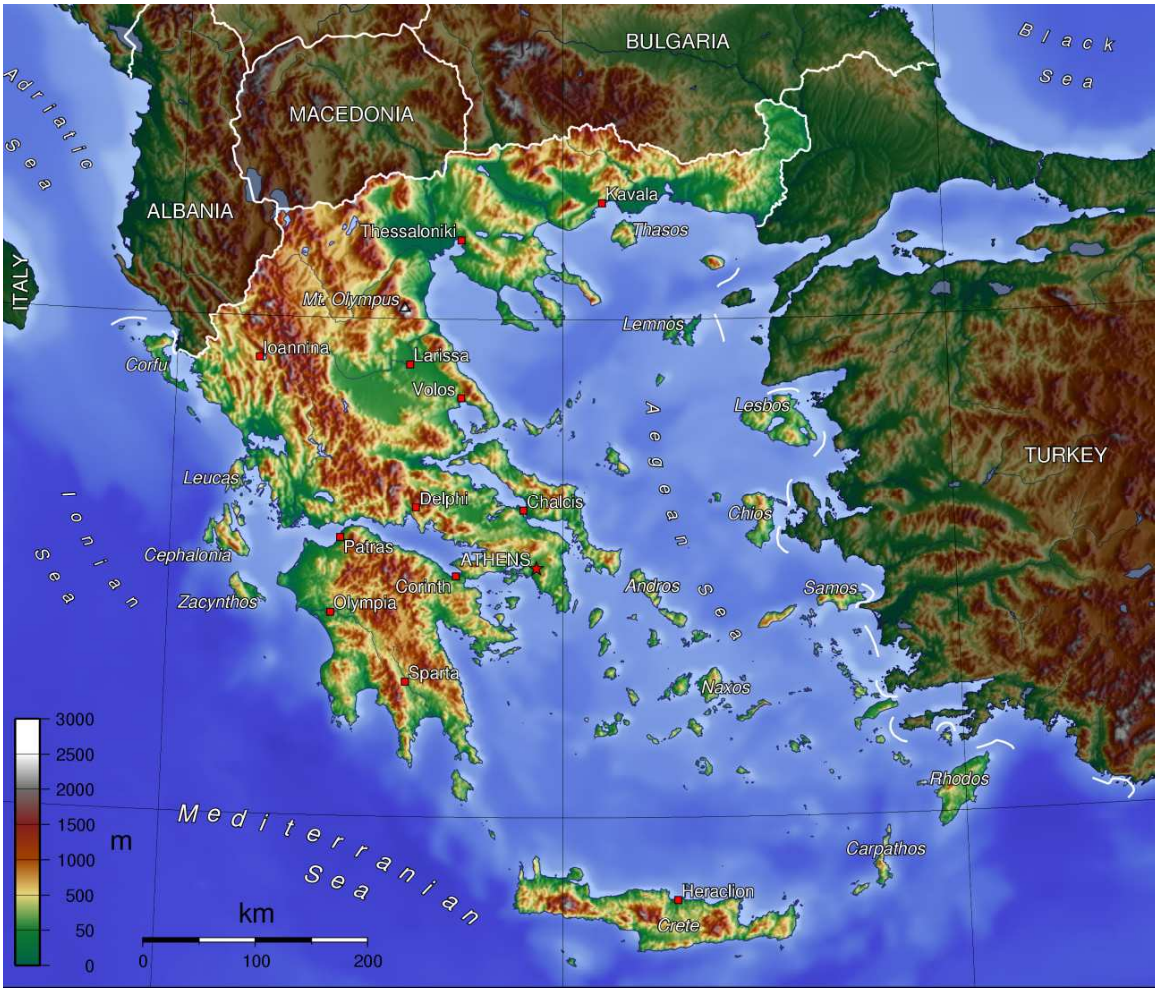


Figure 21 Map of Greece (Source: http://www.answers.com/topic/greece-topo-jpg).

Mean annual precipitation in Greece is around 850mm, showing large regional and seasonal differences. Western Greece has high rainfall levels of up to 1200mm/year while the eastern parts, the islands of the Aegean and Crete receive considerably smaller amounts of 400-600mm/year (Mimikou, 2005). Precipitation occurs mainly during the winter season between October and March, while rainfall during the summer months June-August is rare (UNFCCC - Greece, 2006). Using the UNESCO's aridity indicator (UNEP, 1992), defined as the ratio of mean annual precipitation to potential evapotranspiration, the strong regional differences become again apparent. The south-eastern parts of Greece and the islands of the Aegean have an aridity index of 0.2-0.5 which is characteristic for semi-arid regions, the western parts of > 0.75 which signifies humid zones (Mimikou, 2005). Consequently, the north-western parts experience the shortest dry spell periods in Greece and the Central Aegean Sea exhibits the highest frequency of dry spells. Due to the prevalence of large scale circulation patterns in summer in southern Greece, drought periods with very long dry spells, lasting between 30 days up to 6 months, remain a recurring phenomenon (Anagnostopoulou et al., 2003).

With its long coastlines and low rainfall levels, this south-eastern European country could be particularly vulnerable to the impacts of climate change. Up to 60% of Greece's coastal zone (0-10km) is taken up by industrial and commercial sites (EEA, 2006), which means that rising sea levels could have large economic consequences. Furthermore, about 9% of total electricity generation results from the use of hydropower (Lehner et al., 2001). As electricity production is largely dependent on water availability in the reservoirs and may be affected by weather conditions (EEA, 2005g), climate change has the potential to threaten the secure supply of this renewable energy source. Another important sector that is largely dependent on water availability is of course agriculture. In Greece, the agricultural sector represents the most important water consumer and water demand for irrigation has doubled over the past twenty years. As water shortages in arid and semi-arid regions can severely impact on crop yield, irrigation is vitally important for agricultural productivity and accounts for over 80% of total water abstractions. It should be noted though that while Greece increased its water exploitation index as a result of increases in total water abstraction between 1990 and 2002, abstraction for agricultural use alone was reduced by 2.5%. It is anticipated that this trend may be continued over the next years (EEA, 2005g).

4.6.1 Observations

4.6.1.1 Trends in climatic parameters

Temperature

Temperature developments in Greece over the course of the last century do not follow the annual and seasonal warming trends observed in the Northern Hemisphere. While summers exhibited a warming trend, the winter season has shown a distinct cooling trend during the period 1955-2001. With both not being statistically significant, the overall annual changes have remained close to zero (Feidas et al., 2004; Xoplaki et al., 2003). It is only by the end of the century, during the period 1980-2001, that mean annual, summer and winter temperature finally began to increase and the period 1991-

2000 exhibited already higher mean temperatures than the years 1981-1990. Still, this warming trend was not confined to the end of the last century alone as the years 1910-1920 had also shown distinctly higher temperatures (UNFCCC - Greece, 2006).

Due to the pronounced regional and seasonal differences over the course of the last century, no overall trend for Greece can be identified. In Athens, for example, temperatures between 1900 and 2000 have shown no significant trend, while in Thessaloniki a negative trend has prevailed. During the years 1990-2000, however, temperatures increased in both Athens and Thessaloniki by 0.7°C and 1°C, respectively (UNFCCC - Greece, 2006). It should be noted that these significant warming trends are mainly due to the very high temperatures occurring between 1998 and 2001 rather than resulting from a regular long term positive trend (Feidas et al., 2004).

Precipitation

Analyses of temperature and precipitation changes of the past decades could not detect a significant correlation between changes in the two climatic parameters. While temperature began to increase in the 1980s, mean annual precipitation had already started to decrease since the 1950s and reached significant reductions of 20-30% by the end of the century (Ganoulis et al., 1999). Still, since the mid 1980s, the dry period seems to have become more pronounced throughout most of the country. Overall, these drying trends were mainly caused by decreases in the magnitude of winter precipitation rather than a reduction in the number of rainy days (UNFCCC - Greece, 2006). In addition, the duration of the rainy season has shortened over most of the Greek peninsula, as a result of decreasing rainfall in October and April (Pnevmatikos and Katsoulis, 2006). Summer rainfall, on the other hand, remained at low average values (Ganoulis et al., 1999). Although it is far too early to announce a reversal of this trend, it should be noted that during the last few years, several meteorological stations in Greece have begun to observe increasing precipitation levels (UNFCCC - Greece, 2006).

The drying trend described above occurred particularly pronounced in the islands. In Corfu in the Ionian Sea, for example, mean annual precipitation decreased by 64mm/decade during the second half of the 20th century. And the island of Samos in the Aegean Sea experienced a decline of 100mm/decade. Here, the record low of the year 2000 reached with 400mm approximately only two-thirds of the lowest mean annual precipitation between 1931 and 1999. These observations coincide with the work of other authors, indicating a reduction in precipitation over the course of the last century in this region (Körner et al., 2005 and references therein).

Temperature and precipitation extremes

The occurrence of heat waves has shown distinct changes in recent years as their frequency was found to have tripled during the 1990s compared to the three previous decades. However, changes in their duration exhibited pronounced regional differences. While some areas such as Athens and Corfu have seen the duration of heat waves to extend, others, such as Larissa (see Figure 21) and Methoni, have experienced no or negative trends (UNFCCC - Greece, 2006). Especially the months of

August and September have contributed more to temperature extremes during the period 1950-1999 than June and July (Xoplaki et al., 2003). The occurrence of cold waves, on the other hand, was found to have decreased in Athens and Corfu over the course of the last century, both during winter and on an annual basis (UNFCCC - Greece, 2006).

Extreme precipitation events have also shown significant changes during the 20th century, particularly on the seasonal scale. The average daily intensity of summer rainfall has exhibited a positive trend for most of the country, while the intensity of winter and annual precipitation has shown negative trends. Only Athens has experienced an increase in the magnitude of annual precipitation, mainly due to the clustered occurrence of heavy precipitation events during the period 2000-2003 (UNFCCC - Greece, 2006). An analysis of dry spell occurrence has also revealed an increasing trend at some locations, both during winter and on an annual basis. Despite the previously mentioned rise in intense precipitation events in the area of Athens, this region and Methoni have also experienced an increasing trend in the duration of droughts during summer (UNFCCC - Greece, 2006).

4.6.1.2 Water resources and hydrological extremes

The distribution of water resources in Greece is rather uneven, following that of the regional precipitation patterns. Total discharge in the western parts is around 680mm/year while the eastern regions of the country have levels as low as 100mm/year. Water shortages in the latter area are thus a common occurrence, sometimes even described as “endemic”, and vary according to the changes in weather conditions (Mimikou, 2005). Especially the islands of the Aegean and Crete are affected by this situation. What intensifies the problem even further is that most of the main water users in Greece are located in the eastern and southern parts of the country. A combination of very high water consumption and water losses thus creates “almost permanent conditions of water scarcity” in these regions (Mimikou, 2005).

Despite a situation where water shortages are a regular phenomenon, hydrological extremes with regards to flooding are equally occurring. In Greece, floods appear to be caused by high-intensity and long-duration winter storms whose frequency and magnitudes are determined by the North Atlantic Oscillation (NAO). During the last 150 years, flooding events have mainly occurred when the NAO was going through a negative phase (Maas and Macklin, 2002), which causes southern Europe to become warmer and wetter than average (Met Office, 2006). During the second half of the 20th century, however, the NAO was being locked in a positive phase which led to a decline in storm frequency and magnitude. Studies of a mountain catchment in south-western Crete have thus revealed a significant decline in the occurrence of flooding events (Maas and Macklin, 2002). Still, it remains scientifically uncertain at present if the current trend towards the positive phase of the NAO is caused by anthropogenic climate change or represents a natural climate variability, but is most likely a combination of both (Gillett et al., 2003).

4.6.1.3 Sea level rise

The observed sea level rise across most of the Mediterranean has been in the range of 1-2mm/year. Variations above and below these rates are assumed to have been caused by vertical land movements, such as tectonic uplift in the eastern Mediterranean or subsidence in the several larger river deltas. In Thessaloniki, for example, sea levels have been rising at a rate of 4mm/year (UNFCCC - Greece, 2003). However, it should be noted that so far, systematic research with respect to the long-term trends of sea level changes has been lacking. In effect, sea level measurements were only started after 1970 with the most reliable data series beginning in 1985. As a result, trends for the different regions of Greece remain contradictory and do, at present, not allow any conclusive insights (UNFCCC - Greece, 2006).

4.6.2 Projections

Until recently, projections for future climatic changes in Greece were only available from modelling experiments focusing on the European scale. Giorgi ***et al.*** (2004), for example, used the regional climate model (RCM) RegCM, driven by the global climate model (GCM) HadAM3H, to assess changes for the time period 2071-2100 under the A2 and B2 scenarios (Nakicenovic et al., 2000). Räisänen ***et al.*** (2004), on the other hand, used the regional model RCAO, driven by the GCMs HadAM3H and ECHAM4/OPYC3. Their simulations for the time frame 2071-2100 were also performed under the A2 and B2 scenarios.

In an attempt to obtain spatially more detailed projections, the National Observatory of Athens (NOA) has recently performed a first systematic assessment for Greece. Using the regional model PRECIS, which is based on the GCM HadCM3, simulations for the period 2070-2100 under the A2 and B2 scenarios, with the time frame 1961-1990 serving as the reference period, were carried out (UNFCCC - Greece, 2006).

4.6.2.1 Trends in climatic parameters

Temperatures

By the end of the century, mean annual temperature in Greece is projected to rise between 2 and 4°C (Räisänen et al., 2004). With regard to seasonal changes, both European modelling exercises point towards a more pronounced warming trend in summer than in winter. For the winter months, Giorgi ***et al.*** (2004) expect increases in temperature between 2.5 and 3.5°C, while Räisänen ***et al.*** (2004) anticipate a range of 2.5-5°C. The projections for the summer months are accordingly higher, and while Giorgi ***et al.*** (2004) expect temperature to rise between 3 and 4.5°C, simulations by Räisänen ***et al.*** (2004) show increases of up to 8°C under the A2 scenario.

Outcomes of the regional modelling exercise for Greece also point towards the high changes in summer temperature as projected by Räisänen ***et al.*** (2004). According to the A2 scenario, mean maximum temperature in July could rise between 7-8°C in the southern regions (including the area of Athens) and 8-10°C in central and northern Greece. Projections for mean minimum temperatures for July under the A2 scenario equal those of the B2 scenario for mean maximum temperatures, and show increases between 6-7°C for the southern regions and Athens, and 7-8°C for central and northern Greece (UNFCCC - Greece, 2006).

Precipitation

Mean annual precipitation could decrease between 10-40% in Greece by the end of the century (Räisänen et al., 2004), although some climate scenarios project increases for the seasonal averages. In winter, for example, precipitation may rise by 10-20% according to results of the HadAM3H based modelling experiment under the B2 scenario (Räisänen et al., 2004). And simulations for the Balkan region with the RegCM model by Giorgi ***et al.*** (2004) also show increases in winter precipitation of 10%. Overall, however, most climate scenarios investigated by Räisänen ***et al.*** (2004) point towards decreases in winter precipitation between 10 and 40%. For the summer period, the different climate scenarios also arrive at sometimes contrasting results. While simulations of the RCAO model under the A2 scenario seem to point towards decreases in summer rainfall of up to 60%, future changes according to the B2 scenario could even result in precipitation increases of up to 60%, particularly in the south and the Aegean Sea (Räisänen et al., 2004). Projections by Giorgi ***et al.*** (2004), obtained with the RegCM model for the Balkan region, have shown reductions in summer rainfall by 30%.

As might be expected, outcomes of the regional modelling exercise by the NOA give less ambiguous results and reveal more regional detail. According to the A2 scenario, the winter month of December, which is the rainiest in the majority of Greek regions, could be experiencing significant precipitation reductions in the future. In western Greece, decreases may reach 60-70% of current levels, with decreases in northern and eastern Greece, in the islands of the eastern Aegean and in Crete being less pronounced. During the summer month of July, Northern Greece and the Balkans could experience significant reductions of 20-30% in the future. Important to note in this context are the anticipated decreases for the neighbouring countries of Serbia, Bulgaria and Romania. In these regions, summer rainfall constitutes an important part of the annual water supply to large river systems which ultimately enter Greek territories and thus contribute to its water resources. For southern Greece, the projected decreases in summer rainfall are not particularly pronounced as these areas are already characterised by very low precipitation levels (UNFCCC - Greece, 2006).

Distinct changes in precipitation have also been projected for four large cities in Greece: Thessaloniki in the north, Larissa in central Greece, and Athens and Iraklion in the south. Under the A2 scenario, the highest rainfall reductions are anticipated for the month of July, with -80% in Larissa and -92% in Iraklion. With regard to annual changes, the A2 scenario projects reductions between -32% and -40% in the two cities respectively (UNFCCC - Greece, 2006).

Temperature extremes

During the 30-year period 1961-1990, a total of 28 heat days with temperature >40°C have been recorded in Athens. According to the modelling results of PRECIS under the A2 and B2 scenarios, this number is due to change drastically in the future. In Athens, heat days during the period 2071-2100 could occur up to 1078 times under the A2, and 580 times under the B2 scenario. For the city of Larissa, the projected changes are equally severe with the number of heat days increasing from the current value of 59 (1961-1990) to 1289 and 800 according to the A2 and B2 scenarios, respectively. For Thessaloniki, the respective figures are 188, 1924 and 754, and for Iraklion 3, 537 and 205 (UNFCCC - Greece, 2006).

4.6.2.2 Water resources and hydrological extremes

Several modelling studies have aimed to assess the response of Greek river basins to climate change. In an early work by Mimikou ***et al.*** (1991) the sensitivity of three different catchments in the central mountainous region of Greece, the Mesohora and Sykia of the Upper Acheloos River and the Pyli basin of the Portaikos River in western Thessaly, were examined. The assumed climatic changes involved temperature increases of 1, 2 and 4°C and precipitation changes of 0, ±10 and ± 20%. While higher temperature caused reductions in runoff almost proportional to the hypothetical increase, the impacts of changing precipitation levels on runoff were magnified. In the Mesohora and Sykia basins, for example, minimum annual runoff exhibited a 16-17% change for each 10% change of precipitation. However, the more humid Pyli basin showed only 12-15% change, indicating that the basin sensitivity to changes in precipitation depends also largely on its aridity.

Still, higher temperatures were also found to have a pronounced effect on runoff by changing its seasonal distribution. In the snow-fed Mesohora and Sykia basins, earlier snowmelt processes could increase surface runoff during winter. This would result in a marked reduction of spring and summer runoff, ultimately leading to a prolongation of the dry period (Mimikou et al., 1991). These findings were corroborated in a subsequent study by Mimikou ***et al.*** (1999), where two equilibrium (UKHI, CCC) and one transient scenario (UKTR) were applied to investigate the impacts of climate change on the Aliakmon river and three of its subbasins in northern Greece. According to these experiments, the projected increase in runoff during November, December and January would lead to a reduction in spring runoff, thus causing a severe prolongation of the dry season. Furthermore, all scenarios indicated a decrease in mean annual and mean winter runoff (Nov-Apr), as well as a severe reduction in summer runoff (May-Oct) over the course of this century. According to the UKHI scenario, decreases in annual and seasonal runoff in the three subbasins could be around 20-40% by the 2050s. Overall, runoff is projected to become more extreme with maximum annual values expected to increase and minimum annual runoff projected to decrease (Mimikou et al., 1999). Additional modelling studies (HadCM2, UKHI) for the Ali Efenti basin in central Greece projected again a significant reduction of mean monthly runoff for almost all months of the year 2050. The highest decreases could occur again during the summer months, especially in June when reductions of 26-46% are projected (Mimikou et al., 2000).

Lehner ***et al.*** (2001) have also analysed the development of runoff and floods over the course of this century, using the HadCM3 and ECHAM4 climate models and the WATERGAP hydrological model. They found that in the 2020s, total river discharge volumes in Greece could initially increase by up to 25%, while by the 2070s, decreases of up to 25% could be experienced. As a result, 100-year floods are expected to occur more frequently in the 2020s, while later on in the 2070s, the HadCM3 model projects them to become less frequent and their magnitude to decrease between 10 and 25%. The months with maximum average discharge will shift from December to January in the Peloponnese, and from March to February in the mountainous regions in the north (Lehner and Döll, 2001a).

Towards the end of the century, today's drought season will extend from August and September into October and the magnitudes of 100-year droughts could increase by 25%. According to results of the ECHAM4 and the HadCM3 models for the 2070s, the return periods of 100-year droughts are projected to decrease to 10-40 years (Lehner and Döll, 2001b).

4.6.3 Summary and conclusions

Despite the absence of an overall identifiable warming trend across the Greek peninsula during the second half of the last century, the country seems to have entered a warm period since 1997, which coincided with the "abrupt climatic warming" that occurred in the Northern Hemisphere since 1994 (Feidas et al., 2004). Changes in precipitation appeared unrelated to the observed temperature changes and have already shown decreasing trends since the 1950s, which intensified markedly in the mid 1980s (Pnevmatikos and Katsoulis, 2006; UNFCCC - Greece, 2006). Projections regarding the future degree of warming in Greece depend largely on the season, with the winter months expected to show increases between 2.5-5°C and summers of 3-8°C (Giorgi et al., 2004; Räisänen et al., 2004; UNFCCC - Greece, 2006). Temperature extremes will increasingly become a problem, particularly in the large cities, and the occurrence of heat days is projected to multiply drastically (UNFCCC - Greece, 2006). Mean annual precipitation could decrease between 10 and 40% by the 2070s (Räisänen et al., 2004), and regional modelling studies highlight the potential for severe reductions in winter and summer precipitation (UNFCCC - Greece, 2006). These changes in temperature and precipitation could have a pronounced impact on water resources. Higher temperatures, for example, would change the seasonal distribution of runoff, with earlier snowmelts ultimately leading to a prolongation of the dry season (Mimikou et al., 1991). In addition, the expected decreases in precipitation could cause pronounced reductions in winter and summer runoff (Mimikou et al., 2000; Mimikou et al., 1999). By the 2070s, today's drought season is projected to extend from August and September into October and the return periods of 100-year droughts could decrease to 10-40 years (Lehner and Döll, 2001b).

The anticipated decreases in spring and summer runoff and the resulting prolongation of the dry season will have severe impacts on the availability of water for agricultural use. Combined with the increase in evapotranspiration and the reduction in soil moisture, climate change is expected to lead to a rise in irrigation water demands. It is thus of paramount importance for the agricultural sector to improve water use efficiency to ensure the adequate supply of water for crop and food production (Mimikou et al., 1999). A further sector likely to suffer from the impacts of climate change is energy production from hydropower. With the production of the current annual quantities being at risk in the future, the sector needs to prepare for the new climatic conditions

(Mimikou et al., 1999). In particular, as the times of highest demand during the summer months (UNFCCC - Greece, 2006) will coincide with those of the lowest runoff (Mimikou et al., 2000; Mimikou et al., 1999).

While first steps at assessing the impacts of climate change on agricultural yields are currently being taken (UNFCCC - Greece, 2006), research in other important areas that could be potentially affected by climate change is still scarce. The effects of sea level rise on Greek coastlines, for example, are at present largely unknown and initial studies have mainly concentrated on wetland areas in western Greece. Due to the previously mentioned high aggregation of economic goods and services in coastal areas, further research in this field is strongly required. Current efforts by the Greek government to combat desertification trends serve as a good example of how a coordinated action to address environmental problems can be organised (UNFCCC - Greece, 2006). To allow the detailed assessment of affected and endangered regions, a sound scientific infrastructure was developed as a first step. Subsequently, catalogues of measures and actions to directly and indirectly combat desertification processes were compiled, which address different sectors such as agriculture, forestry and water management. With many of these actions aimed at establishing a sustainable way of resource management, they also provide an excellent basis to adapt to the impacts of climate change on water resources, particularly in the water sector. However, detailed regional projections of future climatic changes in Greece are at present still quite scarce. Future efforts should be thus directed at continuing the initial modelling studies performed by the NOA, to enable the development of a well designed preparation and adaptation strategy to cope with the likely threats of water shortages and sea level rise.

5 Vulnerability in Europe

Extensive research is being undertaken across the EU on climate change and its impacts, with several of these research activities specifically focusing on water-related issues. In 2004 the European Environment Agency (EEA) presented a first summary of climate change impacts in Europe based on a number of indicators (EEA 2004), which made it clear that European societies and economies will be affected in a variety of ways. Work on this issue has been continued since by the EEA (EEA 2005b, 2007), and will be continuted. Currently the EEA is preparing an update of the 2004 report, which is planned to be released in 2008. The Fourth Assessment Report by the IPCC presents a comprehensive review of state-of-the-art research (IPCC 2007a and b).[5] In response to the growing body of scientific evidence, policy makers in Europe are starting to think about possible adaptation strategies in order to tackle the various impacts.

Impacts of climate change will vary between different European regions (chapter 4). Southern and south-eastern countries will be affected more than countries in the North, where communities may actually experience benefits from climate change. Furthermore, the ability to adapt to climate changes is affected by financial constraints. Communities that are affected the worst in Europe may also be communities with few resources to deal with adverse impacts, such as increases in extreme events. Climate change could thus exacerbate already existing inequalities (Stern 2006).

5.1 Vulnerability of focus sectors

The following chapter will give a brief overview of the positive and negative impacts to be expected from climate-driven changes in water resources for the study focus sectors (see section 1.2). Additional relevant impacts on human health and biodiversity are discussed in section 5.2 and 5.3.

5.1.1 Water resources management

Although the impacts of climate change on water resources vary strongly between European regions, three main challenges to the management of water resources can be identified: an increase in the risk of floods along coastal zones and in river beds, a decrease in the availability of water, and a deterioration of water quality.

As a consequence of rising sea level and changing rainfall and snowmelt patterns, flood risk - including storm surges - is expected to increase. Ensuring efficient flood protection and preventing loss of lives and damage to assets in flood prone areas along rivers and coasts may thus become an even greater challenge due to climate change. Higher temperatures in winter mean that less precipitation will be falling as snow, and that snowmelt will be occurring earlier, thus changing the seasonal timing of

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5 See WGII Report: Climate Change Impacts, Adaptation and Vulnerability. Chapter 3 (freshwater resources) and chapter 12 (Europe).

river discharge and groundwater recharge. Combined with decreases in summer precipitation, this could increase the risk of droughts. However, due to the projected increase in the intensity of individual precipitation events, the risk of summer floods may increase at the same time.

Climate change effects, in combination with unsustainable water resources management (e.g. over-consumption and pollution) in water scarcity situations, could result in severe impacts on nature and society. Therefore, drought management in Europe will have to respond to additional challenges under a changing climate (European Commission, 2006i).

However, climate change will not just affect water quantity. Excess water or low water levels can also have a negative impact on water quality. If the trend to an increase in the mean precipitation amount per wet day in western and northern Europe continues, this could lead to more frequent capacity overloads of urban sewer systems. Higher runoff will additionally increase pollution from diffuse sources and sedimentation, thus deteriorating water quality further. Reduced water levels, on the other hand, mean that pollutants will become less diluted. In combination with increased water temperatures and reduced dissolved oxygen levels, this could seriously affect the ecological balance of freshwater systems.

Questionnaire responses:

Flood Management

Especially strong negative impacts on flood management were associated with increased precipitation, increased variability and sea level rise. Correspondingly, decreased precipitation was thought by many countries to have a positive or strong positive impact on flood management. One country noted that increased precipitation does not necessarily lead to negative flooding impacts in cold-temperate regions.

5.1.2 Water supply and sanitation

Water supply and sanitation services will be directly affected by climate change. Firstly, the projected increase in intensity and frequency of extreme precipitation events is likely to put sewerage networks under additional pressure. The current capacity of parts of the networks will more often be exceeded. More frequent localised flooding and sewer overflows would be the result, which might in turn negatively affect water quality in rivers.

In some parts of Europe, for instance in the Mediterranean region, water supply is likely to be affected. The projected reductions in precipitation and runoff and increase in droughts may lead to a decrease in both the quantity and quality of water available for supply. Furthermore, droughts often entail a deterioration in water quality, for instance as less water is available for the dilution of wastewater effluents. Water supply services will be faced by the challenge to satisfy consumer demand during periods of intensified water shortages. Such limitations in the availability of clean and fresh water could lead to the emergence of new or the exacerbation of existing conflicts between different water users.

In coastal areas, the situation could be further aggravated by rising sea or dropping groundwater levels, which could cause saltwater intrusions into freshwater bodies or coastal aquifers.

Drought periods may entail particular challenges for small decentralised water supply and sanitation networks, since their adaptive capacity tends to be low. Safeguarding water supply in rural areas or small scattered settlements is difficult in some Member States already under current climatic conditions, in particular because these small-scale schemes often lack sufficient financial power. As a consequence of climate-driven changes in water resources, problems for these small-scale structures may be exacerbated. From a technical point of view, however, a decentralised supply system with small-scale infrastructures may in fact be more flexible and may be more easily adjusted to changing conditions.

Furthermore, climate change may lead to apparently contradictory consequences. High intensity rainfall, particularly after a long dry period in which the permeability of soil is decreased, leads to rapid run-off and poor recharge. Thus, there may be a need to manage water shortage and flood at the same time.

Questionnaire responses:

Water Supply

On average, responses indicated that increased precipitation might bring a slightly positive effect on water supply. Otherwise, the list of possible changes was expected to bring negative impacts.

The strongly negative impact of decreased precipitation on water supply was noted by recipients. In fact, southern European countries expected strong negative effects for the vast majority of water management indicators as a result of decreased precipitation (except for flood management).

Waste Water Management

Several countries perceive waste water management to be highly sensitive to changes in the water regime, and expect each variable to bring about negative effects: increased precipitation, decreased precipitation, sea level rise, and increased variability and impaired water quality. Some respondents even expect these impacts to be strongly negative. These views reflect the delicate balance needed to maintain waste water facilities between sufficient and maximum flows.

5.1.3 Agriculture

Agriculture is one of Europe’s largest land users and as such highly dependent on environmental conditions. Inter-annual climate variability is one of the main sources for uncertainty in crop yields.

Water shortages, which are amongst the main problems expected in a changing climate, would have a significant impact on the agricultural sector. In central Europe, the projected shifts in precipitation patterns would reduce water availability during the vegetation period in summer and possibly increase the demand for irrigation water. Rising temperatures and evaporation rates would aggravate the situation in southern Europe further, where the dependency on water for irrigation is considerably higher. The consequences for farmers could be critical, starting with higher costs for irrigation, and potentially leading to production losses or the complete loss of land due to desertification. In Spain, one fifth of the land is currently at risk of turning into deserts, as for instance in the Guadalquivir river basin, where years of over-abstraction to irrigate rice fields and olive groves have led to serious water deficits.

Livestock production may also be affected by increases in temperatures and drought frequency. Heat stress may increase the mortality of animals, especially if kept in intensive livestock systems. Droughts may also reduce the productivity of grasslands such that they are no longer sufficient for livestock (Turnpenny et al., 2001; Holden and Brereton, 2002; Holden et al., 2003).

In coastal areas, the water shortage and land-loss problem would be exacerbated by sea-level rise and subsequent salinisation processes, whilst recurring flood events could render agricultural land-use in flood-prone areas uneconomical.

Higher precipitation, on the other hand, is initially perceived as a lesser problem or even an advantage. Combined with an increase in temperature, it will prolong vegetation periods in the northern latitudes of Europe, increase crop yields, allow the cultivation of new crop species or make new land available for farming. On the other hand, increased temperatures will also lead to higher evaporation rates, and net effects are likely to vary strongly according to individual circumstances. However, higher temperatures and humidity might also lead to production losses due to a rise in certain plant diseases (e.g. fungi) or the introduction of new pest species. Overall, the largest risk associated with higher precipitation will probably lie in the anticipated increase in the frequency and intensity of extreme weather events. Subsequent flooding or the occurrence of hailstorms could seriously impact crop yields.

Changes in temperatures and water resources will be accompanied by a change in atmospheric CO_2 content, which in most cases will have a fertilising effect on crop growth. Overall, the combined impacts are expected to lead to small increases in European crop productivity; however, there will be significant variations, and regionally reductions in yield and severe socio-economic impacts are likely to occur (Olesen et al. 2007; Santos et al. 2002).

Agriculture itself contributes to climate change. In the EU-25, agriculture accounts for around 10% of total greenhouse gas emissions,[6] being a source of mainly methane and nitrous oxide. Also, while being highly dependent on water resources and sensitive to changes, the agricultural sector also exerts significant pressures on water resources, being one of the largest users of water (Herbke et al., 2006). The main driving force for the use of water in agriculture is irrigation. The total area equipped for irrigation (***total irrigable area***) in the EU-12 amounted to 11.7% of the total utilised agricultural area (UAA). The demand for irrigation water differs strongly between regions, with the regions with the highest use of water for agricultural being located in southern Europe (EEA 2005d).

Questionnaire responses:

<u>Agriculture</u>

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6 EU press release STAT/05/113, September 9, 2005.

Overall, countries expect agriculture to be negatively impacted by predicted changes in water resources. The greatest area of concern seems to be decreases in precipitation, with many countries expecting a strong negative impact. Some respondents see potential benefits from increased precipitation. Increased variability and decreased quality are considered negative by most, but not to the same extent as the changes mentioned above.

5.1.4 Electricity

Electricity production in the EU has shown a steady increase since the early days of production, and has become an integral part of daily life in European societies. However, affordability and security of supply are under pressure from increasing demand and rising prices for fossil fuels.

The production of electricity is strongly dependent on water, be it for cooling in power plants, hydropower or the production of biomass. Changes in water resources will have impacts on many types of electricity production, and may become a further threat to the reliability of electricity supply in the future.

In some areas, **hydropower** may benefit from increased hydropower potential, while in other countries this potential will decrease due to reduced river runoff. Studies in Switzerland, for instance, have shown that the anticipated increase in evaporation could indeed cause major reductions in river discharge and substantially decrease the contribution of hydropower to meet future energy demands. Countries in Scandinavia and northern Russia could see an increase of 15-30% in hydropower potential, whereas Southern European countries such as Portugal, Spain, Ukraine, and Turkey could see a decrease of 20-50% (Kirkinen et al., 2005). In areas with increased precipitation and runoff, dam safety may become a problem due to more frequent and intensive flooding events.

The generation of electric power in **thermal** (in particular coal-fired and nuclear) **power** stations often relies on large volumes of water for cooling. Few studies have investigated the effect the changing climate will have on electricity from fossil fuels and nuclear power. However, it has become apparent during recent heat waves and drought periods that electricity generation in thermal power plants may be affected by increases in water temperature and water scarcity. The discharge of cooling water may be restricted if limit values for temperature are exceeded, which may force plant operators to work at reduced capacity or even temporarily close plants, with potentially serious consequences for supply. (see Box 1). Furthermore, in regions where water will become increasingly scarce, the use of water for cooling may conflict with other water uses.

Box 1 Climate change and thermal power plants: The French experience 2006

Summer 2006: French electricity producer EDF purchases electricity from the EU wholesale energy market to make up for its lost capacity as a result of increased river temperatures. Nuclear power plants at rivers could not be operated at full capacity, since water law restricted the discharge of cooling water at high temperatures. The move was also aimed at meeting a surge in demand caused by the thirst of air-conditioning units throughout the country, showing the dual impacts of climate changes on demand and supply in the energy sector.

Climate-induced changes in water resources may affect **biomass** production in different ways, and different regions of Europe are likely to experience different net effects. On the one hand, increased precipitation, higher temperatures and higher atmospheric CO_2-concentrations might be beneficial for biomass production. On the other hand, similar to other agricultural production, biomass cultivation may suffer both from water scarcity and drought or from flood damage to harvests, from more frequent extreme weather conditions or from a higher incidence of pests and fungi (see section 5.1.3).

Intense precipitation events, increased flood risk, and sea level rise may increase the risk of **infrastructure** (generation and supply) damage. In some Member States (e.g. UK and Finland), nuclear power plants, nuclear fuel reprocessing or nuclear waste sites are located near the coast, which could lead to security problems as a consequence of sea level rise. Furthermore, energy supply infrastructure, in particular transmission grids, might be endangered and damaged by flooding events and avalanches. In addition, transmission networks may be affected by climate change impacts that are not related to water resources, such as extreme cold and the melting of permafrost soils. Also, since cable resistance increases with temperature, a warming climate may also lead to power losses in transmission in southern countries (Aguiar et al., 2002).

Changes in temperature will also affect seasonal **electricity demand** patterns. On average, the demand for heating in winter is likely to decrease, while the demand for cooling during the summer months will increase. However, since variability and extremes are also projected to increase, there may be years with drought in summer and cold and dry winters, which would represent a worst-case scenario for regions dependent on hydropower. Generally, it may become more challenging to meet energy demands during peak times due to more frequent heat waves and drought conditions (Rothstein et al., 2006).

Questionnaire responses:

Energy/Electricity

The potential positive impact of increased precipitation is recognised by many countries, in particular those that depend to a large extent on hydroelectricity. Decreased precipitation is expected to have a negative and often strong negative impact on the energy sector. This is perhaps also due to the effect of reduced precipitation on other energy sources (e.g. cooling water for thermal power stations). The countries that are potentially affected by rising sea levels expect negative to strong negative impacts on the energy sector.

5.1.5 Inland waterway transport

Generally, inland waterway transport (IWT) is characterised by a high degree of reliability and safety compared to other transport modes. However, the waterway infrastructure is to some extent shaped and influenced by nature, which makes it susceptible to changes in weather conditions and climate change impacts.

In unregulated rivers or river sections, water level fluctuations already pose temporary challenges under current climatic conditions, since they complicate travel and draught planning and prevent a full utilisation of vessel capacity. In regulated waterways and canals, by contrast, management measures can be taken to ensure navigability, and constraints are only to be expected in extreme cases, for instance extended drought periods and low water flows.

IWT is particularly sensitive to extremes in river flow. In particular, low water levels reduce loading capacity and affect transport prices. This problem may be exacerbated by climate change impacts in the future. To a lesser extent, IWT may suffer from the projected increase in frequency of floods and storm surges, which could temporarily disrupt transport. In addition, changed patterns of sediment transport may be a problem.

In some instances, IWT might also benefit from climate change. In winter, higher temperatures and reduced ice cover on rivers could improve conditions for IWT, and some regions may benefit from increased precipitation.

In general however, the increased variability in climate conditions is likely to lead to more unstable navigability conditions on European unregulated waters and to increased costs of routine infrastructure maintenance (e.g. dredging) and renewal. This might to some extent threaten the reliability of this transport mode in the future.

Questionnaire responses:

Inland waterway transport

For inland waterway transport, a relatively small number of countries are concerned about the impacts of changes in water resources, which may be due to the fact that navigation on inland waterways plays an essential role only in some European countries. Those countries that do expect impacts describe them almost exclusively as negative. The greatest concern is a decrease in precipitation and lower river flows. To a lesser extent, the potential negative consequences from an increased variability in precipitation and river flow conditions, from increased precipitation, and from sea level rise are also recognised.

5.1.6 Tourism

Tourism has become one of the European Union's most important and fastest growing sectors. Through increasing emissions, in particular from aviation travel, tourism itself has a considerable impact on the climate system. As a rapidly growing industry, tourism also has negative environmental impacts, in particular on water quantity and quality. For example, tourism may exacerbate water scarcity in Mediterranean regions, where the tourism industry consumes large quantities of water, and the high summer season coincides with dry period and low water regimes.

At the same time, with the tourism industry heavily dependent on weather and climatic conditions, shifts in temperature and precipitation patterns have impacts on tourism and will require adaptation responses.

An increase in the frequency and intensity of heat waves, droughts and water shortages might negatively affect the attractiveness of southern European holiday destinations in summer. Possibly, water-borne and water-related diseases such as malaria might surface on the southern coasts as a consequence of the warming climate, which would further exacerbate the situation. By contrast, northern European and Alpine regions might become more attractive for tourism during summer. In winter, on the other hand, these regions could lose appeal due to reduced or less-reliable snow cover and the resulting threat to winter sports. Studies analysing the situation in the Austrian federal state of Salzburg, for example, project a significant reduction in snow cover duration.

The longer-term impacts could thus lead to an alteration of tourist flows and a shifting of tourism seasons. In summer, the massive movement from northern Europe to the Mediterranean, which today is the largest tourism flow globally (UNWTO 2003), could slow down, with northern Europeans holidaying increasingly within northern Europe, and southern Europeans visiting their own coasts in different seasons or staying in cooler and higher hinterland areas of coastal regions. Southern Europeans may also travel north to escape uncomfortable summer conditions at home. In winter, the north-to-south flow of tourists, which includes residential tourists on the Mediterranean coasts, could become even stronger than it already is today.

In coastal areas, which play a major role for tourism, sea-level rise will pose a major challenge. It will increase the risk for coastal wetlands further, threaten some of the most important recreational areas such as beaches and islands, and endanger famous sights - in the extreme case of Venice, a whole city. Coastal erosion affects around 40% of the European shoreline subject to sea level rise (Seekles, 2004), which poses a high risk to coastal tourism infrastructure.

Furthermore, inland regions more frequently hit by floods or by drought-related forest fires might suffer from a decrease in tourist numbers in the aftermath of such extreme events.

In summary, tourism flows are likely to shift in response to climate change impacts. This will entail secondary effects on other sectors, for instance on water management. Given that per capita water consumption by tourists tends to be much higher than by local residents in holiday destinations, increasing tourist numbers could provoke water-related conflicts. On the other hand, a decrease in tourist numbers might lead to excess capacities in water sanitation and supply networks. Changes in tourist flows generally may have major implications for the affected regional economies, in particular with regard to labour demand and employment (UNWTO, 2003).

European tourism is largely dominated by **small and medium sized enterprises** (SMEs), with over 99% of firms employing fewer than 250 individuals, and is thus characterised by a highly fragmented and locally based structure. Many **rural areas** across Europe are heavily dependent on the visitor economy. As an economic activity, tourism interacts closely with a number of other sectors such as transport, construction, energy, and land-use planning. It is influenced by a wide variety of policy fields, and is closely related to the overall economic development of a given region.

Most potential tourists make short-term decisions about their destinations, and the industry is required to react on a similar time scale. However, many of the infrastructures upon which tourism relies (e.g. water supply and sewage treatment) require long-term investment, planning and management (Viner and Amelung, 2003), and policy responses to climate change impacts require action in the present. Adapting the tourism sector to changes in climate and water resources thus represents a particular challenge.

Questionnaire responses:

Tourism

On average, responses signal a relatively low level of concern with respect to the potential of water-related climate change effects to affect the tourism sector. However, individual countries did indicate that they expect negative impacts, in particular from impaired water quality and sea level rise. Decreased precipitation is seen as beneficial by some respondents and damaging by other, mainly Southern, countries. One respondent explained that the attractiveness of changed weather conditions (e.g. less precipitation) to tourists may have a different effect to the ability of the host country to meet the water requirements of those tourists. Island countries (Cyprus, Malta, Ireland) made the link between sea level rise and disrupted beach tourism.

5.2 Biodiversity

Climate is a key determinant for ecosystems, and organisms and ecosystems have been shaped by regional climatic conditions over time. It is also important to recognise that human activities have been impacting on ecosystems and their species composition for tens of thousands of years. Agriculture and development, for instance, may lead to changes in ecosystems and losses in biodiversity due to soil degradation, water quality and quantity degradation, habitat loss, fragmentation, and the introduction of non-native species.

Being sensitive to climate, organisms and ecosystems will also respond to climate change. Climate change is thus another factor that has the potential to alter ecosystems and the many resources and services they provide. Climate change impacts are directly exacerbating problems associated with biodiversity loss through increased temperatures, changes in precipitation, changes in sea levels and storm frequencies, and indirectly through changing the intensity and frequency of disturbances.

Declines in rainfall and surface water flow will place significant stress on aquatic environments. Less water flow into wetlands and marshes could result in drought falling of these habitats resulting in e.g. less frequent breeding events.

Coastal ecosystems are also sensitive to the impacts of climate change. Floods associated with more intense rainfall events could result in increased sediment and nutrient levels in estuaries and coastal ecosystems. This has the potential to significantly impact habitat areas.

Sea level rise will affect ecosystems in Europe as well. Risks include salt water intrusion in coastal areas, which may threaten wetland ecosystems. Losses of mangroves and wetlands not only negatively impact plant and animal diversity along the coast, but also means losses in ecosystem functions. Currently 9% of all European coastal zones lie below 5m in elevation and are most sensitive to sea level rising (EEA 2005b, p. 27). Losses of coastal land will greatly affect waterfowl, which use select sites for wintering or as stopping points during migration.

5.3 Human Health

The level of health in a population reflects the quality of social and natural environments, material standards of living, and the robustness of the public health and health service infrastructure. Therefore, population health is an important integrating index of the effects of climate change on ecosystems, biological processes, physical environmental media, and the social-economic environment (IPCC 2001, chapter 9).

Climate change impacts may significantly affect human health. An increase in the frequency or severity of heat waves would cause a short-term increase in (predominantly cardiorespiratory) deaths and illness. Heat waves in the recent years have been more common and severe, causing an increase in human mortality. Although people are expected to acclimatise to increased temperatures, predictions still expect mortality rates to increase. Flood events are also increasingly causing fatalities, as the 2002 floods, 15 major floods which affected Austria, the Czech Republic, Germany, Slovakia, and Hungary, caused around 250 deaths around Europe (EEA 2004, p. 76). Since flood risk is likely to increase in many areas due to climate change, adaptation measures need to focus on future predictions and warning mechanisms. Measures to improve warning are already helping, as death rates have decreased although floods have increased.

Not only is immediate physical injury and/or death from heat waves or floods a problem, but increases in water and food borne illnesses also pose a health risk to humans. Decreases in water availability during drought periods can increase water borne diseases, and climate-induced changes in the geographic distribution and biological behavior of vector organisms of vector-borne infectious diseases (e.g., malaria-transmitting mosquitoes) and infective parasites might increase the potential transmission of such diseases.

5.4 Vulnerability assessment of European countries

Respondents to the questionnaire survey provided a general assessment of the impacts of climate-driven changes in water resources, of the effects on key sectors, and of the implications for their societies in general.

General assessment of the effects of climate-driven changes in water resources

A list of possible changes in water resources such as “increased precipitation”, “decreased precipitation”, “increased risk of floods”, or “sea level rise”, was presented, and respondents were asked to assess what effects (from very positive to very negative) these changes would have on their countries. Figure 22 summarises the results.[7] Effects of climate-driven changes in water resources were generally expected to be negative by a majority of countries. However, some respondents saw potential benefits from changes in precipitation patterns. There were clusters of positive answers especially for ‘increased precipitation’. The impacts from ‘decreased precipitation’ are expected to be negative or very negative by the large majority of respondents, while a small number of respondents see potential benefits. The impacts from increases in extreme events (flood and drought risk) were exclusively seen as negative or very negative.

The responses largely reflect national geographical and hydrological circumstances. For example, ‘increased risk of floods’ is a great concern in northern European countries that lie on major flood plains and/or experience heavy rainfall; ‘increased risk of droughts’ in densely populated countries and southern European states with high water stress; and ‘sea level rise’ in low lying coastal states and islands.

[7] Most countries based their answers to this question on a combination of Expert Knowledge and Research Studies.

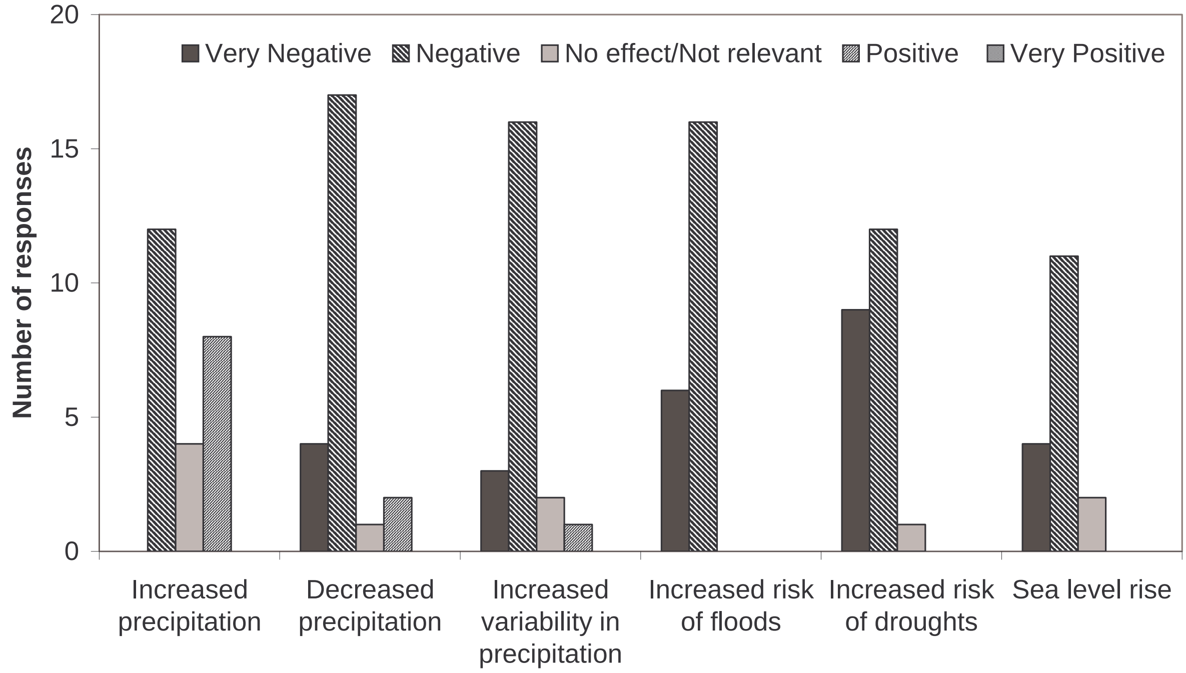

Figure 22 Vulnerability assessment (questionnaire survey).

Effects on key sectors

For a range of sectors, questionnaire recipients were asked to rate the effects of several types of changes (e.g. “more water” or “less water”), using categories from very negative (-2) to very positive (+2). In summary, respondents seem to expect significant impacts from climate-driven changes in water resources on water management and other water-related sectors, with the exception maybe of the tourism sector. There was also a broad appreciation, throughout northern, central and southern countries, of the sectoral impacts of drought conditions, namely decreased precipitation and impaired water quality. Responses reveal a nuanced understanding of impacts - the same predicted change can bring about a range of negative ***and*** positive impacts depending on the sector. For instance, ‘increased precipitation’ may assist the water supply and waste-water management sectors (+2 Germany), whilst making flood management more difficult (-2 Slovakia), potentially helping agriculture (+1 Austria), significantly boosting the energy industry (+2 Norway), detracting from tourism (-2 Sweden), helping navigation (+1 Germany) but harming other transport and construction industries (-2 Norway) whilst positively affecting the Fishery (+2) and Forestry (+1 Lithuania) sectors. For the respondents’ assessment of impacts of the five study sectors, see boxes in section 5.

Wider impacts and relevance

When asked for expected **socio-economic consequences** from the physical changes in climate and water resources, many countries referred to economic losses, loss of life, and damage to property and infrastructure. Negative consequences are in particular associated with extreme events, in particular floods. However, the challenges resulting for societies from increased water scarcity and drought, and the potential need to deal with enhanced competition and conflict over water use, is also recognised by many respondents.

Economic losses are expected to be mediated especially through impacts on agriculture, but also from reduced hydropower and nuclear power plant output.

The consequences of changed water conditions on water dependent **ecosystems and biodiversity** are appreciated by a number of countries. A major concern expressed by respondents is the potential loss of habitats and species and the resulting decline of biodiversity, as well as alterations in species composition. It is recognised that changed water conditions may exert further pressure on already vulnerable ecosystems such as wetlands, riparian woodlands, flood plains, estuarine ecosystems, or peatlands. Some countries also mentioned the heightened risk of forest fires as a consequence of more frequent and intense drought. The productiveness of forests may also be reduced under drought conditions, and they may become more susceptible to pests and diseases.

Many respondents saw potential threats to **human health** from climate change impacts. Higher temperatures in summer and their possible impacts on health, especially in urban areas, were mentioned. But also problems related to changes in water quantity and quality were identified, for instance the potential spread of water borne diseases after flooding events and sewage overflows. Generally the importance of the availability of water in sufficient quality and quantity for public health was recognised.

6 Adaptation: Options and examples

The scientific evidence summarised in chapters 3 and 4 conveys the clear message that a change in climate is occurring, and that it will impact on the processes of the water cycle in the European regions, with wide-ranging effects as stated in chapter 5.

According to the definition used by the IPCC,[8] adaptation is any adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC 2001). Adaptation should thus reduce the sensitivity to potentially damaging impacts, but also enhance the capability to capture any benefits of climate change. The 2006 Stern review states that ***"adaptation will be crucial in reducing vulnerability to climate change and is the only way to cope with the impacts that are inevitable over the next few decades***" (Stern 2006, chapter 18). However, impacts can only be reduced, not removed, and adaptation will come at a certain cost. The report points out that there are limits to adaptation, and that the costs of adaptation will rise sharply in the absence of early and strong mitigation efforts, which implies that in the long term, mitigation will be by far less costly than adaptation.

Mitigation and adaptation are thus bound together by a trade-off across time: the smaller the reduction of greenhouse gas emissions that is achieved today, the greater the required effort and costs for adaptation will be in the longer-term future (Berkhout 2005).

While synergies are possible between adaptation and mitigation, it is important to note that the "problem structure" differs between the two in some essential aspects. Climate change mitigation, i.e. the challenge to globally reduce greenhouse gas emissions, clearly represents a "common good"-type problem – there is little incentive for individual companies or countries to take action if others do not contribute equally. Adaptation efforts, by contrast, usually bring private or localised benefits to those who undertake them. Therefore, it can be expected that adaptation will to a large extent be "**autonomous**", supported by market forces, and occur at decentralised levels.

However, due to several factors private adaptation might remain at a level below what might be desirable, and market forces may not always lead to efficient adaptation (Berkhout 2005, Stern 2006). Among these reasons are potential spill-over effects (the benefits of private adaptation may be shared with others), uncertainty and imperfect information about climate change impacts, uncertainty about the distribution of benefits and costs of adaptation, and the mismatch between the distribution of climate vulnerability and adaptive capacity – the poorest societies or the poorest groups within societies generally will have limited possibilities to adapt due to financial constraints. Anticipatory adaptation to climate change impacts that are projected by climate models but not yet being felt may be particularly difficult to achieve, since planning systems often have short time scales, and the willingness to take adaptive measures is further reduced by uncertainties in model projections and scenarios.

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[8] See also explanation of technical terms in section 2.

These deliberations lead to a broad consensus in the scientific literature that there is a strong role for governments and for **policy-driven adaptation**. Government action can contribute to motivate early adaptation and to support efforts by private actors. A need for policy action is identified in the following major fields (Berkhout 2005, Stern 2006, UK Environment Agency and DEFRA 2006):

- **Research, information and communication.** Government plays a crucial role in improving the information basis by supporting research, e.g. on the impacts of climate change, reducing and dealing with uncertainty, and on the costs and benefits of adaptation. More reliable and spatially differentiated information on climate risk can for example help to change behaviour (e.g. water use efficiency) or to ensure that these risks are priced properly in the market (e.g. insurance against flood damage).
- **Regulation and standards.** Standards and regulations may provide private actors with the freedom and/or the necessary incentives to adapt. Land-use planning standards may be used to direct both private and public investment towards less vulnerable locations. In some cases, performance standards that include headroom for climate change could reduce vulnerability or prevent an increase of vulnerability due to individual decisions.[9]
- **Public infrastructure.** Direct government adaptation action is required in the case of public investment in major infrastructure projects.[10] Public procurement may be a vehicle for highlighting best practice and drive the demand for adaptation services.
- **Early warning and disaster relief.** Effective early-warning and forecasting that allow preparing for imminent threats, and a sufficient emergency planning for cases of natural disasters are crucial to protect human lives and property. They also play an important role with respect to negative environmental effects which might increase the risks of a disaster (e.g. oil spills in a drinking water abstraction zone).
- **Regulating the distributional impacts of adaptation.** Adaptation policy should ensure that issues of ecological justice are taken into account. Differences in adaptive capacity due to resource constraints may have to be compensated, and financial safety nets for the poorest in society may have to be created.
- **Embedding adaptation in sectoral policies.** The priorities and instruments of other policies may conflict with or undermine adaptation concerns. A significant challenge for policy-making thus consists in effectively integrating adaptation into sectoral policies, for instance on water and agriculture, or into funding policies. Horizontal co-ordination of adaptation efforts between sectors may significantly reduce the costs of adaptation.

All levels of government, from the local to the European and international level, need to be involved in adaptation efforts. While infrastructure projects and land-use planning issues are implemented at national or local level, EU level policy may contribute to

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[9] An example for such a case is the paving over of front gardens by London home-owners. In sum, a large number of individual decisions led to the loss of permeable drainage surface equivalent to 22 times the size of Hyde Park, and to a considerable increase of flash-flooding risk (Stern review 2006, p. 420).

[10] For instance the Thames Barrier and Thames Estuary 2100 project, see Box 3.

funding for research and improving communication and dissemination of research results, and to integrating climate change concerns and adaptation into sectoral and planning policies (e.g. the Common Agricultural Policy, structural funds). In addition, there are planning and impact assessment tools at European level that can be used to support adaptation.

However, for adaptation efforts to be effective and successful, non-governmental and private actors and stakeholders also need to be involved in decision-making and implementation processes. Actors are generally considered to be active participants and decision makers in policy development processes, while stakeholders are those who are specifically affected, either positively or negatively, by events and policies, although they are not necessarily active participants in the process of finding solutions. Involving all affected stakeholders and actors in adaptation efforts will help to create ownership and acceptance of action taken, and it will support the dissemination of information among the general public. It will create a broad base of discussion and awareness, and thus will increase the opportunities for a successful implementation of adaptation strategies .

Generally, it can be assumed that European countries have a high adaptive capacity compared to many developing countries, being more affluent, knowledgeable and socially cohesive societies (Berkhout 2005). However, adaptation efforts in Europe are still at an early stage, although it is increasingly recognised that climate change impacts may be more severe than previously expected, and that adaptation at larger scale might be required.

In developing measures for adaptation it has to be recognised that climate change will not affect all countries and regions in the same way and to the same degree, and that not all countries and sectors are equally vulnerable. Therefore the magnitude of action and changes required and the amount of funding that will need to be allocated for adaptation varies widely among the EU Member States (Levina and Adams, 2006). However, although there are differences in the sensitivities and impacts between countries and regions, types of problems (“syndromes”) were identified in the previous sections that will affect many European countries in a similar way, and which may be met by similar adaptation efforts. Amongst these broad syndrome categories are a reduced water availability or exacerbation of water shortages, increased risk of flooding in coastal areas, and potentially increased risk of flooding due to shifts in precipitation patterns and runoff regimes.

6.1 Outline of adaptation measures for focus sectors

Since coastal or river floods or water scarcity, which might be exacerbated or regionally and seasonally shifted by climate change, have long existed, and since human societies have always had to adjust to variability in water resources, a number of options already exist that can be used and further developed for adaptation purposes. The scope for applying no-regret-measures, i.e. measures that would already be beneficial in a situation without climate change, but create additional benefits in a scenario with climate-driven changes in water resources, is immense. For instance, improving the efficiency of water use by all consumers and augmenting the available water resources e.g. by rainwater collection and reuse of grey water is advantageous in regions that are prone to water stress today, such as the Mediterranean, and according to climate model simulations will become more necessary in the future in order to adapt to changes in climate. On the other hand, measures that at first glance seem to support adaptation may not be sustainable in the longer term. For instance, increasing the use of air conditioning or increasing irrigation as a reaction to hotter summers will in the end exacerbate the problems at hand, since they will lead to an increase in energy use and thus a further contribution to climate change (air conditioning), and put additional pressure on water resources (irrigation). In general it can be assumed that societies, sectors and individual industries may adapt more smoothly and with less economic losses if stakeholders are aware of likely long-term developments and are thus able to consider them in their planning.

The following sections give a brief summary of adaptation options that are available within each of the focus sectors.

6.1.1 Water resources management

Human activities are strongly dependent on the availability of water resources in sufficient quantity and adequate quality, while at the same time many of these activities can adversely affect the condition of the aquatic environment. Therefore, adaptation strategies that place a focus on the protection of water resources will improve the adaptive capacity of all sectors and activities that depend on water. On the other hand, an integrated approach to adaptation in water resources management requires contributions by other sectors, and the co-ordination and integration of sectoral activities.

All adaptation strategies need to be based on sound risk assessments. Both existing projections of future changes and analyses of past developments should be considered in order to identify vulnerabilities and uncertainty ranges and to build robust adaptation strategies.

Climate change impacts, in particular decreases in water availability in certain regions and seasons, are likely to lead to conflicts of interests among the users. For example, if water is scarce, water use for irrigation might conflict with minimum flow regimes needed for cooling water. Adaptation may therefore require first the prioritisation of uses and then the selection of sufficient and appropriate ways of implementation. Choices may have to be made concerning the allocation of water resources, and criteria and indicators need to be developed on the basis of which such choices can be made. Decisions should be transparent and comprehensible to the affected sectors and the general public, in order to create acceptance among them.

Adaptation strategies should also consider the costs and the benefits of each measure and of the combinations of measures. These costs and benefits should be discussed among the different users and stakeholders. The following provides a list of several adaptation measures that are available. Measures for water supply and sanitation are listed in section 6.1.2.

Box 2 Belgium's water adaptation measures

Although Belgium does not have a national adaptation plan with respect to climate change, a number of climate change adaptation policies exist, and studies are currently being undertaken to better assess the country's vulnerability to impacts of climate change. Flood risk management and adaptation measures are already in place all three regions. In the Walloon region, a ban on construction in flood risk areas has been imposed. In the Brussels-Capital region, subsidies for using rain water in homes and the rehabilitation of rivers in order to retain water and improve ground infiltration exist. In addition, new storm water basins are being built in order to reduce flood risks in the future. With regard to coastal areas, the Sigma Plan for flood protection was recently revised to include new controlled flooding zones, which take into account a 60cm increase in sea level in the future.

Belgium. Report on Demonstrable Progress under the Kyoto Protocol. Available at http://unfccc.int/essential_background/library/items/3599.php?such=j&symbol=/DPR.

Technical measures

Technical adaptation can be seen as the application of technology in order to reduce the vulnerability, or enhance the resilience, of a natural or human system to the impacts of climate change (Levina and Tirpak, 2006). Such measures include flood protection measures (e.g. in case of more frequent or intense flooding, defence structures may be upgraded), supply and demand measures, water saving techniques (e.g. rainwater collection and greywater recycling), water storage measures, etc. In areas facing water scarcity, measures aiming to close the local water cycle and to encourage more efficient use of the available water should be developed and applied where possible.

Investments in physical water infrastructure may improve the flexibility of water management and increase its capacity to buffer the effects of hydrological variability. However, infrastructure investments are often associated with high costs, which have to be weighed against the potential benefits to be gained in the face of uncertainties in long-term climate projections. They also may have to be reconciled with environmental protection concerns.

Therefore, before undertaking major investments in infrastructure, all available options for adapting the operation of existing structures to changed targets and boundary conditions should be exploited. Changes in management may often provide more flexible solutions and maintain more possibilities to react to further unforeseen changes in the future. In order to identify the need for alterations of management the performance of existing systems has to be analysed regularly.

Land-use related measures

There is a strong feedback link between changes in land use and water resources management (see also section 6.2). Land management has an influence on the ability of the soil to hold back precipitation or flood water: the sealing of large areas, for instance in urban centres, increases the risk of flash floods, while sustainably managed soils in agriculture or forestry may be able to store large quantities of water and thus act as a buffer during intense precipitation events.

Land use therefore plays an important role with respect to flood risk management. In some cases, holding back flood waters through technical measures may not be possible or may be too costly in the long term, and alternative strategies may be employed. In flood-prone areas along rivers where damage to infrastructure, buildings and property cannot be prevented at reasonable cost, it may be necessary or desirable to restrict building development, or even to consider resettlement to areas that are less at risk. Similarly, countries may prefer managed retreat along coastlines to building new dykes, or try to manage water levels and "live with water" instead of holding it back.

Box 3 Thames Barrier and Thames Estuary 2100 project: Flood defence for London

Tide levels in England are slowly rising at a rate of 60cm/century. In response to flooding in central London and the Thames Estuary in the early 1900s, the Thames Barrier was built over a 30-year time span ending in 1982. Built to withstand increasingly dangerous floods, the barrier consists of 10 separate and moveable gates situated end-to-end of each side of the river. Furthermore, banks along the river were raised, in some place 2 meters higher than before. Today, the Thames Barrier is still useful; however, improvement is needed, as the barrier was only built to provide protection until 2030. The Thames Estuary 2100 project, in response to increased flood risks due to climate change, ageing defences, and increased development, aims to create an effective flood protection management plan for the next 100 years, which includes modifications to the Thames Barrier. Included in the plan are goals of public awareness towards flooding, sustainable development, reduction in estuary pollution, and a better understanding of flood management in the context of climate change.

See UK Environment Agency website:
http://www.environmentagency.gov.uk/regions/thames/323150/335688/341764/?version=1&lang=_e
and Thames Estuary Partnership website:
http://www.thamesweb.com/page.php?page_id=60&topic_id=9

Economic measures

Economic instruments might play an important role in adaptation strategies. Firstly, economic incentives, such as water pricing policies and water trading schemes, can be used to encourage changes in consumer behaviour that lead to a more sustainable and efficient use of water and may help to reduce overall water consumption. Secondly, economic instruments can help to recover the costs of adaptation measures. They might be applied across different sectors to account for the costs of additional water use for instance by the agriculture, electricity or tourism sector.

Economic instruments might also include payments for ecosystem services (PES). Water-related ecosystem services can be provided through land-use related measures, for instance forestation, conservation agriculture and extensification of agricultural land use, flood plain restoration, the conversion or restoration of natural land cover, or wetlands restoration. Services delivered by such measures include flood prevention, control and mitigation; regulating runoff and water supply; improving the quality of surface waters and groundwater; withholding sediments, reducing erosion, stabilising river banks and shorelines and lowering the potential of landslides; improving water infiltration and supporting water storage in the soil; and facilitating groundwater recharge.

Payment schemes may contribute to adequately valuing these ecosystem services and to encouraging the protection of such ecosystems and their capacity to provide water-related services. Guidance for establishing PES in water management was published by the United Nations Economic Commission for Europe in 2006 (UNECE 2006).

Information measures

Information measures in combination with risk mapping and/or improved warning and preparedness systems are crucial to reduce vulnerability to climate change driven effects (e.g. flood risks). In addition, such information measures can create a higher awareness and acceptance among the public and stakeholders on the effects of climate change and the need to adapt to climate change (e.g. water saving).

In the case of both floods and droughts, risk mapping and zoning as well as awareness-raising among stakeholders are essential to make informed decisions about prevention and mitigation measures. Insurers may be a natural partner for policy-makers in identifying and quantifying risk, communicating risk, and developing innovative risk management proposals (CEA 2006). Insurance schemes and financial instruments may be adapted to provide for a more equitable sharing of risk (see also section 6.3).

Box 4 UKCIP Adaptation Wizard

UKCIP, the United Kingdom Climate Impacts Programme, is funded by Defra, the Department of Environment, Food and Rural Affairs based at the University of Oxford, and seeks to help organisations assess how they might be affected by climate change, so they can prepare for its impact. The UKCIP adaptation wizard was created in 2005 to aid in this goal. The online program provides individuals and organisations tools and information on climate change for adaptation purposes. The adaptation wizard helps organisations understand impacts of climate change and how to integrate them into decision-making plans. The website outlines principles of adaptation such as prioritising projects in order of climate risk, taking a balanced approach to managing climate and non-climate risks, as well as using adaptive management to deal with uncertainties. Adaptation is broken down into four stages: scoping the impacts, quantifying risks, decision-making and action planning, and adaptation strategy review. The online program provides tools within each of the stages to guide organisations. Furthermore, the wizard provides up-to-date climate change scenarios, providing the most current information on risks and uncertainties.

See UKCIP website: http://www.ukcip.org.uk/resources/tools/adapt.asp

Regulatory measures

Regulatory measures focus on the legal and institutional framework organising water resource protection and management and can be used to foster technical, economic or information measures. In cases of water scarcity it may for instance be useful to impose restrictions of water use and water allocation or rationing schemes. Authorities may also issue mandatory water use standards for appliances or for new buildings to encourage efficient water use. Furthermore, regulation can be used to govern the development of other areas influencing water management, e.g. nature conservation and biodiversity.

Limits of adaptation

There is no doubt that an integrated concept can only be successful if all related and affected sectors are willing to contribute. In several cases interests differ among the various sectors (e.g. creation of wetlands for flood mitigation versus agricultural production), and adaptation constraints in water resources management might be limited by single-sector interests and regional conditions. However, although individual adaptation measures may conflict with single sector interests, it is in the interests of all stakeholders alike to ensure successful adaptation and preservation of precious water resources. Failure to adapt may result in economic loss to all sectors.

Appropriate strategies have to be developed to resolve conflicts between different interests, as the extent to which the conflicts can be solved will set the limits for adaptation.

Further, even if all adaptation measures are applied, the complete adaptation of water resources management to climate change is not possible due to several reasons. For instance land might be lost due to sea level rise and limitations in dyking. Technical limits for adaptation in water management may thus increase the adaptation needs in other sectors. Also, in some cases it may be more cost-effective to implement adaptation measures in other sectors.

Box 5 Spain's National Adaptation Plan to Climate Change

In response to the 2004 report, " A Preliminary General Assessment of the Impacts in Spain due to the Effect of Climate Change", Spain developed its National Adaptation Plan in 2006. With the water resources sector considered a priority in the plan, various adaptation measures were presented. Emphasising adaptive capacity building through research, mapping and modelling, risk assessments, and awareness training, Spain is reacting to current and future climate change impacts such as decreased precipitation and groundwater recharge, declining water quality, flooding, and droughts. Flood risk adaptation measures already implemented include technical flood protection, restrictions on settlement/building development in risk areas, and forecasting improvements. In response to increased drought risks, Spain has implemented technical measures to increase supply and is improving efficiency in water use. Future adaptation measures for water resources build upon existing policies such as continuing to improve forecasting and awareness of climate impacts. Additional measures such as restrictions on water use and landscape planning are to be considered in the future.

Source: Questionnaire response Spain.

6.1.2 Supply and Sanitation

Planning water management and design of water supply and sanitation systems used to be based on the assumption that future climatic conditions would be the same as past conditions. Climate change challenges this approach and makes it necessary to take future changes in climate and water conditions into account in today's planning, in order to make the sector resilient to changes. Uncertainties in climate projections and scenarios make this a difficult task. For instance, it might be more difficult to plan for and justify (expensive) new projects when the magnitude, timing, and even the direction of the changes are uncertain.

The strategies developed should be driven by a long-term approach, as climate change will be developing over the decades and centuries to come. Compared to policy cycles with a 10 to 15 years duration, such long-term strategies require more adaptive approaches allowing for "corrections" over time.

Developing an adaptation strategy also requires to set priorities (e.g. first "human basic needs" followed by "aquatic environments survival needs" to the "human being needs" and "aquatic environments best conditions for life") in order to develop cost-effective measures for implementing the strategy. Such a prioritisation may have wider implications for the economic development of the affected sectors. It therefore needs to be based on transparent criteria and decision-making processes in order to be accepted by those affected. Prioritisation should also reflect the quality of the water available, e.g. clean groundwater should be used for drinking water supply, while water with lower quality could be used for irrigation and cooling purposes.

A particular challenge will be the elaboration of adaptation strategies for small-scale networks (e.g. small scattered settlements, individual farms, etc.) in order to ensure the maintenance of services and to avoid population drain from rural areas affected by drought and water scarcity. Adaptation efforts should be developed which are tailored to the specific needs of these systems.

In order to address the challenges from climate change impacts, adaptation strategies should

- Be based on sound science;
- Seek to influence the abstraction, supply and demand in the long run;
- Be linked to an overarching water protection strategy in order to ensure the availability of sufficient water resources not only today but also in the future;
- Reflect the risk from floods and droughts to water supply and sanitation infrastructure;
- Consider the costs of adaptation and their share among all parties involved.

Different adaptation measures are available:

Technically-orientated measures

Technically-orientated measures are used to ensure a safe drinking water supply of high quality and the disposal of wastewater according to the best available techniques.[11] They are related to the entire infrastructure system, including the modification or extension of infrastructure to collect and distribute water to consumers and to dispose of wastewater. As water quantity strongly influences both the dimensioning of the infrastructure system and the treatment process itself, an appropriate demand management is needed to optimise water supply and wastewater disposal services. Measures such as rainwater collection and water re-use and recycling, but also improving the efficiency of water use, might play an important role.

However, before major investments in infrastructure are undertaken, all available options for adapting the operation of existing structures to changed targets and boundary conditions should be exploited.

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[11] See IPCC (2001) for recommendations for water resources managers on possible technical adaptation measures.

Box 6 Responses to water scarcity in Cyprus

Due to an expanding population and industry, Cyprus continues to increase its demand for water; however, impacts from climate change are reducing the country's water supply, and adaptation measures are needed. In recent years, Cyprus has seen over a 20% decrease in precipitation, which has resulted in more than a 40% reduction in run-off into the country's surface water reserves and has also affected its groundwater supplies. Furthermore, the last five years have seen major droughts, thus aggravating the water shortage. The gap between supply and demand is ever widening. In order to combat this gap, the government is increasing its use of treated and desalinated water as well as imposing severe restrictions on domestic and agriculture water supplies. First implemented in 1994, treated sewage effluent now constitutes up to 72% of the water supply and is mainly used for agriculture. Another adaptation measure has been the construction of desalination plants. The first plant was built in 1997 and deemed so successful that another plant was built in 2001, with subsequent plans to built two more desalination plants in the future. Water from desalination plants is largely used for domestic purposes.

Source: Charalambous, Bambo. ***Desalination Developments in Cyprus.*** Watermark, the newsletter of the Middle East Desalination Center, issue 13, August 2001.

Economic measures

Economic instruments for water demand management can be used to encourage changes in consumer behaviour and the efficient allocation and use of water, and to provide financial resources to cover the costs of providing water, including costs of adaptation (e.g. infrastructure costs).

When setting up economic instruments, the influence of other policies (e.g. specific subsidies) has to be considered. Many of these policies provide incentives to users, thus influencing decisions regarding the use of water, and might counteract the effects of economic instruments.

Information measures

Technical practices and economic instruments alone will not be sufficient in all cases to deal with the projected effects of climate change on water regimes. Stakeholder involvement, public participation and transparency are therefore required to build support for sharing the burden and benefits of the impacts of climate change. Information measures and participative processes are necessary to ensure, on the one hand, a continuous information flow between the various stakeholders in the water and water-related sectors, and, on the other hand, to raise awareness among the general public. Public information and transparent decision-making is essential to generate acceptance for adaptation measures.

Additionally, water supply and sanitation service companies may want to improve the information basis for their own operation by using models to predict future water availability and water demand in their catchment areas, or by monitoring changes in ground and surface water resources.

Water companies may also resort to new forms of customer relationship management, e.g. by co-operating with the agriculture or the building development sector in order to promote increased water efficiency in irrigation or the design of new buildings.

Regulatory measures

Regulatory measures focus on the legal and institutional framework organising the water sector and can be used to foster technical, economic or information measures. Further, they can be used to govern the development of other sectors influencing the water supply and sanitation sector.

Limits to adaptation

Increased demand for water from competing sectors, for instance an expansion of irrigation in agriculture, may limit the adaptive capacity of the water supply and sanitation sector.

Limitations in adaptation capacity might also occur due to financial constraints. Adaptation to climate change might become expensive in some regions, and service providers may not be able to fully cover the costs. Financial constraints are a particular problem in regions or countries where the condition of infrastructure networks is in a bad state and hardly sufficient to cope with current pressure levels. Costs for adaptation may also rise if water is scarce or of low quality, and additional treatment is needed. If high costs and large efforts are needed in order to implement adaptation, this might create concerns regarding the affordability of services and acceptability among consumers, and may thus add a further constraint to adaptation.

A lack in flexibility of policies or regulations might also constrain adaptation efforts. For instance, changing abstraction licences or water rights may be difficult and require extended and time-consuming policy processes, depending on the legal system that is in place in a given country.

Finally, uncertainties in modelling of climate change, hydrology, and demand forecast may also hamper adaptation.

Box 7 Public Water Management in England and Wales

Of main concern for water utility companies is security of supply. During the 1990s, England and Wales experienced a number of small but significant droughts, which affected household water supplies. Recent studies have shown a decrease of up to 30% in water flow during the summer months in the south and east of England, altering the reliability of water sources. In order to respond to these issues, the 2003 Water Act gave local authorities power to implement conservation measures in their regional water plans. Furthermore, the Environment Agency now requires water supply companies to prepare 25-year water resources and drought plans. The government has also created a security of supplies index, "indexing the proportion of a company's consumers living in resource zones where demand would exceed supply during a dry year" (Arnell and Delany 2006, p. 242). This index provides data to the supply companies so that they can respond pre-emptively to drought impacts. These adaptation efforts by the government and local companies are largely due to concerns of service standards, but climate change impacts are also taken into account, as they will exacerbate problems in the future.

Source: Arnell and Delany 2006.

6.1.3 *Agriculture*

In order to avoid or reduce negative impacts of climate-driven changes in water resources on farming systems and to exploit potential positive effects, a range of technological and management options are available. Most adaptation will be performed at farm level, but also the sectoral and regional level will play a role. Farmers carry out adaptive changes to weather conditions (as short term forecasts) continuously. By contrast, adaptation to climate change has to take place on a more permanent, large-scale and structured basis.

Adaptive efforts may for instance include the following measures (Bindi and Howden, 2004; Olesen and Bindi, 2004):

- **Improving irrigation efficiency:** Land management techniques (e.g. conservation tillage) or irrigation management (e.g. adjusting timing and volumes of water application to plant needs) may be used to improve the efficiency of water use in agriculture. A considerable potential for water savings exists here. More effective rainwater harvesting could also help.
- **Crop substitution** to reduce dependence on irrigation or to increase water availability. Some crops use less water or are more resistant to heat so they cope better with dry conditions than others. In addition, the choice of crops may contribute to adaptation in terms of "**evapotranspiration management**", in particular in rain-fed agriculture. In many regions, a large proportion of the water that falls as precipitation is evaporated and transpired again by the vegetation. Through the appropriate choice of crop types, evapotranspiration on agricultural lands may be reduced, which could lead to increased runoff and a generally enhanced availability of water for other plants or purposes.
- **Changes in farming systems** to make them more resilient to changes and to a higher variability in climatic conditions. Mixed farms, for instance, are likely to be

less sensitive to changes than specialised arable and livestock farms, since their income relies on a larger range of products. Diversification of production may thus be a way for farmers to increase their management flexibility and adaptive capacity. Also, organic farming approaches may enhance the capacity of agricultural soils to perform under changing and more adverse climatic conditions.

- **Changes in land use and landscape management** may help conserve water, for instance replacing arable land by grassland. To reduce sensitivity of farming systems to flood damage, a change of land use in flood risk areas might be necessary. For instance, crop farming in flood risk areas may be replaced by extensive grassland management.
- **Crop breeding** and development of more resistant varieties. Seed breeding should be aimed at developing crops that are more resistant to water stress.
- Changing or improving **harvest insurance mechanisms** to protect farmers from the economic impacts of flood or drought damage.
- Furthermore, agriculture may benefit from **adaptation measures** (e.g. flood protection, water supply) taken in the water management sector.

A need for further **research** exists both with respect to the integrated impacts of CO_2 increase and climate change on farming systems, and with respect to adaptation strategies that can improve sustainability and resilience of farming systems under more variable climatic conditions. Issues for research include spatial resolution in vulnerability mapping, technological and management-based adaptation measures, and the breeding of more drought- or heat-resistant crops. A key political issue to be discussed in this context is the role of genetic modification and biotechnology for seed breeding. There are strong concerns among the European public about the risks of genetic engineering, which should be taken into account. Furthermore, little is known yet about the feedback effects from adaptation measures in agriculture on the biosphere-atmosphere system and on regional climate.

Appropriate **communication strategies** are also necessary to ensure that farmers and farm advisory services are sufficiently informed about impacts and adaptation strategies to take the necessary actions.

6.1.4 Energy

The electricity sector has a range of measures at its disposal to adapt to climate change impacts. Given the long lifetime of infrastructures and the magnitude of investments, adaptation has to be included in today's planning and strategies, and adaptation efforts have to be undertaken at different levels of planning and management.

Technical adaptation options for specific energy generation and infrastructure

Climate change impacts, and thus the efforts needed for adaptation, vary between regions, but also between fuel and plant types. Differences also exist with regard to adaptive capacity. Also, the relative weight of the different types within the overall mix of energy sources (see sector overview) should be taken into account.

- **Hydropower:** Adaptation measures have to be tailored to the specific circumstances hydropower might face. In countries where precipitation and runoff will increase, adaptation measures may focus on ensuring dam safety. The energy industry is already taking action in this respect, changing risk levels for flood protection, improving discharge facilities, or using water storage facilities to harness water and to avoid flood damage. Generally, information tools such as flood mapping will become more important in such regions. In areas where water flow will decrease due to drought, using turbines that use lower nominal power could be a way to adapt to lower water flow.
- **Thermal power plants**: The most obvious way to make thermal power plants less susceptible to climate-induced changes in water temperature and availability would be to reduce their water demand, by increasing the efficiency of cooling systems or the overall efficiency of plant operation. In cases of increased flooding frequency and higher flood levels, flood defence measures may have to be upgraded or newly established, in particular to protect nuclear power plants. Dikes should be designed so that, even in the case of a dike breach, the remaining barrier is of sufficient height to prevent the flooding of nuclear power plants (Mai et al., 2002).
- **Biomass:** Agricultural practices and crop choice might be modified in order to adapt to the impacts (see above). Drought-prone regions could switch to crops that can withstand water scarcity better than current types. Adaptation measures might furthermore include improvements to production and harvesting technology. For example, improving integrated pest management could help biomass crops adapt to increases in pest insects.

Diversification

As shown above, types of power plants differ greatly in their adaptive capacity and efforts needed for adaptation. Furthermore, limits to adaptation exist for each individual type of energy production. For example, even if a thermal plant uses a water-saving cooling system, it cannot reduce its water demand to zero, and will thus still be affected by falling water flow levels.

Through the **diversification** of electricity production this vulnerability can be reduced. Broadening the range of power plant types and fuels in the generation mix (e.g. wind, hydropower, solar) and using a mix of centralised and decentralised supply patterns will help to increase the flexibility of the system and its resilience to more variable climatic conditions (Rothstein et al., 2006).

Management of demand

Climate change will change the electricity demand patterns across Europe, together with a multitude of other factors, which makes the exact direction and magnitude of changes hard to predict. Nevertheless there are several approaches that may increase the system's resilience to climate change impacts. **Increasing energy efficiency** will be a very effective adaptation and mitigation measure for European societies, and should be further promoted by policy-makers at national and EU level. **Load management** is used by energy companies as a response to changes in supply and demand patterns. It is mainly based on voluntary demand-response programs with customers and reduces customer peak electric loads at times of supply constraints. Such approaches require load forecasting models in combination with seasonal climate condition models (Rothstein et al. 2006).

Decreasing overall electricity demand, in particular during peak times, may require additional action by other sectors. For instance, an appropriate design of buildings may reduce the demand for cooling power.

6.1.5 Inland waterway transport

Inland waterway transport (IWT) is driven by long-term investments that cannot be easily relocated, redesigned or reconstructed. Thus, there is a need to be forward looking and to consider the longer term future. The following section provides examples of innovations and potential adaptations that may reduce vulnerability related to climate change:

- **Adapting waterway infrastructure and management of waterways:** The objective of such measures is to stabilise the flow regimes in rivers with a view to climate change impacts in order to secure travel. Where possible, fluctuations of water levels may be smoothed out through the appropriate management of dams and reservoirs. In other cases, investment measures such as the construction or adjustment of locks and weirs, harbour infrastructure, and straightening and deepening of waterways may be an option. In canal systems, water transfers may help to respond to regional water shortages under certain conditions.

  However, such measures have to be reconciled with environmental protection concerns, and the effectiveness of adaptation measures has to be carefully assessed. Also, it should be ensured that infrastructure projects undertaken for other purposes do not exacerbate problems caused by climate change. For example, the deepening of rivers or canals may lead to more rapid runoff, which might even accelerate the falling of water levels during dry periods. Similarly, straightening of waterways may increase the risk of flooding.

  Generally, potential adaptation measures for IWT would have to be co-ordinated with integrated river basin management efforts under the Water Framework Directive (WFD) and the Floods Directive. An integrated river basin management approach to co-ordinate the different interests will be crucial.

- **Adapting ship design:** As shown above, the capability of infrastructure development to accommodate ever larger ships and at the same time buffer temporarily decreasing water levels may be limited. Therefore, ship design may also need to respond to the challenge by adapting vessels to the available waterways and waterway conditions. The current trend towards increasing size and decreasing number of ships may not be sustainable under changing climatic and water flow conditions. Given the long lifetime of vessels, investments in fleet modernisation and shipbuilding should not be undertaken today without consideration of climate change trends.

  Technological innovation may improve the carrying capacity at low water levels, for instance by reducing ship weight and thus draught. There is a large potential for innovative win-win solutions in ship design by better adapting it to changed climatic conditions and to improve competitive and environmental performances of vessels.

- **Adapting logistics and information systems:** Under more unpredictable climatic conditions, IWT would also benefit from prompter and more precise information on actual conditions and water level forecasts. New information systems and satellite supported navigation can provide such information.

  The existing trend towards an increase in the share of direct transhipment and the substitution of storage of goods near production sites may have to be reversed. Bottlenecks will increasingly be caused by variability in water flow conditions, so that industry customers who receive raw material via waterways will have to build storage for their goods in order to avoid delivery delays. New logistic processes, more flexible transport chains and integration with different transport modes may also help (Hönemann 2006).

Discussions during the symposium “Climate Change and the European Water Dimension” in February 2007 in Berlin (see section 1.1) showed that deliberations on adaptation in the IWT sector are still at a very early stage.

6.1.6 Tourism

There are various adaptation measures the tourism industry can take in order to mitigate the negative impacts of changes in water resources and to maintain the attractiveness of their regions and facilities.

Summer tourism in water-stressed areas could potentially adapt to increasing temperatures and water scarcity through the diversification of services towards less water-intensive tourism (such as cultural, nature-based or rural tourism in urban and hinterland areas), or through encouraging tourist visits beyond the traditional season. This may lead to more sustainable tourism, and reduce water conflicts between the tourist industry and other local water users.

Adaptation could also include the broader application of water-saving and water-recycling techniques and practices in accommodation, catering facilities, golf courses, and other tourism establishments.

Several adaptation options also exist for **winter tourism** areas. Ski resorts are searching for snow-sure sites for development on glaciers and at higher altitudes. In some cases, artificial snow may be used to extend and supplement natural snow cover. However, artificial snow-making requires large quantities of water and energy and thus cannot be regarded as a sustainable adaptation method if applied on large scales. More promising adaptation strategies could be built on diversifying the ‘product’, e.g. promoting mountain tourism in other seasons and offering non-snow based adventure and ecotourism activities. Tourist resorts in mountainous regions may benefit from warmer summers with more reliable weather conditions when extending the non-ski market.

Mostly such adaptation activities will need to involve other sectors, such as the water supply and sanitation sector (e.g. demand management, see also section 6.1.2), water resources management (e.g. flood protection) or nature conservation (e.g. wetland protection, see also section 6.1.1).

6.2 Spatial planning and adaptation

Land management and spatial planning are important adaptation tools to deal with the effects of climate change across a variety of policy sectors. As the need for adaptation is increasingly being recognised, the potential effects of climate change are being incorporated into spatial planning, especially with respect to natural hazard control. Land management has an influence on the ability of the soil to hold back precipitation or flood water: the sealing of large areas, for instance in urban centres, increases the risk of flash floods, while sustainably managed soils in agriculture or forestry may be able to store large quantities of water and thus act as a buffer during intense precipitation events. Therefore, changes in land management may be an alternative to raising dykes and dams and to large investments in physical flood control structures. In the Netherlands, for instance, spatial planning projects are limiting development along river ways in order to reduce vulnerability to climate change-induced increases in flood risk (See Box 8).

In extreme cases, e.g. in river beds or along coastlines where damage from floods or storm surges to infrastructure, buildings and property cannot be prevented at reasonable costs, it may be necessary or desirable to restrict settlement of private home-owners or businesses, or even to encourage resettlement to areas that are less at risk. While such measures may not easily be accepted by those concerned, they may still be considered in certain cases since they proactively avoid damage, rather than providing assistance and support after a natural disaster has occurred. Restriction of settlement or resettlement does not necessarily have to be imposed by government through coercive instruments such as regulation or zoning, but may be encouraged through “soft” tools such as market based instruments or tax incentives (Akong et al., 2006).

Agriculture as a key form of land use will play a crucial role in adaptive spatial planning approaches. Intensive agriculture in flood-prone areas is at risk of substantial economic loss in the case of flooding. On the other hand, the increased challenges for flood risk management will create a demand for new ways of accommodating flood water and manageing flows, which may increase economic opportunities for water farming (UK Environment Agency and Defra 2006).

For farmers in the different regions of Europe, switching to new crops and farming practices or shifting farms entirely may be necessary if irrigation supplies decrease and temperatures rise. Reforming the Common Agriculture Policy (CAP) in order to create the appropriate incentives and support measures with a particular focus on climate change impacts and adaptation may be necessary (see section 7.3.2).

As biodiversity loss is a major concern in Europe, conservation plans need to use spatial planning as a tool to see what needs to be improved to ensure biodiversity stability. The Natura2000 network which is currently being implemented by the EU Member States may serve as a powerful tool to strengthen the resilience of ecosystems to climate change and to changes in water resources, its main aim being to improve ecological coherence and connectivity. With increased temperatures and increased/decreased precipitation depending on the region, Natura2000 sites need to evaluate whether their management plans will be effective in the future for maintaining biodiversity. Corridors need to be developed for species shifting northwards and Natura 2000 may need to be expanded.

Box 8 The Netherlands' National Spatial Strategy

In anticipation of rising sea levels, higher levels of water discharge, and more precipitation, the Netherlands has developed a National Spatial Strategy to ensure its waterways will be able to cope with increased river flows due to these climate change effects. In this strategy, co-operation with local and regional authorities is heavily emphasised as well as the principle of "going with and anticipating the flow".[12] Regional plans must now include the "water test", which makes sure that spatial plans take water management into consideration from the outset. With respect to river water management, a main concern is flooding, prompted by the 1993 and 1995 floods. Although the main driver is public safety, potential increased risks due to climate change are also considered. The Space for the Rivers policy programme is currently being redesigned to include the creation of extra space for rivers in order to adapt to higher levels of river discharge, thus lowering the chance for flooding. Furthermore, land surrounding major rivers is to be zoned in such a way as to reduce groundwater and surface water pollution. Flooding in coastal zones is also a major concern in the Netherlands. Restrictions on development near and inside dykes include an expansion ban within 100 metres inside the dykes and 175 meters outside the dykes, excluding wind turbines.[13] Furthermore, eight sites along coastal foundations have been designated high-priority for maintenance and improvements in order to strengthen these sea defences.

Source: The Netherlands. ***National Spatial Strategy: Creating space for development.*** Available at http://www.vrom.nl/pagina.html?id=2706&sp=2&dn=4179.

6.3 The role of insurance

Even in Europe, at local or regional level climate-related extreme events may result in significant damage to infrastructure and property. Possibilities for physical protection of assets against flood damage and for enhancing the robustness of buildings and infrastructure are limited, and perfect protection cannot be achieved. Insurance against damage thus plays a key role in coping with the risks posed by climate change impacts.

Insurers may be faced with a rise in claims resulting from the expected increase in frequency and severity of extreme events in combination with pressures caused by demographic trends, economic growth and insured exposure.

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12 Dutch National Spatial Strategy Summary: Creating space for development, p.16.
13 Ibid, p.26.

The insurance sector recognises a responsibility for the mitigation of climate change (CEA 2005, Dlugolecki 2004).[14] In addition, the European insurance industry is becoming an increasingly active participant in the adaptation debate. The industry's expertise in risk management makes it well equipped to make essential contributions to adaptation strategies. It can help to create greater understanding of risks, to raise awareness about the costs of climate change, and to identify risk management solutions that are economically efficient. The role of the insurance industry is not confined to providing assistance during crises, but may also include preparing societies for the consequences of climate change.

In co-operation with public authorities, insurers may for instance enhance information and awareness by creating mapping and zoning systems to determine flood risk areas. They may also help to introduce early warning systems or promote building codes to foster more resilient construction and repairs to older housing stock (UK Environment Agency and DEFRA 2005).

The Association of British Insurers recommends an increased use of risk-based pricing as an instrument that provides market signals to encourage or incentivise customers to avoid or avert risks (Dlugolecki 2004). However, risk pricing requires accurate assessment of impacts and risks and depends on the availability of adequate information tools. Insurers already use geographical information systems in order to adjust insurance tariffs to climate-related risks (Munich Re 2004; Dlugolecki 2001). By way of financial instruments such as risk transfer mechanisms, insurance can enable business and society to manage potential liabilities in the most economically efficient way (Dlugolecki 2004).

The European Association of Insurers (CEA) recently published a report (CEA 2006) which outlines the possible contributions of the industry to coping with climate change. The report seeks to make national and European authorities aware of the interest of public-private partnerships in the field of natural catastrophes and protection against extreme events. It argues for an EU-wide sharing of knowledge by insurers and public authorities in order to take initiatives forward and to ensure efficient use of resources and flexibility of response.

The CEA report recommends action in three areas:

1) Risk management expertise

Insurers should make use of their special risk management expertise and contribute to understanding and analysing risks created by climate change. Suggested action includes the identification of risk, the quantification of risk and the potential costs of climate change, and the communication of information and increasing awareness. On the basis of the information on risk, suitable cover needs to be provided, and adequate underwriting policies have to be developed.

2) Prevention and adaptation

The CEA sees a decisive role the insurance industry in preventing damage linked to climate-induced events. For instance, it may promote the use of warning and

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[14] As investors, insurers may for instance contribute to climate stability by promoting renewable energies and projects for reducing greenhouse gas emissions.

geographical information systems (mapping and flood zoning). New risk transfer tools may also be promoted, such as catastrophe bonds or climate derivatives. Catastrophe bonds may be used by insurers as an alternative to traditional catastrophe reinsurance. They make a transfer from the natural disaster risk with the aid of bonds, the reimbursement of which is subject to the occurrence of one or more natural disasters.

Climate derivatives are tradable financial instruments which allow organisations or individuals to reduce risk associated with adverse climate conditions. They provide protection from non-catastrophic risks such as cooler summers or warmer winters. There may for instance be a demand for climate derivatives in the tourism or agriculture sectors.

3) Public-private partnerships

The CEA argues for enhanced co-operation between governments and insurers, and a well-tuned balance between market capacity and State intervention.

Beyond the EU, the role of the insurance business in adaptation to climate change is also increasingly recognised. At UN level, efforts are currently being undertaken by the UNEP Finance Initiative to bring insurance and creative financial instruments to developing countries through public-private partnerships in order to assist them in adapting to current and future climate change (UNEP FI 2006). Such approaches might also help to avoid increasing strain on international aid budgets.

In the US, new insurance activities are also emerging, spurred by the devastating hurricane season in 2004 and 2005 that caused a $75 billion in insured losses. US insurers stress the need to develop innovative products and services, not only to minimise the impacts of climate change but also to address the root causes of climate change itself. Instruments thus include “green” building credits and incentives for investing in renewable energy (CERES 2006).

6.4 Overview of adaptation measures taken by European countries

Recent evaluations of action taken by the EU Member States show that climate change impacts and adaptation are rising on the national agendas. Many countries have undertaken studies on climate change impacts and vulnerability in key sectors (see for instance EEA 2005b, p. 33-35), and many countries have advanced impact assessments. However, despite the high level of awareness on impacts and vulnerabilities, few governments seem to move on to implementing adaptation initiatives and incorporating long-term climate change risks into actual investment or development plans on a national and local scale (EEA 2005b, Gagnon-Lebrun and Agrawala 2006, Stern 2006). The first national adaptation strategy in the EU was published by Finland in 2005, and national strategies, plans or frameworks for adaptation are under preparation in Denmark, Germany, Lithuania, Norway, Spain and the UK (UK Environment Agency and Defra 2006). In the Czech Republic and in Romania, adaptation is included in national programs or action plans on climate change. In other countries, adaptation measures also take place in the context of natural hazard prevention, environment protection, and sustainable resource management.

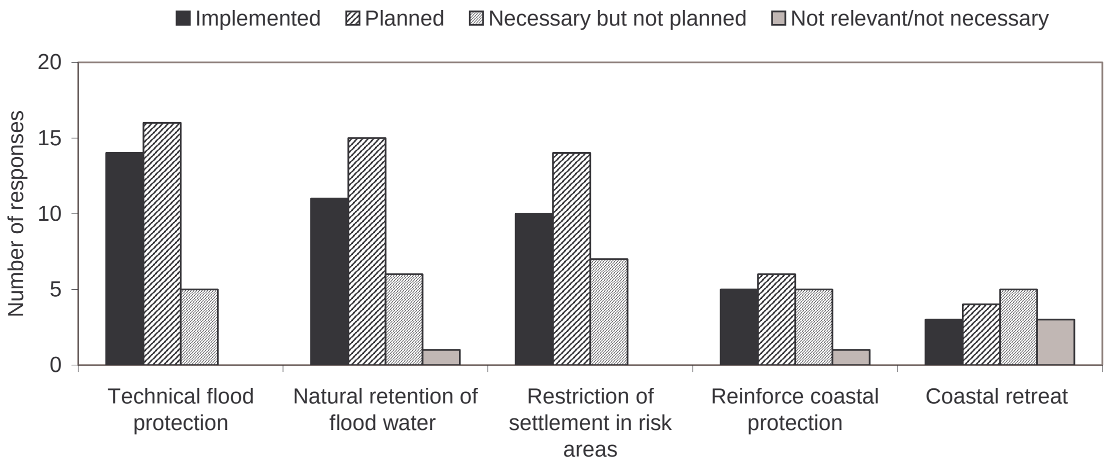
The questionnaire survey undertaken as part of the present research project aimed at collecting information about **adaptation measures and initiatives undertaken by Member States in response to water-related climate change impacts**. The survey results generally support the conclusions drawn by other studies on adaptation: while the degree of awareness is generally high, the implementation of adaptation activities seems to be lagging behind, at least in certain areas. A number of adaptation measures and initiatives are mentioned by respondents, but many of them are still at the planning stage. Furthermore, adaptation activities related to water currently seem to be focused on flood management and defence, while adaptation measures related to the management of water scarcity and drought, although recognised in the vulnerability assessment as equally damaging, do not yet seem to be widespread.

For a list of individual adaptation measures that were suggested by the questionnaire, Figure 23 shows how many respondents indicated that these measures have already been ***implemented***, are ***planned***, are considered ***useful but have not yet been planned or implemented***, or are considered ***not relevant or not necessary***. The first graph (Figure 23 a) summarises responses for measures related to flood protection, the second graph (Figure 23b) refers to measures related to water scarcity and drought management, and the third graph (Figure 23c) summarises all measures related to awareness and information, monitoring and insurance.

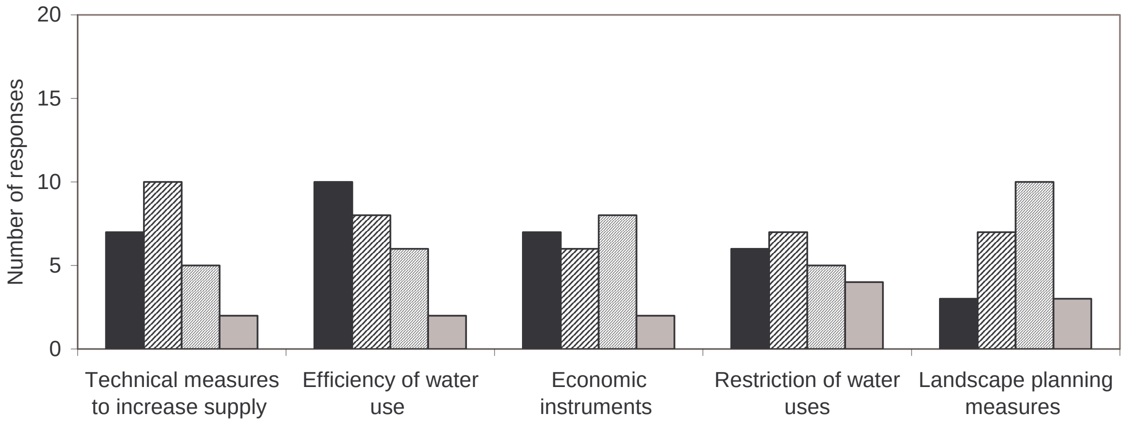
As can be seen from Figure 23, protection against floods generally receives a higher level of attention than protection against water scarcity and droughts. Among the measures that are considered useful, but where implementation is not yet far advanced, are “economic instruments (e.g. water pricing)”, “landscape planning measures to improve water balance”, and improvement of insurance schemes both against flood and against drought damage. A significant number of respondents have either implemented or are planning measures to improve weather forecasting, monitoring and information, and it is also interesting to note that the vast majority of respondents have implemented and are planning awareness raising or information campaigns.

A number of countries clearly indicated that many of the measures mentioned in the questionnaire were being implemented or under discussion, but that this was taking place outside the context of climate change. Not surprisingly, responses also reflect differences in geographical and hydrological conditions. A low level of activity is generally indicated by countries that do not expect to be strongly affected by certain water resource changes (e.g. no drought protection measures in Sweden).

a) Measures related to flood risk management



b) Measures related to management of water scarcity and drought



c) Measures related to information, monitoring, insurance

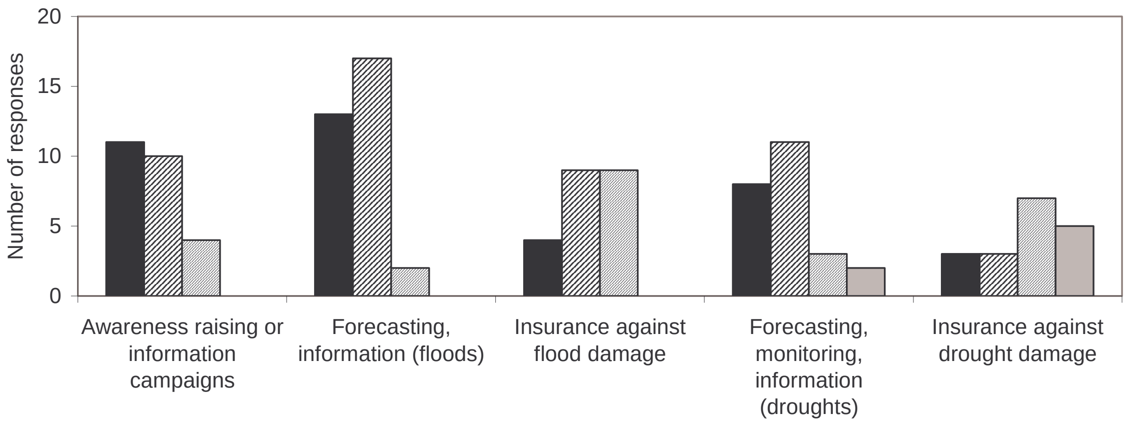


Figure 23 Implementation of adaptation measures in Europe (questionnaire survey).

In addition, the questionnaire invited Member States to give examples of adaptation actions or initiatives currently underway. The responses varied widely with respect to the types of initiatives mentioned and the level of detail provided. An overview of adaptation initiatives that were indicated by the respondents is presented in Annex II.

The responses may be summarised under the following categories:

- **Long Term Planning/ Policy/ Research**. Many countries' adaptation strategies currently exist in the shape of research programmes or policy investigations. These include policy guidelines, planning strategies and consultation processes. They are often responses to the large uncertainties in climate change adaptation, but reflect the country's intention to prepare for managing adaptation efforts (countries include Germany, The Netherlands, UK, Slovakia, Sweden, Spain). National or regional Action Plans or Strategies for adaptation were mentioned by the UK, Spain and Romania.
- **Flood Defence and Management**. Largely in response to observable trends, as well as projected climate scenarios, many countries have invested in projects to enhance their capacity to deal with flood events (countries include Austria, The Netherlands, Belgium, UK, Slovenia, Hungary). The scope of these initiatives differs largely and may include research, technical measures, or land use management.
- **Coastal Defence**: Countries with vulnerable coastlines are adapting defence systems and management structures to better prepare and deal with storm surges and sea level rise (Germany, The Netherlands).
- **Water scarcity management**: Relatively few initiatives related to water scarcity management are mentioned. Most prominently, demand and supply management such as improving irrigation systems and water metering or leakage reduction and desalinisation are referred to by Malta and Cyprus.

Some of these initiatives are small and relatively low budget projects, while others are massive undertakings involving the co-ordination and support of several agencies, departments and stakeholders.

It is interesting to look at the factors that according to questionnaire responses have triggered adaptation activities. Not all of the adaptation activity recorded by the questionnaire was claimed by the recipients to be motivated mainly, or even primarily, by climate change considerations. Often adaptation to climate change is incorporated into existing planning instruments by way of update or revision. In particular, climate model results do not appear to be sufficient grounds for undertaking large scale projects – observable trends and events clearly are a much stronger motivation to take action. Generally adaptation seems to be facilitated if it coincides with other objectives, and if win-win solutions can be implemented that also benefit other purposes. It also becomes clear from the questionnaires that countries are more likely to take concrete steps towards adaptation measures when they are sure of the costs and benefits involved.

7 Adaptation: Policy action at European level

At EU level, the importance of adaptation to climate change for European societies is increasingly being recognised. The European Commission published a Green Paper on Adaptation in June 2007, which represents the first comprehensive review of the discussion on adaptation in Europe, and sets the scene for adaptation efforts in the EU (see below).

The results of the questionnaire survey suggest that European countries would welcome support of their adaptation efforts at European level. The Water Framework Directive is seen as a vehicle for adaptation strategies by many respondents, but a need is also expressed to create a consistent framework for adaptation involving all existing instruments in European water policy and related policies. While many respondents highlight the subsidiarity principle and the need of Member States to react flexibly to the specific challenges in their countries, many see a role for the EU in the co-ordination of sectoral policies, in supporting monitoring and information exchange, and in awareness raising and education.

The existing European policy framework certainly provides scope for integrating climate change concerns and instruments for addressing adaptation. However, to date little has been done to mainstream adaptation into the relevant EU policies such as the Water Framework Directive and the Common Agricultural Policy. The following sections explore options for adaptation to water-related climate change impacts in relevant overarching and sectoral EU policies. For each of the individual sectoral policy areas, a brief outline of the respective European policy and recent/current developments is presented, and the scope for adaptation under the existing policy and/or needs for revision are identified. European funding instruments and their potential role in adaptation are analysed in section 7.1.5.

7.1 Overarching policies and programmes

7.1.1 The European Climate Change Programme and the Green Paper on Adaptation

As older EU legislation insufficiently addressed the issue of climate change, the EU launched the **European Climate Change Programme** (ECCP) in 2000, focusing on mitigation and prevention of climate change[15]. The ECCP is a multi-stakeholder consultative process which aims at identifying and developing all the necessary elements of an EU strategy to implement the Kyoto Protocol. The process has brought together relevant players, such as the Commission, national experts, industry and the NGO community, who actively participated in the search for intelligent and innovative measures to reduce greenhouse gas emissions. The second European Climate Change Programme (ECCP II) was launched in 2005. While efforts to mitigate climate

[15] For further information see http://europa.eu.int/comm/environment/climat/eccpii.htm.

change are continued and further developed, the ECCP II also introduced a new focus on impacts and adaptation. One of the five stakeholder working groups under the ECCP II deals with these issues, with the objective of defining the EU role in adaptation policies, to integrate adaptation into relevant EU policy areas, and to identify good, cost-effective practice in the development of adaptation policy. Topics to be discussed include national strategies for adaptation, impacts on water resources and extreme events, agriculture and forestry, regional planning and built environment, and coastal zones and tourism.[16] The Commission launched a **Green Paper on Adaptation** to Climate Change for consultation in 2007 (European Commission 2007a).

The Green Paper analyses how adaptation efforts could be integrated into existing sectoral EU policies, how Community funding programmes could take climate change and adaptation into account, and also explores the scope for developing new policy responses, in particular with respect to financial services and insurance, and spatial planning. The Green Paper announces that a systematic check of how climate change will affect all Community policy and legislation should be carried out by 2009.

With respect to water policy, the Green paper emphasises the importance of applying economic instruments and the user pays principle across all sectors, and to create incentives to reduce water consumption and the efficiency of water use. It states that for flood protection, soft non-structural measures based on sustainable land-use and spatial planning should be given priority, although structural flood defences will continue to play an important role.

In addition to early action within EU policies, the Green Paper addresses the integration of adaptation into EU external action, the need to reduce uncertainty through integrated climate research, and the involvement of European society, business and public sector in the preparation of coordinated and comprehensive adaptation strategies.

The Green Paper was subject to a public consultation that ended in November 2007. A Communication on adaptation is expected for end of 2008.

7.1.2 The Environmental Action Programme

The cornerstones of EU environmental actions are outlined in the **Sixth Environmental Action Program** (EAP) entitled Environment 2010: Our Future, Our Choice. [17] The Action Programme focuses on:

- climate change and global warming;
- the natural habitat and wildlife;
- environment and health issues;
- natural resources and managing waste.

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16 ECCP II – WG 2: Impacts and Adaptation. Mandate, available at circa server: http://forum.europa.eu.int/Public/irc/env/eccp_2/library.

17 Decision No 1600/2002/EC of the European Parliament and of the Council of 22 July 2002 laying down the Sixth Community Environment Action Programme, see also: http://www.europa.eu.int/comm/environment/newprg/index.htm.

In addition, the Action Programme emphasises the importance of taking the environmental impact into account in all relevant EU policies (e.g. agriculture, development, energy, fisheries, industry, the internal market, transport). Cross-cutting issues are addressed via thematic strategies dealing with air pollution, waste prevention and recycling, the marine environment, soil, pesticides, resource use and the urban environment[18].

With regard to climate change, the 6th EAP demands that the Community should prepare for measures aimed at adaptation to the consequences of climate change, by:

- reviewing Community policies, in particular those relevant to climate change, so that adaptation is addressed adequately in investment decisions;
- encouraging regional climate modelling and assessments both to prepare regional adaptation measures such as water resources management, conservation of biodiversity, desertification and flooding prevention and to support awareness raising among citizens and business.

In order to meet these aims, the Programme focuses among other things on the effective implementation and enforcement of environmental legislation.

7.1.3 Science and Technology

Adaptation to water-related climate change effects will require further research to project the impacts at regional level and to facilitate early prediction of natural disasters in order to enable local and regional public and private sector actors to develop cost-effective adaptation options. Further, adaptation to climate change will also require technological innovations and investment.

Two instruments set up by the EU are relevant for addressing these needs:

- Environmental Technology Action Plan (ETAP). ETAP aims to reduce pressures on our natural resources, improve the quality of life of European citizens and stimulate economic growth. Within ETAP, 25 actions have been outlined to address these aims, containing measures to develop new technologies addressing environmental issues but also to establish technology platforms for some complex technologies, so as to co-ordinate research and improve partnerships and funding.
- The Framework Program for Research is the European Union's main instrument for funding research and development. The Commission's proposal for the upcoming 7th Framework Programme FP7, organises collaborative research into nine themes related to the environment, including the issue of climate change. The first call under the programme, which was released in December 2006, puts an emphasis on the prediction of climate, ecological, earth and ocean systems changes, on tools and on technologies, for monitoring,

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[18] The European Commission prepared seven Thematic Strategies: Air Pollution (adopted 21/09/2005), Prevention and Recycling of Waste (adopted 21/12/2005), Protection and Conservation of the Marine Environment (adopted 24/10/2005), Soil Sustainable Use of Pesticides, Sustainable Use of Resources (adopted 21/12/2005), Urban Environment (adopted 11/01/2006)

prevention and mitigation of environmental pressures and risks including on health and for the sustainability of the natural and man-made environment[19]. Future calls are expected to consider, among other issues, extreme events, non-linear climate impacts and threshold responses, urban floods, non-structural flood protection and interactions between land- use and climate change.

In order to address the growing need for new technologies and new management systems that can ensure security of supply, the Commission has established a **European Technology Platform** on water supply and sanitation (WSSTP) in 2004.[20] This Platform should develop – together with the key stakeholders – a strategic vision for the development of sustainable water supply and sanitation technologies, with a medium to long time frame in order to define a common research agenda and implementation plan. Such innovative technologies as water saving techniques, reuse approaches, clean processes, end-of-pipe treatments, system design, IT-tools for management, monitoring and control systems, flood forecasting techniques, ecological engineering, appropriate technologies, desalination, etc. can help adapt the water supply and sanitation sector to climate change.

The questionnaire survey carried out as part of this study showed that European water managers see a strong role for European research in assisting national adaptation efforts. The responses to the questionnaire identified research needs in several areas (Box 9).

Box 9 Research needs identified by Member States (Questionnaire survey)

The general role of European research in assisting national adaptation efforts was recognised. Respondents identified research needs in the following areas:

- **Climate modelling**: a very popular request was for enhanced regional climate change scenarios or the scaling-down from global to regional and from regional to local climate scenario information. It was also suggested to address uncertainties in climate change scenarios and the seasonality of future changes in climate.
- **Modelling of changes in water resources**. Requests were also made for regional and local data to be merged with hydrological models and to improve the accuracy of hydrological and hydraulic models. The need to improve the coupling of climate and hydrological models was also highlighted.
- **Observation**. With respect to the observation of climate change trends, respondents pointed to the necessity of maintaining observation networks and suggested including remote sensing techniques in hydrological monitoring.
- **Impacts and vulnerability**. The need for research on the vulnerability of European societies to climate change impacts was felt by many of the Member States. Respondents were concerned about several specific issues, for instance water-related climate change impacts on individual sectors (for instance impacts of heavy rainfall and drought on the sewage system), the quantification of impacts, the socio-

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19 see http://www.cordis.lu/fp7/home.html.

20 See http://www.wsstp.org/.

economic consequences of climate change impacts (for instance of sea level rise), the relationship between climate change impacts and land use (e.g. impacts on peatlands, sensitivity and responses of habitats and species), research into the long term use of recycled water in agriculture, and desertification.

- **Adaptation**: Several respondents saw a need for research to develop adaptation measures and assess their effectiveness and efficiency. For instance, research should help design tools that demonstrate the economic benefit and cost-effectiveness of adaptation at the river basin scale and develop indicators for successful adaptation measures.

7.1.4 Public Participation

The implementation of measures to mitigate and to adapt to climate change will strongly rely on public acceptance. Therefore information about climate change and its impacts on water resources and raising awareness about the relationship between water use and the depletion and deterioration of water resources, is crucial. Obligations resulting from adaptation needs will more easily be accepted if the rationale behind them is known and understood.

The most influential document with respect to public participation in the area of the environment on the international level is the Aarhus Convention. This Convention acknowledges that protection of the environment and sustainable development cannot be achieved without the involvement of a well-informed public. It endows citizens with the rights of access to environmental information (Article 4 and 5), public participation in decision-making (Article 6-8), and access to justice in environmental matters (Article 9), thus promoting "environmental democracy".

The Directive 2003/4/EC on public access to environmental information[21], provides that every natural or legal person, regardless of citizenship, nationality or domicile, has a right of access to environmental information held by or produced by public authorities. Environmental information includes air, water and soil quality, biological diversity, noise, health and safety implications. Following implementation of the Directive, the applicant may be able to request environmentally significant information from the public authority, such as data collected on emissions or the results of environmental impact assessments. The Directive also obliges the authorities to make, on their own initiative, such information available on electronic databases that are publicly accessible.

Public participation has become an integral part of European policy making and is anchored in specific sectoral legislation such as the Water Framework Directive. Article 14 of the WFD requires Member States to encourage active involvement of interested parties in the implementation process, particularly in the setting up of river basin management plans. Access to relevant information and to background documents is to be ensured by the Member States.

Public access to relevant information will be a key issue for the successful implementation of both mitigation and adaptation measures.

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[21] Directive 2003/4/EC of the European Parliament and of the Council on public access to environmental information, 28 January 2003.

Box 10 Germany’s new competence centre on adaptation

As part of the German government’s work on a national strategy on adaptation to climate change, in October 2006 the environment ministry and environment agency launched a "competence centre" on climate change impacts and adaptation (KomPass).

The objective of KomPass is to collect data and information on climate change impacts and adaptation and make it available to decision-makers and the public, and to support information exchange and networking among the relevant stakeholders. The centre’s work is expected to increase risk awareness in business and administration, to allow the respective decision-makers to better assess their sensitivity and vulnerability to climate change, and to improve risk management measures. Services of KomPass will include:

- Scientific support to the ministry’s work on the national adaptation strategy
- Collecting the results of scientific research on regional climate change impacts and presenting them in formats that can be used by decision-makers.
- Providing up-to-date information on its website and through a newsletter
- Building networks and organising workshops and seminars.

Among other things, the focus will be on flood protection, planting of crops and trees that can withstand higher temperatures and less precipitation, and a new health warning system for heatwaves.

See the Federal Environment Agency’s website at www.anpassung.net

7.1.5 EU funding of adaptation measures

The structure of European cohesion policy has been reformed for the new programming period 2007 – 2013. During this period, a total volume of € 308 billion (in 2004 prices) will be available to support investment, which is equivalent to more than one third of the European Union budget. The new funding policy focuses on regional growth agendas and the stimulation of job creation, in support of the EU’s strategic priorities of the Lisbon agenda. Of the total amount, 82% will be concentrated on the “Convergence” objective, under which the poorest Member States and regions are eligible. In the remaining regions, about 16% of the Structural Funds will be concentrated to support innovation, sustainable development, better accessibility and training projects under the “Regional Competitiveness and Employment” objective. Another 2.5% finally are available for cross-border, transnational and interregional co-operation under the “European Territorial Co-operation” objective.[22]

The cohesion policy is based on three sources of financing: the European Regional Development Fund (ERDF), the European Social Fund (ESF), and the Cohesion Fund.

The **European Regional Development Fund (ERDF)[23]** will promote public and private investments helping to reduce regional disparities across the Union. The ERDF will

22 See http://www.ec.europa.eu/regional_policy/sources/docoffic/2007/osc/index_en.htm.

23 Regulation (EC) No 1080/2006 of the European Parliament and of the Council of 5 July 2006 on the European Regional Development Fund and repealing Regulation (EC) No 1783/1999.

support programmes addressing regional development, economic change, enhanced competitiveness and territorial co-operation throughout the EU. Funding priorities include research, innovation, environmental protection and risk prevention, while infrastructure investment retains an important role, especially in the least developed regions.

The **European Social Fund (ESF)**[24] will be implemented in line with the European Employment Strategy and it will focus on four key areas: increasing adaptability of workers and enterprises, enhancing access to employment and participation in the labour market, reinforcing social inclusion by combating discrimination and facilitating access to the labour market for disadvantaged people, and promoting partnership for reform in the fields of employment and inclusion.

The **Cohesion Fund**[25] contributes to interventions in the field of the environment and trans-European transport networks. It applies to Member States with a Gross National Income (GNI) of less than 90% of the Community average which means it covers the new Member States as well as Greece and Portugal. Spain will be eligible to the Cohesion Fund on a transitional basis. In the new period, the Fund will contribute alongside the ERDF to multi-annual investment programmes managed in a decentralised way, rather than being subject to individual project approval by the Commission.

The Community strategic guidelines on Cohesion 2007 – 2013,[26] which were adopted in October 2006, set out three general priorities for the targeting of the funding resources:

- Improving the attractiveness of Member States, regions and cities by improving accessibility, ensuring adequate quality and level of services, and preserving their environmental potential;
- Encouraging innovation, entrepreneurship and the growth of the knowledge economy by research and innovation capacities, including new information and communication technologies; and
- Creating more and better jobs by attracting more people into employment entrepreneurial activity, improving adaptability of workers and enterprises and increasing investment in human capital.

Table 7 gives an overview on the new structure of the European Cohesion policy.

The different structural funding mechanisms available under the European cohesion policy are potentially important instruments for supporting adaptation. One of the main aims of the funds is tackle regional disparities and support regional development through actions including the development of infrastructure. Such regional disparities clearly exist also with regard to climate change impacts and adaptive capacity. Climate change impacts and adaptation measures will be beneficial for some regions and

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[24] Regulation (EC) No 1081/2006 of the European Parliament and of the Council of 5 July 2006 on the European Social Fund and repealing Regulation (EC) No 1784/1999.

[25] Council Regulation (EC) No 1084/2006 of 11 July 2006 establishing a Cohesion Fund and repealing Regulation (EC) No 1164/94.

[26] Council Decision of 6 October 2006 on Community strategic guidelines on cohesion (2006/702/EC).

individuals and disadvantageous for others. One of the challenges of adaptation policy is to identify, protect and compensate those who will suffer damaging impacts, and to support those regions where particularly severe impacts are to be expected.

With their focus on environment, risk prevention and infrastructure (see Table 7), the funding instruments of the EU cohesion policy could play a major role in many countries' adaptation strategies. For instance, they could assist many of Europe's poorer regions to put in place the water systems necessary to cope with supply and demand problems resulting from climate change in coming decades.

On the other hand, funding policies could be used to encourage adaptation by making support conditional upon taking into account climate change in projects supported through such investments, and upon ensuring that projects do not run counter to adaptation concerns (UK Environment Agency and Defra 2006).

Table 7 EU cohesion policy 2007–13[27]

Cohesion Policy 2007 – 2013 Budget: EUR 307.6 bn (0.37% of EU-GNI)			
Programmes and Instruments	**Eligibility**	**Priorities**	**Allocations**
Convergence objective			81.7% (EUR 251.33 bn)
Regional and national programmes ERDF ESF	Regions with a GDP/head < 75% of average EU25	• Innovation • Environment/risk prevention • Accessibility • Infrastructure • Human resources • Administrative capacity	57.6% EUR 177.29 bn
	Statistical effect: Regions with a GDP/head < 75% of EU15 and > 75% in EU25		4.1% EUR 12.52 bn
Cohesion fund Including phasing out	Member States GNI/head < 90% EU25 average	• Transport (TENs) • Sustainable transport • Environment • Renewable energy	20.0% EUR 61.42 bn
Regional competitiveness and employment objective			15.8% (EUR 48.79 bn)
Regional programmes (ERDF) and national programmes (ESF)	Member States suggest a list of regions (NUTS I or II)	• Innovation • Environment/risk prevention • Accessibility • European Employment Strategy	15.5% EUR 38.4 bn
	"Phasing-in" Regions covered by objective 1 between 2000 and 2006 and not covered by the convergence objective		3.4% EUR 10.38 bn
European territorial co-operative objective			2.44% EUR 7.5 bn
Cross-border and transnational programmes and networking	Border regions and greater regions of transnational co-operation	• Innovation • Environment/risk prevention • Accessibility • Culture, education	

[27] See http://www.ec.europa.eu/regional_policy/sources/slides/slides_en.htm#2007: Ppt - Presentation: "After the European Council's Agreement on the Financial Perspectives: Putting EU Cohesion Policy into practice 2007-2013".

Another EU funding instrument that may be used in the context of climate change adaptation is the European Union **Solidarity Fund**. The Solidarity Fund has an annual budget of one billion Euro and can be used for immediate actions after a major disaster event such as flooding and droughts. Support can for instance be provided to

- restoration to working order of infrastructure in the fields of energy, water and waste water, telecommunications, transport, health, and education;
- providing accommodations and rescue services;
- securing of preventive infrastructures and measures for immediate protection of the cultural heritage; and
- cleaning up disaster-stricken areas, including natural zones.

To qualify for funding, countries hit by a “major disaster” (damage above three billion Euro or more than 0.6% of the gross national income) must give a precise appraisal of damage caused and fulfil specific criteria, which ensures that EU funds are used where they are needed most. Under exceptional circumstances, a region could also receive assistance from the fund when it has been affected by an extraordinary disaster, affecting a major part of its population, with serious and lasting repercussions on living conditions and the economic stability of the region.

The structure of agricultural subsidies, which form the largest item in the EU’s budget, may also be adjusted to take into account climate change impacts and support adaptive action. This issue is discussed in more detail in section 7.3.2.

7.2 Relevant international activities and processes

Several international activities in which the EU or its Member States are involved deal with adaptation to climate change and could potentially influence policy action within the EU. For instance, a five-year programme on adaptation was initiated under the **United Nations Framework Convention on Climate Change in 2005**,[28] which aims to improve the understanding and assessment of impacts, vulnerability and adaptation, and to make informed decisions on practical adaptation actions and measures to respond to climate change. While focusing on developing and least developed countries, the collection and dissemination of methods and tools for adaptation which is foreseen under the programme might also assist European countries in their efforts.

The **Alp Convention** in its 2005-2010 work programme commits to elaborating a protocol on water resources, and mentions climate change impacts on water resources in relation with other water issues such as drinking water supply, hydropower, protection of glaciers, snow, and floods.[29] At the 9th conference of the parties of the Alp Convention in November 2006, environment ministers issued a declaration on climate

[28] Decision 2/CP.11: Five-year programme of work of the Subsidiary Body for Scientific and Technological Advice on impacts, vulnerability and adaptation to climate change. FCCC/CP/2005/Add.1., available at www.unfccc.int.

[29] Das Mehrjährige Arbeitsprogramm der Alpenkonferenz 2005 – 2010. Available at www.alpenkonvention.org.

change and adaptation,[30] which calls for the development of adaptation strategies for the Alps region, and for international research initiatives in order to improve understanding of the impacts of climate change on the Alps. The declaration contains recommendations to be considered in national policies and in the common activities of the Parties of the convention. These recommendations focus on the land use and forestry, tourism and transport sectors, but also put an emphasis on strategies for adaptation to changes in water resources in order to meet challenges from increases in extreme precipitation events and drought periods, and to solve conflicts of interest in water use.

The declaration also announces that in the implementation of the 2005-2010 work programme and the corresponding research agenda, options for adaptation to climate change impacts on the water balance will be treated as a priority issue.

Box 11 Switzerland's adaptation strategies in its mountainous region

Switzerland is a hazard prone country with natural disasters ranging from floods, landslides, and snow avalanches. Climate models have shown that Switzerland is particularly vulnerable to the impact of climate change, as its temperature rise in the 20th century between 1.3 and 2.0 ºC exceeded the global average of only 0.8 ºC. This increase in temperature has increased precipitation in the country, thus exacerbating natural hazard risk. In response to increased flood risks, the Swiss government has created a new flood management policy, which integrates flood protection aspects in the planning and co-ordination of all land-use activities, including agriculture, forestry and the water supply. The federal law on flood control emphasises prevention, improving the handling of uncertainties, and protection of the economic environment. Increased precipitation due to climate change has also increased landslides and avalanches in the country since the 1970s. The National Platform for Natural Hazards (PLANAT) was created in 1997 to improve management of such disasters. Substantial changes to the framework have subsequently been undertaken, and increasingly the emphasis is shifting to preventative and adaptation measures. Cantons in Switzerland are now required to use regional maps to depict hazardous areas to better understand risks. Furthermore, in assistance with the federal government, the cantons are enhancing protection of built-up areas, transport infrastructures, and information systems.

Source: Schädler 2004.

Adaptation to climate change impacts furthermore plays a role under the international **Convention on Biological Diversity** (CBD). The risks climate change poses for instance to coral reefs has been highlighted by the Conference of the Parties, and attention has been given to the relationships between climate change, adaptation and biodiversity, which are explored in an ad hoc Technical Report by the CBD (CBD 2003). The reports concludes that there are significant opportunities for mitigating climate change, but also for adapting to climate change while enhancing the

[30] IX. Tagung der Alpenkonferenz, Anlage 1: Deklaration. Dokument IX/07/01, 98.11.2006. Available at http://www.bmu.de/int_umweltpolitik/weitere_multilaterale_zusammenarbeit/doc/38179.php.

conservation of biodiversity. Furthermore, it identifies a number of tools that can help decision makers assess the likely impacts and make informed choices, and examines the likely impacts of adaptation options in different terrestrial and aquatic ecosystems.

7.3 EU policies related to focus sectors

7.3.1 Water policy

The adaptation of water management to climate change requires planning under uncertain conditions and a constant consideration of the potential risks and of the costs and benefits connected with adaptation measures. The European Water Policy was developed over the years with the main aim to clean up polluted waters, and to ensure that clean waters are kept clean and available in a sufficient quantity. Up to now, climate change impacts have not been a major concern in EU water policy. The current water legislation therefore contains only a limited number of explicit references to climate change impacts. However, there is broad scope within the different policies to integrated adaptation efforts.

Water Framework Directive

The Water Framework Directive (WFD)[31] shifts the focus of policy-making from addressing problems individually to integrated river basin management. The main objective of the Directive is to ensure that by 2015 all European waters achieve “good status” – a concept which integrates chemical, ecological and morphological indicators. River basins are required to set up appropriate management plans to achieve the objectives and revise them periodically.

Climate change is not explicitly included in the text of the WFD. However, recent analyses have shown that climate change impacts may interfere with several of the key phases and with the delivery of key environmental objectives of the WFD (Eisenreich et al. 2005, p. 136; Wilby et al. 2006). Climate change is likely to influence or pose risks to the characterisation of river basins and their water bodies, risk assessments to identify pressures and impacts, programmes of measures options appraisal, monitoring and modelling, and policy and management activities (Wilby et al. 2006). On the other hand, if climate change impacts and adaptation concerns are considered in the WFD implementation process, it may provide a powerful tool for supporting climate change adaptation policies on a national and regional scale, and for integrating climate change adaptation measures in river basin management planning. Its integrative approach to management allows to encourage the contribution to adaptation efforts by all relevant sectors and stakeholders.

The WFD makes reference to extreme events, which are relevant in the context of climate change. Article 1 mentions the mitigation of the effects of floods and droughts as one of the purposes of the Directive, in addition to other objectives such as the promotion of sustainable water use based on a long-term protection of available water

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[31] Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for community action in the field of water policy. Official Journal L 327, p 1-72.

resources, and the provision of a sufficient supply of good quality surface water and groundwater. Article 4(6) classifies extreme floods and prolonged droughts as events of ***force majeure***, in the case of which a temporary deterioration in the status of water bodies is to be allowed.

The essential element of the WFD, the integrated river basin management planning process, may represent an important mechanism to support adaptation to climate change impacts. The WFD utilises the river basin as the natural unit for water management. Each river basin within a Member State must be assigned to a river basin district (RBD) and the Member State must co-ordinate administrative arrangements for water management in relation to each RBD lying within its territory.

Article 11 of the WFD forces Member States to define and implement for each RBD and for those parts of international river basin districts falling within its territory, a summary programme of measures to address the pressures on waters. These so called Programmes of Measures (PoM) can be considered as the principle mechanism for implementing the environmental objectives required by the WFD by 2015 and the specific environmental objective of each river basin district (Hansen et al., 2004). PoMs have to be carried out based on the risk assessment outlined under Article 5 of the WFD. Such programmes of measures represent a new framework for controlling activities within an RBD. These activities do not have to be water-based only, they also might include land-use activities. A Programme of Measures may include wide-ranging actions such as:

- measures to manage specific pressures arising from forestry, agriculture, urban development, etc;
- control regimes or environmental permitting systems;
- water demand management measures;
- economic instruments such as incentives, taxes on fertilisers, etc;
- river restoration strategies, etc.

A summary of the programme of measures forms part of the River Basin Management Plan (RBMP) which can be considered as the main reporting mechanism to the Commission and to the public. The plan is a detailed account of how the objectives set for the river basin (ecological status, quantitative status, chemical status and protected area objectives) are to be reached within the timescale required. The RBMP have to be reviewed every six years, which is quite a short period compared to the time scale at which climate change takes place. The six year planning cycle allows each river basin to set short- and long-term targets and related measures to be achieved stepwise. At the beginning of each cycle a reflection of the previous one is required to make necessary adjustments. This allows for a stepwise and continuous adaptation process, and for the consideration of new results from climate change projections and adaptation measures in other sectors.

Furthermore, Article 9 of the WFD introduces water pricing as a central element. It requires the design of policies having regard to social, environmental, economic effects and to the geographic and climatic conditions of the region or regions affected to address problems of water quality and quantity. This approach allows to recover costs resulting from the adaptation to climate change with some flexibility.

Including public participation and stakeholder involvement in the WFD (Article 14) allows for the balancing of various groups' interests for taking decisions on the most appropriate measures to achieve the objectives in the river basin management plan. The economic analysis requirement is intended to provide a basis for this, but it is essential that the process be open to the scrutiny of those who will be affected. This approach allows for informing on and raising awareness for effects of climate change. It further offers the opportunity to involve stakeholders and the interested public in the development of appropriate and commonly agreed adaptation measures.

For making full use of the WFDs potential to support adaptation, guidance on water resource management and climate change adaptation at the European level may be helpful, and new typologies and screening tools may be needed to identify which water bodies are most vulnerable to climate change (UK Environment Agency and Defra 2006, Wilby et al. 2006).

Box 12 Member States ideas on adaptation and the WFD (questionnaire survey)

The questionnaire asked respondents to suggest ways in which elements of the Water Framework Directive (WFD) could be used to address climate change impacts. The general impression given by the responses is that the implementation of the WFD overlaps with many of the aims of adaptation measures, such as maintaining quality and quantity of water resources. The greater control and quality of information offered by the WFD policy system will aid water managers in their efforts to adapt to changing conditions.

In few instances it was also indicated that some of the requirements of EU policy, such as meeting 'good status' in all waters, might also hinder adaptation efforts. This was especially the case when contemplating the upgrading of certain water courses as part of flood defences, and the impact this upgrading work might have on the ecological condition of water systems.

Additionally, one country (Norway) replied that the Floods Directive was a more relevant EU policy in terms of climate change adaptation than the WFD, again revealing the focus of many respondents on physical impacts and adaptation, especially flooding.

The responses received can be summarised under the following categories:

1. ***Programmes of Measures: examples of and ways in which PoMs will help increase the adaptive capacity of water systems in respondents' countries.***

Suggestions include that each RBD should conduct a climate change impact assessment and then formulate PoMs to implement adaptation measures; using formal cost-benefit analysis. The potential role of PoMs in reducing the secondary impacts of climate change was highlighted. Some respondents called for PoMs to pay more attention to trends related to water availability, and to introduce measures for mitigating water scarcity, including control of groundwater abstraction. Another respondent argued that the WFD did not pay sufficient attention to extreme events, and called for additional management plans for flood and drought management.

2. ***Water Management: ways in which water management principles and models associated with the WFD will enable countries to better adapt to changes in water***

systems.

Some respondents pointed out how the implementation of the WFD might have the synergetic effect of improving adaptive capacity. Catchment-wide solutions as required by the WFD are considered more suitable to adaptation management than previously existing management systems. The cyclical review process of RBMPs provides means that procedures are amended regularly using the latest available evidence and information, which makes the management system more flexible and therefore adaptive. Furthermore, respondents emphasised that WFD assessment of flood risk is relevant to adaptation planning, as are cross-border management and early warning systems.

3. ***Monitoring: the role of monitoring practices and information in helping the adaptation process.***

According to the responses, monitoring and risk assessment as foreseen under the WFD will provide valuable information for regional planning and development and thus create an adequate knowledge base which is a key prerequisite for adaptation. The collection of information under the WFD would provide information on water systems that are at, or near to, capacity, and it would help define which impacts are the result of climate change. One respondent pointed out that flood risk mapping would support policy makers in flood management.[32]

In 2003, a **water scarcity initiative** was established under the WFD common implementation process. A first interim report on water scarcity and drought was adopted by the Water Directors in November 2006 (European Commission, 2006i). The report shows that the impacts of climate change on frequency and severity of droughts is of concern among Member States, and that the WFD is seen as an important instrument for addressing drought and water scarcity management, through the implementation of water management plans and associated programmes of measures. It also outlines how other EU and national funding and policy instruments might be used for mitigating water scarcity and drought.

Flood Risk Management Directive

The new EU Directive on flood risk management,[33] which entered into force in November 2007, introduces new instruments to manage risks from flooding, and is thus highly relevant in the context of adaptation to climate change impacts.

The rationale of the Directive recognises climate change as one of several factors that might increase the likelihood and the adverse impacts of floods in the future. The Directive itself also makes reference to climate change in Article 4, stipulating that projected climate change should be taken into account in the assessment of future flood risk and of its consequences on human health, the environment, and the economy.

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[32] Note that the forthcoming EU Flood Risk Management Directive was not mentioned by the questionnaire.

[33] Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks. OJ L 288, pp. 27-34, 6.11.2007.

Overall, the Directive offers a basis for improved and more transparent flood management in Europe, and thus potentially constitutes an instrument to reduce and manage the risks which floods pose to human health, the environment, infrastructure and property.

The Directive introduces a three-step approach. First, Member States have to undertake a preliminary assessment of flood risk in river basins and coastal zones. Where significant risk is identified, flood hazard maps and flood risk maps have to be developed. Finally, flood risk management plans must be developed for these zones. These plans have to include measures that will reduce the potential adverse consequences of flooding for human health, the environment cultural heritage and economic activity; and they should focus on prevention, protection and preparedness.

The Floods Directive represents a powerful tool for addressing increased flood risk from climate change in Europe. In combination with the WFD, the Floods Directive provides an instrument to take full account of climate change effects on flood risk, and, on the basis of the risk assessment and mapping, should encourage water managers to respond to challenges by means of an integrated management approach. The cyclic review process within both Directives allows for a long-term strategic adaptation process that is however flexible enough to react to shorter term changes.

Box 13 Scotland: Flood risk mapping

Increased river flows has led the Scottish Government to create a flood map, which highlights areas where during heavy storms flooding is likely to occur. Heavy storms are likely to increase in the coming years due to the effects of climate change, and the flood maps are designed to aid in planning and to raise awareness within the community. Although the current flood map does not currently include future predictions on increased flooding due to climate change, the map has the potential for revision as new climate models are developed.

See http://www.sepa.org.uk/flooding/mapping/

Marine Strategy Directive

In December 2007, agreement was reached between the European Parliament and the Council on a Marine Strategy Directive. The Directive[34] follows in many aspects a similar approach as the WFD. Member States will have to identify pressures and respond to them by defining specific measures. The Marine Strategy Directive recognises that pressures and impacts on marine ecosystems may vary with the evolvement of different patterns of human activity and the impact of climate change. Therefore, programmes of measures for the protection and management of the marine environment should be flexible and adaptive and take account of scientific and technological developments. While it does not suggest any specific adaptation measures, the Marine Strategy provides a framework and policy instruments that can be used to promote adaptation.

[34] Consolidated Text of the Directive as available on the website of the European Parliament on 6 March 2008.

The Marine Strategy Directive represents the environment pillar of the European Maritime Policy. A policy package on integrated maritime policy launched by the Commission in October 2007 announces work on a strategy for mitigation of climate change and adapting to climate change effects in coastal regions, and pilot actions to reduce the impact of and adapt to climate change in coastal zones (European Commission 2007b and c). The 2006 Green Paper on Maritime Policy, which provided the basis for the development of the integrated Maritime Policy package, mentions that adaptation strategies including the organisation of sea defence may be required to manage risks for coastal and offshore infrastructure resulting from sea level rise, increased flooding and storm surges. It also mentions that Mediterranean coastal zones are likely to be affected by changing precipitation patterns, and that an increased need for desalinisation may result from this (European Commission 2006a).

7.3.2 Agricultural policy

Policy-making at regional, national and EU level may play a key role in facilitating adaptation. The adaptation dimension in particular needs to be considered in the European Common Agricultural Policy (CAP) in order to set appropriate incentives and support adaptive measures.

The Common Agricultural Policy

Among the main drivers behind agricultural production patterns in the EU is the CAP. Its primary objectives are to increase agricultural productivity, to ensure a fair standard of living for the agricultural community and to stabilise markets. Recent reforms have increasingly incorporated environmental concerns.

Financial support is provided to farmers based on two 'pillars'[35] which influence farmers’ production decisions.

- **Market and income support (Pillar 1)** covers direct payments to farmers and market-related measures under the common market organisations (CMO), such as intervention schemes (buying of products into public storage), surplus disposal schemes, and export subsidies.
- **Rural development policy (Pillar 2)**, among other objectives, aims to encourage environmental services and the sustainable use of resources in rural areas, providing assistance to difficult farming areas and promoting food quality, higher standards and animal welfare. These objectives are reflected in the new Rural Development Regulation for the period 2007-2013 (RDR[36]) and its related funding mechanism. It is built along four axes including several rural development measures that can be used to improve the environment (see Dworak et al., 2005). Member States (and regions) select measures from the catalogue provided by the RDR for their national (regional) rural development strategies and programmes, in order to target them specifically to their needs.

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35 See http://europa.eu.int/comm/agriculture/.

36 Council Regulation (EC) No 1698/2005 of September 20, 2005, on support for rural development by the European Agricultural Fund for Rural Development (EAFRD).

Adaptation under the Common Agricultural Policy

Current European policy on climate change takes account of the role of agriculture for mitigation (European Commission 2000), but also recognises that the agricultural sector will have to adapt to climate change impacts in order to secure food production and the functioning of rural areas (ECCP 2006). Despite the lack of explicit references to adaptation in the current framework of the CAP, adaptation concerns might be integrated into the CAP and supported through the existing instruments.

Market and income support

Since the establishment of the CAP, changes in land management practices and agricultural production patterns were significantly influenced by product-related (coupled) payments that farmers received. As a consequence, production decisions not always considered environmental conditions. The 2003 CAP reform introduced the “de-coupled” single farm payment, and market-based incentives became more relevant. Income support is still provided to the agricultural community, but its influence on production decisions is reduced. The de-coupling of support encourages farmers to respond to market signals generated by consumer demand rather than by production-related policy incentives.

However, under the 2003 CAP reform not all payments were de-coupled, and several water-intensive products still receive specific area payments (for example rice). During a transitional period lasting until 2007 at the latest, Member States and regions have options for partial de-coupling in different sectors (cereals, livestock). During this period, incentives for farmers to grow water-intensive crops in dry areas continue to exist.

Rural development policy

The new Rural Development Regulation also provides opportunities to strengthen the contribution of the CAP in combating climate change and supporting adaptation. Climate change mitigation and adaptation are acknowledged as Community priorities in the Community strategic guidelines for rural development (RD[37]), and Member States (and regions) are encouraged to incorporate appropriate actions in their RD programmes to address these priorities. Axis 2 (improving the environment and countryside) of the new regulation could play a crucial role in meeting this objective. In addition, a wide range of measures available under all four axes can make a contribution to the adaptation of agriculture to **long-term effects** resulting from climate change. These measures include:

- investment support for new equipment needed for adaptation (e.g. Art 26 RDR modernisation of agricultural holdings),
- support for the development of new products, processes and technologies in the agricultural, food and forestry sector (Art 29 RDR),
- training and information measures (e.g. Art 22 RDR and Art 58 RDR).

[37] Council Decision of 20 February 2006 on Community strategic guidelines for rural development (programming period 2007 to 2013) (2006/144/EC), published in OJ L 55 of 25.2.2006.

In addition, the new RDR provides an opportunity to set up measures that aim to restore agricultural production damaged by **natural disasters** (for example, extreme events such as flooding) and introducing appropriate prevention actions (Art 20 (b) (Vi) RDR). In a 2005 communication (European Commission, 2005b), the Commission explores possibilities to introduce **new risk and crisis management measures** into the menu of rural development policy. It suggests instruments such as financial contributions to premiums paid by farmers for insurance against natural disaster, support for mutual funds in the agricultural sector, and a generalised approach to respond to income crises. Increasing frequencies of extreme events due to climate change and the associated risks for farmers might be an additional argument to further pursue such approaches.

Currently, Member States are in the process of selecting measures and drafting their national RD programmes. It will depend on the priorities set by the Member States whether the measures provided by the new RDR will be used to encourage the adaptation process. If, for the moment, adaptation measures are not featured, Member States have the opportunity to rearrange their RD strategies towards an adaptation strategy in the future; however, as experiences from previous programmes have shown, changes on a broader scale cannot be expected (European Commission, 2004).

It is important to note that the total share of CAP funding spent on the rural development pillar is still small compared to the budget available under pillar one.

Interaction with other policy areas

Other EU policy areas related to agriculture, such as energy and environmental policy, or national or regional spatial policies, may influence the adaptive capacity of the agricultural sector. There is a need to discuss potential conflicts of interests between different policy objectives, and to identify policies that may exacerbate problems caused by climate change or counteract adaptation efforts.

For instance, the EU has the objective, as part of its energy policy, to promote the use of biomass in order to double the share of renewable energy in total EU energy consumption. The Community Biomass Action Plan (European Commission, 2005c) aims to increase total biomass production from 56 Mtoe[38] in 2001 to 74 Mtoe by 2010. Given that some of the crops used for the production of biofuels, such as maize, may require large amounts of water, fertiliser and pesticides, this development may further exacerbate pressures on water resources (e.g. increase of abstraction for irrigation and risk of groundwater pollution) by agriculture, which may raise concerns with respect to the resilience of agricultural systems to the expected changes in climate. However, it has to be taken into account that the relative environmental impacts of biofuel crops production will depend to a large extent on the farmland areas used, the crops cultivated and the farming practices, and the wide range of climatic, physical, and economic conditions across the EU, which makes the overall assessment difficult.

Adaptation measures in water and flood management may also impact on the agricultural sector. Further, adaptation measures in the water supply and sanitation

[38] Megatonnes of oil equivalent.

sector might require a prioritisation of water uses (see section 6.1.1) resulting in lower preferences for agriculture.)

7.3.3 Energy policy

The EU is taking steps to address its own greenhouse gas emissions in the energy sector. In the context of Europe’s climate policy, adaptation of the electricity sector to climate change is currently less high on the political agenda compared to mitigation. Nevertheless there are several elements in the current policy framework that can be used for the development of adaptation strategies.

With the launch of the “Strategy for a Sustainable, Competitive and Secure Energy” in March 2006 (Green Paper, European Commission 2006f), the European Commission set out the EU’s approach to a future comprehensive energy policy. The document focuses on the aim to satisfy growing energy demand and safeguard supply. It proposes measures in six key areas: 1) competitiveness and the internal market; 2) diversification of the energy mix; 3) security of supply and solidarity between Member States in the case of supply crises; 4) sustainable development; 5) innovation and technology; and 6) external policy. While the Green Paper does not specifically address the issue of adaptation to changing climatic conditions, some of the measures may provide a basis for the development of adaptive action.

- **Strategic approach to future energy mix and technology development.** Under the second priority area, a **Strategic EU Energy Review** is proposed which should analyse the advantages and drawbacks of different energy sources, and which would offer a clear European framework for national decisions on the energy mix. It is furthermore suggested to agree on an overall strategic objective, based on thorough impact assessment, that would balance the goals of sustainable energy use, competitiveness and security of supply. As part of the fifth key area the need for a **strategic energy technology plan** is pointed out. The aim of the EU’s strategic approach to energy research and development is to deliver security of supply, sustainability and industrial competitiveness.
When developed and implemented, these strategic approaches might take account of the impacts of climate change on energy production, and use adaptive capacity and flexibility as a criterion for assessing different energy sources. For the long-term sustainability of Europe’s energy system, its resilience to future climatic change plays a key role.

- **Security of supply and solidarity between Member States**. This priority area includes the protection of the physical security of Europe´s energy infrastructure against risk from natural catastrophes. The development of smart electricity networks, demand management and distributed energy generation are mentioned as possible measures. The strategy further proposes to establish a European Energy Supply Observatory, to improve network security through increased collaboration and exchange of information between system operators, and to improve the physical security of infrastructure. These measures might also help to increase the adaptive capacity of energy supply systems, and should be implemented with a view to climate change impacts.

- **Coherent external energy policy**. The EU's external policy should also consider global effects of climate change and their implications for a secure energy supply. Climate change impacts on international supply grids may have to be considered.

Other EU legislation and policy documents in the field of energy, for instance on the construction of grids/interconnectors, renewable energy and other energy sources, energy efficiency, and electricity, may be applied or reviewed in the light of climate change impacts and adaptation.

The adaptation of thermal power plants might be supported through recommendations on Best Available Techniques under the EU **Directive on integrated pollution prevention and control (IPCC Directive)**.[39] This Directive establishes common rules for permitting and controlling industrial installations. Permit conditions must be based on Best Available Techniques (BAT), which are defined through an exchange of information between experts from the EU Member States, industry and environmental organisations, and published in BAT Reference Documents (BREFs).

For cooling systems of thermal power plants, the state of the art is described in the BAT Document "Cooling Systems" (European Commission 2001a). The document currently focuses on increasing the overall energy efficiency and reducing emissions into the aquatic environment and to the air. However, since the environmental aspects of cooling systems vary with the cooling configuration applied, the BAT document might be reviewed to set standards for cooling systems that make them more resilient to increasing temperatures and water shortages.

Adaptation efforts by the electricity sector related to water resources should be co-ordinated with other water uses under the integrated management approach of the **Water Framework Directive (WFD)** as it will be to hydromorphology. In some cases, efforts by the industry to implement technical adaptation measures may have to be reconciled with WFD objectives. The expected increase in hydropower potential in some European regions might make further exploitation of hydropower an attractive option. New developments in sensitive areas might conflict with the aim of the WFD to achieve a good water status. The Strategic Steering Group "Water Framework Directive and Hydromorphology" under the Common Implementation Strategy states that the potentially negative impacts of hydropower development on water bodies should be avoided (CIS-WFD 2006a), and suggests that in order to minimise the need for new sites, the development of hydropower capacities could be supported by modernisation and upgrading of existing infrastructures.

Furthermore, new standards for water established under the WFD might also limit the abstraction and discharge of cooling water and the production of biomass (derogation of water quality due to fertiliser use and of water quantity due to over-abstraction), which may set constraints to adaptation efforts by the electricity sector.

[39] Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control.

7.3.4 Policy on inland waterway transport

In the context of an entirely deregulated inland navigation market since 1 January 2000 (Directive 96/75/EC),[40] the European Commission aims to promote and strengthen the competitive position of IWT, and to facilitate its integration into the intermodal logistic chain (European Commission 2001b). The Commission wants to encourage companies to use IWT in order to increase the sustainability of the transport system.

In January 2006 the Commission adopted a Communication specifically on the promotion of IWT (**Navigation And Inland Waterway Action and Development in Europe – NAIADES**; European Commission 2006c). The communication is addressed to the European Community, Member States and the inland navigation industry, and it recommends legislative, co-ordinative and financial support measures that should be implemented in co-operation with national and regional authorities, River Commissions and the industry. While IWT's contribution to climate change mitigation is an issue in EU policy documents, they **currently do not address adaptation to changing climatic conditions** as a specific challenge.

However, there is an opportunity to incorporate adaptation efforts (see above) under the NAIADES action programme. The action programme covers the period 2006-2013 and focuses on five strategic areas: 1) creation of favourable conditions for services and new markets, 2) modernisation of the fleet, 3) jobs and skills, 4) improving the sector's image, and 5) waterway infrastructure. Two of these strategic areas, namely fleet modernisation and infrastructure, are relevant in the context of adaptation. The NAIADES programme furthermore highlights the importance of River Information Services (RIS), which may also be supportive to adaptation efforts.

Modernising the fleet

The **objective** is to improve logistics efficiency, environmental and safety performance of IWT. The NAIADES working paper (European Commission 2006c) mentions that particular attention should be paid to vessels operating under extreme circumstances (e.g. low water depths) and that vessels may be adapted to the conditions of particular rivers. **Instruments** proposed for this action focus on financial support (national support programmes, EU RTD and support programmes, state aid guidelines for support schemes). The set-up of an innovation fund is proposed that should support innovative concepts and encourage the modernisation of the vessel fleet.

Infrastructure

The **objective** is to support and provide guidance at European level for the improvement of European inland waterway networks. The main concern is the maintenance/improvement of infrastructure and elimination of bottlenecks e.g. from limited width and depth of rivers and canals, bridge clearance and lock dimensions. Furthermore, maintenance and upgrading of existing structures is relevant in the context of climate change adaptation. These issues might be included into the envisioned **European Development Plan** to support and guide the improvement of the

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[40] Council Directive 96/75/EC of 19 November 1996 on the systems of chartering and pricing in national and international inland waterway transport in the Community and others.

European inland waterway infrastructure and transhipment facilities at European level. The plan should provide guidance to Member States, for instance with regard to the definition of standards for waterway width and depth. It should also prioritise required investments, ensure a regular examination of the condition of Europe's waterway network, and ensure co-ordination with river basin management plans under the Water Framework Directive.

The latter issue is currently subject of an ongoing debate on the EU level as conflicts of interest may arise due to the fact that the WFD strongly emphasises the quality of hydro-morphological conditions while navigation infrastructures often require major hydro-morphological changes. As a preliminary result of the debate, the Strategic Steering Group "WFD and Hydro-morphology" under the WFD Common Implementation Strategy points out the necessity to integrate and reconcile the objectives of relevant sectoral policies by enhancing the recognition of the different interests, fostering the co-operation between the different competent authorities and stakeholders, and promoting more integrated development strategies (CIS-WFD 2006a). In the WFD context, infrastructure development will not only have to investigate and apply good practice but may also need to develop alternatives to traditional solutions in order to avoid deterioration and to ensure that measures are compatible with ecological objectives.

To **finance** infrastructure improvement and maintenance, the European Commission proposes EU RTD and support programmes (FP7, PHARE, ISPA, CARDS, INTERREG), national funding schemes and TEN-T (Trans-European Transport Networks).[41] Furthermore, the Commission calls for a gradual charging for the use of infrastructure and a price structure that reflects the costs (including external costs) to the community. It should be noted that **infrastructure charging** that allows external costs, especially environmental costs, to be internalised in the price of transport could be used to cover also the cost for adaptation measures for climate change.

River Information Services

River Information Services (RIS) projects support traffic and transport management in inland navigation based on information technology and telecommunication. In 2005, RIS was established under EU Directive2005/44/EC (RIS Directive)[42] laying the ground for the establishment of a pan-European information network. The Directive aims to ensure compatibility and interoperability between existing and new RIS systems. An infrastructure project fostering the RIS implementation in Europe is envisioned within the Trans European Networks for Transport. Systems that ensure rapid and efficient information exchange between all actors involved in waterway transport may serve as important tools in dealing with the challenges posed to IWT by changing climate conditions. For instance, the RIS Directive requires Member States to ensure that notices to skippers on waterway conditions, including water level or maximum allowable draught, are provided as standardised messages.

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[41] Currently two projects are funded: Project No. 18: Rhine/Meuse–Main–Danube inland waterway axis; Project No. 30: Inland waterway Seine–Scheldt.

[42] Directive 2005/44/EC of the European Parliament and of the Council of 7 September 2005 on harmonised river information services (RIS) on inland waterways in the Community, Official Journal L 255 , 30/09/2005 p. 152 – 159.

7.3.5 Tourism policy

In general, adaptation by the tourism industry will be a reaction to the specific changes in a given region, and adaptation measures will have to be adopted by the private actors at local level. However, policy may play an important role in supporting the tourism sector in its adaptation efforts, for instance by creating incentives for the application of environmental management techniques. The tourism sector will benefit strongly from all policy measures that help to **protect the resources upon which tourism enterprises depend**. The basic resources of a tourist destination are its natural and cultural capital, tourist facilities, and infrastructure. All of these may be affected by climate change impacts, and thus adaptation measures will have to be taken in a number of different policy areas. Policy that promotes wiser use of resources will reduce the negative impacts of the tourism sector and support the many diverse, small-scale tourism enterprises in adapting to changes in climate and water resources.

EU Tourism policy

Recognising the importance of tourism in terms of the economy and employment, the European Community has been increasingly involved in tourism since the early 1980s. Tourism is considered an important sector for the EU Lisbon strategy, and in 2006 the Commission issued its latest communication on tourism (European Commission, 2006e). The communication declares the aim of the Commission to put in place a renewed European tourism policy, to improve the competitiveness of the European tourism industry, and to create more and better jobs through the sustainable growth of tourism in Europe and globally. It also emphasises that this policy will be developed in close partnership with Member States' authorities and the stakeholders in the tourism industry.

While climate change impacts and adaptation are not addressed in the communication, the need for sustainable and environmentally friendly tourism is recognised as one of the key challenges, next to demographic changes and external competition. The policy will focus on three main areas:

1. Mainstreaming measures that affect tourism,
2. Promoting tourism sustainability,
3. Enhancing the understanding and the visibility of tourism.

In all three areas, measures are suggested that might be used to facilitate adaptation in tourism. The first area calls for Member States, regions, local authorities and industry to collaborate and **ensure that tourism fully benefits from all funding instruments** available at EU level (structural funds, cohesion fund, innovation and research framework programmes), and is taken into account in the planning of related projects. Funding will also be essential to support adaptation by the tourism industry.

Under the second area, the European Commission is developing and implementing a "European Agenda 21" for tourism, which should contribute to **ensuring the economic, social and environmental sustainability of tourism**. The sustainability concept includes longer-term perspectives and should thus take adaptation to climate change impacts into account.

The third area includes among other things the **improvement of statistical information** in the field of tourism. This would provide better tools for monitoring the reaction of tourists and the tourism industry to environmental and climate-induced changes, and could thus improve the knowledge base on which adaptation decisions may be taken.

EU Water policy

Many tourism activities, such as beach holidays, water sports, snow sports, or eco-tourism, are centred around water and thus depend on the good condition of hydrological and hydrological-dependent resources.

Therefore, adaptation efforts related to EU water policies, in particular the **Water Framework Directive** and the new **Flood Risk Management Directive**, will be essential to support adaptation by the tourism sector (see section 7.3.1). The tourism sector could for instance use the risk maps drawn up under the Floods Directive as a basis for developing further activities. Given the importance of coastal tourism in Europe, and the potential for tourism development elsewhere on Europe's shores in response to warmer temperatures in future, the **EU Maritime Strategy** also is a key tool for adaptation based on resource protection.

The issue of **preparedness** for extreme events has to be considered further in future, especially in highly vulnerable areas, such as coastal zones with high concentration of tourism facilities. Such preparedness strategies must include early warning systems and will call for sufficient energy and water supplies in the case of unforeseen events. In case of emergencies, adequate rescue strategies that can cope with massive volumes of people have to be developed.

National and regional policy

Many of the practical policy requirements that affect tourism enterprises are taken **at national, regional and local policy** levels. Climate change considerations should be integrated into national tourism policy and other relevant policies that affect the tourism landscape. Regional and local authorities responsible for providing basic infrastructure will have to adjust to the changing needs and demand patterns.

Relevant national policy actions include, for instance, designating and protecting vulnerable ecological areas; assessing and controlling the carrying capacity of specific tourist sites; providing information to tourists on the state of the local environment and best practice guidelines for reducing resource consumption; and implementing strict control measures on land-use. National and regional tourism policies may also support the diversification of tourism activities and the development and marketing of less climate-dependent activities.

For the development of tourism, particularly in vulnerable regions and protection areas, Environmental Impact Assessments and integrated planning are essential tools to ensure that adaptation efforts are in line with environmental objectives and do not create additional pressures on the natural resources.

Finally, demand patterns may also be influenced by national policies, for instance through adjusting holiday periods and school vacations in order to reduce high concentration of tourists in water-stressed periods.

7.4 Adapting the management of water in Europe – a cross-sectoral perspective

Given the manifold dependencies and influences on water resources of the different users, it is clear that in order to ensure effective and efficient adaptation different actors have to work together, and contributions from different sectors are necessary. There is a need for overarching adaptation strategies that consider the individual sector objectives and contributions from an integrated perspective.

Complex inter-relationships exist between different sectors with regard to adaptation. Adaptation efforts in different sectors may be mutually supportive, but they might also counteract each other or conflict with general sustainability objectives. For instance, under a warming climate the demand for electricity by the tourism industry for air conditioning may further increase, which would reduce profitability of the industry while at the same time further contributing to greenhouse gas emissions and making it even more difficult for the electricity supply services to meet peak demand during drought periods. Similarly, the demand for water by agriculture, tourism, electricity and households is likely to increase precisely during the times when there is likely to be the greatest water stress. Generally, if climate change impacts result in increased water stress in a region, conflicts of interest among different water users are likely to emerge. For example, if water is scarce water use for irrigation might conflict with minimum flow regimes needed for cooling water.

Similarly, conflicts may arise between different environmental objectives. For instance, the aim to increase the share of renewable energies is likely to lead to a more widespread cultivation of energy crops. Since these tend to be rather water-intensive, it is necessary to mainstream this development with the need to reduce water use in agriculture. Another example for potential conflicts between climate change mitigation and adaptation objectives is the promotion of inland waterway transport. The European Commission aims to increase the share of inland waterway transport as a particularly climate-friendly form of transport. However, this may have repercussions on flood protection measures or on objectives of the WFD (see section 7.3.4).

Infrastructure investments in river basins, for instance for flood control measures, hydropower infrastructure or inland navigation, may not easily be reconciled with WFD objectives, since they may require major hydro-morphological changes. However, as the recent CIS document on WFD and hydro-morphological pressures (CIS-WFD 2006a) points out, such activities can also deliver important benefits in other areas, for instance reducing the impacts of climate change, and conflicts may be avoided by better integration of different policies and by enhancing the recognition of the different interests.

On the other hand, a variety of win-win and no-regret measures and solutions are available. Adaptation measures that enhance water use efficiency and reduce total consumption in any sector will reduce pressure on the total available water resources and thus also benefit other sectors. Better information and increased awareness will help all stakeholders in a country, region or river basin to adjust their planning, investment and management to expected and observed changes. Increasing the awareness of risk and encouraging corresponding behaviour will contribute to reducing damage in the case of extreme events. Participative management processes will, in any case, create support and ownership among those involved and are an important pre-requisite for balancing different interests in a democratic way.

Box 14 Finland's National Strategy for Adaptation to Climate Change

In response to climate change scenarios, Finland has incorporated key elements of the adaptation policy into its National Climate Strategy. The National Strategy for Adaptation to Climate Change identifies future effects of climate change on various sectors such as water resources, agriculture, forestry, and outlines adaptation measures to be undertaken as well as highlights adaptation measures currently underway. Finland foresees an increase in mean temperatures and rainfall and a change in intensity and frequency of extreme climatic events in future due to climate change, with impacts varying between sectors. Adaptation measures are defined as immediate, short-term, and long term. Immediate, 2005-2010, adaptation measures for water resources include planning of water services, surveying of risk sites and preparation of general plans for risk sites, and construction of irrigation systems for agriculture. Short-term, 2010-2030, projects include investments in projects that improve preparation for exceptional situations and regional co-operation, increasing the discharge capacity of dams, and restrictions on water use. Long-term, 2030-2080, plans focus on adapting national plans to climate change effects and improving climate forecasting. As adaptation strategies need to be dynamic, an environmental impact assessment of the National Climate and Energy Strategy will be carried out to assess how well current policies work and whether future measures are still applicable, as climate scenarios are constantly being updated.

Source: Ministry of Agriculture and Forestry of Finland. ***Finland's National Strategy for Adaptation to Climate Change.*** 2005

For these reasons, it is crucial that the different funding and policy instruments presented above are utilised in concert in order to ensure consistency between policies in which water plays a key role. Coherent multi-sectoral objectives need to be set in order to avoid contradiction with other legal instruments and to enhance synergies. This applies both to the EU level for the different sectors dealing with water, agriculture, energy, transport, tourism, and other water-related issues and to the Member States, who are responsible for achieving various objectives across the different sectors. There is a need to harmonise the objectives of different policies, as well as the ways of achieving them. An inter-sectoral and flexible management approach is also needed to ensure adequate investment and priority setting across different sectors, for instance in land use and spatial planning, or in deciding about the allocation of scarce water resources.

A workshop on the research policy interface of climate change impacts on the water cycle held by the European Commission in September 2006 concluded that for decision-making, economic analyses of climate change impacts and adaptation will very helpful. The wider economic impacts of climate-driven changes in water resources, for instance changes in competitiveness of different forms of agriculture or between different forms of electricity production, should be considered. Policy makers should be enabled to strike a balance between the costs of adaptation measures incurred today and their potential benefits for the future (European Commission 2006h).

8 Conclusions: Building adaptation strategies

The following paragraphs make an attempt to outline building blocks and essential elements to consider in the development of strategies that are aimed to encourage and support adaptation to climate-driven changes in water resources. They were developed on the basis of the outcome and the conclusions of the February 2007 symposium “Time to Adapt”.[43]

It is time to adapt – scientific evidence is sufficient to urge action

The scientific evidence conveys the clear message that a change in climate is occurring, and that this change will impact water cycle processes in the European regions. Although there are still uncertainties in the scenarios, the model simulations, and projections, there is now consensus among science and policy communities that climate is changing, and that adverse effects both for European societies and for ecosystems and biodiversity are to be expected. For Europe as well as for other world regions, the IPCC predicts with high confidence that the negative impacts of climate change on freshwater systems will outweigh its benefits IPCC 2007, WG II).

Even if climate protection measures are effectively implemented, it will not be possible to completely prevent climate change. Therefore, while climate change mitigation should remain a priority for policy-making, there is a need to develop strategies for adaptation to climate-change-driven effects on the water resources.

Current efforts in scientific research focus on improving projections of changes in climate at the regional scale. Climate change will affect European regions in different ways, not only with respect to temperature, but also precipitation rates and water flows. There also will be differences in the distribution of benefits and negative effects of climate change. These differences have to be reflected by an overall adaptation strategy that takes into account the principle of solidarity.

Integrated water management as a starting point for adaptation

Adapting the management of European water resources to climate change impacts should be based on the modern approaches of integrated water resources management (IWRM) and integrated coastal zone management (ICZM). Integrated management should be regarded as the encompassing paradigm for adaptation to contemporary climate variability and as a prerequisite for coping with the still uncertain consequences of global warming and their repercussions on the water cycle (van Beek et al. 2002). In addition, the principles of adaptive management (Pahl-Wostl 2005) might be helpful. This concept is motivated by the insight that management problems in river basins are generally of a very complex nature, and that it is likely that unforeseen problems will occur or that new pressures will make it necessary to adjust plans and management programmes to these new pressures or problems. Climate change impacts will add to these uncertainties, and it is, therefore, crucial that the planning

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43 See www.climate-water-adaptation-berlin2007.org.

framework applied is flexible enough to adapt to new ideas and solutions. Adaptive Management approaches could be used as a systematic process for continually improving management policies and practices by learning from the outcomes of already implemented management strategies. (Pahl-Wostl 2005).

In general, decision-making under increasing uncertainty is one of the greatest challenges posed by climate change, and a flexibility of approaches is needed when developing adaptation measures and strategies. Emphasis should be placed on no-regret and win-win measures that will deliver benefits under different scenarios. Infrastructure investments should be made “climate-proof”, i.e. it should be ensured that they will still be viable under changing climatic conditions.

Furthermore, it is essential to ensure the long-term sustainability of adaptation measures and strategies, and to consider environmental, economic and social aspects. In particular, the protection and preservation of aquatic and water-dependend ecosystems should be an integral element of adaptation strategies.

There is no alternative to an integrated approach to adaptation, given the fact that human activities exert various pressures on water resources, which often are driven by more short-term developments. Population size and density, economic and consumption patterns, land use and land cover, and technology are key factors that also impact water resources. For instance, the decline of the population in several areas of Europe may pose larger immediate challenges to water supply and wastewater disposal networks than climate change impacts. Migration to cities and urban sprawl causes changes in the hydrological pattern of the landscape and may lead to increased risks of flash floods and a deterioration of water quality in urban areas. Similarly, changes in agricultural management practices, reallocation of arable land to different uses, e.g. biomass production, and other changes in land use have repercussions on the hydrological balance of European regions. Such pressures are the dominant factors in many cases, with climate change impacts acting as an additional driver that often exacerbates existing problems. Therefore, adaptation should not be discussed in isolation. Both in the assessment and modelling of future conditions and in the development of strategies, all factors influencing the quantity and quality of water resources need to be considered. Enhancing and intensifying efforts to protect the water resources of Europe and reducing existing pressures on water bodies and ecosystems will improve adaptive capacity.

Existing EU water policy provides tools that can be used for adaptation

Adaptation in water management should make use of the tools and instruments provided by existing EU water legislation such as the Water Framework Directive, the Floods Directive, and the Marine Strategy. The WFD and the Marine strategy both call for an integrated and strategic planning approach that paves the way for including adaptation measures in water management in the short and in the long term. The proposed Floods Directive, with its requirements for comprehensive assessment and mapping of flood risk, could be a central element for raising awareness about the risks and vulnerability resulting from flooding.

However, it needs to be ensured that climate change impacts and adaptation concerns are sufficiently considered in the implementation of these EU water policies. Climate change impacts should be taken into account in the implementation of the Water Framework Directive, for instance when assessing pressures and impacts on water resources. Measures to cope with these impacts should be included in the WFD Programmes of Measures. At the conference “Time to Adapt – Climate Change and the European Water Dimension” in February 2007 in Berlin it was concluded that as far as possible, the consideration of climate change impacts should be incorporated into the first planning cycle in 2009. At a minimum, a screening of the likely effects of climate change on the pressures identified in the article 5 analysis and of the climate impact sensitivity of the Programmes of Measures was recommended. This should help selecting measures today that will be effective, sustainable and cost-efficient under changing conditions. In the second planning cycle, climate change impacts should be taken fully into account.

The six-year planning cycle of the WFD allows each river basin to set short- and long-term targets and related measures to be achieved step-wise for a continuous review and adjustment, and thus, for an implementation of adaptive management approaches. However, it needs to be ensured that at the same time the long-term perspective of climate change over the next 50 to 100 years is kept in mind, and that long-term targets and strategies are also developed.

In this context, monitoring and information tools provided by the WFD and other water legislation should be used for further analysis of the vulnerability of water bodies to climate change impacts, to monitor trends in water resources and to assess how they are related to or caused by climate change impacts (e.g. under Article 8 WFD).

At all levels of policy-making, European, national and regional, it should be ensured that all relevant issues receive due attention. While extreme events, in particular floods, are high on many national agendas, challenges from long-term, more gradual changes such as increasing water scarcity should be equally met by adaptation efforts. Climate change will enhance water scarcity problems with negative impacts on water quality and aquatic ecosystems. Protection and integrated sustainable management of water resources will thus be particularly important under water scarce conditions. Present action at the EU level on water scarcity and droughts should be closely linked to activities on climate change impacts and adaptation.

Better integration and co-ordination of sectors

Even if the current policy framework can be used to implement several adaptation measures, water management will not be able to cope with all impacts from climate change. Successful adaptation strategies have to include additional measures in water-related sectors such as agriculture, energy, navigation and tourism. Therefore, better integration with the water management of these sectors is required, as well as an improved co-operation among relevant stakeholders. Such a co-operation between actors, particularly those developing or implementing sector adaptation strategies, can potentially deliver common, acceptable and cost effective solutions.

For adaptation it may be necessary to define priority water uses and to find appropriate ways to implement prioritisation. Choices may have to be made concerning the allocation of water resources, and criteria and indicators need to be developed on the basis of which such choices can be made. Integrated approaches that involve all sectors and stakeholders will help to create ownership and acceptance among those concerned.

At the policy level, potential conflicts between sector policies and adaptation needs should be identified, and efforts should be made to make different policies consistent with each other and compatible with adaptation. More intensive co-operation between different departments of government is necessary. Implementation of policies should consider climate change impacts, and policies may also have to be revised with a view to adaptation. The WFD may serve as an instrument to achieve a better integration of sectors and water uses. It for instance requires that physical adaptation measures in the hydropower or navigation sectors (construction and infrastructure) be compatible with the environmental objectives related to hydro-morphology. However, adjustments in other policy areas may be necessary or beneficial, and some options were identified by this study for the focus sectors agriculture, energy/electricity, inland waterway transport, and tourism.

There is certainly scope for improving the adaptive capacity of European agricultural systems through the funding schemes provided by the **Common Agricultural Policy** (CAP) of the EU. A general interest should be to reduce the dependency of farming systems on irrigation, and to make sure that the incentives set by the CAP do not run counter to this objective. Under the direct payments scheme, remaining incentives to grow water-intensive crops in water-stressed areas should be removed. Adaptive capacity might thus benefit from further de-coupling of payments, in particular with respect to water-intensive crops such as maize.

In addition, a strengthening of the rural development policy is likely to enhance the adaptive capacity of European agriculture, since the financial resources provided under this pillar might be used to directly support measures aimed at adaptation. It may have to be explored in more detail to what extent rural development funding can be used to support the purchase of new equipment needed for adaptation, the development of new products, processes and technologies that are more adaptive, or educational measures.

Policies related to the **European energy system and the production of electricity** may also be adjusted to encourage adaptation. For instance, the adaptive capacity of both individual power plant types and comprehensive energy supply concepts should be an important criterion for the further development of the energy sector and in the implementation of the EU Energy Review under the Green Paper of the Commission (European Commission 2006f). Benchmarks or standards at EU level, for instance for cooling systems for thermal power plants under the IPCC Directive, could contribute to increasing the efficiency of cooling systems and thus making power plants more resilient to increasing temperatures and water shortages. The management of cooling water demand, in particular under low flow conditions, should also be made a part of the river basin management plans, and should include hydro peaking, minimum flow, and reservoir management.

Increasing energy efficiency should play a key role both in mitigation and adaptation policies. Decentralised approaches and a diverse energy mix are also likely to be beneficial for adaptation.

The electricity sector should take into account in its planning the vulnerability of the European electricity system to intensified climate variability and water related extreme events.

Consistency between energy and water policies with regard to adaptation requirements should be an aim of policy-making. The incentives provided by the biomass action plan may run counter to adaptation requirements; on the other hand, climate change impacts may make it more difficult to achieve the aims set out in the action plan. Policy-making in this field should aim to find ways to resolve this conflict and to exploit the potential of biomass for energy production and climate change mitigation without further compromising European water resources.

In the area of **inland waterway transport**, development of adaptation strategies is still at an early stage. A more detailed assessment of the vulnerability of inland waterway systems to climate change impacts on river discharge levels and the frequency of extreme floods and droughts is needed, as well as of the associated risks and of possible adaptation measures.

Nevertheless, no-regret policies based on current knowledge on increasing variability of the hydrological regime can be a starting point. To maintain flexibility, reversible measures should be given priority. It may be worth considering whether climate change impacts should be explicitly included in European policies as one of several challenges the sector will face in the future. Also, some of the instruments contained in existing policies may be adjusted in order to support adaptation. For instance, the innovation fund to encourage modernisation and the European Development Plan proposed by the NAIADES action plan (see section 7.3.4) might be used to support and guide the improvement of IWT infrastructure. The promotion and development of adapted ships that are economically feasible and environmentally friendly should be encouraged.

The adaptive capacity of the sector may also benefit from improving the available information tools. River Information Systems will be an important instrument to support the adaptation of the management of waterways and of individual IWT companies, and further efforts to make the different systems more compatible and to improve interoperability would certainly bring benefits in terms of adaptation.

European policy on **tourism** is already concerned about the economic, social and environmental sustainability of the sector. While this concept implicitly covers threats from climate change impacts, it might be beneficial to have adaptation explicitly addressed by the policy. Policy action on tourism should generally aim to support a diversification of tourism activities in order to make the sector more resilient to changes in climatic conditions and water resources. The promotion of greater efficiency of the use of water resources within the sector should be a priority, since it would both reduce sensitivity to water scarcity situations and reduce pressures on the environment from the tourism sector.

Adaptation of the tourism sector cannot happen in isolation, but will, to a large extent, depend on action taken in related sectors, in particular water supply and sanitation, but also transport, construction, energy supply, land management, and nature protection. In addition, funding instruments under the European cohesion policy (see below) will be crucial to support adaptation of the tourism industry and to mitigate and compensate the distributional impacts that shifts in tourism patterns might entail.

While autonomous adaptation by individual sectors will be essential for the implementation of adaptation strategies, the efficiency and effectiveness of local and regional adaptation approaches can be increased if co-ordination and support is provided by policies at the national and European level. This is particularly important with regard to sectors where investment in infrastructure has a long lifetime and will thus be affected by long-term changes in climatic conditions and water resources (e.g. energy or the water supply and sanitation sector).

Increasing efficiency in water use should be a key element of adaptation

In many regions, adaptation to climate change will be closely linked with adaptation to water scarcity. Measures that reduce water consumption and increase efficiency will be essential elements of adaptation strategies in these cases and should be promoted in all sectors. Such measures include water-efficient irrigation techniques, less water-intensive crops, water-saving appliances, reduced leakage in supply systems, water recycling and rainwater harvesting.

Economic instruments such as water pricing or charging systems may be useful tools to encourage efficient use and allocation of water and to support necessary changes in behaviour. They may also allow to recover the costs of adaptation from those who benefit, for instance residents, tourists or industries.

Economic instruments, as set out in the WFD, should be widely applied to recover the costs, including environmental costs, of coping with and adapting to climate change impacts, and to ensure that these costs are shared fairly between users, providers and polluters. A gradual move towards full cost recovery should be envisioned in all sectors, taking into account social aspects. One way forward is the 'user/polluter pays principle', regardless of whether the water is taken from a tap, a river or an aquifer or used for shipping and energy production. Water prices that fully reflect at least all investment and operational costs set strong incentives for consumers to reduce water consumption and increase water use efficiency. Experience shows that this approach can be highly successful, and suggests that appropriate water pricing forms a valuable adaptation option.

Land use as a key tool for adaptation at regional and local level

Spatial planning and climate change are inextricably linked. While spatial planning can contribute to reducing emissions and stabilising climate change (mitigation), it also may be used as an instrument to react to the unavoidable consequences of climate change (adaptation).

Reducing vulnerability to extreme weather events is key for adaptation and is closely related to spatial and land use planning. Appropriate risk assessment for building development is essential to avoid the accumulation of assets in high risk areas, for instance in floodplains and along the coast. Changes in land management may be an alternative to raising dykes and dams and to large investments in physical flood control structures. Land management has an influence on the ability of the soil to hold back precipitation or flood water. Restricting development and the accumulation of infrastructure and assets in flood-prone areas may prevent damage.

Agriculture as a key form of land use will play a crucial role in adaptive spatial planning approaches. Intensive agriculture in flood-prone areas is at risk of substantial economic loss in the case of flooding. On the other hand, the increased challenges for flood risk management will create a demand for new ways of accommodating flood water and managing flows, which may increase economic opportunities for water farming (UK Environment Agency and Defra 2006).

Planning future land and resource use to accommodate change requires a shift towards more geographically sensitive scales such as river catchments and coastal cells that work with natural processes. There are some current innovations in policy that could form the basis for a new spatial planning framework for natural resources, principally the River Basin Management Plans required under the Water Framework Directive, which offer significant potential (Stern 2006).

Synergies with climate change mitigation efforts and sustainability of adaptation

Adaptation approaches should be embedded in the context of the European Union's overarching aim of sustainable development. Where possible, synergies with other environmental and sustainability aims should be created, and additional pressures from adaptation measures on the environment should be avoided. Generally, a beneficial side-effect from climate change impacts on water resources could be an increasing awareness that water is a precious resource and needs to be effectively protected and the creation of a new focus on water conservation and efficiency.

Mitigation of climate change and adaptation to climate change are two complementary objectives. Therefore, interactions between both aspects should be considered when developing appropriate adaptation strategies, and where possible, synergies should be created and trade-offs and conflicts should be avoided. For example, the electricity sector is a field where the potential for synergies between climate change mitigation and adaptation is obvious. For instance, an increase in efficiency of energy production and energy use and in consequence a reduction of total energy demand would both contribute to a reduction of greenhouse gas emissions and reduce the dependence on water resources of the energy supply system as a whole, which would make it more resilient to changes in climate.

Similar win-win solutions might be implemented in agriculture. In less intensive and more diverse agricultural systems, greenhouse gas emissions as well as pollution loads to water and soils would be smaller, and, at the same time, such systems would need less water for irrigation and thus be less vulnerable to climate-driven changes in water resources and water scarcity situations. Organic farming approaches can also increase resilience, since they generally emphasise balanced and sustainable production methods and might increase the capacity of agricultural soils to perform under changing and more adverse climatic conditions.

On the other hand, it needs to be ensured that adaptation responses to climate change impacts do not create additional pressures on water resources. In some cases, environmental impact assessments may be necessary to investigate potential consequences of adaptation measures.

Funding and financial instruments as instruments to support adaptation

The funding resources of its cohesion policy are essential instruments for EU level action to influence, support and steer adaptation efforts in the Member States and by individual actors (see section 7.1.5). They could be used to tackle regional disparities with regard to climate change impacts and adaptive capacity. Compensation could be provided to regions that will be hit particularly hard by climate change impacts, or that have a low adaptive capacity. For instance, cohesion funding might play a role in buffering the distributional effects that might result from a shift in tourism patterns across Europe and to mitigate social hardship resulting from limits to adaptation in certain region's agricultural businesses. Also, with their focus on environment, risk prevention and infrastructure, the cohesion policy funding instruments could assist Europe's poorer regions to put in place new or upgraded existing infrastructure in order to cope with challenges resulting from climate change impacts. Financial support from the regional development fund might also benefit projects that increase certain sectors' resilience to climate change impacts.

On the other hand, financial support from EU funding instruments might be directly used to encourage adaptation, by making grants conditional on the long-term sustainability of planned investments and on their ability to perform under changing climate and water conditions.

Information, awareness and participation

Better information and raising awareness on the effects of and challenges from climate-driven changes in water resources may be a key area for action by national and European policy. Improved information and awareness of long-term perspectives, the necessity to adapt, and potential measures for adaptation are prerequisites for creating support for adaptation and for reaching agreement between different stakeholders on adaptation strategies.

By launching consultation and dialogue processes and promoting exchange and the creation of networks between different actors, co-operation between stakeholders can be encouraged, which will also be crucial for the success of adaptation in many sectors. For instance, water supply and sanitation services providers may co-operate with agriculture or building development in order to promote efficiency of water use and exploit the water saving potential of these sectors, or the tourism sector will benefit from supportive action in the water supply and sanitation sector.

With respect to the identification, quantification and communication of risks from climate change, in particular related to flooding events, insurers may be a partner for policy-makers in their efforts to raise awareness and improve information (see section 6.3).

Participative approaches are particularly relevant to deal with climate impacts and adaptation in the context of transboundary waters and water management at river basin level, and to ensure equitable use of water between different stakeholders and between upstream and downstream users.

Better knowledge base and support of research

In order to improve the information basis on which decisions about adaptation measures and strategies are taken, further research both on climate change impacts and on adaptation will be necessary. Both European and national research funding will be required to support scientific research and to direct scientific activities to the issues that are most relevant to policy makers.

Among the issues that need to be further investigated are the regional impacts of climate change on water resources, for instance in individual river basins and river stretches, and seasonal variations in impacts.

Furthermore, research may be helpful to better assess the vulnerability of individual sectors as well as the relationship between and integration of adaptation measures in different sectors. For instance for the electricity sector, more information is needed on how different energy sources and transmission and distribution grids will be affected by climate change impacts and what options for adaptation are available for each of them. Research on impacts should be based both on modelling projections of future conditions and on the monitoring of existing trends. For instance, monitoring is necessary to improve data and statistics that show how tourist flows and the tourism business will respond to changes in climate and water resources.

Adaptation measures, their costs and benefits, and their effectiveness under different conditions and scenarios should become a focus of research in the future. Cross-sectoral and interdisciplinary approaches are needed. A scientific evaluation of pilot adaptation measures and strategies that are currently implemented throughout Europe is important to identify good and best practice and to collect information about possible barriers and success factors. Limits to adaptation by individual sectors or regions need to be delineated. If such limits are clearly identified and recognised, other ways have to be identified to mitigate the consequences for society. For instance, if flood risk can not be controlled in a certain area, restriction of building development or even resettlement of residents to other areas may be the last option for policy-makers to prevent damage. However, such measures can only be taken on a solid information basis.

In modelling and impact assessment approaches that aim to prepare long-term strategies for adaptation, integrated assessments should be performed that take into account not only climate change impacts but also other driving forces for change that may equally influence future conditions.

For the assessment of climate change impacts on water resources and the resulting challenges for human societies, existing tools at EU level such as the Environmental Impact Assessment (EIA) and the Strategic Environmental Assessment (SEA) might be used.

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Annex: Adaptating water management to climate change - initiatives in Europe

Country	Adaptation Initiative	Notes	Triggers and Drivers
AT	FloodRisk –integrated flood management	Adaptation is main objective	Felt impacts, recent incidences
	StartClim (flexible focus - heat waves and droughts, health, tourism)		
BE	Veilige Kunst (Flanders): coastal management	Adaptation is additional motivation	Weather events, risk assessment, CBA, land use pressure
	Sigma Flood Protection Plan: Regional initiative, focus flood protection and control	Adaptation is additional motivation	Weather events, risk assessment, CBA
BG	Initiatives are mentioned but not specified		
CH	Flood risk management measure	Long-running programme, initially adaptation as side-effect, growing importance	Weather events
CY	New and improved irrigation systems and desalinisation units	Adaptation is main objectivew	Felt impacts, e.g. decrease of agricultural production due to water scarcity
DE	Improvement in landscape water balance guideline (Brandenburg)	Adaptation is main objective	Policy and authorities, research results
	Adaptation to climate trends and extreme weather conditions and sustainable groundwater management strategy (Hesse)	Adaptation is main objective	Risk assessment
	Master Plan Integrated Coastal Defence Management (update)	Sea Level Rise scenario important, master plan has long existed	Observations and research
	KLIWA and ESPACE projects (Bavaria)	Mainly research/capacity building Adaptation is main objective	Weather events, research results
ES	National Adaptation Plan	Water resources is priority as key driver for many other systems and sectors; Adaptation is main objective	Evidence, social awareness, political support
FI	Improve Dam Safety and re-Design of Major Dam Discharges	Adaptation is main objective	Recent events
FR	Study on adaptation recently launched		
HU	VAHAVA project (co-ordination, publication/dissemination, expert debates on climate change issues)	Not specified	Not specified
	The New Vásárhelyi Plan (emergency reservoirs along Upstream- and Middle Tisza sections to enhance flood safety. Focus on flood control,		

Country	Adaptation Initiative	Notes	Triggers and Drivers
	conservation and env. Protection, ecotourism, agro-ecological farming, rural development)		
IE	Inter-basin water transfer	Planning stage Main objectives: growing population, decreasing resources, but climate change impacts are taken into account	Risk assessment, CBA, research results
LT	National initiative, demand management and water quality		
MT	Water conservation and water saving measures (e.g. reducing leakage from distribution network; water metering in households and establishments	Adaptation is main objective	Weather events, heightened awareness resulting from research on climate change
NL	Space for the river –long term spatial reservation Agreement between authorities on incorporating climate change into planning for 2015 Increase capacity (pumping, discharge capacity of sluices) Strengthening coastal defence to incorporate seal level rise and extension of beach nourishment programme.	In some cases adaptation is main driver, it is always one of several objectives	Wave and climate research; reassessment of risks
RO	Adaptation under different water legislation; National Action Plan on Climate Change (2005) highlights the need for an Action Plan on Adaptation by 2007	Measures to be implemented to enhance resilience and reduce vulnerability; adaptation is main objective	Risk assessment
SE	Ongoing survey on vulnerability of society Permit system for water users	Research/survey Adaptation is side effect	
SK	Planning strategies	Adaptation is side effect	Weather events, research results, risk assessment, CBA
SL	Strategies for flood and drought mitigation under National Environmental Programme (determination of risk areas; regulation of land use)	Adaptation is not the main objective	Weather events, policy/legislation
UK	Incorporating climate change in long term planning Climate change allowances and flood risk management Changing Our Ways – impacts and adaptation strategy (Scotland)	Adaptation is main objective	Scenarios and felt impacts