DANUBE STUDY – CLIMATE CHANGE ADAPTATION

"Study to provide a common and basin-wide understanding towards the development of a Climate Change adaptation strategy in the Danube River Basin"

Danube River Basin
Climate Change Adaptation

In the framework of the International Commission of the Danube River (ICPDR) and the EU Strategy for the Danube Region

on behalf of:

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

LMU Ludwig-Maximilians-Universität München

icpdr iksd

Final Report

Reporting Period: 1.12.2010 – 31.1.2012

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Summary

The *Danube Study – Climate Change Adaptation* was initiated by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety to provide foundations for a common, Danube-wide understanding and procedure for adaptation to water resources related climate change impacts with the aim to develop suitable adaptation strategies in the Danube River Basin. The outcomes of the study should provide a basis for the development of a basin-wide adaptation strategy in the Danube River Basin with the ICPDR team of experts. It started in December 2010 and was finished by the end of January 2012.

A close collaboration with experts in the Danube River Basin (DRB) was intended within the Danube Study. Therefore several meetings, workshops and conferences were attended to present and discuss the outcomes of the study. Additionally, a special study workshop with experts of the DRB was organized in Munich to discuss the first results and determine further project step in a round-table discussion at the halfway of the project.

In order to identify climate change impacts in the DRB and appropriate adaptation measures, ongoing and finalized research and development projects and studies as well as adaptation activities were analysed. Neither further model calculations were carried out nor adaptation activities were suggested by the authors. The presented results are solely based on the analysed studies, projects and adaptation activities. Besides climate change impacts, also other factors such as social, demographic, and economic development are crucial for future adaptation strategies. However, they were not the subject of the present study, but are indirectly considered in the analyzed scenarios.

The applied models and scenarios of different projects and studies were analysed due to their future temperature and precipitation development and the projected extreme weather events. According to the analysed scenario results, the air temperature is likely to increase in the future with a gradient from northwest to southeast, both annually and in all seasons. In the future period from 2021 to 2050 an annual increase between 0.5 in the upper basin parts up to 4°C in the lower basin parts of the DRB are projected, whereas from 2071 to 2100 an increase between 2.5 and 5°C is modelled. At the end of the century, the increase will be particularly large during summer in the south-eastern region of the DRB. Since the DRB is located in a transition zone between increasing (Northern Europe) and decreasing (Southern Europe) future precipitation, overall small precipitation changes are to be expected. The mean annual precipitation sum is likely to remain almost constant, but seasonal changes will probably occur with a decrease in summer precipitation and an increase in winter precipitation. Particularly in the south-eastern parts a reduction of about 25 and 45 % is shown in the scenario results.

Next, climate change impacts on water related issues and possible adaptation measures were complied for different fields. This includes impacts on water availability considering runoff and evapotranspiration, groundwater, snow, ice and permafrost, and extreme hydrological events like floods, droughts and low flows as well as water temperature and water quality. Moreover, impacts on water supply and water demand as well as different water uses are focused on. This encompasses impacts on agriculture, irrigation, forestry, land use, soils, biodiversity and ecosystems, limnology as well as water related energy production, navigation, health and tourism. Where it is possible to distinguish between the entire DRB, the Upper (UDRB), Middle (MDRB) and Lower Danube River

Basin (LDRB), the impacts are presented separately. According to the analysis, climate change impacts will be of different magnitude in the DRB regions and almost all water related sectors are likely to be triggered by a north-west to south-eastern gradient of the temperature increase and the north-southern transitions zone of precipitation changes. These changes are likely to cause a reduction in water availability with changes in the seasonal runoff pattern, mainly triggered by reduced snow storage and increasing evapotranspiration. Main reasons for quantitative changes in water availability are the significant temperature increase as well as changes in precipitation, groundwater recharge, soil water content and glaciers. Regarding the extreme event of floods no clear picture can be drawn from the results. Droughts, low flow situations and water scarcity, however, are likely to become more intense, longer and more frequent in the DRB. Together with an expected increase in water temperature, good water quality might be endangered. Consequently, an assumed general increase in water demand for households, industry and agriculture together with a pronounced water scarcity in the MDRB, the LDRB and some areas of the UDRB during summer is likely to lead to high water stress. Water dependent sectors such as agriculture (irrigation), forestry, navigation and water related energy production will suffer under these projected future conditions. Changes in ecosystems and biodiversity with shifts of the aquatic and terrestrial flora and fauna are to be expected as a consequence. However, there might also be some positive effects due to climate change impacts, like a reduction of the ice days on rivers regarding the impacts on navigation or longer vegetation periods regarding agricultural issues.

Although there are commonalities in the expected climate change impacts, they are all connected with uncertainties due to the methods (e.g. used models, selected scenarios, region, time period & downscaling method) and the available information (e.g. amount, agreement and certainty assessment of projects/studies, insufficient data and/or knowledge). Future temperature increase can be seen as a hard fact, whereas changes in flood events are quite uncertain. Nevertheless, uncertainty is not a reason for doing nothing. Win-win / no-regret adaptation measures should be considered. Therefore, for each impact area possible adaptation measures were identified according to the analysed activities. The suggested measures are further classified in the different categories of preparation measures, general measures, ecosystem-based measures, behavioural/managerial measures, technological measures and policy approaches following [118, 47] . Additionally, the time horizon of the effects of the measures is analysed, where it is possible, short-term (up to five years), medium-term (one or two decades), and long-term measures (about 30 years) are distinguished. Thus, measures with medium-term effects also have long-term effects, and short-term measures have both, medium and long-term effects. Measures with options for an international cooperation within the DRB and measures, where challenges in reaching a common understanding might arise, are indicated.

The analysis of adaptation activities in the different impact fields as presented before show some overall commonalities. Changes in behaviour and management (e.g. education, capacity building, and water saving behaviour, application of good agricultural practice) are often addressed. Most activities contain the implementation of technological solutions and political measures (e.g. improvement of infrastructure, definition of legal limits, and implementation of restrictions). Monitoring activities to assess climate change impacts or an intensification of the monitoring is often mentioned by the activities as preparation measures. Furthermore, it is asked for a basin-wide or an international commitment to threshold values. Based on the monitoring results and consistent threshold values, potential risk areas should be identified. The activities seem to agree on the demand for forecasting and warning services, e.g. for extreme events as floods and droughts. Thereby a lot of options for cooperation among the DRB countries within the ICPDR are identified in the measures. However, challenges to bring the different interests to a common approach may arise.

In order to develop an Adaptation Strategy for the entire DRB until the end of 2012, this study provides the basis and will be discussed during upcoming meetings and workshops.

1. Project Overview: Objectives of the Study

The *Danube Study – Climate Change Adaptation* was initiated by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety to provide foundations for a common, Danube-wide understanding and procedure for adaptation to water resources management related climate impacts with the aim to develop suitable adaptation strategies in the Danube River Basin. The outcomes of the study should provide a basis for the development of a basin-wide adaptation strategy in the Danube River Basin with the ICPDR team of experts. It started in December 2010 and was finished by the end of January 2012.

The study was divided into the following four work packages:

1. Compilation of results and data of research and development projects as well as adaptation activities in relation to the water related impacts of climate change in the Danube River Basin.
2. Analysis of the data collection to comprise
    a) commonalities, contradictions in results and approaches
    b) dependencies, competing interests and possible conflicts
    c) deficits of knowledge
3. Derivation of requirements for integrative, sustainable ("no regret measures") adaptation to climate change in water related issues in the Danube River Basin on national, regional and international level.
4. Suggestions as basis for development of a basin-wide adaptation strategy to climate change in water related issues in the Danube River Basin with / for the ICPDR team of experts.

A close collaboration with experts in the Danube River Basin was intended within the Danube Study. Therefore the preliminary study results were presented during the following meetings, workshops and conferences. In order to establish contacts with experts in the Danube River Basin and to gather further information from projects and climate change adaptation activities, conferences were attended.

- **XXVth Conference of the Danubian Countries**, 16-17 June 2011 in Budapest, Hungary (M. Prasch, funded by another project)

  An outlook on the Danube Study was given besides the presentation of the outcomes of the project GLOWA-Danube in a presentation. Information about ongoing climate change projects in the Danube basin was gathered and contacts with people were established.

- **Anpassungsstrategien an den Klimawandel für Österreichs Wasserwirtschaft** (Climate change adaptation strategies for Austria's Water Management). Study of TU Vienna and ZAMG, 9 June 2011 in Vienna, Austria (F. Koch)

  Information about adaptation strategies due to climate change on water resources and ongoing climate change projects in Austria were gathered and contacts with people were established.

- **AdaptAlp Final Conference**, 6 July 2011, Munich, Germany (F. Koch)

  Information about adaptation strategies due to climate change on water resources and ongoing climate change projects in Alpine areas were gathered and contacts with people were established.

- **13th Ordinary Meeting of the ICPDR**, 9 December 2010, Vienna, Austria (W. Mauser)

  An overview of the Danube Study with the overall aim and the work packages was given.

- **33rd River Basin Management Expert Group Meeting**, 18-19 April 2011, Odessa, Ukraine (M. Prasch)

  The milestones of the study and first results were presented and discussed with the experts. The next steps were coordinated with suggestions by the experts.

- **Danube Climate Change Adaptation Stakeholder Workshop**, 12 September 2011, Munich, Germany (W. Mauser, M. Prasch, F. Koch, R. Weidinger)

  In order to discuss first results and further project steps with experts in the Danube River Basin a round-table discussion was carried out. Firstly, the preliminary results were presented. Secondly, important points and the further steps were discussed. Additionally, presentations about the project Carpivia and ongoing adaptation activities in Bavaria gave further inputs to the discussion. Finally, the next steps were determined.

- **34th River Basin Management Expert Group Meeting**, 27-28 October 2011 , Belgrade, Republic of Serbia (M. Prasch, W. Mauser)

  In order to include the feed-back from the national experts of the RBM EG, the following questions in a tour de table were discussed, based on the first results presented during a special session on climate change impacts.

  - *Is there a common agreement on the presented climate change impacts for water related issues in the DRB? Which climate change impacts are most urgent in the Danube River Basin from the perspective of the national members?*
  - *Did you already include measures on climate adaptation of the water sector in your national River Basin Management Plans or national planning approaches? Did you already perform a "climate check" of the measures included in those plans (as suggested by the CIS Guidance Document No. 24 on Climate Adaptation)?*
  - *In which impact fields is a basin-wide coordination of adaptation measures within the ICPDR required (prioritization)? Does it make sense to take required steps on specific climate adaptation issues on bi- or multilateral level (Upper, Middle and Lower Danube) or are some of the issues specific for certain sub-basins? (Suggestions of additional, transboundary adaptation measures are welcome.* Example: In order to define risk areas for droughts, international threshold values should be defined.)

- **15th Ordinary Meeting of the ICPDR**, 13 December 2011, Vienna, Austria (W. Mauser)

  The main outcomes of the study were presented.

Please note: Neither further model calculations were carried out nor adaptation activities were suggested by the authors. The presented results are solely based on the analysed studies, projects and adaptation activities that are listed in the Appendix. Furthermore, other factors such as social, demographic, and economic development are crucial for future adaptation strategies to climate change. However, they were not the subject of the present study, but are indirectly considered in the analyzed scenarios.

2. Data Compilation and Analysis

2.1 Research and development projects

The main focus of the analysis of several research and development projects and studies lies on the impacts of climate change on the water sector in the Danube River Basin (DRB). This includes the analysis of impacts on climate elements, water availability, extreme hydrological events, water quality and temperature, different types of water use like agriculture, navigation and water related energy production as well as biodiversity and conservation.

In total, 90 research and development projects and studies are included in this analysis, listed in Appendix 1. They are classified due to their project status: a) finished and much information available, b) ongoing and not so much information available yet, and c) less or no information available yet. Furthermore, the projects and studies cover spatially either the entire DRB or single sub-regions or sub-catchments on different regional, national or local scales. To get a better overview, they are classified into three priorities due to their importance depending on the spatial coverage and the number of the following impact fields which they deal with

- Climate / meteorology
- Water availability
- Extreme hydrological events (floods and droughts)
- Water temperature
- Water quality
- Impacts on: water supply / water demand, agriculture, irrigation, forestry, land use, soils / erosion, biodiversity / ecosystems, limnology, coastal zones, water related energy production, navigation, health and tourism

Countries with the highest spatial coverage are Hungary, Austria, Serbia and Slovakia with more than 50 projects and studies, followed by Romania and Germany (see Fig. 1). The entire DRB is covered by more than 30 projects, which are mostly EU projects. Thereby, the majority of projects is funded by EU programmes, namely the 5th, 6th and 7th framework programmes, the Interreg programmes Alpine Space and CADSES as well as the South East Europe Transnational Cooperation Programme or other EU programmes (see Fig. 2). Further projects are funded either internationally by UNDP, WWF and the Worldbank or by the countries Germany, Austria, Hungary and Romania. The studies, however, are mostly funded nationally.

The information gathered by the analysis of the research and development projects and studies is stored in a database within 14 individual tables, which were updated periodically. Several tables contain general information such as project and study aims and objectives, contacts, literate links, project partners and running periods. Moreover, they contain information about the scientific research methods, climate change scenarios and applied models. Further tables store the results of each project and study, namely the expected change of climate parameters, which are described in section 4, and the expected future impact on the water-related issues, which are considered in section 5.

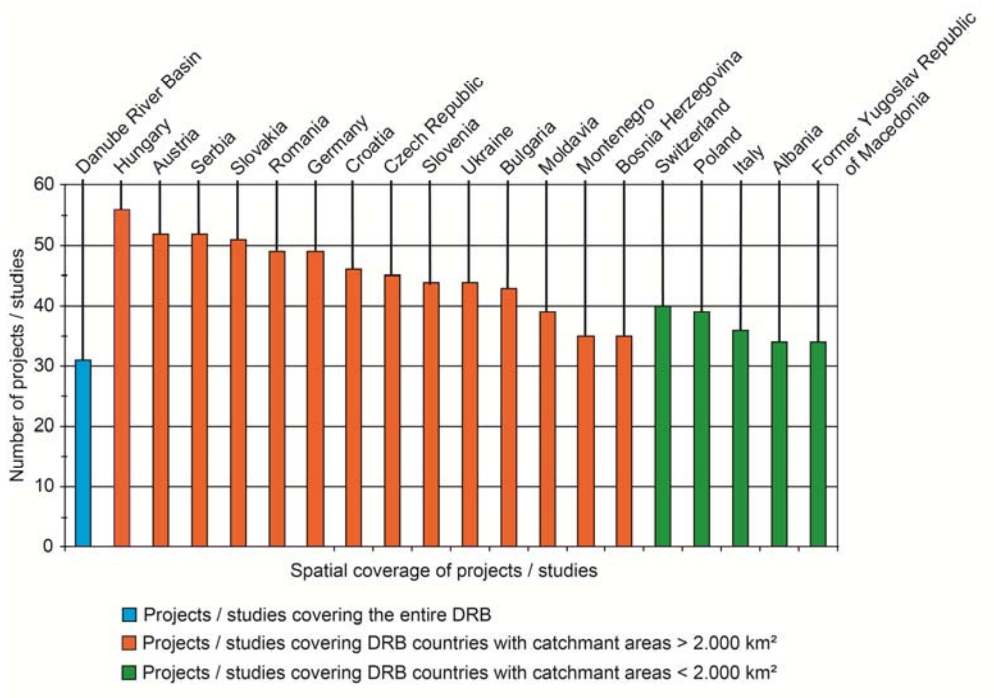


Figure 1: Spatial coverage of projects and studies.

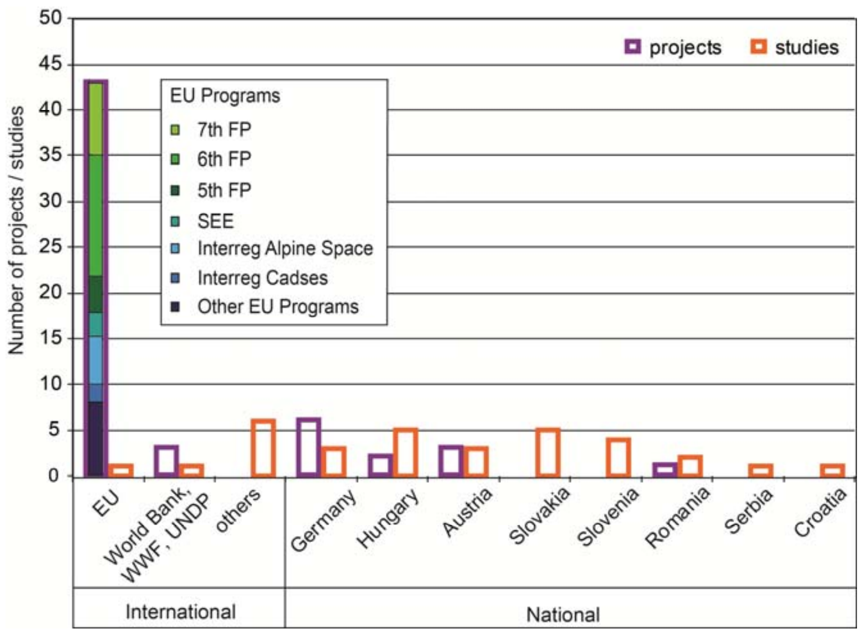


Figure 2: Funding of projects and studies.

With a total length of 2,857 km from its source in south-western Germany to the Black Sea, the River Danube is the second largest stream in Europe. With an area of 801,463 km², the DRB includes parts of 19 countries, several mountain areas like parts of the Alps, the Carpathian Range and the Dinaric Mountains. For a better assignment, all findings were classified into statements about the entire Danube River Basin (DRB), the Upper Danube River Basin (UDRB), the Middle Danube River Basin (MDRB) and the Lower Danube River Basin (LDRB) (see Fig. 3), which are based on ten sub-catchments (see Fig. 4). The separation between the UDRB and MDRB is defined by the gauge Bratislava at the boarder of Austria and Slovakia, and between the MDRB and LDRB by the gauge Iron Gate at the border of Serbia and Romania. The hydrological longitudinal section of the River Danube indicates the mean and extreme annual runoff values (see Fig. 5). The mean average discharges reach approximately 2,000 m³/s at the gauge Bratislava, approximately 5,500 m³/s at the gauge Iron Gate, and approximately 6,500 m³/s at the Danube Delta at the Black Sea. The main tributaries with the highest mean annual runoff are the rivers Inn within the UDRB, and Sava and Tisza within the MDRB, leading to a significant increase of the mean annual runoff of the Danube at their confluences.

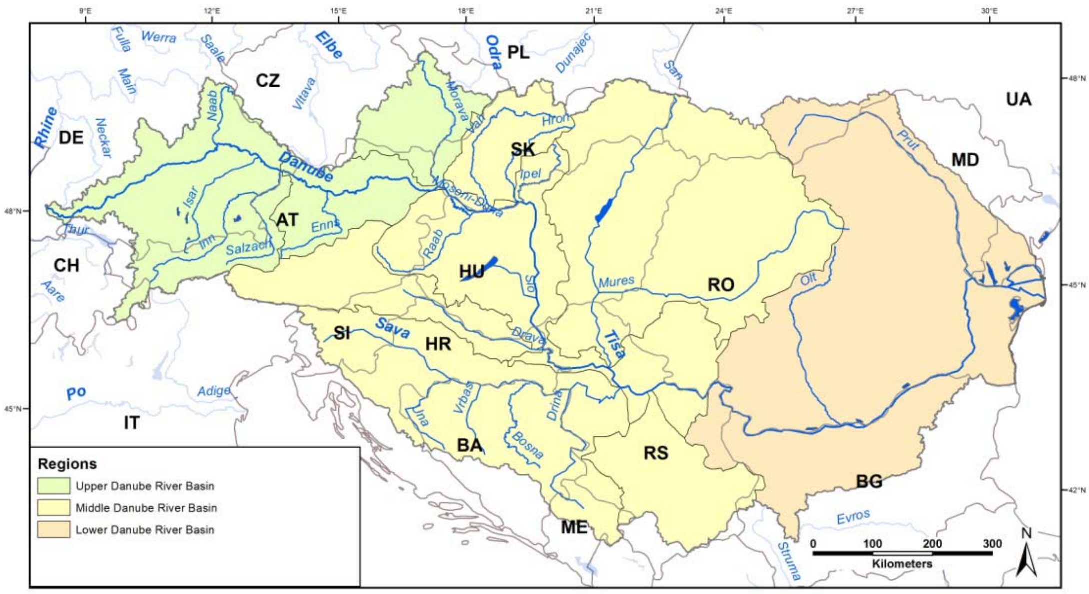


Figure 3: Main regions of the Danube River Basin.

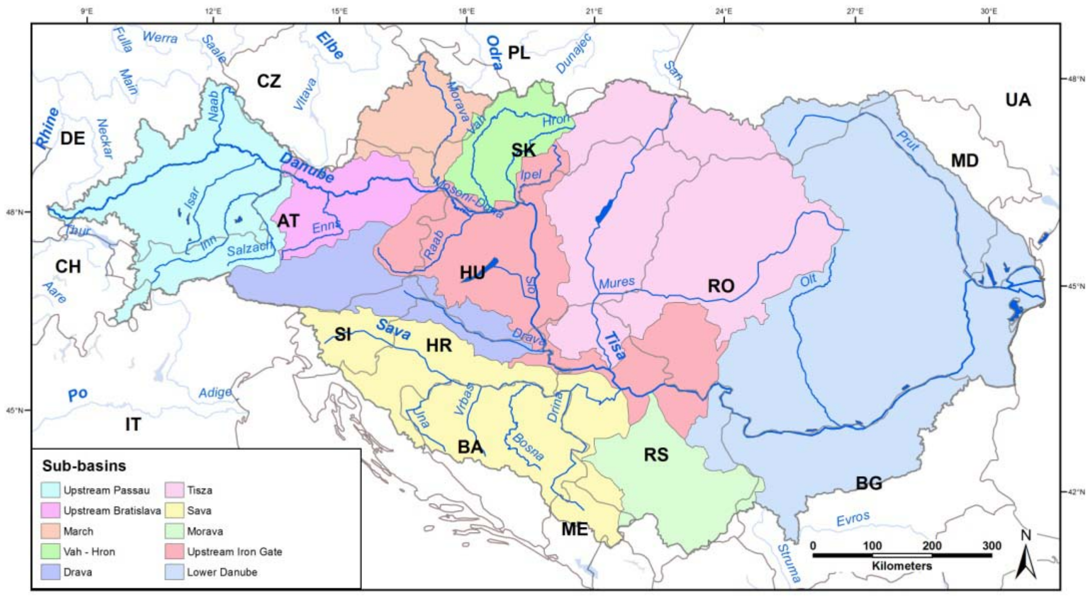


Figure 4: Main sub-basins of the Danube River Basin.

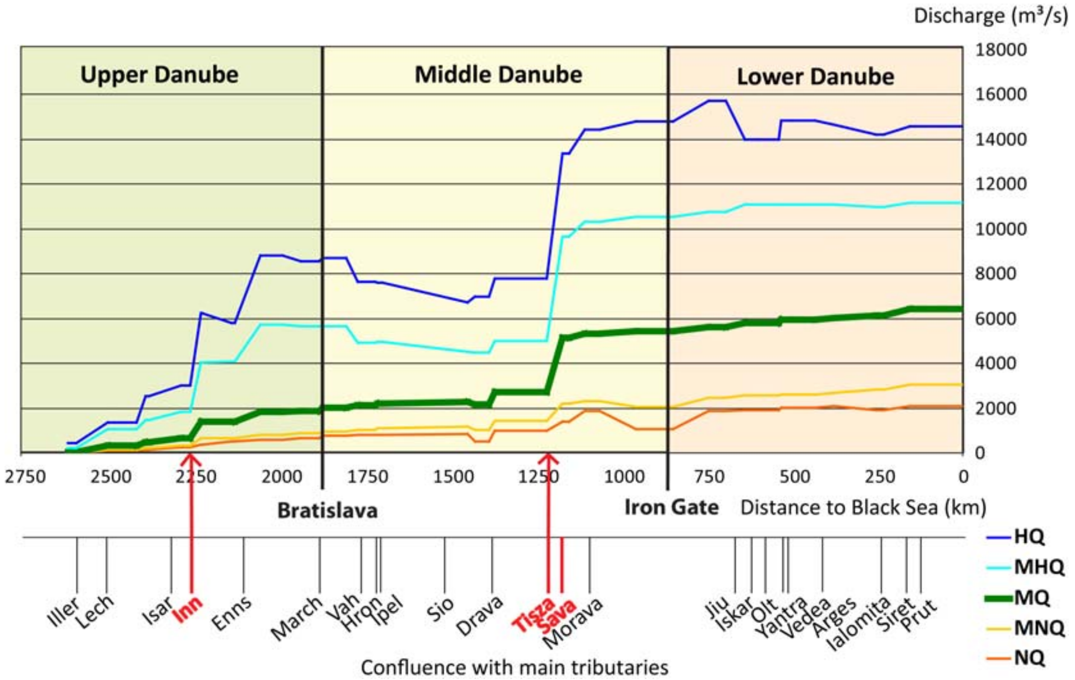


Figure 5: Hydrological longitudinal section of the River Danube (HQ = highest high-water discharge, MHQ = mean high-water discharge, MQ = mean discharge, MNQ = mean low-water discharge, NQ = lowest low-water discharge; data base: 1971-1990; based on [20] .

2.2 Adaptation measures and strategies

In order to compile all relevant information of ongoing, adopted and planned adaptation activities in the water sector in the DRB, adaptation strategies at the regional and the national level are collected and integrated in the data base, if available. The national communications under the UNFCCC (5th or initial) provide an overview of the present and future impact of climate change and adaptation measures per country and at the EU level. Additionally, relevant reports and further activities on the administrative level in relation to climate change impacts are considered as for example the EEA report (8/2009) “Regional Climate Change and Adaptation: The Alps facing the challenge of changing water resources”. Administrative regulations, such as the EU White Paper, the EU Guidance Document No. 24 on Climate Adaptation, the Water Framework Directive, and other related directives or River Basin Management Plans and conventions are collected to cover the political background of the study. Figs. 6 to 10 provide an overview of the analysed activities. Appendix 2 shows further details of the compiled information including the title, type, content and spatial coverage. The list is sorted by their type.

Most of the analysed activities cover only parts of the DRB (Fig. 6), while there are conventions, declarations, guidances and programs that affect the entire area of EU member and non-EU-member countries (Fig. 7). Almost all countries already have National Adaptations Strategies or are preparing one (Figs. 8, 9). The National Communications under the UNFCCC are available for all countries, but unfortunately the Ukrainian document is not yet translated into English, so that it could not be used in the present study (Fig. 10). This is also the case with the River Basin Management Plans of EU member countries, which are not written in English or German.

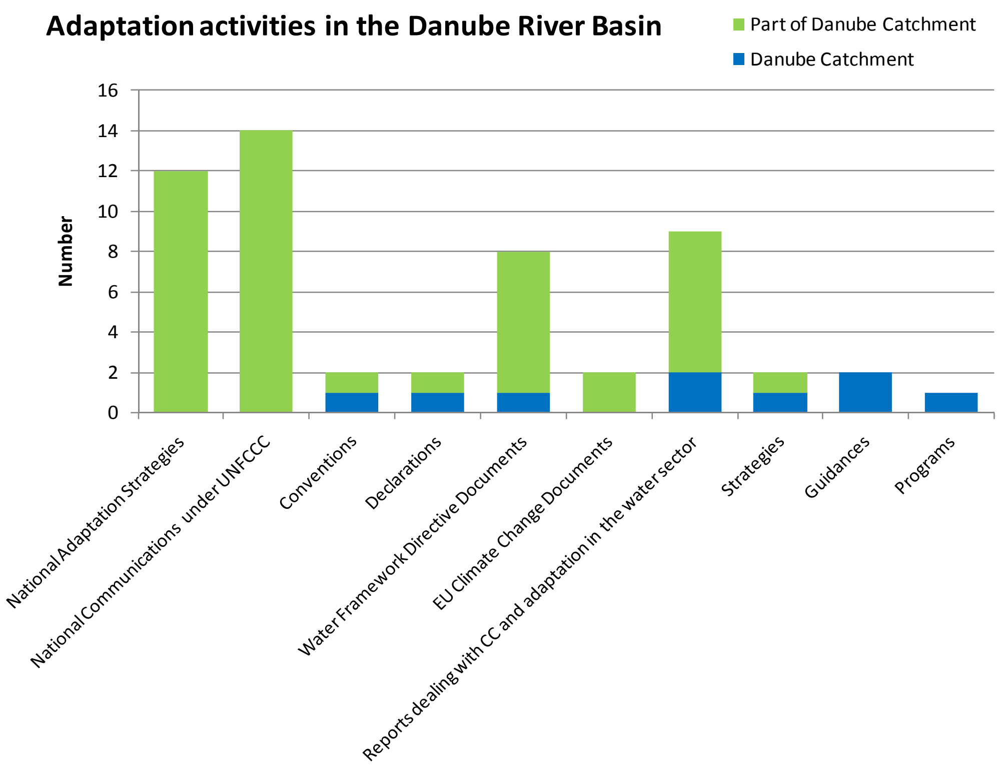


Figure 6: Overview of analysed adaptation activities, covering parts of (green) or the entire (blue) DRB.

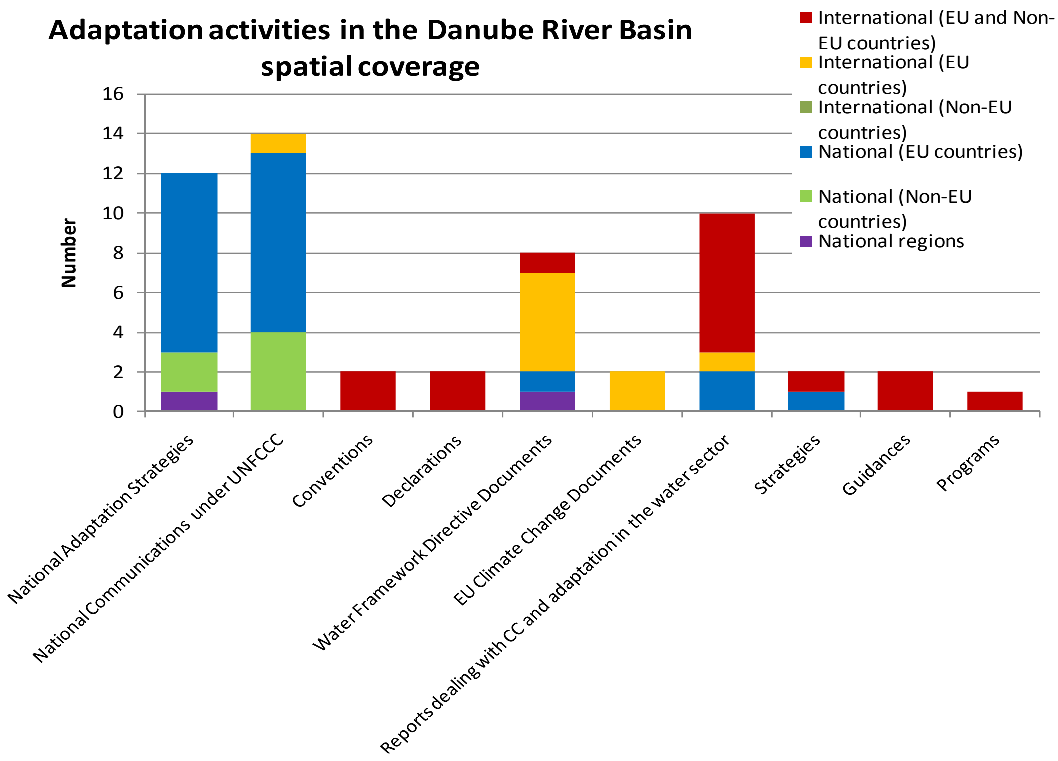


Figure 7: Spatial coverage of the analysed adaptation activities.

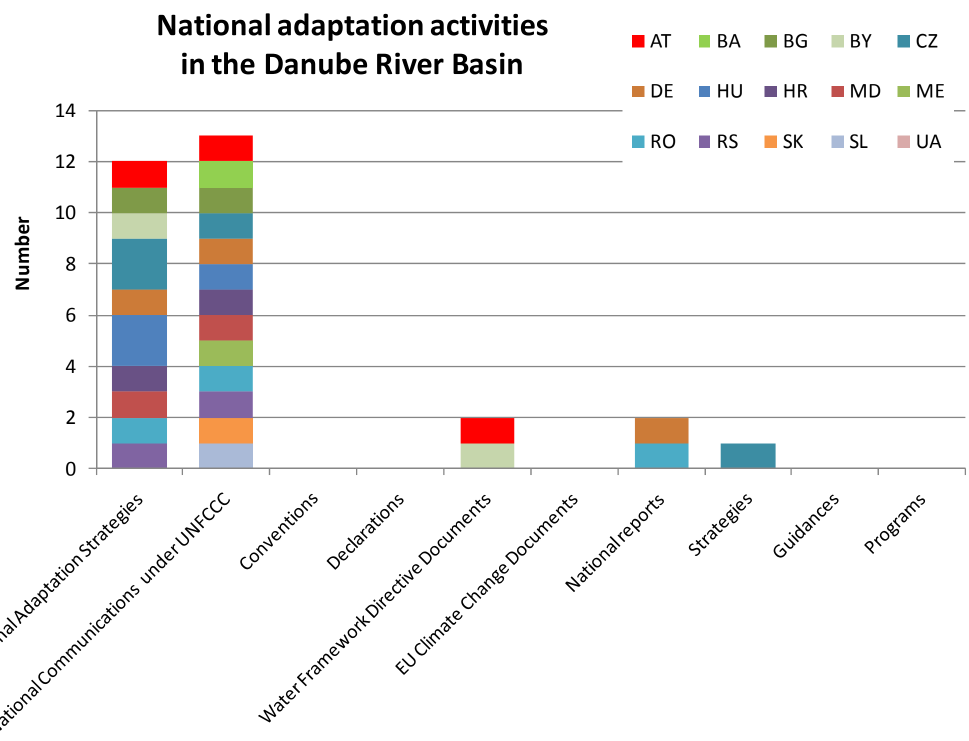


Figure 8: Countries with National Adaptation Activities in the DRB.

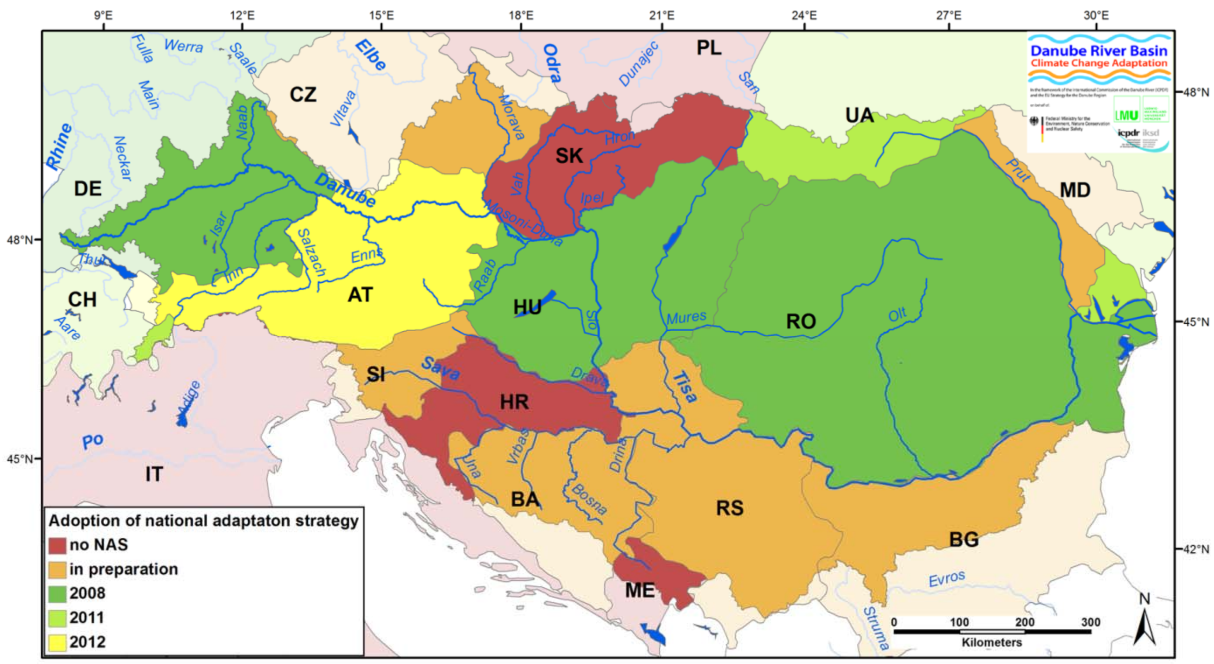


Figure 9: Overview of the present status of National Adaptation Strategies in the DRB.

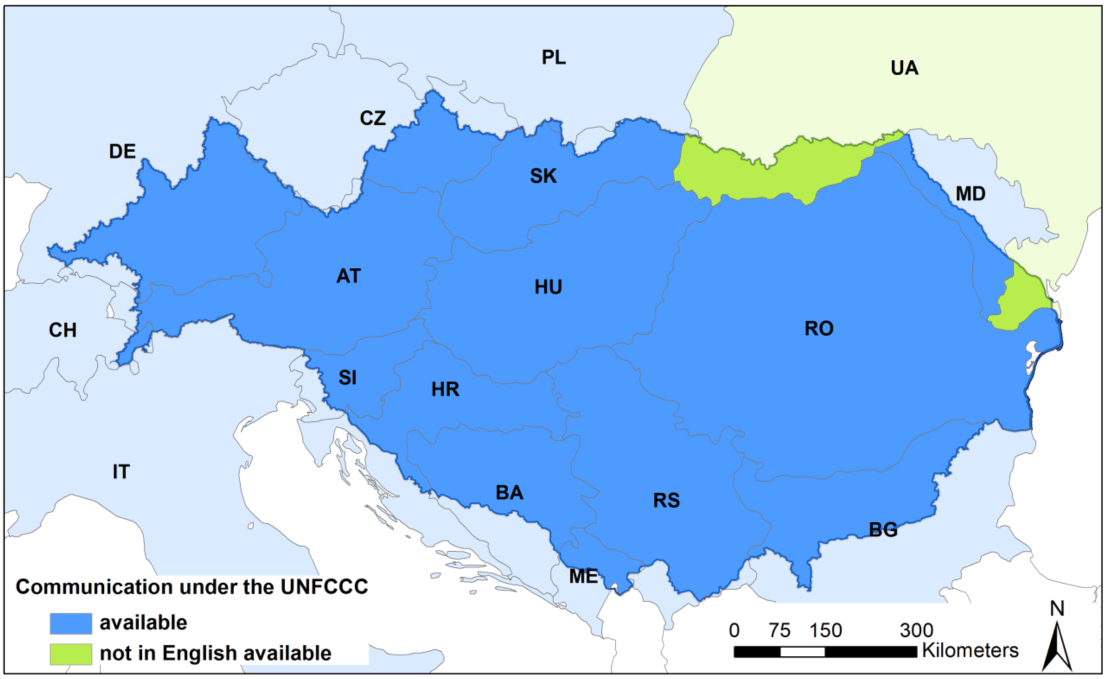


Figure 10: Overview of National Communications under the UNFCCC in the DRB.

The National Adaptation Strategies focus on the assessment of the present situation and of the requirements for adaptation to climate change. Based on this analysis, options for appropriate adaptation actions are suggested. In some countries within the Danube River Basin, some adaptation measures are already implemented. The Bulgarian National Action Plan on Climate Change is implemented in all sectors of the Bulgarian economy (energy sector, industry, transport, agriculture, households and services). The Water Act of the Czech Republic put a Flood Forecasting and Warning Service and a Strategy for Flood Protection into service. The German Action Plan for the next steps of the National Adaptation Strategy was presented in August in Berlin, while Bavaria implemented a low flow information service (2008) and applies a climate factor ("Klimazuschlag") of 15% for new flood protection infrastructure.

Next, it was analysed which impacts of climate change are addressed by the activities, and for which issues adaptation measures are suggested. Fig. 11 shows the percentage of both, addressed issues and suggested adaptation measures for the different impact fields according to the analysed activities. The ranking of the impact fields were prioritized due to the number of the suggestions can be seen in Tab. 1.

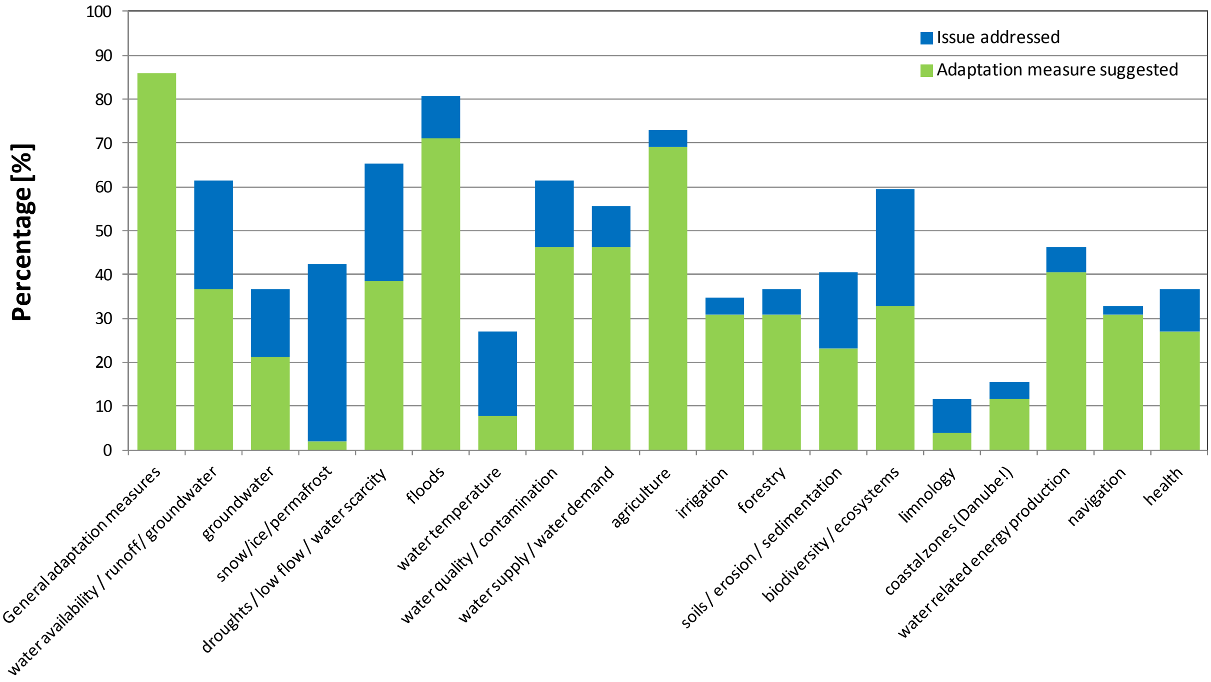


Figure 11: Percentage of addressed issues (blue) and suggested adaptation strategies (green) of the analysed adaptation activities in the DRB.

Table 1: Prioritization of impacts fields due to the suggested adaptation measures by the analysed activities.

Impact Field	**%**
General, water related adaptation measures	86
Floods	71
Agriculture	69
Water quality / contamination	46
Water supply / demand	46
Water related energy production	40
Droughts / low flow / water scarcity	38
Water availability / runoff/ groundwater	37
Biodiversity / ecosystems	33
Forestry	31
Irrigation	31
Navigation	31
Health	27
Soils / erosion / sedimentation	23
Groundwater	21
Coastal zones	12
Water temperature	8
Limnology	4
Snow/ice/permafrost	2

Besides general, water related adaptation measures, which are provided by 86 percent of the analysed activities, floods are mostly addressed by the adaptation activities, followed by the agricultural sector. The adaptation fields of coastal zones, water temperature, limnology and snow/ice/permafrost are rarely considered.

A detailed overview of activities addressed and issues suggested by National Adaptation Strategies and National Communications under the UNFCCC for different impact fields is given in Appendix 3.

3. Uncertainties

Before presenting the main findings of several research and development projects and studies about impacts of climate change on climate elements in section 4 as well as on different water related issues in section 5 in detail, the uncertainty of each impact is described within this section.

Dealing with climate change impacts requires focusing on uncertainty issues. These can be seen on two levels; firstly, the result uncertainties of each single project or study due to general uncertainties in the climate change modelling chain, and secondly, the uncertainty by comparing the results of different projects and studies due to different data basis and methods. In this section mainly the latter is addressed as the results of climate change impacts of several different research and development projects and studies were compared and analysed. This encompasses for example uncertainties by using different models, scenarios and downscaling methods as well as differences in application regions, scales and projection periods. Moreover, uncertainties might occur due to different available information for certain applications (amount and agreement of projects/studies, insufficient data and/or knowledge) which lead in sum to a number of certain, uncertain or even contradictory results (level and timing of the impact)[82]. Accordingly, it is important to estimate the range of possible future changes in relation to their certainty. In general, the uncertainty of climate change issues is often classified in so called “soft” and “hard” facts, whereby, the uncertainty of a hard fact is small and of a soft fact large [21].

In this study, the certainty of a parameter encompasses all projects and studies regarding a certain impact and is assigned by the following three variables for each impact: the amount of projects and studies, the agreement of the statements and results, and the certainty assessment of these statements and results (see Appendix 4).

For each of the three variables eight values were assessed and four certainty-categories were defined: very high (green), high (yellow), medium (orange), and low (red). Each certainty-category was calculated by the cube root of the product of the three variables presented by the eight values. If for example, the amount of all projects and studies considering one special impact is large and the agreement and certainty assessment is high, the certainty-category indicates a high overall certainty. However, if the amount of all projects and studies is high, but the agreement or the certainty assessment of the statements and results is low, the certainty-category shows a medium-ranged overall certainty.

Appendix 4 lists for each impact the three defined values amount, agreement and certainty assessment of all projects and studies as well as the calculated certainty-category. Besides the amount of statements of all projects and studies, the amounts of statements of all adaptation strategies are listed for each impact. Fig. 12 gives an overview about the degree of uncertainty of the climate elements and the main impacts considered in this study, which are presented in Appendix 4. The impacts are assigned to the impact areas climate elements, water availability, extreme hydrological events, water use and water quality and ecosystems.

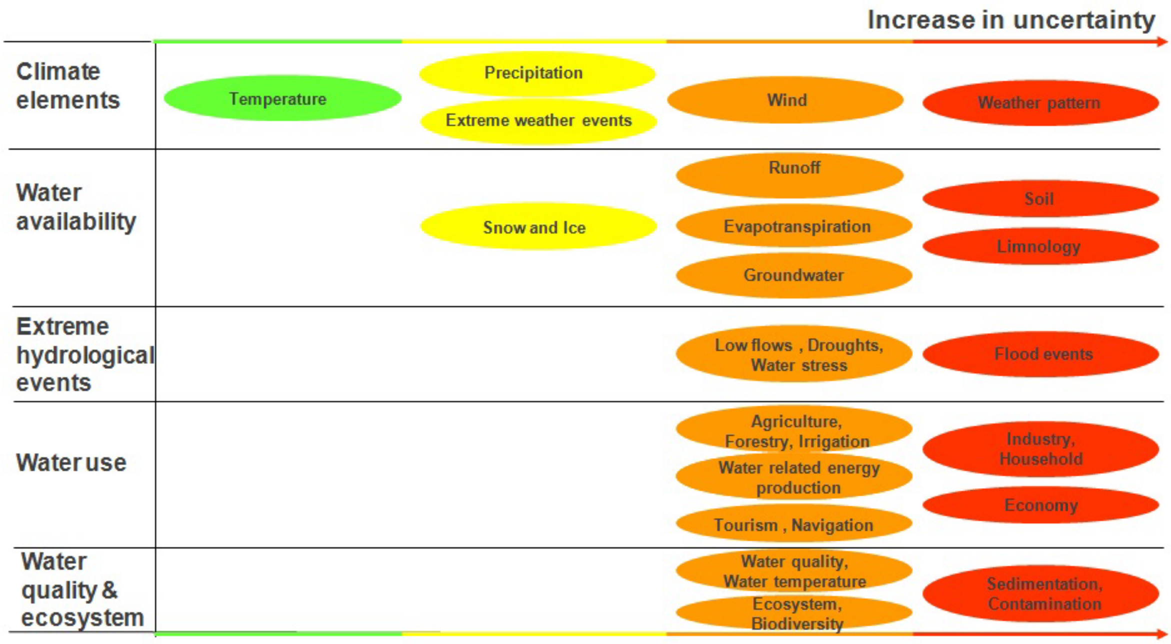


Figure 12: Uncertainty of climate elements and main impacts due to the four certainty-categories: very high (green), high (yellow), medium (orange) and low (red).

Climate elements: According to Fig. 12 changes in temperature are classified with very high (green) certainty. Thereby, future development of both, the mean annual and seasonal temperature, is a hard fact. The certainty of the future development of precipitation is high (yellow), however, less reliable than temperature changes, mainly for spring and autumn. In future, extreme weather events, classified with a high certainty, will show more often variabilities in quantity, seasonality and space.

Water availability: The certainty of changes in the water storages snow and ice is high, too. Changes in winter precipitation from snow to more rain are a quite hard fact, but changes in quantity are less reliable. The impacts, runoff, evapotranspiration and groundwater are all rather uncertain and classified with a medium (orange) certainty. Changes in water availability depend largely on precipitation, which might decrease in summer, especially in the southeast of the DRB with a strong tendency to water stress. Due to only few reliable findings on changes in soil water and limnology, these impacts were classified with low certainty (red).

Extreme hydrological events: In general projections of extreme hydrological events are rather uncertain than changes in the mean water availability. Although climate change impacts on low flows, droughts and water scarcity are medium, they are more reliable than changes in floods showing a low certainty. Regarding the latter, few contradicting statements e.g. about changes in flood frequency in different regions, exist.

Water use: Regarding the impacts on different fields of water use, most issues are classified with a medium certainty and depend largely on changes in climate elements, water availability and extreme hydrological events. This means their certainty can’t be better than of the triggers. The impacts on agriculture for example are investigated to a high degree, but the important future yields for maize and wheat are not uniform. Navigation might benefit in winter due to less icing but in summer shipping will be restricted due to more days with low water conditions. For water related energy production there is a similar assessment, e.g. hydroelectric power generation might possibly increase in winter and decrease in summer. The impacts on industry, household and economy are categorized with low certainty due to little available information.

Water quality and ecosystems: With a medium certainty, climate change could lead to the fact that water quality deteriorates and water temperature increases. Moreover, vulnerability due to climate change might increase for aquatic ecosystems and biodiversity might decrease with medium certainty. The low certainty of sedimentation and contamination occurs from little available information. However, for all these impacts quantitative, seasonal and spatial changes are not necessarily clear.

4. Climate Change Scenarios for the Danube River Basin

4.1 Climate Models and Scenarios

In order to assess the future development of the climate parameters air temperature and precipitation, most of the projects and studies use the IPCC emission scenarios A1B, A2, B1 and B2 [96]. However, other emission scenarios are also applied in a few projects and studies. As meteorological drivers different Global (GCM) and Regional Circulation Models (RCM) are used. Thereby, the spatial resolution varies between 0.3 and 2° (50-150 km) (GCMs), and between 20 and 50km (RCMs). Finally, different dynamical and statistical downscaling methods are applied to model the future development of air temperature and precipitation with a spatial resolution between 1 and 10 km. The resulting development is based on single or ensemble model runs.

Mainly the periods 1961 to 1990 and 1971 to 2000 serve as reference periods for the presented parameters. For the future simulations often the periods 2021 to 2050 and 2071 to 2100, but also decades or other periods are used.

4.2 Air temperature

In total, 59 projects and studies with statements regarding IPCC scenarios or trends were analysed. All projects and studies assume a temperature increase during this century, both annually and in every season with a rising gradient from northwest to southeast in the DRB. Therefore temperature increase is classified as a “hard fact”. Nevertheless there are considerable differences in the investigated areas due to climatic factors like altitude, mountainous massifs, seas, etc., but the main future trends are similar for all areas. In all models the uncertainty is largest in winter. The mean temperatures of all seasons are likely to increase from northwest to southeast in the DRB. In the course of the century, these tendencies are expected to strengthen. In the near future mean annual temperature is expected to rise between 0.5°C and 4°C, with a distinct gradient from west to east, and in the far future it is expected to get warmer, so the increase of temperature lies between 2.5°C in the north-western parts and up to 5°C in the southeast. In summer in the near future the expected rise is 1-2°C, and in the far future 3-6°C. In winter in the near future an increase of 1-3°C and in the far future of 2-4°C are projected. The projected annual and summer mean temperature in the DRB under A1B conditions is illustrated in Fig. 13.

In the following details are presented for the entire DRB, the UDRB, MDRB and LDRB, followed by commonalities, possible challenges and knowledge gaps.

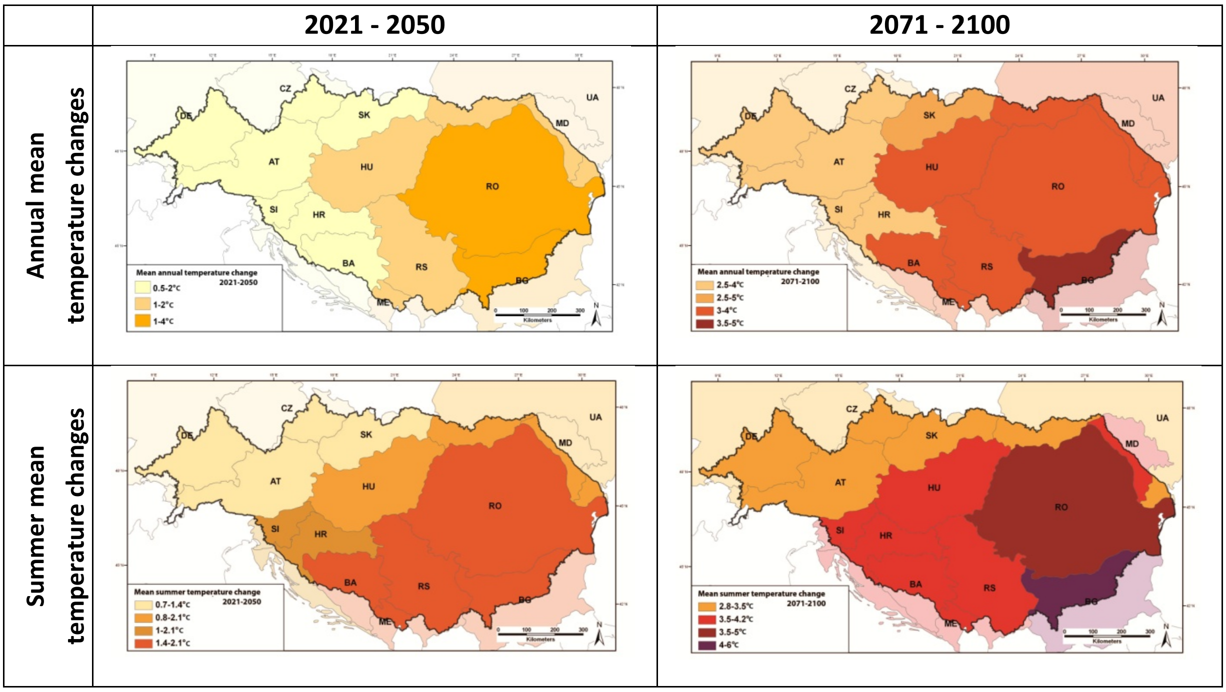


Figure 13: Increase of mean annual and summer temperature in the Danube River basin for 2021-2050 and 2071-2071 for A1B scenarios according to different model results.

Danube River Basin (DRB) [29, 28, 33, 34, 49, 72, 101, 102, 115, 114, 125, 129]

Mean annual air temperature

Within the A1B scenarios an increase of 0.5 to 4°C for the near future period from 2021 to 2050 and an increase of 2.5 to 5°C for the far future period from 2071-2100 are to be expected. The A2 scenarios show increasing temperatures of 2 to 3°C and 3 to 4°C for 2040 to 2069, and of 3 to 4°C and 4 to 5°C for 2071 to 2100 with a gradient from west to east.

Mean summer air temperature

Both, A1B and A2 scenarios simulate for 2021 to 2050 an increase of 0.7 to 2.1°C, and an increase of 2.8°C until 5 to 6°C for 2071 to 2100 in the east (Romania, Bulgaria). The occurrence of future extreme hot summers is projected.

Mean winter air temperature

For winter the projects and studies agree that the results are not as certain as for summer. But the tendencies within the A1B and A2 scenarios are similar with an increasing trend from northwest to southeast and project increases of 0.8 to 2.1°C (2021-2050) and of 2 to 4°C (2071-2100). CLAVIER [34] simulates for Hungary an increasing frequency of extreme warm periods in winter.

Mean spring air temperature

For spring there is little information, but the A1B as well as the A2 scenarios show an increase of 0.7 to 1.4°C in the period from 2021 to 2050 in the whole basin, of 2 to 3°C in the UDRB and MDRB, and of 3 to 4°C in the LDRB for the period from 2071 to 2100.

Autumn mean temperature

For autumn there is also little information. For 2021 to 2050, higher temperatures of 0.7 to 1.4°C in the UDRB and of 1.4 to 2.1°C in the MDRB and LDRB are shown (A1B, A2), whereas in the far future period from 2071 to 2100 the temperatures are expected to rise faster, about 2 to 4°C.

Upper Danube River Basin (UDRB) [7, 12, 64, 68, 75, 77-79]

- For the UDRB an increase of about 2.5°C in the near (2021-2050), and 4°C in the far future (2071-2100) in summer and an increase of about 2°C in the near and 3.5°C in the far future in winter is assumed [77]. This corresponds to the climate trends applied in GLOWA-DANUBE [64].
- The Alps are very sensitive to global warming which means that warming is twice as fast in the Alps than at the global scale. It can be observed that at the meteorological scale (decade) this warming rate may have a significant variability. HistAlp [68] supposed an increase of 2.6°C for 2040-2060 and of 4.4°C for 2080-2099 for the Austrian part within the DRB.
- KLIWA [79] states for Germany, that the winter temperature increase of 2°C is higher than the summer temperature increase (1.4°C).

Middle Danube River Basin (MDRB) [16, 17, 62, 86, 87, 91]

- For Hungary an increase of 0.3°C per decade is expected. The expected warming by 2071-2100 is more than 2.5°C and less than 4.8°C for all seasons and for both, A2 and B2 scenarios. The smallest difference is expected in spring (0.6°C), while the largest is expected in winter (1°C). The temperature increases in summer for both scenarios with a zonal gradient from north to south, and in winter from west to east.
- CLAVIER [34] confirms a temperature increase for the Tisza River Basin with an increase of 1.7°C in winter and 1°C in summer (both 2021-2050, A1B).

Lower Danube River Basin (LDRB) [27, 40, 42, 105]

- For Romania the summer temperature increase is higher (1.8-2.1°C) than in winter (1.4-1.5°C) for the period 2021-2050 under A1B conditions. For the far future period 2071-2100 an increase of 3°C for all seasons and especially for summer an increase of about 4.1-4.5°C is simulated.
- For the last century the highest significance level recorded by the data series was in the south-east, on the Black Sea shore; this fact seems to be closely related to the increase in sea surface temperature. The very important and generalized warming appeared in the last period (1971–2006) for most of the country. The analysis emphasized that the annual data series is most closely related to the summer data series, and thus, the importance of the summer temperatures in the annual variability was revealed.
- In winter all models show substantial increases in mean air temperatures over Eastern Europe. The mean warming signal is above 4°C in large parts of Eastern Europe. Similar to summer, changes in the more extreme conditions are larger than on average

Commonalities: Increase in air temperature; tendencies strengthen in the course of the 21st century.

Challenges: Regional evaluations with small spatial resolutions, because differences in temperature patterns on the small scale are not visible in most results.

Knowledge gaps: Less information for spring and autumn, high uncertainty for winter; MDRB and LDRB are mainly represented by Hungarian and Romanian studies.

4.3 Precipitation

The Danube River Basin is located in the transition zone between increasing (Northern Europe) and decreasing (Southern Europe) future precipitation (IPCC). The project ENSEMBLES simulated for Europe a zonal distribution with more precipitation in the north and less precipitation in the south (Fig 14). The DRB mainly lies in the transition zone where few changes are expected. However, in the south-eastern borderland of the DRB the changes are larger.

While an increase in heavy precipitation in warmer climate is a remarkably robust model result, seasonal and regional differences are not clear. The results show generally more torrential precipitation events and a widespread drying in southern and eastern Europe. The project PRUDENCE [101] simulates that "intensive rain events - like those leading to like those leading to the flooding in 2002 in different regions and catchments like Moldova, Danube, Elbe and Rhone - will become more frequent and even more intensive. In other words: When it finally rains in a drier and hotter Europe, it pours down (http://prudence.dmi.dk/public/christensen_et_al.html)."

According to the analysed projects, mean annual values will most likely remain almost constant, but seasonally and regionally large changes are projected for the 21st century. A decrease in summer precipitation above 20% and an increase in winter precipitation in most areas of between +5% and 20%, up to +35% in some parts are to be expected. While winter variability increases significantly, there are no clear trends for spring and autumn. The simulations show a decrease of summer precipitation up to -20% for Central Europe and a decrease of about -25% to -45% for Eastern Europe (Bulgaria, Hungary, Slovakia, and Romania). The Alpine Space is divided into a wetter north and a drier south, especially the south-eastern part of Austria is likely to become drier [8, 12]. In Hungary a reversal of seasonal precipitation distribution is often mentioned [17, 98]. In the future, more extreme events, e.g. more torrential precipitation events and widespread drying in southern and eastern Europe are to be expected.

The certainty in precipitation is high, however, compared with air temperature, less robust and reliable. Different GCMs produce partly contrasting patterns of spatial distribution of precipitation. Regional projections should be handled with care. There are a lot of quantitative uncertainties in the changes of both mean and extreme precipitation amounts. The changes in mean precipitation largely vary among the different scenario simulations, some are even contradictory as for example the A2-scenario for the summer period 2010-2039: the models MIMR [106, 107] and REMO project no changes or a slight increase in rainfall (up to 15%), whereas the model IPCM4 [106, 107] and the ENSEMBLES-multi-model [125] project no changes or a decrease in rainfall up to -30%.

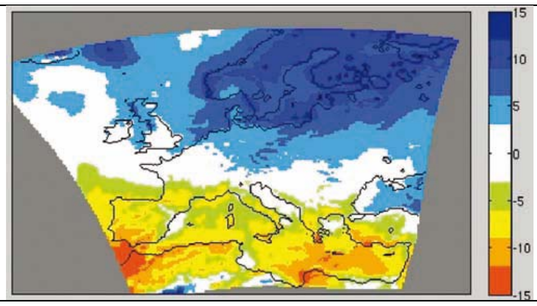
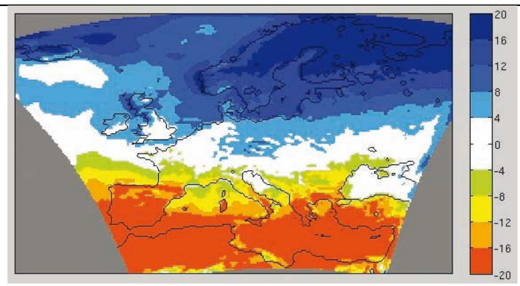
	
2021–2050 compared to 1961–1990	**2071–2100 compared to 1961–1990**

Figure 14: Climate-change signal for total annual precipitation (%) for the multi-model mean of the ENSEMBLES RCMs [125]

Danube River Basin (DRB) [18, 29, 28, 33-35, 49, 57, 88, 102, 103, 106, 107, 125]

Some models show similar future trends but differ in the magnitude of the signal. The results can be summarized as follows:

- Mean annual values remain almost constant, but seasonally and regionally large changes are projected.
- A decrease in summer precipitation of up to 20% or more, and an increase in winter precipitation in most areas of between 5 and 20% and in some parts of up to 35% are to be expected.
- The results for future winter precipitation are not unique, some are contrary.
- The findings confirm that the tendencies strengthen in the 21st century.
- There are no clear trends for spring and autumn.

Annual mean precipitation A1B (Fig. 15)

- A1B, 2021-2050: unchanged with a slight tendency to decreasing values, especially in Bulgaria (-8 to -20%)
- A1B, 2071-2100: UDRB and MDRB: tendency to more precipitation, in the LDRB in tendency to less precipitation (up to -20%)

Annual mean precipitation A2/B1

- A2, 2040-2069: precipitation remains constant with a slight tendency to decreasing values, especially in Bulgaria (-5 to -30%)
- A2, B1, 2071-2100: no changes in the UDRB and MDRB, less precipitation (-10 to -40%) in the LDRB

Summer mean precipitation A1B

- IPCM4 [107] and the multi-model ENSEMBLES [125] simulated less (up to -30%) rainfall
- MIMR [107] and REMO simulated no changes or a slight increase in rainfall
- Tendency: decreasing rainfall from northwest to southeast

Summer mean precipitation A2/B2

- A2: Change in the length of summer drought: DE, AT, CZ: 0-10 days, HU, CR, RS, RO, BG: -5 to +5 days. The regional climate model shows a coherent spatial pattern of future change in precipitation intensity with an increase in the number of intense rainfall events across northern Europe and decreases across southern Europe. An examination of the length of the European summer drought season confirms this behaviour indicating that the number of dry days may increase in the future, particularly in the Mediterranean region [67].

Fig. 16 illustrates the strengthening of the diminishing rainfall from northwest to southeast in the course of the century due to the results of different scenario runs.

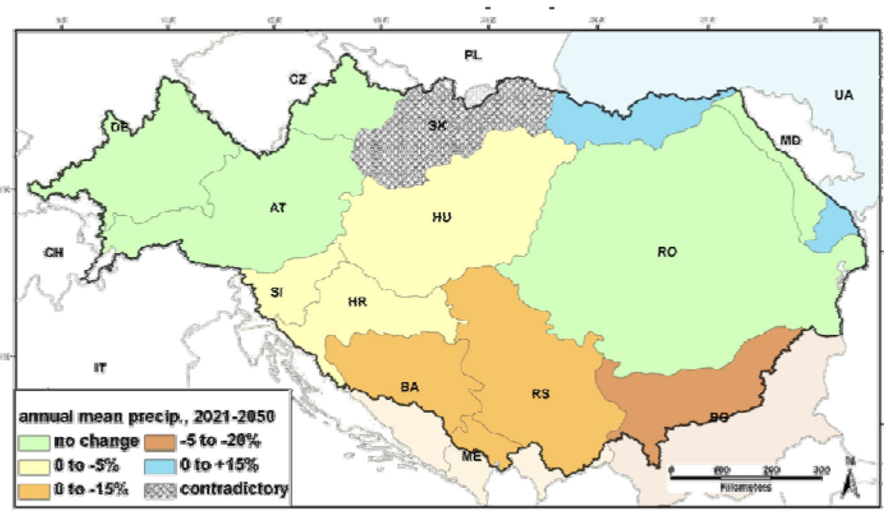


Figure 15: Change of mean annual precipitation in the Danube River Basin for 2021-2050 of A1B scenarios according to different model results.

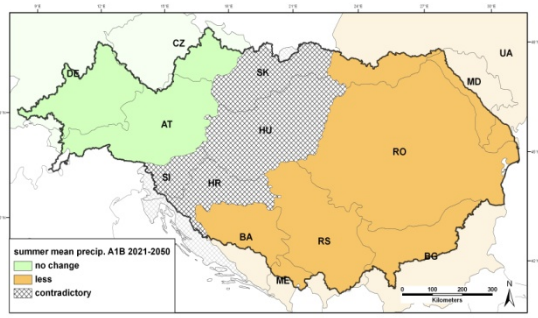
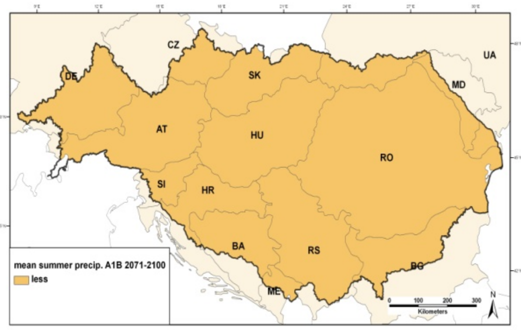
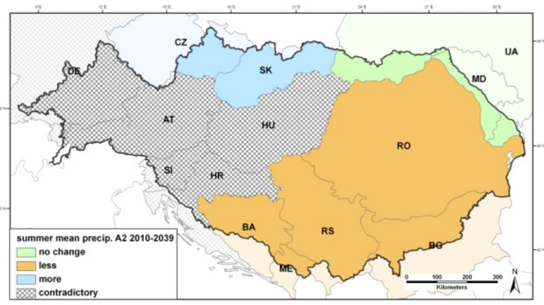
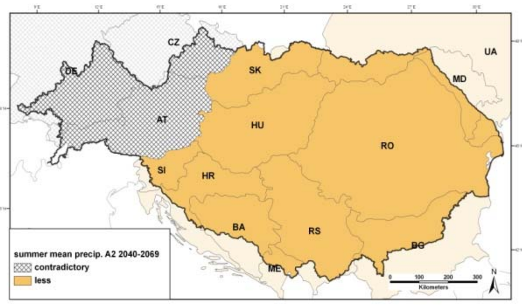
	2021-2050	2071-2100
A1B		
	2010 -2039	**2049 -2060**
A2		

Figure 16: Change of summer mean precipitation in the Danube River Basin for different periods and scenarios according to different model results.

Winter mean precipitation A1B

- 2021-2050: Tendency towards increasing precipitation in the entire DRB with values between +5 to +40% except in the southern Alps and in Slovenia, where decreasing values are simulated. The amount of precipitation can vary high, both, during the winter season and from year to year, so dry winters are also simulated in Hungary and parts of Romania, and in the most southern parts of the DRB.

- 2071-2100: increasing trend in the northern parts of the Basin, especially at the Alpine foothills, the Central Alps and Hungary, but little information about the other parts of the Basin is available.

Winter mean precipitation A2/B2

- Similar tendencies as for A1B

Spring and autumn mean precipitation

- No clear trends

Upper Danube River Basin (UDRB) [7, 8, 21, 25, 36, 64, 79, 128]

- The Alpine Space is divided into a wetter north and an drier south, the eastern part of Austria is most affected
- A2: Regarding the Alps, the total summer rainfall is likely to decrease by over 150 mm (±30 mm). North of about 44°N, winter rainfall is expected to increase by 100 mm (±15 mm) with a remarkably greater increase (and higher uncertainty) over the Alps. South of this line, winter rainfall will decline by 50-100 mm (±10 mm).

Middle Danube River Basin (MDRB) [27, 99, 113, 130, 136, 137, 17] [60, 62, 69, 70, 86, 87, 112]

- Eastern Europe: decrease of summer precipitation up to 25-45% (Bulgaria, Hungary, Slovakia, Romania); Precipitation is expected to decrease in summer (-25 up to -45%), while for winter the projections are not uniform, some models show the possibility of an increase and some of a decrease; Hungary and the Carpathian Basin are likely to become drier until 2100. By the end of the century the annual amount of precipitation in the Carpathian Basin is likely to decrease by about 20% for both A2 and B2 scenarios [17] .
- For the Tisza River Basin almost no change in the total annual amount of precipitation is modelled, however, the annual cycle of precipitation over Hungary shows that a decreasing summer precipitation is more or less compensated by increasing winter/autumn precipitation [97, 98] . Also VAHAVA [122] projects an increase in winter rainfall (A2: 23-37%, B2: 20-27%) and the results of Bartholy [17] show a slight increase in winter (in spatial average about 14%), which is significant in the case of A2 conditions in the Transdanubium, where the simulated winter precipitation change may exceed 30-40%. The largest change is expected for summer, when significant drying for the whole country is projected (the simulated precipitation decrease is 43% in the case of B2 scenario conditions and 58% in the case of A2 conditions in spatial average**.**
- In Hungary, a reversal of seasonal precipitation distribution is expected: summer, which is now the wettest season, will be the driest period (40-50% less rainfall than today); winter, which is now very dry, is expected to get a wet season (+14-40%). Winter variability increases significantly. In the recent climate (1961-1990), the wettest months in Hungary are in late spring and early summer (from April to July), when the monthly mean precipitation sum exceeds 60 mm. The driest months are January and February with about 30-35 mm total precipitation on average. The PRECIS simulation outputs suggest that the annual distribution of monthly precipitation is very likely to be restructured by 2071-2100 both, in the case of the A2 and B2

scenario. The driest months are expected to be July and August (A2: with less than 20 mm, B2: with about 25-30 mm on average). The wettest month of the A2 scenario runs is April with about 65-70 mm precipitation on average, while in the case of the B2 scenario the wettest months are April, May and June with about 60 mm total precipitation on average [16, 17] .

- The projections from IPCC and PRUDENCE and some others confirm the results of drier summers and wetter winters for Hungary and the Carpathian Basin with different magnitudes for the near and far future (summer: -3.7 to -8.2% until 2030 and -24 to -33% (A2), respectively -10 to -20% (B2) until the end of the century) [122, 123].

Lower Danube River Basin (LDRB) [72, 91, 105]

- Less mean annual precipitation in the future: -5 to -15%, mainly due to less summer rainfall and unchanged or slightly increased winter precipitation.

Commonalities: Trend on decreasing summer rainfall; tendency to increasing winter precipitation with high variability

Challenges

- Different GCMs produce partly contrasting patterns of spatial distribution of precipitation
- There are a lot of quantitative uncertainties in the changes of both mean and extreme precipitation amounts.
- Climate models are not very good in reproducing convective precipitation events, which could in the Alps make up a considerable part of summer precipitation [39] .

Knowledge gaps: There are more detailed results for the UDRB and the MDRB than for the LDRB. No clear results for winter precipitation, no trends for spring and autumn. To derive distribution patterns for rain and snow at higher elevations more detailed results, respectively results from models with a higher spatial and temporal resolution are required.

4.4 Extreme weather events

A1B-simulations of Regional Circulation Models (RCM) for Europe show considerable changes in extreme temperatures in summer and winter. In both cases these changes are larger than changes in the median for large areas. A comparison with historical data shows that the spread of the simulated extreme temperatures is larger than the natural variability during the last centuries, at least for the observational stations with long enough records [28] .

The changes in the annual mean number of days with heavy rainfall show a twofold pattern over entire Europe. Roughly a north-south division at Alpine latitudes becomes evident. For most areas at lower latitudes average decreases in annual heavy rainfall of up to 5 days and more are simulated, whereas for the areas north of this division line a gain in the average number of days with heavy rainfall is projected. For most of these regions an increase will amount up to 3 % [50]. Also all scenarios show local and regional increases in extreme rainfall in most parts of Europe overall, but the exact patterns appear to be controlled primarily by the driving global model and are modified further by the RCM formulation [75]. The trend towards increased heavy winter rainfall in northern

Europe and decreased heavy rainfall in southern Europe is consistent with the trend of the North Atlantic Oscillation towards positive values.

Wind extremes seem to strengthen particularly in the UDRB.

Upper Danube River Basin (UDRB) [6, 25, 36, 64, 79, 128, 131]

There are different results for the future change of general weather situations: Scenarios from the GCM ECHAM5 indicate a decrease of the probability for the weather pattern (Vb cyclone), which caused e.g. great damages in Austria in 1999, 2002 and 2005, but the scenarios give no information about a potential increase in intensity. Another simulation shows an increase of cyclonal west-facing weathers with high precipitation sums and an increase of the possibility of winter storms. Nevertheless most projects show the following statements:

- Increase in the frequency and intensity of heat waves
- Increased risk of future intense storm-related precipitation events and flooding
- Weather extremes such as storms or dry spells are expected to increase
- Increase of heavy precipitation events, heavy rainfall and torrential rainfall
- It is also likely that a warmer future climate would have fewer frost days
- Growing season length is related to the number of frost days, and has been projected to increase as climate warms
- There is likely to be a decline in the frequency of cold air outbreaks (i.e., periods of extreme low temperatures lasting from several days to over a week) in winter
- Wet extremes are projected to become more severe in many areas where mean precipitation is expected to increase
- Dry extremes are projected to become more severe in areas where mean precipitation is projected to decrease.
- Increasing variability in the weather in all seasons with rapid changes of short periods (five to ten days) of extremely cold or warm weather (heat and cold waves) and periods with extremely high levels of rainfall, as well as droughts
- Possible increase in frequency, duration and height of storm surges and accordingly storm damage

Middle Danube River Basin (MDRB) [16, 17, 27, 33, 34, 60, 70, 112, 136, 137]

In the past three decades less precipitation occurred in the Carpathian Basin, but heavy or extreme precipitation days increased considerably by the end of the 20th century. The simulation results suggest that the future climate tends to be wetter in winter and drier in summer in the Carpathian Basin. Cold extremes are expected to decrease, while hot extremes tend to increase significantly. Both changes imply regional warming in the Carpathian Basin. With the frequency of summer droughts, on the one hand, and increasing heavy precipitation events in autumn and winter on the other, it is 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 [89]. Extreme precipitation events in winter will be more intense and more frequent, in summer with a general decrease of extreme precipitation. The spatial patterns of the annual number of heavy precipitation days are similar for the reference period (1961-1990) and the last three decades of the 21st century (2071-2100). Extreme rainfall occurs then on more than 30 days per year in the mountainous regions, while it will not exceed 24 days per year inside the basin. The smallest values are simulated for the southern part of Hungary. The results of the A2/B2-scenarios are similar but more pronounced than for the A1B-scenarios.

A1B-scenario results for Hungary/CADSES region

- *Summer days* (Tmax > 25 °C): no changes in the near future (2021-2050); by the end of the century (2071-2100) the annual percentage of summer days is likely to increase by about 7-14% (up to 120 days per year)
- *Hot days* (Tmax > 30 °C): increase until 2071-2100 of 4-12% (RegCM simulations about 62 hot days yearly)
- *Frost days* (Tmin < 0 °C): In the future, the frequency of frost days is likely to decrease, by about 3-8% and 8-14% by 2021-2050 and 2071-2100 (less than 55 days, in the lowlands less than 25 days). The decrease is evidently larger in mountainous regions where frost days occurred more frequently in the past.
- *Heat waves* (Tmean > 25-27°C for at least 3 consecutive days): occurrence is clearly projected to increase: the frequency of heat wave warning cases is likely to increase by 2-5 days by 2021-2050 and 10-20 days by 2071-2100 relative to 1961-1990. In the southern parts the frequency of heat wave warning cases is likely to increase by 24-30 days by 2021-2050, and by 40-50 days by 2071-2100). Heat waves tend to occur earlier and last later in the year. The total length of the possible occurrence of heat waves is likely to extend by about a month by 2071-2100 (approximately 3 days per decade).

Lower Danube River Basin (LDRB) [16, 17, 27, 91, 105, 136, 137]

- Longer periods with warmer temperatures
- Strong humidity deficits
- *Tropical nights* (Tmin >20°C): increase (A1B: 0.4-1 day/decade)
- *Frost days* (Tmin < 0°C): decrease (A1B: -3 days/decade)
- *Extreme precipitation* in the Black Sea region is significantly affected by the Black Sea surface temperatures in winter. This result is confirmed for present climate by sensitivity experiments with a regional climate model in which the Black Sea surface temperature raised by 2 K. Extreme precipitation characterized by higher amounts are likely to occur both in summer and winter season, especially over the south-eastern parts of Romania.

Commonalities: More extreme events, fewer frost days in winter, more summer and hot days in summer, heavy rains become more frequent. Increase in frequency and intensity of storms.

Challenges

- The projections for Alpine regions are difficult, for heavy precipitation it's not possible to make predictions until now. For Eastern Europe both possible future developments are projected in the scenarios, less [16, 17] and more [115, 114] intense precipitation in winter.

Knowledge gaps: Seasonal and regional distribution of heavy rainfall.

5. Climate Change impacts on water related issues and possible adaptation measures in the DRB

In the following, several climate change impacts on water related issues and possible adaptation measures are considered. This includes impacts on water availability, groundwater, snow, ice and permafrost and extreme hydrological events like floods, droughts and low flows as well as water temperature and water quality. Moreover, impacts on water supply and water demand as well as different water uses are focused on. This encompasses impacts on agriculture, irrigation, forestry, land use, soils, biodiversity and ecosystems, limnology as well as water related energy production, navigation, health and tourism.

Firstly, for each impact, the main outcomes of the research and development projects and studies are described. After a short summary, details of the main findings for the entire DRB and for the regions UDRB, MDRB and LDRB (see Fig. 3) are presented separately. Moreover, the main commonalities, challenges and knowledge gaps for each impact field are presented. However, due to the application of different scales and catchment sizes, different climate models and scenarios, as well as different statistical methods and models for hydrological, water quality and water usage purposes, it should be mentioned that the results are not necessarily comparable. Besides the application of locally known hydrological models, several studies refer to LISFLOOD [44, 124], WaSIM-ETH [109] [110], PROMET [92] and WaterGAP [45] [9].

Secondly, for each impact area, possible adaptation measures are introduced, following the analysed activities which are referenced. Despite the uncertainties in the climate change impacts, adaptation measures are presented. In order to avoid regrettable adaptation activities, it is focussed on win-win and no-regret options. Measures of these categories minimize climate risks but also have other social, environmental or economic benefits. They should be worthwhile whatever the extent of future climate change is [119]. The suggested measures are further classified in the different categories of preparation measures, general measures, ecosystem-based measures, behavioural/managerial measures, technological measures and policy approaches following the UNECE [118], EEA [47]. However, there is no sharp separation possible between these categories. Additionally, the time horizon of the *effects* of the measures is analysed, where it is possible, short-term (up to five years), medium-term (one or two decades), and long-term measures (about 30 years) are distinguished. Thus, measures with medium-term effects also have long-term effects, and short-term measures have both, medium and long-term effects. Measures with options for an international cooperation within the DRB and measures, where challenges in reaching a common understanding might arise, are indicated. After the description of the climate change impacts in the different fields, common adaptation measures are summarized, followed by a table which presents the detailed adaptation measures.

Before describing the climate change impacts and the related adaptation measures for the different analysed sectors (Tab. 1), general adaptation measures are presented. They summarize measures which are relevant for (almost) all sectors with a huge common agreement among the analysed activities.

5.1 General adaptation measures

In order to select appropriate adaptation measures to be prepared for the impacts of climate change in the DRB, the activities agree on several preparation measures. At first, the overall vulnerability to climate change should be determined. Therefore existing monitoring networks should be enlarged by further stations or observed parameters, particularly in regard to climate change. The observed data are supposed to be stored in homogenous data formats and then exchanged within the DRB. Based on these observations, information systems, forecasting and early warning systems should be implemented in different water related fields, e.g. floods, droughts or water quality. There is also a common agreement in the activities on the demand for further research to identify knowledge gaps and to reduce the uncertainty (which cannot be totally deleted).

Education, trainings and information campaigns should be carried out to raise public awareness,. This also includes capacity building and strengthening the exchange among institutions on local, regional, and transboundary levels.

The implementation of integrated river basin management plans is supposed to involve co-ordinated management of the protection and use of all water bodies so that ecosystems functions are also taken into account, which provides options for transboundary cooperation, but challenges among different groups and water users might also arise. Further cooperation in risk management systems and an intensified dialogue with knowledge transfer among institutions seems to be an important adaptation measure, too. Water saving measures as behavioural measures and the construction or modification of infrastructure, e.g. dams, reservoirs, river beds, retention areas, as technological measures are commonly addressed by the analysed adaptation activities.

Policy approaches with a common understanding include strengthening and forcing the exchange among institutions in the administration, e.g. in implementing relevant legal policies such as the Water Frame Directive.

*Table 2: Suggested general adaptation measures for water related climate change impacts (*Time horizon of the effects of the measures: short-time (s), medium-term (m), long-term (l); abbreviations of the sources can be found in Appendix 5; [47, 119]).*

Type	Possible adaptation measures	Time horizon*	Options for cooperation	Challenges	Source (Countries)
Preparation measures for adaptation	**Determine vulnerability** • Improvement of the understanding of socio-economic and institutional aspects of vulnerability and adaptation (including costs and benefits) is urgently needed. • Identification of particularly vulnerable areas by sectors • Assessment of climate change impacts on the natural status of surface and underground waters, for important rivers (e.g. for each hydrographical basin > 1000 km², out of which the necessary adaptation measures should result) • Conduct a climate vulnerability assessment of basin ecosystems	m	x		UNFCCC (RS, RO, HU, ME, EU), NAS (HU, DE), White Paper EU, RBMP (DRB)
	Data handling • Homogenous data production • Digital mapping • Establishment of **Information Systems** (hydro-meteorological), GIS, low flow information services (e.g. development of a Hydrological Information System (HIS)) , cadastre of water resources with all characteristics, extreme meteorological and hydrological events and disasters, • **Emergency operation plans** in digital format, enabling digital archiving and the utilisation of their information and data base in digital **decision support system** (DSS) • Establish a **centralized database** to monitor the direct socioeconomic impacts of extremes in a distinct region	m	x		NAS (AT, RO, DE), UNFCCC (BA, ME, RS, HR), SDR, UNECE 2010, RBMP (TRB), BAYKLAS
	Forecasting and early warning service • Improvement of early warning systems for climate and hydrological extreme events • Promotion and support of the early recognition of potential hazards influenced by climate change, such as avalanches, flooding, mudslide and landslide hazards	m	x		UNFCCC (RS, BA, SI, CZ, HU), Alpine Convention, EEA Alps 2009, CC (DE), UNECE 2010, NAS (RS, DE, MD)
	Risk mapping: identification of potential risk areas (areas, infrastructures and utilities)	m	x		UNFCCC (ME), JRC 2005, UNECE 2010, NAS (AT, DE), Alpine Convention

Monitoring • Establishment of national monitoring networks to follow the ecological changes caused by that of the climate and integrating this system into the relevant international networks • Introduction of Automatic Weather Stations and connection with hydrological stations, particularly with the purpose of automatic monitoring and software control of the situation at river basins, as well as for planning water consumption for the needs of electricity supply, water supply, agriculture, other activities, and the population • Ensuring that monitoring systems used in the DRB have the ability to detect climate change impacts on ecological and chemical water status as well as the effects of climate change adaptation measures • Intensification of the monitoring of climate-related impacts on the water balance variables • Observation of changes in surface and groundwater systems, floods, droughts and water quality, climate-related warming of lakes and rivers) • Cooperation in the field of monitoring and assessment - in particular Danubian States shall agree upon monitoring points, river quality characteristics and pollution parameters regularly to be evaluated for the Danube River with a sufficient frequency taking into account the ecological and hydrological character of the watercourse concerned as well as typical emissions of pollutants discharged within the respective catchment area • Health and water/environmental agencies should merge their data bases and harmonize monitoring programmes • Review of the monitoring programmes under the WFD for their adequacy in reliably detecting and assessing such impacts	m	x		UNFCCC (DE, RS, BA, EU, HU, MD, RO, SI, AT, ME, HR), RBMP (DRB), BAYKLAS, JRC 2005, UNECE 2010, RBM (AT), WFD 24, NAS (BG), Declaration (DRB), VAHAVA
Research • Identifying knowledge deficits • Identification of areas / regions that are particularly affected by the climate change Detailed research on climate change impacts in the water sector and the adaptation options (to reduce **uncertainty**) • Further research on distinguishing climate change signals from natural variability and other human impacts • Regional and sectoral adaptation research • Investigation of the effects of climate changes on eco-regions, typologies and reference sites as well as proposals for solutions • Fostering the improvement of models (climate and hydrological aspects) and of scenarios for the DRB as well as ensuring the improvement regarding the presentation on climate fluctuations • Economic analyses of the costs of adapting to climate change in the water sector • Consideration of uncertainty • Develop and apply regional climate change models at the sub-regional and river basin scale to assess potential	m	x		RBMP (DRB), UNFCCC (BA, HR, EU, DE, MD, RS, AT), JRC 2005, VAHAVA, BAYKLAS, WFD 24, NAS (AT, DE, RO, BG), ClimateWater

	response of land and water systems, and mitigation strategies with associated costs • Improvement of research in the area of numerical modelling of hydrological processes (precipitation/snow-runoff for different time intervals) • Develop methods in order to solve **transboundary** environmental crisis, particular in the water sector • Improvement and coordination of **scenario analysis** of impacts and vulnerability (Regular interaction between the climate modelling community and the user community that analyse impacts, vulnerability and adaptation to develop climate change scenarios appropriate for the development of regional and local adaptation measures) • Research the possible increase of natural hazards to enhance the scientific basis and to reduce uncertainty (flood, mudflow and avalanches, low flow and droughts)				
	Promotion and application of methodologies and standards for climate-proofing infrastructure projects and integrating climate considerations into EIA and SEA procedures; need to consolidate and generalize present findings and to study feedbacks	s-m	x		RBMP (DRB), UNFCCC (AT, HU)
	Assessment of water needs for the main utilities (drinking water supply, industrial water, water for zootechnics, fishing related activities, etc.) under the circumstances of climate change	s-m	x		UNFCCC (RO)
	Creation of scenarios for water use under severe drought and water shortage conditions, and **prioritisation of water use** (focusing on drinking water and irrigation) under these conditions	s-m	x	x	NAS (MD)
General measures	Development and application of innovative solutions to adapt to climate change, e.g. catchment/seasonal consenting, diffuse pollution source controls, and financial incentives for developers who provide surface run-off reduction measures	s-m	x		ClimateWater
	Prevention, control and reduction of transboundary impact: develop, adopt and implement relevant legal, administrative and technical measures as well as provide for the domestic preconditions and basis required in order to ensure efficient water quality protection and sustainable water use and thereby also to prevent, control and reduce transboundary impact	m	x		Declaration (DRB)
Ecosystem-based measures	**Integrated management of river basins** involving co-ordinated management of the protection and use of all water bodies in a river basin with the aim to ensure that water bodies remain in a healthy state	m	x	x	UNFCCC (DE), NAS (DE), VAHAVA
	Protection plan: Each water resource needs to be addressed individually, and therefore, an individual strategy plan for the management and exploitation, as well as a protection plan, needs to be adopted for each one of them.	s-m	x	x	UNFCCC (ME), NAS (HU)
	Preference of measures that **maintain or reinforce water bodies' natural ability to adapt**, as well as their habitat diversity (for example, renaturation of water bodies and riparian meadows; enhancement of water retention via setting-aside of retention areas; and properly adapted agricultural management)	m-l		x	UNFCCC (DE), NAS (MD)
	Increase the self-regulatory function of water bodies in both water quality and quantity by diminishing the human impact on existing water bodies.	m-l		x	UNFCCC (DE), NAS (MD)
	Expansion of water conservation areas	m	x	x	CC (DE), NP (CZ)

	Rebuilding natural rivers	m-l		x	CC (DE)
	Development of **Local Programs on the Use, Conservation And Development of Natural Resources** (forests, other types of forest vegetation, grasslands), establishing community level ecological networks taking into account the geographical, pedo-ecological features, the relief, etc., including in the context of prevention/mitigation of natural hazards	m	x		UNFCCC (MD)
Behavioral /managerial measures	**Risk management system** • Promotion and support of integrated risk management that fully exploits the potential of possible protective measures in a coordinated way. These protective measures include prevention (land use planning, early warning systems, care of protective forests, renaturation of waterways, protective structures), disaster management (intervention) and reconstruction • Integration of the objective of risk prevention and vulnerability reduction into all levels of spatial planning • Improvement of understanding of public perceptions to establish the optimal balance between levels of service, risk and adaptation costs	s-m	x	x	Alpine Convention, ClimateWater, UNFCCC (CZ), UNECE 2010, White Paper EU, NAS (AT)
	Dialogue, participation, information exchange, social networking • Better communication among institutions • Collaborative and partnership strengthening, building of networks • Targeted, consistent risk dialogue with all of the parties involved in order to strengthen prevention efforts and promote risk-consciousness and the acceptance among the public of risk-appropriate action • International cooperation: strengthen cooperation at sub-basin level, initiate new dialogues, facilitate exchange of good practice in integrated water management issues in the Danube Basin among decision-makers at all levels and among the population of the Region • Creating supportive social structures (changing internal organisational systems, developing resources to deliver the adaptation actions, and working in partnership) • Improving the quality of climate knowledge; more information on good practices and avoiding mal-adaptation, development of exchange mechanisms (EU Clearinghouse to make data and information available) • Communication campaigns: Danube Ship Tour, Danube Exhibition Tour, Danube Film, Danube Day event, visiting of protected areas on the Danube • Development or enhancement of platforms for networking and dialogue • Establishment of an internet portal with all the relevant information and examples of good practice	m	x	x	ClimateWater UNFCCC (ME, MD, SI, EU), EEA Alps 2009, UNECE 2010, White Paper EU, Alpine Convention, Declaration (DRRB), SDR, NAS (DE, AT), EEA 2007, CC (DE)
	Sustainable and integrated management • Creation of new alliances and ways of working for innovative solutions, e.g. catchment management, source controls etc. • Implementation of the complex system of water management, as required by the WFD of the EU, along with the consideration of requirements of nature conservation	m	x	x	NAS (AT, DE, MD), ClimateWater, UNFCCC (ME, SI), White Paper EU, VAHAVA, EEA Alps

	• Ensuring sustainable management of natural resources and integration of climate change issues • Consolidation of a watersaving culture and ethic, considerable use of water, protection of water resources **Example of good practice:** In Bavaria (Germany) coordinated measures have been implemented to optimise water retention by combining reservoirs for exudation renaturation of peatlands and wetlands, creation of depressions and drains, modification of growing techniques, reforestation, ecological valorisation and renaturation of water resources (Alpine Convention)				2009
	Knowledge transfer • Enhancement of sharing of research information on climate change in the DRB • Ensuring that scientific information is 'translated' to water managers • Integration of all knowledge, results and lessons learnt related to climate change threats in the next DRBM Plan • Mobilizing actors and multiplying success **Example of good practice:** ADAM has produced an open-access web-based digital compendium that combines the heterogeneous knowledge of European impacts, vulnerability and adaptation	m	x		RBMP (DRB), White Paper EU, NAS (AT, RO), SDR, UNFCCC (ME)
	Education, training and awareness rising • Public awareness and information campaigns: Raise the public awareness level and improve information on climate change impacts and possible adaptation measures • Staff training • Inform the public • Raising stakeholder awareness (in written, visual, oral or data-based form) • Promote "climate friendly" tourism or publications about pilot projects • Further expansion and development of the already established information services (information and warning service websites)	m	x		UNFCCC (RS, SI, BA, CZ, SK, HU, MD, ME, AT, RS), NAS (MD, AT, DE, RO, RS, BG), EEA Alps 2009, SDR, UNECE 2010, VAHAVA, White Paper EU, BAYKLAS, CC (DE), Alpine Convention, EEA 2007
	Capacity building and strengthening among institutions on local, regional and transboundary levels	m	x		SDR, RBMP (AT), RBMP (TRB)
Techno-logical measures	Determination of the need for **widening and deepening riverbeds** and their additional cleaning	m-l	x	x	UNFCCC (RS)
	Construction and modification of dams and accumulation reservoirs for hydropower generation, agriculture, drinking water, tourism, fish-farming, flood control, irrigation, navigation etc.	m-l	x	x	UNFCCC (BA, RO), UNECE 2009, NAS (DE)
	Support **water company business plans** that draw attention to vital aspects of adaptation programmes, e.g. the need to protect critical infrastructure or ensure the safety of dams and reservoirs (reconstruction and enlargement of most of the existing spillway structures will be needed over a large part of Europe)	m	x	x	ClimateWater, UNFCCC (RO)
	Increase of energy efficiency by 20% by 2020	s-m			UNFCCC (SK)
Policy	**Administration**	m	x	x	UNFCCC (SK), NAS

approaches	• Harmonization of national legislation in the area of water with the EU legislation, especially concerning the implementation of the EU WFD • Intergovernmental coordination and exchange of information to reinforce the implementation of relevant policies ((Water Framework Directive), flood protection (Flood Directive), and biodiversity conservation (Flora-Fauna-Habitat Directive and Birds Directive)) • Review environment and health risk management for extreme conditions • Establishment of an institutional framework for rational water sector management **Already established**: the International Commission for the Protection of the Danube River (ICPDR), which is the Steering Body of the DRPC, aims: to implement the Convention and the transboundary aspects of the EU Water Framework Directive (WFD); the International Sava River Basin Commission (ISRBC) which aims at establishing sustainable water management and navigation for the Sava; Tisza river basin cooperation is coordinated by the Tisza Group of the ICPDR				(RS), SDR, UNECE 2010, Declaration (DRRB)
	Creating a **supportive institutional framework** (changing standards, legislation, and best practice guidance, and developing appropriate policies, plans and strategies) for • New regulations and standard criteria for options/measures • Creating supportive social structures (changing internal organisational systems, developing resources to deliver the adaptation actions, and working in partnership) • Guidelines, governance and co-ordination – price signals, market -based instruments and private financing – EU Financing schemes	m	x	X	White Paper EU
	Development of a **climate policy of nature conservation** and the harmonisation of this with those of the forestry, agriculture, power generation and water management	m	x	x	NAS (DE, RO), VAHAVA
	Establishment of criteria for **prioritisation of adaptation options** to improve the assessment and prioritization of adaptation policies and measures, including the economic consequences of different adaptation measures	m	x	x	NAS (DE, RO), VAHAVA
	Consideration of the links between **adaptation and mitigation** by policy makers, regulators and others, e.g. water/energy efficiency, sustainable drainage systems, catchment protection and management and the promotion of policies that do not potentially increase emissions	m	x	x	ClimateWater
	Paying attention in national and regional economic planning by the Government on the vulnerability of the economy and local communities to water supply	m			NAS (MD)
	Adjusting the existing institutions to the needs of active implementation of climate protection policy and fulfilling obligations resulting from international agreements (UNFCCC, Kyoto Protocols, etc.)	m	x		NAS (RS)
	Insurance system • Improvement of insurance systems to protect farmers from the economic impacts of flood or drought damage	m		x	EEA Alps 2009, EEA 2007, CC (DE),

	• Share loss (Insurance-type strategies, using other new financial products that lay-off the risk, diversification) • Creation of reserve funds for damage reparation and future adaptation measures • Consider governance aspects such as legislation on, inter alia, insurance for a clear policy for rehabilitation and proper institutional settings				UNECE 2009
	Financial measures: implement special tax regimes for investments, companies, people in relation to climate change impacts	m	x	x	UNECE 2009

5.2 Water availability

Temperature and precipitation as well as other meteorological parameters are highly important for processes of the water cycle. Changes in these parameters are expected to have considerable impacts on the hydrological balance and will trigger future changes in water availability. This includes changes in runoff, evaporation and water storage like groundwater, soil water, snow and glaciers. According to the equation of the water balance ($P = R + E + \Delta S$), precipitation P is the sum of runoff R, evaporation E and water storage changes ΔS. In this section the future water availability according to changes in runoff and evaporation is described. Developments in the field of precipitation were already presented in section 4.3. Changes in water storage like groundwater, soil water, snow, glaciers and permafrost will be shown in the following sections.

The DRB is situated in a transitional zone with an increase of mean annual precipitation in Northern Europe and a decrease in Southern Europe [18] . The future development of water availability shows a similar tendency. For the near future (until 2050), most studies indicate a decrease in water availability for the southern and eastern parts of the DRB, whereas in the northern and western parts no trend or even a slight increase is projected. But changes in water availability can highly differ locally or regionally. In the far future (until 2100), however, water availability might be reduced in the entire DRB, whereby in the south-eastern parts the reduction will be more pronounced.

Runoff seasonality shows a future increase of the mean annual discharge in winter and a decrease in summer for the entire DRB. Seasonal changes may differ locally. Main reasons are changes in precipitation and the snow (and ice) storage. A decrease in snow precipitation and accordingly in snow cover together with an earlier snow melt causes a shorter snow season in all altitudes and will in turn lead to a shift of the runoff regime. In high-alpine headwatersheds, this will cause a shift of the peak runoff from early summer to spring. Due to less future precipitation in summer in most areas of the DRB, water availability is likely to be lower, particularly in this season. This can lead to medium up to severe water stress in the MDRB and to severe water stress in the LDRB. Because of generally high water availability in the UDRB, water stress will be low in the UDRB [57, 88].

An increase in evaporation can even lead to an acceleration of water stress. Potential evaporation is the amount of water that would be evaporated if there is sufficient water available. It will increase due to warmer temperatures in all regions of the DRB, especially in summer. Actual evapotranspiration describes the sum of evaporation and plant transpiration with the available amount of water. The latter, however, is likely to increase only in regions with high water availability like mountainous regions, in the most parts of the UDRB and some regions of the MDRB. In regions with low water availability like the south-eastern parts of the DRB, evapotranspiration will decrease, especially during dry periods because less water is available to evaporate or transpire through plants.

Danube River Basin (DRB)

Runoff [37, 38, 57, 88, 18, 106]

- According to several project and study results, changes in mean annual discharge show a range of no clear trend to a pronounced decrease for the entire DRB
- Regarding changes in mean annual precipitation and runoff, Europe is situated in a transitional zone with an increase in northern Europe and a decrease in southern Europe, respectively an

increase in mean annual runoff in the north-western parts and a decrease in the south-eastern parts

- south-eastern parts: decrease of -5 to -20% until 2020 [88], or rather a decrease of 0 to -23% until 2020 and -6 to -36% until 2070 [18]
- north-western parts: no significant trend to slight decrease of 5 to -10% until 2020 [88]
- main reasons for changes in mean annual discharge: changes in precipitation, evapotranspiration

- Seasonal changes
  - increase of mean annual discharge in (late) winter; decrease in summer; especially in Eastern Europe pronounced decrease in summer
  - mountain regions: pronounced shift of runoff peak from summer to spring due to an earlier snow-melt
  - reasons: changes in precipitation, earlier snow-melt conditions, longer and more frequent dry seasons in summer, increase of heavy precipitation events

Evapotranspiration / potential evaporation [18, 50, 30, 31]

- Increase in potential evaporation
- Regional differences regarding changes in evapotranspiration
  - in regions with high water availability (e.g. Alpine space) increase in mean annual evapotranspiration, in all seasons, especially in winter
  - in regions with low water availability (e.g. south-eastern Europe) decrease in mean annual evapotranspiration is possible, especially in summer

Upper Danube River Basin (UDRB)

Runoff [64, 8, 76-79, 128]

- In general, high water availability also in the future; no large-scale water scarcity is predicted, however, local water shortages are possible; only slight changes for annual values
- Changes in mean annual runoff
  - most studies: decrease in mean annual discharge in near and far future
  - few studies: no significant trend of mean annual discharge, especially in small Alpine catchments or natural variability is higher than climate change signal
- Seasonal changes
  - higher water availability in winter; shorter water availability in summer;
  - shift of runoff peak from summer to spring due to changing snow period
  - more balanced hydrograph, less variability
  - Alpine space: runoff increase in winter and spring; decrease in summer and autumn
- Higher anthropogenic influence might change the hydrograph

Evapotranspiration / potential evaporation [8, 21, 64]

- Most studies indicate an increase in mean annual evapotranspiration; however, no clear findings considering the dimension of increase

Middle Danube River Basin (MDRB)

Runoff [28, 34, 40, 74, 73, 117, 87]

- Changes in mean annual runoff
  - most studies: decrease in mean annual discharge in the near and far future; decrease of mean annual discharge e.g. in some sections of the Tisza and Mureş, Sava, Drava and Morava rivers
  - few studies: no significant trend of mean annual discharge
  - runoff is more likely to increase in Alpine headwatersheds; further downstream a decrease is more likely (example Tisza: Upper part: slight increase; central and southern Tisza: no trend to clear decrease [34]
- Seasonal changes
  - increase in runoff in winter; some contradictory statements for the rest of the year
  - more balanced hydrograph
  - Examples: Vah-Hron: increase in winter due to more winter precipitation (esp. in the northern mountain region); decrease in summer; Tisza: increase in winter; decrease in spring and autumn; Mureş: increase in spring and early winter; decrease in mid winter and late spring to autumn (esp. Aug), but not in July due to an increase in extreme precipitation events in this month [40]
- Due to less future precipitation in summer in most areas, low water availability will be particularly strong in this season; medium to severe water stress in summer

Evapotranspiration / potential evaporation [87, 62]

- Range of possible increase to decrease of mean annual evapotranspiration, depending on water availability
- Significant increase of potential evaporation and decrease of evapotranspiration in the growing season between April and September in Slovakia
- Evapotranspiration depends on the location: it is higher in the lowlands than in mountain regions; also highly depended on precipitation and soil moisture changes

Lower Danube River Basin (LDRB)

Runoff [28]

- Decrease in mean annual discharge in the near and far future
- Due to less future precipitation in summer, low water availability will be particularly high in this season in most areas of the DRB → severe water stress in summer

Commonalities

Runoff

- Quantity: due to its location in a transitional zone, the DRB shows for the near future a range of no trend to a decrease in mean annual discharge; however, the decrease will become more significant in most regions for the far future and will be more pronounced in the south-eastern parts

- Seasonality: most findings indicate an increase in winter and a decrease in summer with a more balanced hydrograph over the year; in mountainous areas, a snow dominated runoff peak shift from summer to spring will occur

Evapotranspiration / potential evaporation

- Potential evaporation will increase in all regions, especially in summer
- In regions with high water availability the mean annual evapotranspiration will increase; in regions with low water availability it will decrease

Challenges / Knowledge gaps

Runoff / evapotranspiration / potential evaporation

- Only few findings about runoff for the LDRB (and some parts of the MDRB like within the Sava and Morava river basins)
- Only few projects/studies considering the entire DRB and its bigger (sub)catchments
- Results depend largely on the underlying climate scenarios, models and catchment size
- Some contradictions in the consideration of water availability in quantity and seasonality
- Not exactly feasible in which regions evapotranspiration will increase or decrease

Adaptation measures

The adaptation measures in this field mainly address reduced water availability in future. Accordingly, behavioural and technological water saving measures are mentioned in many studies.

*Table 3: Suggested adaptation measures for reduced water availability (*Time horizon of the effects of the measures: short-time (s), medium-term (m), long-term (l); abbreviations of the sources can be found in Appendix 5; [47, 119]).*

Type	Possible adaptation measures	Time horizon*	Options for cooperation	Challenges	Source (Countries)
Preparation measures for adaptation	**Monitoring** to determine changes, resp. assessment of CC impacts on volume and quality of water bodies	m	x		NAS (HR, ME, RS), GLOCHAMORE
	Identification and **mapping** of potential risk areas (lacking water resources, floods…)	s			UNFCCC (ME, SK)
	Forecasting and warning service	s-m	x		UNFCCC (ME)
	Research on future water quantity under different research scenarios and on mechanisms behind the changes	s-m	x		GLOCHAMORE, ST_BLOESCHL_AT
	Development and validation of **new models**	m	x		GLOCHAMORE
General measures	Consideration of the impacts of climate change in integrated river-basin management	m	x		UNFCCC (DE)
Ecosystem-based measures	Increase **water retention properties** of the landscape, e.g. by restoring bogs/swamps and wetlands	m		x	NAS (CZ), BAYKLAS
Behavioral /managerial measures	Efficient use of water	s			NAS (DE), CC (DE)
	Use of "grey-water", roof drainage water or process water for technical and industrial purposes that do not require drinking water quality	m-l			NAS (DE)
	Use of purified and microbiologically safe wastewater for watering farmland	m			NAS (DE)
	Introducing new crops and agricultural practices to reduce water demand in agriculture	m-l	x		NAS (MD)
	Low-loss irrigation of agricultural land	s-m			NAS (MD, DE)
	Review the sustainable exploitation of water resources	s		x	UNFCCC (SK)
	Better communication among institutions, forecasting and warning service	s-m	x		UNFCCC (ME)
Techno-logical measures	**Water storage** Use of existing dams and reservoirs as well as additional ones to redistribute precipitation, snow and ice-melt between seasons by water storage. Risks ➔ older dams could break, if there is a lack of maintenance work ➔ more dams would lead to a decrease in both the amount and the velocity of stream flow on the rivers ➔ increase in potential evapotranspiration	m, l	x	x	NAS (MD), UNFCCC (MD)

	Should only be applied after a thorough analysis of all possible alternatives!				
	Adapting the infrastructure	m-l	x		NAS (DE)
	Precautions against water losses in distribution networks	m	x		NAS (DE, MD), UNFCCC (DE, MD)
	Planning an irrigation infrastructure	m			UNFCCC (MD)
	Further development of water-saving methods, especially in manufacturing processes in trade and industry	m	x		NAS (DE)
	More efficient cooling of power stations	m	x		NAS (DE)
Policy approaches	Restrictions on developing activities in water shortage areas	s-m	x	x	NAS (DE)
	Water protection against pollution and depletion caused by anthropogenic activities (both groundwater and surface water)	m	x	x	UNFCCC (MD),WFD 24, DRPC, Declaration (DRB)
	Adopt more rigorous legislation to protect water resources in localities, where water resources will be presumably less affected by climate change	m		x	UNFCCC (SK)
	Putting in place requirements for prior authorization of abstractions	m	x	x	DRPC

5.3 Groundwater

Regarding the groundwater storage, the findings of most projects and studies show a general decline in groundwater storage and recharge for Central and Eastern Europe, especially in summer. Besides shortages in water availability, a decline in groundwater recharge could also draw negative effects on groundwater quality. Additionally, a possible increase in irrigation using groundwater resources will strengthen the decline. Pointing out regional differences, a pronounced decline is particularly indicated for the Hungarian Great Plain Area, which has already started in the past. For some Alpine regions, however, a local increase in groundwater storage is likely to occur.

Danube River Basin (DRB) [14, 13, 18]

- Most findings show a slight to clear decrease of future groundwater storage and recharge in Central and Eastern Europe
- Decline in groundwater recharge also due to an increase in future groundwater abstraction
- Groundwater bodies will become more vulnerable to pollution with an enhanced transport of pollutants after long droughts
- Higher influence of environmental parameters on biogeochemical processes affecting the mobility of metals in the vadose zone

Upper Danube River Basin (UDRB) [21, 108, 79, 128]

- Most findings indicate a decrease of the groundwater storage; only few studies show no trend or even a slight increase; some contradictory statements for mountain regions
- Possible reason for reduced groundwater recharge: less snow cover
- German Danube region: decline in groundwater recharge by 10 to 25 % (2021-2050) [79]
- Risk of less water availability in regions with decreasing groundwater table
- Conspicuous decrease in groundwater storage and recharge in summer; however, in winter possibly more percolating water
- Additional stress factor: increase in irrigation
- Due to higher groundwater temperatures, acceleration of groundwater processes is possible

Middle Danube River Basin (MDRB) [14, 136, 137]

- Decrease of groundwater storage; pronounced decrease especially in the Hungarian Great Plain Area
- Groundwater quality will probably be affected by changes in annual rhythms of water levels caused by a decreased snow melting
- Due to less infiltration, decrease in groundwater quality

Lower Danube River Basin (LDRB) [27, 85, 111, 137]

- Decrease in future groundwater storage and recharge

Commonalities

- Quantity: most regions in Central and Eastern Europe show a decline in groundwater recharge leading to a decrease of groundwater storage

- Seasonality: highest decrease of groundwater recharge in summer
- Quality: A decline in groundwater recharge affects groundwater quality; fresh groundwater bodies will become more vulnerable to pollution with an enhanced transport of pollutants after long droughts

Challenges / Knowledge gaps

- Only few findings about groundwater for the LDRB and some areas in the MDRB
- Only few projects/studies considering the DRB as a whole and its bigger (sub)catchments
- Some contradictory statements for the development in Alpine areas

Adaptation measures

The preparation measure of further monitoring of the status of groundwater is addressed by most adaptation activities. There seems to be a common demand for more groundwater protection areas and for (legal) precaution measures against pollution due to lower groundwater recharge as described above.

*Table 4: Suggested adaptation measures for impacts on groundwater quality and quantity (*Time horizon of the effects of the measures: short-time (s), medium-term (m), long-term (l); abbreviations of the sources can be found in Appendix 5; [47, 119]).*

Type	Possible adaptation measures	Time horizon*	Options for cooperation	Challenges	Source (Countries)
Preparation measures for adaptation	**Monitoring and mapping** • Producing and/or updating a Cadastre of Groundwater Sources • Enumeration of groundwater resources subjected to long-term protection as well as protection zones valuable for existing or future drinking water supply purposes establishing a system for monitoring of groundwater volume and quality • Assess total storage and available amount of groundwater in hydrogeological zones for RBM Plan • Higher density of monitoring networks in intensively used areas • Re-evaluation of usable groundwater quantities, in particular formations in relation to ecological limits and Climate Change • Monitoring of abstraction of fresh surface water and groundwater, and impoundment of fresh surface waters (including a register of water abstractions) • Monitoring of surface water pollutions ➔ Identification of prospective and supplementary sources of water supply and risk localities for the purpose of decision making of the state administration	s-m	x		NAS (RS, CZ), UNFCCC (SK), KLIWA, ST_BLOESCHL_AT, Declaration (DRB), RBMP (Bavaria), DRPC, RBMP (DRB)
	More observation and research of groundwater temperature	s-m	x		NAS (AT), ST_BLOESCHL_AT
General measures	Intensification of planning on using groundwater resources	m		x	NAS (AT)
	Water saving measures	s			NAS (DE)
	Prevention of the pollution of groundwater resources, especially those in a long-term perspective reserved for drinking water supply, in particular caused by nitrates, plant protection agents and pesticides as well as other hazardous substances, including increase of waste water treatment efficiency	s-m	x		Declaration (DRB), RBMP (Bavaria), DRPC, RBMP (DRB)
Ecosystem-	Expansion of groundwater protection areas; water retention to support groundwater recharge; increase water retention properties of the landscape	m	x	x	NAS (AT), NP (CZ),

based measures					WASKLIM
	Exploration of solutions for the rehabilitation to prevent deterioration of groundwater quantity as well as the deterioration of dependent terrestrial ecosystems; restoration of wetland areas which are in direct contact with aquifers should be included	m	x		RBMP (DRB)
Behavioral /managerial measures	Avoid over-abstraction of GW-bodies by sound groundwater management	m	x		RBMP (DRB)
	Review of existing building regulations in case of an (seasonally) increasing groundwater level e.g. to prevent rewetting of cellars	s-m	x		ST_BLOESCHL_AT, KLIWA
	No use of high quality groundwater in water stress areas for irrigation purposes	s		x	WASKLIM
	Elimination/reduction of the amount of hazardous substances and nitrates entering the groundwater bodies to prevent deterioration of groundwater quality and any significant and sustained upward trends in the concentrations of pollutants in groundwater.	m	x		RBMP (DRB)
	Increased regional planning safeguards for water resources and planning efforts are needed to ensure appropriate use for the case of falling groundwater recharge rates as a result of climate impacts to prevent regional water shortages	s-m			NAS (DE)
Techno-logical measures	Setting of all necessary measures required to prevent significant losses of pollutants from technical installations	s-m	x	x	RBMP (DRB)
	Implementation of Best Available Techniques (BAT) and Best Environmental Practices.	s-m	x	x	RBMP (DRB)
Policy approaches	National legislation to prohibit direct discharges of pollutants into groundwater	m	x		DRPC, Declaration (DRB), RBMP (Bavaria, DRB)
	Putting in place requirements for prior authorization of abstractions	m		x	DRPC
	Implementation of important directives to protect groundwater resources • The principle concerning prevention/limitation of pollutants inputs to groundwater according to the EU Groundwater Directive (GWD, 2006/118/EC). • EU Nitrates Directive (91/676/EEC). • Plant Protection Directive (91/414/EEC) and the Biocides Directive (98/8/EC). • Urban Wastewater Treatment Directive (91/271/EEC). • Integrated Pollution Prevention Control Directive (96/61/EC), which also relates to the Dangerous Substances Directive (76/464/EEC)	s-m	x	x	RBMP (DRB)

	Passing a law on geological research, in line with EU standards, which includes the design of groundwater reservoir balance	m	x	x	NAS (RS)
	Development restrictions by the riverside belts and floodplains and areas of high groundwater level	m	x	x	NAS (HU)

5.4 Snow / Glaciers / Permafrost

Climate change affects snow cover, glaciers and permafrost, especially in mountain regions. Future decrease in snow precipitation and snow cover together with an earlier snow melt causes a shorter snow season in all altitudes. This in turn will trigger a shift of the runoff peak from summer to spring in headwatersheds of the Alps and the Carpathian Range, which will also change the regimes in the lowlands. However, some findings for mountainous areas state no trend or even a slight increase of snow fall due to a possible increase in winter precipitation. All studies considering glaciers show a significant retreat in the DRB. Climate change leads to the total disappearance of glaciers in all mountainous areas of the MDRB. In the Alpine part of the UDRB, only few small glaciers will be left in the far future. An increase in glacier melt has only relevance for the summer runoff situation in the headwatersheds and has almost no influence on the runoff regime of larger river systems. A further retreat of permafrost in mountainous regions will lead to a higher frequency of rock falls, other natural hazards and more sedimentation in rivers.

Danube River Basin (DRB)

Snow [43, 58, 75, 50]

- Decrease in snow precipitation and snow height; remarkable decrease of snow depth in most European regions by the late 21st century
- However, increase in (snow) precipitation in mountain regions in winter is possible
- Decrease in number of snow days, especially in Eastern Europe
- Largest decline of snow cover in lower altitudes
- Decreasing snow cover leads to a lower albedo which allows more short wave radiation to be absorbed at the ground, which in turn can trigger a further reduction of the snow cover
- Reduction in the length of the snow season and earlier snowmelt conditions during the year

Ice [18]

- Significant glacier retreat in all mountain areas in the DRB

Permafrost [48, 56, 134]

- Retreat of permafrost in mountain regions
- Increasing destabilisation of mountain areas; higher frequency of rock falls and debris flows
- Geotechnical and maintenance problems with high-mountain infrastructure

Upper Danube River Basin (UDRB)

Snow [8, 6, 81, 36, 131, 103]

- Decrease in snow precipitation due to milder winters in most regions; snow precipitation component declines in winter
- However, stable condition or even an increase due to more winter precipitation in mountain areas; higher Alpine regions appear to be less sensitive to temperature and precipitation changes projected for this century than those at lower latitudes and altitudes
- Decrease in snow cover, snow cover duration and snow-melt, especially at lower altitudes and in the south-eastern parts of the Alps; altitudinal upward shift of present snow situation

- Earlier snowmelt conditions in the year (about 1 month earlier); slower/later build-up of snow coverage and faster/earlier melting
- Possible shift of nival to nivo-pluvial regime in Alpine watersheds (higher influence of rain)

Ice [21, 36, 64]

- Significant glacier retreat in the Alps with intense melting conditions
- At the end of this century, only a few small glaciers will be left; not influential for larger watersheds (e.g. the Danube is not significantly influenced by ice melt changes)

Permafrost [21, 36, 19]

- Retreat of permafrost in mountain regions
- Fast warming during the last century in the upper decametres of Alpine permafrost has been confirmed by borehole measurements
- Permafrost temperatures are now rising at high rate but this can be drastically intensified by changes in snow cover conditions in early wintertime
- Impacts: higher sedimentation rate in rivers and higher rock instability; possibly higher frequency of natural hazards such as landslides, mudslides and avalanches

Middle Danube River Basin (MDRB)

Snow [62, 117, 137]

- Decrease in snow precipitation due to milder winters in most regions; snow precipitation component declines in winter
- Decrease in snow cover and snow cover duration
- Upper Drava: Shift from nival regime to a nivo-pluvial regime

Ice [137]

- Significant glacier retreat; could lead to a disappearance of glaciers

Lower Danube River Basin (LDRB)

Snow [105, 136]

- Generally, decrease of snow cover period; however possibly slight increase in mountains areas
- Earlier and faster snowmelt conditions in the year

Commonalities

- *Snow* (Quantity): decrease of snow height/snow water equivalent, snow cover and snow cover duration as well as snow precipitation due to a decline of the snow precipitation component in winter; possible difference in Alpine areas
- *Snow* (Seasonality): reduction of snow season length and earlier snowmelt
- *Ice*: significant glacier retreat up to disappearance of glaciers
- *Permafrost*: retreat of permafrost in mountain regions; impacts: higher frequency of rock falls and other natural hazards

Challenges / Knowledge gaps

- Only few findings about snow for the LDRB and some areas in the MDRB
- Only few projects/studies considering the entire DRB and its larger (sub)catchments
- Some contradictory statements about changes in winter snow precipitation in mountain regions in the UDRB
- Not all glaciers / permafrost areas are documented in detail

Adaptation measures

As already mentioned in the introductory paragraph of this section, there are only few measures suggested for climate change impacts on snow, ice and permafrost. Since the main consequences of the projected retreat and seasonal changes regarding snow, ice and permafrost are an increase in natural hazards, a reduction in runoff as well as changes in runoff seasonality, the important water related measures can be found in the section discussing reduced water availability (see Table 2).

As already mentioned in the introductory paragraph, there are only few measures suggested for climate change impacts on snow, ice and permafrost. Since the main consequences of the projected retreat of snow, ice and permafrost are instabilities and a reduced runoff as well as changes in runoff seasonality, the important water related measures can be found in the section with reduced water availability (see Table 2).

*Table 5: Suggested adaptation measures for climate change impacts on snow / ice / permafrost (*Time horizon of the effects of the measures: short-time (s), medium-term (m), long-term (l); abbreviations of the sources can be found in Appendix 5; [47, 119]).*

Type	Possible adaptation measures	Time horizon*	Options for cooperation	Challenges	Source (Countries)

Preparation measures for adaptation	**Monitoring and mapping**
	• Permanent monitoring of the development of permafrost
	• Optimization of the network of meteorological stations dedicated to snow depth and energy balance measurements
	• Mapping of areas with permafrost
	• Survey of glacier and permafrost-related hazards
	  • glacial snow melt to verify model predictions
	  • discharge, snow pack extent and properties in selected drainages at a fine temporal scale; mass balance
	• measure glacier extent periodically using glacier inventory work with regular coverage at the regional scale (Landsat, Spot, Aster); broader cooperation with the Global Land Ice Measurements from Space (GLIMS) project and World Glacier Monitoring Service (WGMS)
		s-m			BAYKLAS, GLOCHAMORE

	Research • On the extent of glaciers under different climate scenarios (Glacier Extent and Glacier Mass Balance) • On the spatial and temporal extent of snow cover under different climate scenarios • On the timing and amount of runoff generated from the snow pack under different climate scenarios • Development of quantitative palaeo-ecological indicators of glacier change and application of the indicators to test and validate prediction models for climate change with long-time records	s-m			GLOCHAMORE

	Modelling • Development of models to predict the timing and amount of snow melt under different meteorological conditions, including rain-on-snow events • Glacier mass balance: using direct field methodologies (stakes and pits) in combination with distributed energy and mass balance models; mass balance calculation needs to be calibrated and validated using repeat geodetic or stereo photogrammetric analysis • Variation in glacier surface area using satellite imagery, digital terrain information, meteorological data, and scenarios from regional climate models • Permafrost: simulate scenarios for temperate-climate mountain sites related to ground measurements • Validation of snow melt models against empirical data; test spatially explicit models of snow cover against historic records	s-m			GLOCHAMORE

5.5 Droughts / Low flows / Water scarcity

Within the DRB, drought and low flow events as well as water scarcity are likely to become more intense, longer and more frequent. Thereby, frequency could increase especially for moderate and severe events. Due to less precipitation in summer these extreme events will be more severe in this season, whereas they will become less pronounced in winter. In some parts of the DRB, the drought risk will increase drastically in the future leading to possible economic loss, increase in water conflicts and water use restrictions. The Carpathian Area, particularly the southern parts of Hungary and Romania as well as the Republic of Serbia, Bulgaria and the region of the Danube Delta are likely to face severe droughts and water stress resulting in water shortages. In Alpine areas, e.g. some parts of Austria, no clear trend or even a slight improvement of the low flow and drought situation were identified. Therefore Alpine headwatersheds remain important for downstream areas during drought periods. The future low flow situation depends also on changes in water use, which could worsen or improve the general trend.

Danube River Basin (DRB) [14, 13, 38, 37, 57, 88, 99, 18]

Drought

- Occurrence of droughts, water scarcity, heat waves and dry periods may increase
- Increase of drought risk, especially in the south-eastern parts of the DRB
- Possible increase in drought frequency; more frequent and intense summer droughts, associated with a decrease in rainfall amount in this season; possible summer drying across many regions in Europe
- Change in the length of summer droughts; the number of dry days may increase

Low flow

- Increase in low flow periods as a result of more summer droughts, especially in the south-eastern parts of the DRB
- Increase in 100-year frequency in most parts of the DRB, except in Alpine areas, which show a decrease in low flow frequency
- Mountain regions: possible shift of low flow events from winter (in the past) to the end of summer / autumn (in the future)

Upper Danube River Basin (UDRB) [8, 6, 21, 64, 78]

Drought

- Longer and more frequent droughts are possible
- Negative drought effects at a local scale are possible
- Decrease of drought events in winter, increase in summer

Low flow

- Possible increase of low flow duration / period
- Decrease in low flow in summer and autumn (worsening of summer low flow situation)
- Winter low flow situation will be less severe due to an increase in runoff in this season; possible shift of low flow periods from winter to late summer in Alpine areas

- Water stored in the Alps remains important for water supply during droughts / water scarcity in downstream areas

Middle Danube River Basin (MDRB) [16, 17, 34, 33, 18, 73, 117, 136]

Drought

- Increase of annual drought events and water scarcity
- Decrease of drought events in winter, increase in summer
- Possible increase in extremity and frequency of droughts; more frequent and intense summer droughts, associated with a decrease in rainfall amount in this season
- Regions in southern Hungary and the Republic of Serbia are expected to experience desertification; e.g. less severe development in the (Slovenian) mountain area

Low flow

- Possible increase in frequency
- Tisza: more expressed and longer low flow periods are possible
- Hungary: longer low flow periods; shift of low flow events from autumn to earlier months

Lower Danube River Basin (LDRB) [28, 66, 91, 136, 90]

Drought

- Droughts will become more frequent, longer and more intense
- Increase of serious droughts during summer in Romania (esp. in the south/southeast)
- Regions in Romania and Bulgaria are expected to experience desertification and extreme water shortages

Low flow

- River-system Dyie-Jihlava: increase in low flow frequency

Commonalities

- General: increase in drought and low flow events, especially in the south-eastern regions; water scarcity could occur; increase in the duration and intensity is possible. In Alpine areas, however, slight improvement of the low flow situation (especially in winter)
- Frequency: increase in frequency is likely to occur
- Seasonality: in mountain areas, decrease of drought and low flow events in winter and increase in summer

Challenges / Knowledge gaps

- Only few findings about the future drought and low flow situation for the LDRB and also for some regions in the MDRB (e.g. Sava and Morava)
- Few contradicting findings about the behaviour of changes in frequency
- The present projects and studies show mostly tendencies; quantity is not always clear
- Results depend largely on the underlying climate scenarios, models and catchment size

Adaptation measures

Therefore water saving and efficiency measures, e.g. in irrigation or by industries are often suggested by adaptation activities to deal with droughts, low flows and water scarcity. In order to be prepared for droughts, there seems to be a common understanding to create early warning systems and action plans. Additionally, the increase or enlargement of water reservoirs is commonly addressed in the analysed activities.

*Table 6: Suggested adaptation measures for impacts on droughts / low flows / water scarcity (*Time horizon of the effects of the measures: short-time (s), medium-term (m), long-term (l); abbreviations of the sources can be found in Appendix 5; [47, 119]).*

Type	Possible adaptation measures	Time horizon*	Options for cooperation	Challenges	Source (Countries)
Preparation measures for adaptation	**Monitoring systems** • Establishment of new and maintenance, optimization and extension of existing monitoring systems • Measures are required to improve the quality, spatial coverage and accessibility of meteorological, hydrological, water use, water quality, social and economic data, including the use of remote sensing methods (e.g. improvement of the drought forecasting capacity of the National Weather Forecast Services by providing access to European forecasts and EUMetsat satellite data) • Adaptation of the hydrometric networks to track the impact of climate change on water resources, providing enough redundancy to obtain accurate estimations of naturalised stream flow series from observation, closing the water balance in each sub-basin	m	x		NAS (AT, CZ, MD), WFD 24, EU COM, BAYKLAS, JRC 2005, UNFCCC (BA), UNECE 2010, UNECE 2009, ADAM
	Development of **early warning systems** on droughts and low flows • Consideration of European and national levels • Provision of information on spatial extent, duration, time of occurrence in relation to the crop calendar, and severity • Development of prototypes and set up implementing procedures for an operational European Drought Observatory and early warning system	s-m	x	x	EU COM, NAS (AT), UNECE 2009, ADAM, JRC 2005, EEA 2007, ST_BLOESCHL_AT
	Carrying out **drought risk mapping** and development of **drought risk vulnerability** profiles • Identification of methodologies for drought thresholds and drought mapping • Development of drought status indicators based on indicators for meteorological, agricultural and hydrological droughts and guidelines for indicator thresholds setting for different drought status in specific water distribution systems • Identification of the most drought-prone zones at a micro-level in order to develop more specific adaptation measures	m	x		NAS (CZ), WFD 24, UNECE 2009, EU COM, UNFCCC (BA), NAS (MD), ADAM, ST_BLOESCHL_AT

	• Improvement of understanding of a region's drought climatology to get critical information on the frequency and intensity of historical events • Taking the hydrological extreme year 2003 as a possible example to orientate on • Complementation of an early warning system with a vulnerability profile of the area to provide a direction to decision makers on how and where to respond for maximum effectiveness				
	Creation of new and intense existing **low flow and drought risk management and action plans** • Drafting and mitigation of drought risks is becoming a priority task, which should be implemented into the WFD and its river basin management plans • Development of methodologies for drought risk assessment and introduction of new indicators into the current practice • Diagnosis of water scarcity based on past water demands and improvement of knowledge about past and current water demands as well as on future trends • Fostering exchanges of information and best practices on drought risk management • Embedment of drought management policy (e.g. in a review of Water Act)	s-m	x	x	NAS (AT, CZ), OECD, WFD 24, EU COM, Alpine Convention, UNECE 2009, UNFCCC (SK), ADAM, VAHAVA, BAYKLAS
	Development of further appropriate **measures for action** • Checking the adequacy of existing measures, identification of gaps and suggestion of new measures where gaps are identified • Carrying out a check of earlier implementation of measures because of higher impact of GCC due to model results • Involvement of stakeholders for engagement to realise decisive measures to tackle water scarcity • Assessment of other climate change adaptation and mitigation measures on their impact on water scarcity and drought risks and analyzation how predicted changes in mean annual runoff will change supply reliability and how those changes will affect the socioeconomic system behind the water resources system	s-m	x		WFD 24, EU COM, NAS (AT)
	Establishment of coordinated **research programmes**, e.g. • Promotion of scientific research on extreme events to gain an improved understanding of droughts, leading to systems which “trigger” different levels of response • Research to improve the accuracy of climate models, and in particular, predictions of the spatial extent, severity and duration of drought events in the medium and long term • Research into the risk management aspects of drought management	s-m	x		UNFCCC (HR, AT), JRC 2005, EU COM

	• Process, statistical and operational systems research to develop improved criteria and tools to identify the onset • Research into the integration of all available instruments (technologies, systems, policies) to improve water efficiency in industrial, domestic and agricultural water use, including desalination • Research on drought tolerant crops, non-conventional water resources and more efficient irrigation technologies				
General measures	Taking additional efforts to prevent water scarcity and be better prepared to tackle the impacts of droughts	m	x		WFD 24
	Following an integrated approach based on a combination of measures (compared to alternatives based on water supply or economic instruments only)	m	x		WFD 24
	Incorporation of climate change adaptation in water management by continuing the focus on sustainability (sustainable balance between water availability and demand)	m	x		WFD 24
Ecosystem-based measures	Investigation of droughts and their impacts on ecological conditions of water bodies	m	x		UNFCCC (SK)
	Supporting sustainable land use management to secure water retention and ensure environmental flow, e.g. by grazing restrictions and ecological restoration	s-m	x	x	CC (DE), WFD 24, ADAM
	Supporting water conservation measures, e.g. • Conservation and drought contingency planning with a more efficient use of existing water supplies and minimization of the environmental impacts associated with developing new supplies, and delay the high cost of additional water supply development • Encouraging voluntary water conservation • Reviewing the local governments and water supply providers' conservation and drought contingency plans • Conservation of rainwater and surface water	m	x		UNECE 2009, ADAM, EU COM, WFD 24, JRC 2005
Behavioral /managerial measures	Implementation of **water use restriction** and limitations in water abstraction and pumping during drought events.	s-m	x	x	JRC 2005, SDR, UNECE 2010, UNECE 2009, EEA 2007
	Implementation of suitable **water saving measures** and strategies in industry, agriculture, forestry and private households to avoid restriction of usage (e.g. permit systems for water users, education and awareness-raising)	m		x	CC (DE), WFD 24, RBMP (AT), UNECE 2009, UNFCCC (BA)
	Raising public awareness of water-saving behaviour	m			CC (DE), WFD 24, RBMP (AT), UNECE 2009, UNFCCC (BA)
	Managing urban water demand through the right mix of restrictions, pricing and water efficiency for ensuring safe	s-m	x	x	WFD 24, EEA 2007,

	and reliable water supplies in times of low water availability. Increasing **water efficiency**, reuse and alternative sources (development of water infrastructure, rainwater and greywater harvesting, appropriate use of irrigation reservoirs, matching different water qualities to different uses), e.g. • Sustainable Urban Drainage • Water Recycling (for non-drinking purposes by industries, irrigation and households) • Managed Aquifer Recharge • Water wise rebate scheme • Water allocation and planning including making new housing development water neutral				UNECE 2009, ADAM
	Creation of a **hierarchy of water supply restrictions** applied during the drought event and coordination of communities among institutions involved in water management	s	x	x	NAS (CZ)
	Application of **modern farming methods**, e.g. by • Achieving optimal irrigation methods (e.g. correct timing) • Adapting plants to future climate conditions (e.g. growing less water-intensive crops) • Modification of crop rotation according to the natural soil water regime (means an introduction of more "winter crops") • Selection of proper drought-resistant crops, plant species and varieties • Popularization of new technologies addressing soil structure stability and soil treatment for enlarging the active layer of the root zone for enlarging water uptake • Introduction of mulch technology for increasing infiltration into the soil and decreasing soil water loss by evaporation • Runoff reduction by agronomic practices (No-tillage and cropping systems can reduce water runoff. Runoff, depending on soil characteristics, can also be delayed by tillage methods combined with plants having a high root density and lush surface cover) • Development of new complex agricultural water management programmes (combining irrigation, fishery and excess inland water management) • Promotion of indigenous practices for sustainable water use	m-l	x	x	NAS (MD), UNFCCC (BA), JRC 2005, VAHAVA, UNECE 2009, ADAM, ALP-WATER-SCARCE
	Import of agricultural products from countries with high water availability (virtual water)	s-m			UNECE 2009
Techno-logical	**Increasing water storage** • Precaution measures to enable sufficient water storage in water dams with volume increase of retained water	m	x	x	NAS (AT), UNFCCC (BA), BAYKLAS, CC

measures	resources behind dams to reduce drought severity; Reservoir safety and management will in these situations require further attention • Investigation and ensuring further locations for storages in order to raise low flows and create barrage for drinking water; these waters could also be used against fire and for irrigation • Use of local water reserves by constructing farm ponds for catching precipitation runoff • Enhanced use of rainwater tanks and stormwater harvesting • Changing reservoir operation rules and better use of multi-purpose reservoirs				(DE), WFD 24, RBMP (AT), UNECE 2010, UNECE 2009, EEA 2007, ADAM, ST_IPCC
	Consideration of **additional water supply infrastructures**, creation of local and regional water networks or establishment of further water treatment systems, identification and evaluation of **alternative strategic water resources** (surface and groundwater)	m-l	x	x	EU COM, BAYKLAS, UNECE 2009, ADAM, UNECE 2010, OECD
	Foster **water-efficient technologies** and practices and the emergence of a water-saving culture • Implement modern water saving irrigation devices and adapted cultivation techniques in agriculture and forestry to be prepared for water shortages • Implement improved production process in industry to save water • Creation of alternative technological solutions like desalinization and reuse of wastewater	m-l	x		EU COM, CC (DE)
	Leakage reduction of reservoirs and water distribution networks	m			EU COM, UNECE 2010, UNECE 2009
	Improvement of **infrastructure resilience**	m			EU COM, UNECE 2010, UNECE 2009
	Increase in **water retention** properties	m-l			UNFCCC (HR), NAS (HU), RBMP (AT)
	Installation of windbreaks in windy areas	m-l		x	UNFCCC (BA)
Policy approaches	Improvement of the **linkages** between European policymakers, operational water management agencies and researchers to ensure current operational best practice is shared	s	x		UNFCCC (HR), UNECE 2009, JRC 2005
	Cooperation with other countries to exchange experiences in combating droughts	s	x		UNFCCC (HR), UNECE 2009, JRC 2005
	Awareness raising and support of strong public education and training programmes, which will require major investments in monitoring, research, technology transfer and education	m-l	x		JRC 2005, WFD 24, ADAM
	Ensuring risk communication and full public participation to avoid social conflicts, e.g. restrictions on water use need to be carefully communicated to consumers.	m			UNECE 2009, UNECE 2010

	Putting the right **price** tag on water and allocating water and water-related funding more efficiently (financial aid with loans, tax reduction, debt reduction)	m		x	EU COM, ADAM, WFD 24, OECD, UNECE 2009
	Encourage "soft" demand management approaches, rather than "hard" infrastructure supply side approaches; this will need to be tuned to local and national circumstances, and fit within a suitable pan-European framework	s-m			JRC 2005
	Implementation of a clear definition and methodology for estimating economic, social and environmental cost of droughts	m	x	x	JRC 2005
	Extension of methodologies to assess the cost effectiveness of different uses of water in different EU to imported agricultural products, especially from developing countries	m-l	x	x	JRC 2005
	Clearwater information exchange (clearwater is a not-for-profit organisation that aims to accelerate the uptake of sustainable urban water management. Its website and associated activities are intended to provide a 'space for learning')	s	x		ADAM

5.6 Floods

In general, it is less reliable to model the future development of extreme events like floods than changes in the average water balance. This is especially the case at the local scale [7]. Some studies studies even clearly affirm that future flood predictions include a high uncertainty.

According to the partially contradicting findings of the investigated research projects and studies on floods, there is no clear tendency in the development of future flood events for the DRB as a whole. Most studies predict an increase in flood intensity and frequency, especially in winter. Small and medium flood events are likely to be more frequent in future. However, other findings show no clear trend for changes in the return periods. Seasonal changes are triggered by changes in precipitation and snow cover. Within the DRB there are different local tendencies, especially for the development of extreme flood events.

For the UDRB, some studies show an increase in the frequency of extreme flood events (100-year frequency) whereas others indicate a slight decrease or point out that the future development lies in the range of the natural variability. However, most studies indicate an increase in and a shift of flood hazards in the Alps, triggered by changes in winter precipitation and snow storage changes. Particularly for the MDRB, studies show a pronounced increase in flash floods due to more extreme weather events (torrential rainfall) for small basins, e.g. in the Carpath Range or the Sava and Tisza headwaters. The very few studies of the LDRB show an increase in flood frequency. The uncertainty of flood prediction is especially high in small catchments, because of a, for the task of flood predictions, relatively low spatial resolution of climate models.

Danube River Basin (DRB) [18, 38, 57, 43, 50]

- In general, high uncertainty in flood predictions; high regional and local differences
- Flood risk is projected to increase throughout Europe
- Extreme flood events (100-year frequency) may increase or decrease; little agreement of findings in spatial pattern
- Possible increase in winter floods
- Development of flood events depends largely on changes in precipitation patterns, extreme weather events and snow cover

Upper Danube River Basin (UDRB) [7, 78, 64, 21]

- High uncertainty in flood projections, especially for small catchments
- Flood risk is projected to increase due to more extreme weather events
- Probably slight increase of small and medium flood events; no clear conclusion and contradicting findings about the behaviour of extreme flood events (100-year frequency)
- Development of flood intensity is unclear; possible increase in winter flood intensity and frequency and possible shift of timing of floods from spring to winter
- The probability of flash floods resulting from more-frequent and more intensive strong rainfall in summer will increase
- Alpine Space:

  - Increase in frequency of extreme floods is possible but can lie in the natural range of variability
  - Increase in volume and duration in autumn to spring, possible decrease in summer; due to changes in snow cover duration, possible increase of spring floods; shift of flood peak due to earlier snow melting
- High anthropogenic impacts due to river regulation, retention areas and reservoirs

Middle Danube River Basin (MDRB) [33, 2, 40, 106]

- High uncertainty in flood projections; no clear picture can be drawn about possible changes of flood conditions
- Increase of flood hazard probability and magnitude as well as increase in vulnerability, especially in small catchments / headwatersheds
- Development of flood events depends largely on changes in precipitation patterns, extreme weather events and snow cover; flood peak may occur earlier because of rain/snow changes
- No clear conclusion and contradicting findings about the behaviour of extreme flood events (100-year frequency) → they may increase or decrease
- Mountain areas: possible increase in frequency and magnitude of flood events
- Tisza: increase of flood frequency in winter is likely to occur
- Torrential types of hydrological extremes such as flash floods will likely be more frequent and severe (e.g. in small catchments / headwatersheds of the Tisza, Sava and Mureş); possible increase in floods in summer due to more extreme precipitation events (e.g. Mureş)

Lower Danube River Basin (LDRB)[29, 50]

- Flood risk may increase
- Possible increase in flood frequency
- Short-term flood events due to flash floods may occur more frequently
- Lower risk of early spring floods because of reduced snow coverage
- Changes concerning coastal flooding in Romania might be severe

Commonalities

- General: high uncertainty in flood prediction, especially at the local level in small catchments and mountain areas; however, most studies indicate an increase in flood events and risk
- Frequency: flash floods as a result of extreme meteorological events (e.g. torrential rainfall) are likely to become more frequent
- Seasonality: floods events could increase in winter; a shift of timing of floods is likely to occur due to changes in precipitation patterns, snow cover and extreme meteorological events (e.g. torrential rainfall)

Challenges / Knowledge gaps

- Only few findings about floods for the LDRB

- Little regional and local agreement of the findings regarding flood intensity, frequency and seasonality
- No clear conclusion and some contradicting findings about the behaviour of changes in flood frequency, especially of extreme flood events (100-year frequency)
- The present projects and studies show mostly tendencies; quantitative changes are not always clear
- Results depend largely on the underlying climate scenarios, models and catchment size; the uncertainty of flood prediction is especially high in small catchments, because of the spatial resolution of climate models

Anthropogenic acting with for instance land use changes, silting up of flood plains, overgrowth of flood channels by vegetation or river regulation will also influence future flood occurrences.

Adaptation measures

Despite the high uncertainty in climate change impacts on floods, adaptation measures are mentioned most often in the analysed activities. Summing up, mainly the maintenance, improvement and enlargement of flood protection services and constructions are addressed. Thereby, often the functions of natural retention areas, both for ecological and safety reasons, are mentioned. Furthermore, there seems to be a common understanding for the demand of restrictions in future development along flood prone areas.

*Table 7: Suggested adaptation measures for impacts on floods (*Time horizon of the effects of the measures: short-time (s), medium-term (m), long-term (l); abbreviations of the sources can be found in Appendix 5; [47, 119]).*

Type	Possible adaptation measures	Time horizon*	Options for cooperation	Challenges	Source (Countries)
Preparation measures for adaptation	**Development of a Danube-wide flood forecasting system** • Assessment of existing national and international flood forecasting • Development of a system for timely and reliable flood forecasting and information based on the relevant regional and national systems • Improvement of existing systems and their interconnection, e.g. by the implementation of mathematical models and radars, which can give a quantitative forecast of precipitation, by provision of additional information to national and regional flood-forecasting authorities, by including plans for early warning evacuation • Further development and testing of a basin-wide Danube Flood Alert System in cooperation with the FP EG as part of the European Flood Alert System for medium-range forecasts, e.g. based on the LISFLOOD system • Implement forecast for flash floods	s-m	x	x	UNFCCC (ME), NAS (RS, AT, CZ), EEA 2007, RBMP (TRB), Water Act (CZ), VAHAVA, ICPDR FAP, WFD 24, Declaration (DRRB), ClimateWater, ST_IPCC, CC (DE), UNECE 2009, KEO, BAYKLAS, CLIMCHALP
	Implementation of a **flood risk assessment** for the identification of areas exposed to floods	s-m	x		UNFCCC (DE, MD, ME, CZ), NAS (DE, RS), SDR, BAYKLAS, Floods Directive, Water Act (CZ), ICPDR FAP RBMP (TRB), ADAM
	Establishment, use and regularly adaptation of **flood hazard, risk and vulnerability maps and databases** including uncertainty related to climate change impacts (e.g. support the Danube FLOODRISK project) in order to increase public awareness of the areas at risk from flooding, to provide information of areas at risk to give input to spatial planning and to support management and the reduction of the risk to people, property and the environment	s-m	x	x	UNFCCC (RS, DE), NAS (RS), BAYKLAS, ADAM, UNECE 2009, ClimateWater, WFD 24 JRC 2005, SDR, Floods Directive, RBMP (TRB), ICPDR FAP, UNFCCC (BA),

					SDR, ST_BLOESCHL_AT, RBMP (TRB), Water Act (CZ), ADAM
	Development of Strategies and Plans • National Protection and Rescue Strategy for emergencies and design of protect and rescue plans • Contingency, confinement and possibly evacuation plans of trans-national flood areas (floodplain basins) should be worked out jointly by the interested countries • Drafting and implementation of a Water and Climate Adaptation Plan for River Basins (fill the knowledge gap on the impact of climate change on water sector and inform decision making sector (e.g. governments and other national authorities) how to increase the climate resilience of the critical water management infrastructure investments and integrated water resource management) • Preparation of working plans for the sub-basins • Establishment of incorporated concepts for the protection of torrents in order to assess the risk of flood and define precautions	s-m	x		NAS (RS), BAYKLAS, RBMP (TRB), Water Act (CZ), SDR, ICPDR FAP
	Monitoring • Of changes of flood patterns by gathering comprehensive information on past floods • Development of a "past floods database at European level" • Development of a monitoring network with modern measuring equipment at stations and software packages for the assessment of the intensity of precipitation, with the use of radar imaging systems • Development methodologies on monitoring of the condition of flood defence structures incl. remote sensing techniques	m	x		UNFCCC (ME), NAS (RS), WFD 24, VAHAVA, RBMP (TRB), Water Act (CZ)
	Improvement of information systems • Planning and implementation of informatics system supporting the planning process and utilisation of digital contingency and confinement plans in DS in order to enhance flood protection • Organisation of flood and reporting services, flood recording and documentation • Creation of forums for exchange of expert knowledge • Upgrading confinement planning in digital format, enabling digital archiving and the utilisation of their information and data base in DSS • Making sure that best available information is taken into account when flood scenarios are reviewed regularly • Implementation of effective public communication systems for managing crisis situations • Enabling influencing the communication specific mass audience should be able to influence	s-m	x		Declaration (DRRB), Water Act (CZ), ICPDR FAP, RBMP (TRB), WFD 24, ADAM, RBMP (TRB), VAHAVA, BAYKLAS, Floods Directive, EEA 2007

	• Improvement and increase of information exchange				
	Re- evaluation of flood protection and water structures taking into account climate change impacts	s-m		x	UNFCCC (RS, SK), BAYKLAS, WFD 24, Water Act (CZ)
	Updating flood design values	s-m	x	x	NAS (AT), ST_BLOESCHL_AT
General measures	**Promotion and extension of insurance systems** for protection of goods and persons against damages from floods	s-m			UNFCCC (RO), NAS (RS), EEA Alps 2009, EEA 2007, ADAM, ICPDR FAP
	Considering both, use and protection in supporting new infrastructure	m			WWF-DCP
	Implementation of integrative flood prevention programs to support flood-preventions measures with retention	s-m	x		UNFCCC (CZ), NAS (AT)
	Improvement of resistance • Strengthening existing protection • Increase the resilience of civil protection and disaster management infrastructure in view of climate change • Development and strengthening emergency organisations and their cooperation • Raising preparedness and emergency response capabilities • Increase the level of flood protection for cities and settlements along major water streams, by enlarging and rehabilitating existing systems	s-m	x		UNFCCC (RS), NAS (RS), WFD 24, RBMP (TRB), ICPDR FAP, UNFCCC (RO), NAS (RS), CC (DE), EEA 2007, Water Act (CZ)
	Prevention of accidental pollution during floods affecting the storage facilities of dangerous substances	s		x	RBMP (DRB)
Ecosystem-based measures	**Using synergies of flood protection and biodiversity conservation,** e.g. in the renaturation of rivers and riparian systems in order to create additional flood plains and habitat for rare ecological communities and to buffer run-off peaks	m	x	x	EEA Alps 2009, UNECE 2009
	Protection and restoration of water retention areas, including natural reservoirs • Creation or restoration of retention areas to increase water retention properties of the landscape • Use water retention capacity of wetlands • Provision of further information on natural retention (e.g. the appropriate strategy consists of three steps: retaining, storing and draining; therefore protection and restoration of infiltration areas in the upper parts of the catchment and conservation and restoration of wetlands are crucial for the water retention) • Increasing natural retention and storage capacity (e.g. construction of artificial side channels, reconnection of old river arms and increasing water transport and retention capacity of floodplains): the storage effect of	m-l	x	x	UNFCCC (CZ), NAS (DE), NP (CZ), UNECE 2009, EEA 2007, ICPDR FAP, Declaration (DRRB), RBMP (AT), KEO, WFD 24, CC (DE), NAS (DE), EEA Alps 2009, SDR, RBMP

	vegetation, soil, ground and wetlands has an important mitigating effect particularly in minor or medium-scale floods; each of these storage media is capable of retaining certain quantities of water for a certain length of time; a large natural storage capacity results in slow rises in water levels, thus reducing the flood wave, and enables sustaining or contributing to the restoration of self-purification capacity of water				(TRB), Declaration (DRRB), KEO, UNFCCC (DE), NAS (HU
	Regional planning • Making extensive use of all available potentials to achieve a considerable expansion of retention areas and to provide effective long-term protection against the flood risks • Improvement of the opportunities for rainfall to soak away naturally by reducing new land take of open spaces for settlement and infrastructure • Provision of planning support for restoration, unsealing, restoration • Reservation of areas for flood control (going beyond the designation of flood control areas required by water legislation), in order to safeguard existing discharge and retention areas and preparation of their necessary expansion • Spatial planning and construction activities in the context of climate change and increased threats of floods	m	x	x	NAS (DE), WFD 24, SDR
	Reintroduction of alternative and more sustainable measures, such as widening the area between dikes, creating accumulation polders for capturing flood waves instead of permanent reservoirs, revitalizing streams and increasing natural retention capacities	m	x	x	KEO
	Preparation of an overview of the implementation of future measures to achieve the WFD environmental objectives while ensuring an appropriate level of flood protection	s	x		RBMP (DRB)
Behavioural /managerial measures	**Awareness raising, training and education of the general public** • Raising awareness and ensuring the preparedness of the general public through dissemination of printed materials on floods risks and prevention organization of public meetings and training • Including climate change related flood risk changes in ongoing education initiatives to improve flood risk awareness and preparedness • Professional consultation on flood prevention • Information through mass-media • Using informal networks for information dissemination • Establishment of community self-protection teams promoting self-reliance among residents and businesses to minimize the risk to personal safety and property damage during a flood events • Building ability to "live with floods" • Carrying out public awareness and information in order to encourage citizens to behave in suitable ways before, during and after the passage of the floods and to take their own precautionary	m	x		UNFCCC (DE, RO), CC (DE), ClimateWater, WFD 24, RBMP (TRB), ADAM, ICPDR FAP, Water Act (CZ), BAYKLAS, VAHAVA, RBMP (TRB)

	• Establishment of a training program for dyke defence • Organisation of regular defence exercises on local, regional, national and trans-national level to test preparedness and co-operation between water authorities, disaster and rescue services, leaders of public administration and local governments, police, road administration, military forces, hydropower companies and local industry				
	Adaptation of floodplain systems • Establishment of new floodplain areas • Increasing the size of existing floodplain areas • Removing of hydraulic obstructions • Conservation, effectively protection and restoration of floodplains • Promotion of transnational conservation of the remaining floodplains along the entire length of the Danube by completing existing initiatives and promoting new ones • Avoiding possible negative effects on agriculture, rural settlements and water pollution from contamination due to intensive use of chemicals on agricultural lands in planning the reactivation of protected floodplains • Delimitation of inundation zones for safe passage of major floods through affected territory	s-m	x	x	NAS (HU), UNECE 2009, RBMP (TRB), Declaration (DRRB), SDR, CC (DE), ICPDR FAP, ADAPTALP, ST_IPCC, UNFCCC (CZ), NP (CZ)
	Adaptation of flood management • Implementation of proper flood control practice • Implementation of appropriate floodplain management to explore the benefits of flooding • Implementation of so-called non-structural means of flood control, such as organisational tasks • Involvement of local stakeholders • Concentration on the reduction of current vulnerabilities to extreme events • Highlighting floodplains in river basin management when designating areas for restoration and flood control storage • Combination of non-structural and structural measures of flood risk management • Increasing river basins protection by means of both passive safety measures and active river regulation • Correlation of the territorial development and improvement plans with the strategy and the risk management plans in the case of floods • Improvement of bilateral and multilateral cooperation in planning enhancements, especially in contingency planning • Integration of flood risk management into land use planning	s	x	x	UNFCCC (RO), NAS (AT, HU, DE), RBMP (TRB), OECD, VAHAVA, ADAM, ICPDR FAP
	Sustainable agricultural practices	m	x	x	NAS (AT), ADAM,

	• Introduction of flood-tolerant species • Following nature conservation and flood control requirements • Using agricultural practices such as avoiding bare soil during precipitation season, minimise plough land on the slopes of hills • Improvement of drainage • Support runoff reduction by agronomic practices like no-tillage and cropping systems				SDR EEA 2007, BAYKLAS
	Changing land use and adaptation of land use management • Replacement or complementation of the prevailing intensive agriculture dependent on flood levees and drainage in order to balance hydrological processes • Enabling natural ecosystems to return to their former territories through the rehabilitation of naturally flooded areas • Ensuring a coordinated approach in land-use planning (through this action synergy effects between river basin management and flood risk management could be used) • Afforestation in upper basin areas and on broad floodplains along the river to increase the water retention capacity of the river basin • Maintenance and expansion of the forest population in river basisn by semi-natural reforestation, particularly in mountain and hilly ranges; • Maintenance of the vegetation edging waterways to support biodiversity of these environments, and help against risk of flood damages • Implement land use regulation to preserve and enhance natural retention across the river basin	m-l	x	x	NAS (DE, MD, AT), CC (DE), ADAM, UNECE 2009, SDR, White Paper EU, RBMP (TRB), UNFCCC (RO), JRC 2009, OECD, AQUATERRA
	Capacity building: raising preparedness of the organisations responsible for flood mitigation	s			NAS (RS), RBMP (TRB)
	Adaptation of flood management concerning the water infrastructure • Regulation of the flow regime by increasing the flow capacity of the channels of water courses • Increasing the safety of water works • Increasing the capacity of safety overflows • Change the operation of reservoirs and lakes • Creation of accumulation polders for capturing flood waves instead of permanent reservoirs • Cutting a flood carrying clearance, a corridor, within the floodplain, in the dense vegetation	s-m		x	UNFCCC (CZ), UNECE 2009, Water Act (CZ), VAHAVA, KEO
Techno-logical	**Structural flood protection / adaptation of urban infrastructure** • Adaptation of stream canalization	m-l	x	x	UNFCCC (DE, RO, CZ), NAS (DE, MD),

measures	• Improvement of existing drainage systems and capacity, including the separation of sewage, sewer relief from flood waters by offsite pumping and other solutions • Installing pumps for water extraction at the floods events • Installation of non-return valves in all building connections to the public sewage network • Construction of removable or modifiable structures e.g. bridges, which can be moved out of the water's way • Modification of transport infrastructure, including the development of appropriate pavements to provide the infiltration of the rain water at pedestrian platforms, for parking and for storage • Implementation of artificial infiltration and retardation to reduce impermeable areas • Creation of local storages (ponds, building storages, groundwater cisterns) • Roof planting • Construction of new protection structures e.g. tidal barriers • Construction and renewal of polders • Keeping spaces for emergency overflow free as a emergency storage				ADAM, ClimateWater, BAYKLAS, UNECE 2009, RBMP (TRB), ADAM, SDR , ICPDR FAP, WFD 24, EEA 2007, ST_IPCC
	Creation / adaptation of dams and dykes • Dam building and the construction of new dykes including the possibility to modify the height of the dam later • Development of plans for restructuring, displacing or removing the so called "summerdikes" of floodplains (internal dikes protecting objects within floodplains) • Widening the area between dikes • Construction of temporary dams • Implementation of measures to maintaining dam safety *Challenges: in some countries maybe none of these (high-cost infrastructural projects like dam building, the construction of dykes and stream channelization) are an optimal solution; considerable external funding would be needed for these measures to be successful*	m-l	x	x	UNFCCC (CZ, BA), NAS (MD, HU), UNECE 2009, VAHAVA, EEA 2007, KEO, WFD 24, KLIWA, ST_IPCC, WWF-DCP
	Elaborating new design standards of the protection works against floods • New building codes and regulations • Precautionary construction planning: building resilience precaution in constructions • Building resilient housing	m		x	UNFCCC (RO), EEA 2007, WFD 24, CC (DE), UNECE 2009
	Introduction of a climate change adaptation factor on dams and dykes (example Bavaria) *Challenge: due to no projected increase in future flood magnitude no climate change adaptation factors (AT)*				KLIWA, RBM (Bavaria), NAS (AT), ST_BLOESCHL_AT
	Creation / adaptation of reservoirs • Building new reservoirs like emergency flood reservoirs and multi-purpose reservoirs, which serve as an	m	x	x	UNFCCC (CZ), ClimateWater,

	adaptation measure for both floods and droughts • Reconstruction and modification of existing water reservoirs • Creation of a series of reservoirs in order to reduce flood-peak height significant • Using lowland floodplains for flood relief reservoirs, which can be used as multipurpose areas, adjusted to floods • Construction of a second flood channel *Besides objectives related to downstream flood control, reservoirs can be also used for other purposes such as municipal and industrial water supply, agricultural irrigation, navigation, fisheries, recreation, and water quality control and salinity control* *Challenges: a very important note on reservoir systems is that using them will highly influence the quantity of available water in downstream countries (in case of transboundary catchments), therefore these methods also require improved international regulation and water policy between the affected nations*				ADAM, WFD 24, VAHAVA, ST_IPCC
	Technological development to improve the efficiency of emergency interventions to raise the capacity of defences during floods	m	x		Water Act (CZ), CC (DE), RBMP (TRB)
Policy approaches	**Implementation of the Floods Directive** including the impacts of climate change on the management of floods arising from surface waters and in coastal areas; the six-yearly risk analyses, hazard/risk maps and flood management plans, are regularly adapted to take account of the latest state of knowledge	s-m	x	x	UNFCCC (EU),NAS (DE)
	Legal legitimating the creation of retention areas	s-m		x	NAS (AT)
	Development of a strategy for flood protection	s-m	x		NAS (CZ)
	Use the EU Floods Directive as a legal framework for a coordinated approach to assess and manage flood risks	s-m	x		SDR
	Institutionalization of civil protection system as a part of protection and rescue in emergency situation	s			NAS (RS)
	Strengthening operational cooperation between the emergency response authorities in the Danube countries and improve the interoperability of the available assets in order to reduce damages, protect citizens and ensure an appropriate response to emergencies	s-m	x		UNFCCC (ME), SDR
	Establishment, maintenance and updating of agreements upon procedures for mutual assistance among riparian countries in critical situations, including arrangement of formalities to facilitate the travel of flood response personnel from abroad and interoperability of emergency services’ equipment (whether by plane, boat or on land) during flood events	s	x		RBMP (TRB)
	Further investment and provision of financial aid • Further investments in flood defence • Establishment of a national fund for assistance in the case of natural disasters • Implementation of various ex ante measures such as reserve funds, contingent credit schemes for disaster loss financing	s-m		x	UNFCCC (HR, RS) NAS (RS) ADAM ClimateWater

	• Implementation of subsided loans for risk adjustments and ex post measures such as external borrowing and loan conversions				
	Improvement of institutional awareness of potential climate change related impacts on flood risk, for instance ensure that authorities responsible for climate change adaptation and flood risk management coordinate with river basin management	s	x		WFD 24
	Consequent implementation of restrictions of development in risk areas like in riverside belts and floodplains and areas of high groundwater level as well as restrictions on storing materials, substances and objects that could be washed away	m	x	x	NAS (HU), CC (DE), BAYKLAS, EEA 2007, UNECE 2009, RBMP (TRB), Water Act (CZ)

5.7 Water temperature

Following the future increase in air temperature, water temperature will most likely increase in the DRB. Thereby, the relationship of increasing air and water temperatures need not to be linear. While in the last century an increase in water temperature of 1 K was observed in European rivers, an increase of 2 K by 2070 is modelled [56]. However, exact numbers differ regionally and locally. Consequently the freezing periods in winter are most likely reduced and the ice cover on lakes and rivers might decrease. Problems with heat loads of thermal power plants using cooling water for instance might arise. Additionally, changes of ecosystems, lifecycles and biodiversity in all aquatic systems are expected because of the increasing water temperatures. Due to resulting changes of all temperature dependent chemical and biological processes, water quality is likely to be reduced, e.g. by a decreasing oxygen concentration in rivers, aquifers and lakes.

Danube River Basin (DRB) [18, 132, 133, 119, 118]

- Rivers: significant increase in mean monthly and annual water temperatures in river systems; European rivers: increase of 2K until 2070 than today [56]; increase especially in autumn and early winter
- Lakes: increase in lake water temperatures, especially surface waters; decrease in ice-cover of lakes
- Problems
  - Heat load of thermal power plants
  - Possible changes of the chemical composition of groundwater bodies
  - Changes of aquatic ecosystems and biodiversity; alteration in life-cycle events (e.g. earlier blooms of phytoplankton and zooplankton); increase of harmful cyanobacteria; movement of freshwater species northwards and to higher altitudes

Upper Danube River Basin (UDRB)[21, 12]

- Increase in water temperature; particularly of surface waters and groundwater in summer
- Highest increase in water temperature in Alpine areas; however, melt-water could be a possible cooling effect in headwatersheds in summer
- Decrease in oxygen concentrations due to higher water temperatures
- Anthropogenic impact: Human impact has influenced and will undoubtedly influence the thermal regime of the Danube (discharge of thermal power plants, construction of barrages for the production of hydroelectric power generation)
- Increasing problem of heat loads in discharge water

Middle Danube River Basin (MDRB) [136, 22]

- Increase in water temperature
- The increase in air temperature was identified as the main factor affecting water temperature, but the relation between water and air temperature is not necessarily linear
- Freezing of water bodies occurs less frequently in winter
- Rising temperatures induce direct physiological effects on aquatic organisms

- Increase in water temperature in lakes lead to a change in stratification patterns
- High anthropogenic impacts: regulations and drainage works, hydroelectric structures

Lower Danube River Basin (LDRB) [136]

- Increase in water temperature
- Winter and especially transitional months will be the most affected

Commonalities

- Increase in water temperature of all aquatic systems (rivers, lakes, groundwater bodies)
- Less freezing periods in winter and less ice cover on lakes and rivers
- High anthropogenic impact due to regulations, drainage and hydroelectric structures; increasing problem of heat loads to waters
- Changes of the aquatic ecosystems and lifecycles are likely to occur; decrease in biodiversity; changes of biological and chemical processes

Challenges / Knowledge gaps

- Only few findings about water temperature changes for the LDRB
- Some contradictions about the season with the highest increase in water temperature

Adaptation measures

The analysed adaptation activities only provide very little examples for adaptation measures in this impact field, but there is a demand for further monitoring and research on the future impacts of water temperature to create a better understanding of ongoing processes as a basis for adaptation activities. Attention should be paid on considering environmental issues, e.g. in the heat loads of discharge water.

*Table 8: Suggested adaptation measures for impacts on water temperature (*Time horizon of the effects of the measures: short-time (s), medium-term (m), long-term (l); abbreviations of the sources can be found in Appendix 5; [47, 119]).*

Type	Possible adaptation measures	Time horizon*	Options for cooperation	Challenges	Source (Countries)
Preparation measures for adaptation	**Monitoring** • Establishment of a continuous and automatic water temperature monitoring systems in order to get more data, e.g. for the determination of the water temperature regime of rivers; this also includes the observation of meteorological and hydrological data and their interactions • Reassess thermal discharge	s-m	x		ST_BONACCI_HR, NAS (AT), ST_BLOESCHL_AT
	Research • On causes and consequences of water temperature changes for a better understanding of the related processes, especially the rising of river water temperatures over the last 20 years. This is particularly important because of the increasingly frequent occurrence of low-water flow and drought in the study area during recent decades. • On discharge of warm waste water from power plants (cooling water) into rivers and the higher concentrations of pollutants in summer because of low flow	s-m	x		ST_BONACCI_HR, WASKLIM
General measures	Development of a DSS (Decision Support System) Tool	s-m			WASKLIM
Ecosystem-based measures	-				
Behavioural /managerial measures	Increase consideration of water temperature in water management, e.g. in heat load discharge	s-m	x	x	NAS (AT), ST_BLOESCHL_AT
	Updating of heat load and cooling water quantity / low flow management plans	s	x	x	WASKLIM
	Raise low water by means of adaptive control of reservoirs	s	x	x	WASKLIM
	Decrease the heat load in water bodies e.g. caused by cooling water	m	x	x	BAYKLAS, RBMP (Bavaria)
Technological	Development of alternatives for cooling, e.g. using cooling towers or cell cooling techniques which need less	m	x		WASKLIM, NAS (AT)

measures	cooling water				
Policy approaches	Implementation of special regulations for thermal discharge during extreme events	s	x		NAS (AT)
	Development/Implementation of strict rules for discharge of water into rivers and for water withdrawal	s	x	x	WASKLIM

5.8 Water quality

In some parts of the DRB, water availability will be most likely reduced in the future. Moreover, seasonal changes and changes of river regimes will occur. Additionally, drought and flood events could become more frequent and severe. All these climate change impacts could in turn lead to a decrease in water quality and the fact that water bodies will become more vulnerable to pollution. After long droughts for example, preferential flow is likely to enhance the vertical transport of pollutants to groundwater. Increasing water temperatures might worsen the water quality and can lead to an increased algal bloom. More frequent flooding and flash floods can cause a higher mobility of particle-associated pollution and changes of the redox balance of inorganic compounds cause release of organic colloids. Especially in the MDRB and LDRB higher stress on aquatic ecosystems, especially on littoral communities and fish might occur.

Danube River Basin (DRB) [18, 13, 14, 119, 118]

- Increase in water temperature could result in a decrease in water quality
    - Reduced oxygen solubility and increase biological respiration rates in streams and lakes → lower dissolved oxygen concentrations
    - Increase in mineralization and release of nitrogen, phosphorus and carbon from soil organic matter
- Shifts from oxic to anoxic conditions after floods (especially in areas of frequent flooding) could cause release of organic colloids and in turn persistent organic pollutants and redox sensitive inorganic compounds; higher mobilization of particle-associated pollution in areas affected by floods
- After long droughts preferential flow will lower dilution and enhance vertical transport of pollutants to groundwater
- Decrease in drinking water quality as a consequence of less pollutants being diluted
- Increase of negative effects on sewage systems because of a future deterioration of the low flow situation → lower waste water discharge, water rotting, higher risk of disease dissemination and accumulation of solid waste
- Release of phosphorus from bottom sediments in stratified lakes is expected to increase; decreased nutrients from increased stratification or longer growing period
- Change in timing of algal blooms and increase of harmful algal blooms
- High anthropogenic impacts (e.g. fertilizers, pathogens...)

Upper Danube River Basin (UDRB) [21, 15]

- Increase in water temperature and increase in low flow events could result in a decrease of water quality
- Change and shift of aquatic biocenosis is likely to occur
- Higher concentration of contaminants / pollutants is possible
- If heavy rain events will increase, this will lead to higher erosion, infiltration of nutrients and an exceeding possibility of overflowing sewage systems
- Accumulation of nutrients due to milder temperatures can lead to more algal blooms in lakes

Middle Danube River Basin (MDRB) [29, 127]

- Lower water quality is expected because of an increase in water temperature and higher flow variations of rivers
- Higher stress on aquatic ecosystems, especially on littoral communities and fish
- Groundwater quality is in danger

Lower Danube River Basin (LDRB) [29, 104, 100]

- Decrease in water quality due to rising water temperatures
- Decline of the dissolved oxygen level
- Higher stress on aquatic ecosystems, especially on littoral communities and fish
- Possible increase of saline intrusions in coastal aquifers

Commonalities

- Decrease in water quality is likely to occur; main reasons are an increase in water temperature, drought and flood events
- Higher vulnerability of aquatic systems during droughts; preferential flow will lower dilution and enhance vertical transport of pollutants to groundwater
- Increase of algal bloom is possible

Challenges / Knowledge gaps

- Only few findings about water quality changes for all regions and the DRB as a whole
- The present projects and studies indicate tendencies; quantitative changes are mostly unclear
- High anthropogenic influence

Adaptation measures

In order to be prepared for the impacts of climate change on the water quality, a reduction of pollution by the application of modern technology and good agricultural practices is the aim of many adaptation activities. This also includes an improved sanitation and wastewater treatment. Additionally, the rehabilitation and remediation of polluted watercourses as an ecosystems-based measure is commonly addressed as well as an increased protection of drinking water resources as policy approaches. Thereby the Water Frame Directive supports the demand for maintaining a good water quality in the water bodies.

*Table 9: Suggested adaptation measures for impacts on water quality (*Time horizon of the effects of the measures: short-time (s), medium-term (m), long-term (l); abbreviations of the sources can be found in Appendix 5; [47, 119]).*

Type	Possible adaptation measures	Time horizon*	Options for cooperation	Challenges	Source (Countries)
Preparation measures for adaptation	**Mapping** • Definition and mapping of vulnerable regions (i.e. eutrophic water zones) • Producing a **cadastre** of water resources, endangered areas, water facilities and systems, water use and polluters	s	x		UNFCCC (AT), RBMP (DRB), NAS (RS)
	Improvement of water quality **monitoring and control systems** • Water quality monitoring with measurement of quantity and quality of water intake and consume in the urban, industrial and agricultural sector • Periodically **inventories** of the relevant point and nonpoint sources of pollution within the Danube River basin including prevention and abatement measures already taken for the respective discharges under consideration of the actual efficiency of the measures • Regular monitoring of urban waste water and drinking water • Establishing of a monitoring network for wastewater emissions • Modernization of monitoring network for surface and ground water • Monitoring of the quality of irrigation water from surface runoff and groundwater • Introducing a monitoring system for the use of fertilizers and pesticides on agricultural land in order to reduce the impact on water • The use of **isotopic analysis** as part of environmental monitoring in order to distinguish between anthropogenic and natural sources of contamination	s-m	x		UNFCCC (BA), DRPC, UNECE 2009, NAS (RS), Declaration (DRB), AQUATERRA
	Specification of the number of **wastewater collecting systems** and **wastewater treatment plants**, which are planned to be constructed by 2015	s	x		RBMP (DRB)
	Intensification of eco-hydrological **research** (e.g. analysing of counteracting effects as for example higher deposition rates of persistent organic pollutants in areas with more precipitation and otherwise more mobilisation of particle-associated pollution in areas affected by floods)	m	x		RBMP (DRB), ClimateWater, AQUATERRA

General measures	**Reduce contamination**, i.e. by modern agricultural techniques to reach good water quality	m	x		NAS (AT), NP (CZ), NAS (HU), UNFCCC (MD)
	Water saving	s-m	x	x	NAS (DE)
	Rehabilitation and remediation of polluted watercourses	m	x		EEA Alps 2009, NAS (HU), BAYKLAS, NAS (DE), EU-WATERUSE, UNECE 2009, NAS (RS), Declaration (DRB)
Ecosystem-based measures	Mitigate the effects of extreme summer water temperatures, for example through measures to improve the water structure	m-l		x	BAYKLAS
Behavioral /managerial measures	Development and maintenance of an Accident Early **Warning System**	s	x		RBMP (DRB)
	Use of purified and microbiologically safe wastewater for watering farmland, because an increase in irrigated areas and / or in irrigation water withdrawals may deteriorate the ecological and chemical status of freshwater bodies	m	x		EEA Alps 2009, NAS (HU), BAYKLAS, NAS (DE), EU-WATERUSE, UNECE 2009, NAS (RS), Declaration (DRB)
	Improved sanitation and waste water treatment • Immission-oriented controlling of waste water loads • Improvement of water and sewage networks and waste water management • Regulation of wastewater discharge; improved drinking water intake • Monitoring of safety and effectiveness of waste water systems • Isolation of dump sites in flood risk zones • Temporary wastewater storage facilities (improved waste water treatment reduces conflict potential as upstream water uses have less impact on downstream use)	m	x	x	EEA Alps 2009, RBMP (Bavaria), NAP (BG); RBMP (DRB); UNECE 2009, UNECE 2010
	Promote **alternative collection and treatment of waste in small rural settlements**; places where water does not correspond to quality norms, the population should be offered filters or they should be informed on methods for cleaning their water, these activities should be performed in joint action with health authorities	s			SDR, NAS (MD)
	Prevention and cleaning up of dump sites in flood risk zones	m			UNECE 2009

	Application of a combined adaptation system for **reducing the runoff induced diffuse phosphorus load** to recipient waters	m			ClimateWater
	Changes in farming practices, land use and cultivation practices • Agricultural programs to reduce nutrient infiltration • Construction of wetlands on arable land close to large point sources • Increased use of spring crops, catch crops • Fertilization in spring • Establish **buffer strips** along the rivers to retain nutrients • Reduction of nitrate infiltration in increasing cultivation of catch crops • Crop rotation which saves water quality • Set-aside of areas and greening • Soil tests in spring to determine nitrogen demand • Controlled use of fertilizers and plant protection substances including consideration of the underlying geology of the agricultural fields	m		x	ClimateWater, RBMP (Bavaria), NAS (RS), AQUATERRA, SDR
	Consideration of land-use with vegetation schemes in order to avoid erosion in regard to the prevention of contaminant migration by river basin managers	m-l			AQUATERRA
	Reduction of the total amount of nutrients • from diffuse sources and from the largest point sources entering the Danube and its tributaries to levels consistent with the achievement of the good ecological/chemical status in the Danube River Basin District by 2015. • discharged to such levels necessary to permit the Black Sea ecosystems to recover to conditions similar to those observed in the 1960s as agreed on in 2001 in the Memorandum of Understanding between the International Commission for the Protection of the Black Sea and the International Commission for the Protection of the Danube River to reduce the loads	m	x	x	RBMP (DRB), ClimateWater, DRPC
	Regulation of runoff to guarantee residual water; reduction of runoff maxima, determined by usage	s	x		RBMP (Bavaria)
Techno-logical measures	Adaptation of **waste- and sewage-water treatment** technologies to the altered climate change induced situation: • Upgrade waste water treatment technologies and facilities in rural private houses and for large areas, considering possible increased storm water infiltration • Replacing of combined systems by separating and/or building new much larger systems (but: the inadequacy of sewer systems in draining the much increased and much flashier, urban storm runoff volumes. The overflow from combined sewer systems are causing serious health risks, but separated systems also cause serious pollution and inundation problems)	m	x	x	ClimateWater, NAS (RS), EEA Alps 2009

	• Building large diameter and long tunnels which can store sewage until it can be treated to reduce combined sewer overflow frequency				
	Use of **Best Available Technology** (BAT) for: • low- and non-waste technologies • abatement at source and/or for waste water purification • treating hazardous substances and contaminated sludge • developing and promoting remediation measures for hazardous or abandoned industrial sites and waste deposits	m	x		ClimateWater, SDR, RBMP (DRB), Declaration (DRB)
	Dilution as an adaptation strategy for water pollution (quality) control (but: conflicts during water scarcity periods)	s		x	ClimateWater
Policy approaches	**Regulations to limit emissions** • Enhancement of the "Emission legislation due to higher demands on removal of ammonium and phosphor" • **Emission limits** should be set, applicable to individual industrial sectors or industries in terms of pollution loads and concentrations, harmonised step by step with the emission limitation pursuant to the Danube River Protection Convention	m-l	x	x	NAS (AT), Declaration (DRB)
	Regulations to release hazardous substances • Supplementary provisions for **preventing or reducing the release of hazardous substances** and nutrients shall be developed for non-point sources, in particular where the main sources are originating from agriculture, taking into account the best environmental practice • Assure the proper **control and progressive substitution of substances** that are considered problematic for the Danube Region (identified under REACH - Regulation 1907/2006- as substances of very high concern)	m-l	x	x	Declaration (DRB), SDR, RBMP (DRB), NAS (RO)
	Regulations on wastewater treatment • Speed up the **construction and rehabilitation of wastewater collection systems and treatment plants** wherever possible and appeal to the international financial institutions and donors to give priority to this process • Undertake significant further efforts in the second cycle of the implementation of the EU Water Framework Directive with the aim to realise wherever possible the removal of phosphorus in wastewater treatment plants >10,000 Population Equivalents by 2021	m-l	x	x	DRPC, UNECE 2009
	Legislate at the appropriate level to limit the presence of phosphates in detergents	m	x		SDR, RBMP (DRB), Declaration (DRB)
	Define **water quality objectives and** apply **water quality criteria** for the purpose of preventing, controlling and reducing transboundary impact together with basin-wide, sub-basin and/or national **quantitative reduction targets** (i.e. for point and diffuse sources) taking the respective preconditions and requirements of the Danube Countries	m	x		Declaration (DRB), RBMP (DRB)

	(EU Member States, Accession Country, Non EU Member States) into account				
	When planning, licensing and implementing activities and measures the competent authorities take into account **risks of accidents** involving substances hazardous to water by imposing preventive measures and by ordering rules of conduct for post accident response measures; activities likely to cause transboundary impacts are carried out in compliance with the permits and provisions imposed	m	x	x	Declaration (DRB)
	Implementation of Directives: WFD, Integrated Pollution Prevention Control Directive, Urban Waste Water Treatment Directive, Sewage Sludge Directive, EU Nitrates Directive, Best Agricultural Practice to guarantee a substantial water quality improvement	m	x	x	RBMP (DRB), SDR, NAS (RO)
	Protection • of drinking water generation and resources, e.g by increasing the number of protected sub-basins, generation of water priority areas and water reservation areas • Implementation of operational plans for the protection of water against pollution caused by accidents (for 1st class water bodies)	m-l	x	x	EEA Alps 2009, NAS (HU), BAYKLAS, NAS (DE), EU-WATERUSE, UNECE 2009, NAS (RS), Declaration (DRB)

5.9 Water Supply / Water Demand

As a consequence of the modelled decreasing water availability according to the scenario results, a decrease in water supply is also expected. An assumed general increase in water demand for households, industry and agriculture together with the pronounced water scarcity in the MDRB, the LDRB and some areas of the UDRB during summer is likely to reinforce the problem and lead to high water stress [57]. An increase in water using conflicts is thereafter probable. Furthermore, a possible decrease in water quality in some parts of the DRB and an increase in water temperature will have a remarkable influence, too. Possible consequences are difficulties in water supply with an increased risk of water shortages and an over-exploitation of aquifers in the future. However, besides climate change impacts, future water demand is also triggered by anthropogenic impacts and political regulations and restrictions. In general, future changes in water demand in the sectors energy, industry, households and agriculture are, due to many factors, difficult to assess.

Danube River Basin (DRB) [57, 51, 118, 47, 4, 53]

Water supply

- Increase in water stress, especially in the south-eastern parts of the DRB
- Increased risk of (illegal) groundwater abstraction might result in reduced aquifer levels
- Greater soil movements as a consequence of more frequent wetting and drying cycles; piped water supply systems might become more prone to cracking
- An increase in intensity, severity and frequency of extreme weather events may affect drinking water supply systems
- Possible industrial production losses during droughts and hot summers due to less water supply; especially water related and exposed (e.g. at coastal and river flood plains) industries are highly vulnerable [53]
- Possible higher difficulty and cost of using water resources (esp. food and paper industries)
- New water-intensive industries will be conditioned by water availability and will be located to areas with less water stress

Water demand

- Increased water demand / withdrawal for agriculture, industry, energy and human consumption is possible, especially in the southeast and in the hot season
- High uncertainty in future energy, industrial and domestic water demand
- Increase in garden watering and irrigation
- High anthropogenic and political impacts
- Possible increase of a conflicting demand between different users

Upper Danube River Basin (UDRB) [64, 21, 116, 25, 95] [59]

Water supply

- Possible quantitative and qualitative problems regarding future water supply
- Reduction of water storages caused by climate change may lead to more restrictions and possible closures of some water resources

- No fundamental drinking water supply problems are expected (however regional exceptions could occur during prolonged droughts); some troubles might occur e.g. for drinking water supply in the south-east of Austria in communities depending on small and shallow springs; some karst springs can run dry
- More phases with chlorinated water are possible
- High anthropogenic impact

Water demand

- Possible decrease of water consumption of private households due to restrictions and new technologies
- Increasing water demand due to more frequent dry spell events is possible

Middle Danube River Basin (MDRB) [23, 127, 93, 19, 27]

Water supply

- Difficulties in water supply for households and industries may increase; increased risk of water shortages
- During droughts reduced water supply; shortage of cooling water for thermal power plants and other industrial processes due to decreasing water levels and higher water temperatures
- More areas facing water deficit
- Less water supply from surface waters in some regions; consequently, exploitation of groundwater resources might increase

Water demand

- Ever-growing drinking water requirements
- High anthropogenic and political impacts on this topic (e.g. pricing of water services)

Lower Danube River Basin (LDRB) [104, 100]

Water supply

- Loss of water in distribution networks and lack of reservoirs is a problem in particular in combination with more droughts during summer
- Some regions will face further water scarcity, especially in summer

Water demand

- Development of water demand in the industry sector and for domestic use is unclear
- Decrease of water resources could lead to an increase of production prices and might drop of competitiveness on international markets

Commonalities

- *Water supply*: decreased water supply, especially in the south-eastern parts and in summer; impacts on the sectors energy, industry, household and agriculture
- *Water demand*: development of water demand is uncertain; high anthropogenic impact

Challenges / Knowledge gaps

- Unclear development of industrial and domestic water demand especially for the MDRB and LDRB; some contradicting statements concerning the energy sector (e.g. cooling water)
- The present projects and studies indicate tendencies; quantitative changes are mostly unclear

Adaptation activities

The adaptation measures in the field of water supply have a lot of similarities with those of the field of droughts. Accordingly, an increase in water saving, recycling and efficiency are addressed by the activities. An improved management is suggested for water supply, water using and reservoirs, particularly during extreme events such as droughts. The maintenance and / or the construction of water supply systems as technological measure is also often addressed.

*Table 10: Suggested adaptation measures for impacts on water supply and water demand (*Time horizon of the effects of the measures: short-time (s), medium-term (m), long-term (l); abbreviations of the sources can be found in Appendix 5; [47, 119]).*

Type	Possible adaptation measures	Time horizon*	Options for cooperation	Challenges	Source (Countries)
Preparation measures for adaptation	**Research** studies within the water and sanitation supply services on • the development of demand, supply, risk, and water shortage functions • Carrying out detailed hydro-geological exploration focused on passive areas in conformity with the requirements of the development of public water supply systems • the performance of the technologies necessary to integrative water recycling • investigations for revitalization of existing technologies and development of new technologies • adaptation of economic activities concerning water scarcity and droughts, water efficiency and decision-making tools (include the effects of water prices)	s-m	x		UNFCCC (RO, SK), NAS (RS), EU COM, CC-WATERS, EU-WATERUSE
	Planning and calculating • Strategic water resource planning: quantitative and qualitative assessment of water reservoirs and water demand and supply trends to ensure water management (industry, commerce and agriculture, energy production and low flow augmentation) • Review of operation plans of existing dams also in the case of perennial dry periods • Update the thermal loads plans and create low flow management plans • Identify water catchment areas for various water uses	s	x	x	BAYKLAS, UNECE 2010, UNFCCC (SK, SI), NAS (HU, MD), Alpine Convention, CC-WATERS, ClimateWater
	Monitoring • Supervision systems for resource optimization (telemetry monitoring systems coupled with SCADA (Supervisory Control and Data Acquisition) & automated control) • Observation of spatial rainfall distribution with radar • Improvement of density of the meteorological observation network • Permanent surveillance and control of hydrological measurements (including groundwater levels & quality, lake water levels, spring discharges, drainage canal discharges) • Enhanced monitoring to detect deterioration during (predicted) droughts • Checking potential leaks in water supply structures demographic change, economic change and land-use changes)	m	x		UNECE 2010, NAS (AT), UNFCCC (ME, DE), CC-WATERS
	Establishing a **water supply information system**	s-m	x		NAS (RS)
	Development of a comprehensive and comprehensible **handbook of management measures**, aiming to support	s-m	x		SDR, NAS (RO, DE),

	water suppliers, spatial planners and development agencies in coping with impacts of climate change on public water supply based on scientific findings on the catchment scale				UNFCCC (RO), EU-WATERUSE, CC-WATERS
General measures	**Infrastructure improvement** • Improvement of the water supply infrastructure (taking into account not only climate change impacts but also • Maintaining and improving water and sewer infrastructure • Avoidance of supply bottlenecks (especially in the summer months) → development of regional and supra-regional network solutions	m	x	x	UNFCCC (BA, ME), KLIWA, NAS (MD)
	Closing the gap between water supply and demand including non-conventional water supplies	m	x		ClimateWater, UNFCCC (SI)
	Providing safe potable water and sewerage services to the majority of urban areas by 2015 and establishing efficient regional structures for water and wastewater management	m	x	x	SDR, NAS (RO, DE), UNFCCC (RO), EU-WATERUSE, CC-WATERS
Ecosystem-based measures	Expansion of rainwater harvesting to improve rain-fed cultivation and groundwater recharge	m			ClimateWater
	Restoration of aquatic habitats and ecosystem services	m		x	ClimateWater
Behavioral /managerial measures	**Education and awareness raising** • Rational water usage campaigns to increase the efficiency of water use (i.e. the use of surface, rain and grey-water as well as water-saving practices, water pricing, leakage reduction, water re-use for certain activities, more efficient irrigation, more efficient water-use appliances as well as the reduction of personal daily water use) • Fostering the emergence of a water-saving culture (the possibility of launching an alliance initiative on the efficient use of water) • Knowledge transfer: facilitate exchange of good practice in integrated water management issues in the Danube Basin among decision-makers at all levels and among the population of the Region; existing initiatives such as Danube Day or the Danube Box should be built upon and expanded • Introduction of certain inventive economic mechanisms for water saving as well as coercive measures for exceeding the specific water consumption to all types of users	m	x		UNFCCC (BA, RO), EEA Alps 2009, SDR, EU COM, NAS (RS), ClimateWater, RBMP (AT)
	Water saving and efficiency • Development of economic water usage (favour rain water collection and the use of waste water), improvement	s-m	x	x	UNFCCC (HU, DE, EU, SK); EU COM, Alpine Convention, EEA

	of water-use efficiency by water recycling, "grey-water", roof-runoff water and process water should be used for technical and industrial purposes that do not require water of drinking water quality • Higher involvement of local water assets and precipitation • Forcing of efficient water saving measures to avoid restriction of usage by supporting an integrated approach of the resource and its uses (especially in the context of commercial/industrial/agricultural production processes) • Suitable water saving measures in private households to avoid restriction of usage • Increase transfer of water and adoption of water transfer schemes • Withdraw only usable quantities of water from the Danube river • Recycling of grey-waters and collection of rainwater runoff in cisterns				2007, ClimateWater, EEA Alps 2009, NAS (AT, MD), CC (DE),
	Improved management in water supply • Reduce knowledge deficits, promote developing and transferring tools, methods and guidelines concerning the safeguarding of drinking water supply • Foster an intense cooperation between drinking water suppliers. Ways in which to implement the cost recovery principle and general water pricing issues should be discussed and experience exchanged • Integrate the water management infrastructure (dams, reservoirs and retention basins) on a multifunctional basis in the catchment areas over all water management systems for drinking water supply, hydro power and discharge regulation (low-water equalisation, flood control)	m	x	x	SDR, NAS (RO, DE), UNFCCC (RO), EU-WATERUSE, CC-WATERS
	Improved management in water using • Development of voluntary agreements among all economic sectors that need water (builders, building managers, manufacturers, tourism professionals, farmers, local authorities) to develop more water-friendly products, buildings, networks and practices; favour collaborative management between the various uses for water • Adjustment of the practices of companies in the sectors of energy generation, industry, transport, agriculture and forestry, utilities and housing to the climate protection policy • Fulfilment of obligations resulting from international agreements	m	x	x	EU COM, Alpine Convention, NAS (RO, RS)
	Improved management for exceptional situations • Improvement of the effectiveness of the management under non-stationary conditions and for decision-making processes in dangerous or uncertain situations • Ensure that industrial processes with low water demand are made available in due time to face situations of water scarcity • Properly trained and regularly tested staff for well-handled emergency (recognize the danger, analyse the risk	s-m	x	x	ClimateWater, UNFCCC (CZ), UNECE 2010, BAYKLAS, ST_BLOESCHL_AT

	and properly respond) • Establish a management concept for extreme low flow events in order to distribute the available water supply properly considering all relevant water utilities (with a priority for public water supply) • Revision of manipulating and operating regulations in water works to increase safety against overflowing • Development of alternative strategies for cooling and extreme situations • Interlink decentralized water supply systems with the main environmental authorities and install agreements with the centralized systems' management for emergency interventions, because these systems face different constraints to climate proofing management due to small networks and limited budgets				
	Good communication among everyone involved – system operators, owners, state administration, river basin authorities, the management of official rescue systems and all other stakeholders	s-m	x	x	ClimateWater, UNFCCC (CZ), UNECE 2010, BAYKLAS
	Improvement of reservoir management: differentiated management of storage capacity and rationalisation of the use of water resources in terms of time and space, considering the environmental and water resources requirements of downstream residents	s-m	x	x	UNFCCC (SK), NAS (DE), Alpine Convention
Techno-logical measures	**Maintenance of water supply systems** • Undertake periodical maintenance and cleaning of the most significant nodes of the network • Installation of accurate water meters • Leakage reduction: precautions against water losses and decrease water losses in distribution network • Investments in new water pipelines	s-m			UNFCCC (BA, CZ, RO), UNECE 2010, NAS (DE), EEA Alps 2009, NP (CZ)
	New infrastructure • Development of certain storage facilities for drinking water and expansion of drinking water networks • Increase reservoir capacity (more retention and storages for drought periods: create safety sources for extreme cases) • Initiate measures to combine constructions on a local and regional level • Expand the sewerage systems and water treatment systems • Construction and/or reconstruction of environmental infrastructure in industry (build wastewater treatment stations and / or rehabilitate existing ones) • Include space for reservoirs and aqueducts in future plans • Introduction of modern technologies into technologic processes in order to produce drinking water and to clean the waste water	m		x	UNFCCC (BA, RO), EEA 2007, ClimateWater, RBMP (AT), NAS (RO, RS), BAYKLAS
	Water recycling • Recycling of purified water and its further processing into an important source for the coverage of the	s-m	x		EEA Alps 2009, NAS (RO), UNFCCC (RO),

	industrial and public water demand, having currently a non-drinking quality • Increase of the recycling degree of the water for industrial needs; treatment of water (purification and disinfection) and reusing the sewage, first of all for industry, trade and agriculture • Re-use of return flows and the use of wastewater can replace the conventional water supply for irrigation • Fostering water efficient technologies and practices				BAYKLAS, EU COM, ClimateWater
	Increase in water efficiency of households • Development of construction standards for green buildings, which should provide storage and cycling of rain water, water saving by efficient installations and the development of patches at the terrace level • Switching from flush toilets to dry forms of sanitation	s-m	x		UNFCCC (RO), ClimateWater
	Increase in water efficiency in the industrial sector • Further development of water-saving methods, especially in manufacturing processes in trade and industry • More efficient cooling of power stations and low-loss irrigation of agricultural land • Treat wastewater by using "green infrastructure" such as sand filters and wetlands	s-m		x	ClimateWater, NAS (DE)
	Desalination of water can provide an important source of non-conventional fresh water supply in coastal areas	s-m		x	ClimateWater
Policy approaches	The changes expected as a possible consequence of climate change and the objectives to be achieved within the Energy Policy for Europe must be fully considered in order to avoid any incompatibility	s-m	x		EU COM, ClimateWater, NAS (AT), UNECE 2010
	Ensure that all adverse effects linked to any additional water supply infrastructure like dams or desalination plants are fully taken into account in the environmental assessment	s-m		x	EU COM, ClimateWater, NAS (AT), UNECE 2010
	Include water efficiency criteria in performance standards for buildings when harmonising Life Cycle Assessments and Environmental Product Declarations	m	x	x	EU COM, ClimateWater, NAS (AT), UNECE 2010
	Development of a new directive similar to the EU Directive on energy performance of buildings (2002/91/EC) for water performance of buildings, for example covering taps, showers and toilets, rainwater harvesting and reuse of "grey-water"	m	x	x	EU COM, ClimateWater, NAS (AT), UNECE 2010
	Considering adopting of a performance indicator on the use of water in the revision of the EMAS Regulation to be presented by the Commission	m	x	x	EU COM, ClimateWater, NAS (AT), UNECE 2010
	Working towards the possible certification in water use of all buildings of the European Institutions gradually over the next years	m	x	x	EU COM, ClimateWater, NAS (AT), UNECE 2010

	Adoption of binding performances for new buildings and for public and private networks, with systems of fines for excessive leakages	m	x	x	EU COM, ClimateWater, NAS (AT), UNECE 2010
	Include rules on water management in existing and future quality and certification schemes	m	x	x	EU COM, ClimateWater, NAS (AT), UNECE 2010
	Encourage the development of educational programmes, advisory services, exchanges of best practices and large targeted campaigns of communication focused on water quantity issues	m	x		EU COM, ClimateWater, NAS (AT), UNECE 2010
	Explore the possibility of expanding existing EU labelling schemes whenever appropriate in order to promote water efficient devices and water-friendly products	m	x		EU COM, ClimateWater, NAS (AT), UNECE 2010
	Promote fiscal policies (pricing policies aimed at reducing waste and incentives for efficient use)	m	x	x	EU COM, ClimateWater, NAS (AT), UNECE 2010
	Follow the WHO's Guidelines for Drinking-water Quality in Water Safety Plans (WSPs)	m	x		EU COM, ClimateWater, NAS (AT), UNECE 2010

5.10 Agriculture

The vulnerability to climate change in agriculture rises from northwest to southeast in the Danube River Basin because the limiting factor is water availability. If the basin is threatened by more extremes (heavy rainfall, storms, hail, floods and droughts, heat-waves and frost) the appearance and development of pests and diseases will increase. The expected earlier occurrence of phenological development stages leads to latitudinal and altitudinal shifts of plant ranges. The UDRB might benefit from a longer growing period, but in the MDRB and especially in the LRDB a shortening of the growing season with yield losses is expected. Due to more unstable weather conditions the interannual variability of crop yields increases, so that farmers will have higher economic risks. Considering wheat, the yields are expected to increase (fertilizing CO_2 effect). Because of warmer and drier summers, water demand for livestock and irrigation will become higher. In the southeast of the catchment precipitation deficits during the warm half-year leads to a high vulnerability of crops at non-irrigated areas. The consequences are set-aside and aridification. Possible spatial conflicts might occur in the decisions whether using areas as agricultural land or for flood protection. Also, producer and consumer prices for agricultural products might increase.

Upper Danube River Basin (UDRB) [78, 36, 14, 64, 135, 15] [84]

- The humid and cool regions benefit from higher yields in contrast to warm and dry regions because of increasing drought
- A warmer climate is positive for winter wheat, grassland, clover, and fruit and wine, but negative for maize and fish
- Earlier onset of flowering is more at risk of frost damage
- Earlier harvesting is projected up to 21 days as well as similar harvesting for winter and summer cereals
- The yields remain stable
- In Austria the impact of climate change seems relatively small compared to the impact of agricultural policy change

Middle Danube River Basin (MDRB) [5, 129] [41, 34, 14] [29, 136]

- In the majority of the simulations the yields of maize and sunflower will decrease due to dryer and hotter summers. This negative effect could not be counterbalanced by the increased CO2 promoted photosynthesis
- Higher yields are expected for winter wheat
- Earlier flowering seasons and longer vegetation periods result in more growing degree days
- Earlier ripening and harvesting in a range of 10-14 days is projected
- Partly unfavourable climate conditions are???
- Increase of water demand and irrigation

Lower Danube River Basin (LDRB) [60] [112] [34, 123, 42] [16, 17, 71, 42]

- Earlier flowering and maturity (in the past three decades about 1–3 days/decade), but a shortening of the vegetation period of 20-29 days and particularly the reduction in the grain-filling period is projected because of very dry summers; these results confirmed the agriculture practitioners' opinions that considered increasing temperature, and not precipitations amounts, as main climatic factor is responsible for reducing the winter wheat maturity period

- Maize yields get lower due to the shortening of the vegetation season, the increase in temperature, as well as due to water stress during grain filling caused by diminished precipitation amounts
- Winter wheat grain yield may increase due to a positive effect of increased CO2 concentrations in the atmosphere
- The shortening of the vegetation period can usually be correlated with a reduction in the yield potential. The impact of these observed changes may be compensated for by breeding efforts and adaptive agronomic measures.
- Precipitation deficits during the warm half-year lead to set-aside and aridification
- South-East Romania: Increases of temperatures with 1 or 2°C are not expected to have a negative impact on the long term average yield, but the differences between years will increase and the penalties for the non-adapted cultivars will be higher according to scenario results

Commonalities

- Earlier flowering and earlier harvesting; extension of growing season
- In warm and dry regions higher demand of water for irrigation

Challenges / Knowledge gaps

- Yields of maize and wheat may decrease or increase, depending on the management method, the natural prerequisites, and the agricultural policy; therefore, climate change scenarios are difficult to interpret.

Adaptation activities

Besides the common preparation measures considering monitoring and research activities in this impact field, the application of new technologies, which should be environment-friendly, is suggested. Commonly addressed are changes of management methods, an introduction of new crops and cropping patterns, as well as following the principles of good agricultural practice, e.g. in the application of fertilizers and pesticides and using water saving techniques. Additionally, changes in land-use and the adaptation of policies in rural development are mentioned as adaptation measures to climate change impacts in the field of agriculture.

*Table 11: Suggested adaptation measures for impacts on agriculture (*Time horizon of the effects of the measures: short-time (s), medium-term (m), long-term (l); abbreviations of the sources can be found in Appendix 5; [47, 119]).*
Please note: irrigation is considered separately in the following section.

Type	Possible adaptation measures	Time horizon*	Options for cooperation	Challenges	Source (Countries)
Preparation measures for adaptation	**Monitoring** • Climate: Enhancement of climate monitoring to improve data for weather, climate and hydrologic modelling to aid understanding of water-related impacts and management options • Soil water: Development of a monitoring system for soil water content of agriculturally used areas as part of agrometeorological monitoring stations • Vegetation: Improvement of the monitoring for the phytosanitary situations • Observation of water consumption of plants	m	x		UNFCCC (BG), NAS (BG), ClimateWater, BAYKLAS, NAS (AT), UNFCCC (RO), CLAVIER
	Research on new plant species resistant to climate change • Research and development of new sorts and hybrids and/or halophytic crops (which can be irrigated with brackish water) • Research, development and application of production technologies on plants that are tolerant against water stress, or which adapt to different climatic conditions	m	x	x	UNFCCC (RS, HU), NAS (RS), ClimateWater, BAYKLAS
	Research on pesticides • Analysis of the way of their utilization and potential effectiveness of the chemical method against crop diseases and pests • Analysis of the most affected plant genotypes, their drought and thermal stress tolerances and their relation to environmental factors • Assessment of the need for further measures to enhance water efficiency in agriculture for specific and major plant types • Analysis of the climatic needs of the plants according to their phenological phases in a complex context with precipitation and temperature changes	s-m	x		UNFCCC (BG, HU, EU)

	Development / enhancement of models for • Climate: Elaboration of regional models and climate scenarios for each agropedoclimatic zone to provide information on the frequency and duration of droughts and frosts and to diminish the uncertainty rate • Vegetation: Development of special sub-models incorporated into models of agroecosystems which simulate plant-protection situations, related to climate change; extension of the phenological models with stochastic elements, risk functions for races, types, regions	m	x		UNFCCC (BG, HU), NAS (MD)
	Detailed assessment of vulnerability to climate change • Development and application of methods and models for the integrative assessment of climate change impacts on agriculture and economic parameters of adaptation options • Determination of the vulnerability of agricultural crops under climate change, long term droughts and water deficits in the major agroclimatic regions, respectively their impact on the quantity and quality of the yield • Examination of the need of drainage in the case of areas with marginal yields • Assessment of the sensitivity of particular regions to climate change, and to isolate the most sensitive areas	s-m	x		UNFCCC (BG, RS, ME, RS), BAYKLAS, White Paper EU
	Establishment / enhancement of early warning systems of droughts and other extreme climate episodes of importance to agriculture	s-m	x		UNFCCC (RS)
	Improvement of short-term weather forecasts by implementing comprehensive and efficient forecasting systems	s-m	x		NAS (MD), ClimateWater, ST_JOLANKAI_HU
	Examination of the capacity of the Farm Advisory System to reinforce training, knowledge and adoption of new technologies that facilitate adaptation	s	x		UNFCCC (EU)
	Development and application of indicators in agroclimate and agroecological zoning to connect indicator analysis to modelling techniques in order to create model based indicators	s	x		UNFCCC (RS, HU)
General measures	**Development / adaptation of the agricultural infrastructure** • Implementation of irrigation and hail protection • Promotion of the retention of water in the agricultural landscape, especially in drought-risk farm and forestry landscapes • Implementation of precaution measure to enable sufficient water storage in water dams • Construction of reservoirs and canals for agricultural needs • Open possibility to transport water through long-distance pipelines • Elaboration and implementation of hydro- and agrotechnical complex systems of accumulation and efficiently utilization of atmospheric precipitations e.g. small-scale water conservation measures, such as collecting water from farm buildings and constructing on farm reservoirs to supply water for agricultural activities	s-m		x	UNFCCC (BA, CZ, MD, DE), NAS (MD, DE), CC (DE), EEA Alps 2009, ClimateWater

	Implementation of a rational land consolidation	s-m		x	NAS (MD)
	Expansion of agriculture to new regions characterized by improved thermal and moisture conditions	m		x	UNFCCC (BG), NAS (BG)
	Increasing the heterogeneity and mosaic character of agricultural landscape (ridges, hedges, alleys, smaller cultivated lots)	m		x	VAHAVA
	Favouring synergies and co-operations between tourism and agriculture in order to diversify mountain tourism activities	s-m	x		Alpine Convention
	Support sustainable rural development and improve the competitiveness of rural areas	s-m			SDR, KEO, White Paper EU
	Ensuring socio-economic conditions to provide profitable farming				UNFCCC (MD)
Ecosystem-based measures	**Encouraging the use of farming methods that are compatible with environmental protection, conservation of biodiversity, improved quality of water, soil and natural landscape** in order to preserve and improve the condition of natural resources and of habitats	s-m	x	x	NAS (RO)
	Promotion of the internalisation of environmental externalities in agriculture, making the transition towards full cost resource pricing, including environmental and social costs	m		x	OECD
	Support agricultural holdings and territories which aim for excellence in terms of production and environment protection	s		x	Alpine Convention
	Development and application of new, sustainable and environment-friendly technologies, e.g for plant protection and priority development of nonchemical methods against crop diseases and pests	s-m			UNFCCC (HU, BG), NAS (BG), VAHAVA
	Definition of quantitative and qualitative conditions of agricultural products to aid climate friendly product penetration on the market	s	x		UNFCCC (HU)
	Promotion of less intensive land management techniques in sensitive areas and also in other places, in order to reduce environmental pressure	s-m		x	VAHAVA
	Avoidance of a distinct expansion of arable farming in traditional grassland farming areas due to ecological and aesthetic reasons	m		x	CLIMCHALP
Behavioural /managerial measures	**Change management methods** • Introduction of new sustainable resource management systems • Introduction of new land management techniques • Use the land according to its soil and climate conditions potential • Improvement of inter-sector planning and integral management of water resources in catchment areas of importance to agriculture • Consideration of all management and planning aspects of agricultural activity adapted to climate change and of	m		x	UNFCCC (RS, BG), NAS (MD), NP (CZ), COST734

	variability with specific short- and long-term strategies with respect to crop protection, watering, fertilisation, plant breeding, production, site selection, etc.				
	Use of soil-fertility maintaining and soil-water-saving techniques • Adaptation of cultivation methods that maintain soil fertility/structure and save water, e.g. application of mulch and plough-less soil treatment in order to lower water losses through transpiration, and decrease the release of carbon and the risk of erosion • Use of mulching plastics and fibres increase water use efficiency (especially effective in horticulture) • Performance of periodical soil analysis and tests, in order to assess and correct the limiting factors which hinder the normal growth and development of plants (acidity, nutrient excess or deficit, etc.) • Modification of soil spreading, or the density of planning to preserve a certain volume of moisture in the root zone system • Use new agrotechnical methods to reduce loss of soil moisture • Conservation of soil moisture by fallowing and weed control • Implementation of sustainable soil management procedures, including agricultural lands and pastures • Implementation of agricultural systems contributing to the reduction of soil erosion and degradation • Combination or reduction of a number of field operations in order to prevent or lessen unfavourable soil conditions • Implement site specific precision methods	m		x	UNFCCC (AT, RS, RO, SK, MD, ME) NAS (MD, BG), CC (DE), WFD 24, BAYKLAS, White Paper EU, VAHAVA, ST_JOLANKAI_HU
	Increasing the ability to shift water within and between sectors (including agriculture to urban)	s-m	x	x	ClimateWater
	Changing land-use • To maximize yield under new conditions • Use frequently flooded land for grazing instead of arable production • Harmful reduction of non-arable lands with afforestation • In taking advantage of modified agro-climatic conditions	m-l		x	UNFCCC (HU, BG), NAS (BG), ClimateWater, White Paper EU
	Measures to save and protect water • Reduction of evaporation • Reduction of water demand • Improvement of water use efficiency by appropriate/sustainable land use (for example conservation tillage, mulching, adapted irrigation and cultivation methods that save water) and water conservation technologies • Implementation of water pollution control areas along rivers • Use of reclaimed wastewater	m		x	NAS (BG), CC (DE), RBMP (Bavaria), EEA Alps 2009, WFD 24, BAYKLAS, ClimateWater

	Changes in agricultural practices • Promotion of extensive and ecological agricultural practices, using modern farming techniques • Change cultivation method: change to systems which may be more resilient e.g. mixed farming, organic farming (in addition these measures potentially contribute to biodiversity conservation) • Consolidation of the application of good practice in agriculture • Implement adapted cultivation techniques in agriculture and forestry to be prepared for water shortages	m		x	UNFCCC (RO, HU, ME, BG), NAS (RO), CC (DE), JRC 2008, White Paper EU, VAHAVA, WWF-DCP
	Adaptation of the sowing / harvest dates and the field work calendar • Modification of crop calendars (e.g. timing or location of cropping activities) to the new climate conditions (e.g. changing sowing dates in relation to changing precipitation seasons) • Minimization of the effects of drought by early planting of cultivars with rapid rates of development • Sowing summer cereals earlier due to increasing temperatures to increase soil moisture levels in the early year, yield through longer growth phase, and to decrease risk from water stress, but beware of increased risk of damages through late frosts • Sowing winter cereal later than currently customary to avoid damages through a late onset of the cold phase, which is important for plant development	s-m			UNFCCC (RO, AT, BG, RS), ClimateWater, EEA Alps 2009, CC (DE), BAYKLAS, ClimateWater
	Changing cropping patterns e.g. avoiding monoculture, going for longer rotations, taking sensitive crops out of the rotation, modification of crop rotation e.g. reduce the share of summer crops and increase the share of winter crops in the harvest structure, altering cultivation intensity, diversify production to increase flexibility	s-m			UNFCCC (RS), CC (DE), White Paper EU, VAHAVA, EEA Alps 2009, ClimateWater, ST_JOLANKAI_HU
	Development /adaptation of pesticides /fertilization and the pest system/management • Use of natural organic fertilizers, adapted to needs/demands • Reduction of fertiliser and pesticide use • Reduction of health and environmental risks from the use of pesticides • Use nitrogen fertilizers more efficient • Reduction of nitrification by draining agricultural areas • Establishment / support of agricultural programs to reduce nutrient infiltration, and also review the utilization of other chemicals • Application of rational and properly timed fertilization in order to minimize the effect of growing spring crops, which might imply an environmental protection risk due to the prospectively increasing nitrate leaching rates • Application of integrated pest management	s-m		x	UNFCCC (BG, RO, RS), NAS (RS), CC (DE), RBMP (Bavaria), WFD 24, BAYKLAS, OECD, ST_FODOR_HU, ST_JOLANKAI_HU

	Challenges: need for adaptation, because of an increased demand for nitrogen with increasing CO2-content; otherwise, increased nitrogen fertilisation increases water use, so that a suitable balance needs to be achieved				
	Improvement of water management to prevent water logging, erosion and leaching, e.g. including agriculture in water management programmes	s-m			UNFCCC (BA), ClimateWater, EEA Alps 2009
	Introduction of new crop types • Use of cultivars resistant to abiotic stresses like drought, high temperature, ect. • Breeding and use of drought tolerant crop varieties • Preference of robust varieties with wide climatic tolerance and low susceptibility to pests (diversification of the range of crop types lessens the risk of yield losses through climate extremes and damages through pest outbreaks) • Growing of thermophilic crop types with high water use efficiency such as e.g. some maize cultivars or millet • Use new varieties of zea mays (this cop plant has the capability to overcome the periods of moisture deficiency) • Starting with tests and - in case of getting positive results – starting to grow alternative crops such as energy crops like robinia (Robinia pseudoacacia), poplar (Populus), etc. or crops native or successfully grown at Mediterranean areas such as fenugreek (Trigonella foenumgraecum L.), lady's thistle (Silybum marianum (L.) Gaernt.) or cotton (Gossypium) • Growing of new crops with Mediterranean origin • Selecting cultivars with shorter germination and shorter growing season • Improvement of genetic resistance and/or tolerance of crop plants by breeding • Use a variety of cultivars and hybrids, especially long-maturing, high-productive cultivars and hybrids with better industrial qualities	s-m		x	UNFCCC (BA, AT, RO, SK, BG, ME, MD), NAS (BG), NP (CZ), CC (DE), ClimateWater, White Paper EU, BAYKLAS, EEA Alps 2009, EEA 2007, VAHAVA, CLAVIER, CLIMCHALP, ST_FODOR_HU, ST_JOLANKAI_HU
	Implementation of an efficient system of farmers' and decision-makers' training and education on new technologies for land cultivation, on protection of livestock against overheating	s	x		UNFCCC (BA), NAS (MD), CLIMCHALP
	Development of an active process of dialogue, knowledge transfer and cooperation between authorities responsible for agriculture and improvement of the way in which experts are informed about climate change impacts and possible ways of adaptation	s	x		UNFCCC (RS), NAS (DE), SDR
	Education and awareness raising	m			UNFCCC (RS), NAS (RS, MD), EEA Alps 2009, ADAGIO
	Reinvention and maintenance of traditional elements of land use and landscape management, e.g. cutting and	s-m	x	x	VAHAVA, EEA Alps

	harvesting the grass of meadows and/or grazing animals on them, in mountain areas traditional extensive grazing under shepherd supervision (to prevent increased risk of erosions and landslides, due to unsupervised livestock rambling on steep unstable slopes)				2009
	Changing management intensity in the species mix, rotation periods, adjusting to altered wood size and quality, and adjusting fire management systems	s			ClimateWater
Technological measures	**Building of buffer zones** in the vicinity of sensitive areas to reduce water run-off	m	x	x	EEA Alps 2009, ClimateWater, VAHAVA
	Implementation of novel crop production technologies and breeding with regard to adaptation to climate change, crop nutrient balances, resistance properties and quality characteristics	s-m			NAS (DE), ST_JOLANKAI_HU
	Use of adapted, more flexible and efficient **machinery**	m			ST_JOLANKAI_HU
	Development and application of new, water-use efficiency related techniques • Use of drip irrigation techniques • Application of technological measures to increase the efficiencies of irrigation systems • Implementation of technical measures to decrease non-point water pollution • Adoption of water-efficient technologies to 'harvest' water, conserve soil moisture (e.g. crop residue retention), and reduce siltation and saltwater intrusion	m			UNFCCC (BG, BA), EEA Alps 2009, ClimateWater, CLAVIER
Policy approaches	**Review the WFD River Basin Management Plans** by the Member States including their technical, financial and social dimension	s	x	x	EU COM
	Increase the coordination between water and agricultural policies	s	x		EU COM, ADAGIO
	Use water pricing according to consumption as an effective economic instrument	s		x	ClimateWater, EEA Alps 2009
	Using the results of scientific-research work both domestic and foreign to create a policy attitude towards climate change within the framework of sustainable regional development and development of rural areas	s-m	x		UNFCCC (ME)
	Adaptation of the funding opportunity for agricultural management systems, which make synergy effects between the protection of nature, the water management system (flood protection, establish WRRL) and the adaptation measures to cc possible	s		x	BAYKLAS
	Adaptation of policies for rural development • Consideration of how adaptation can be integrated into the three strands of rural development and give adequate support for sustainable production including how the Common Agricultural Policy (CAP) contributes to the efficient use of water in agriculture • Force interaction with stakeholders and agricultural decision-makers to point out which other relevant policies, as CAP, WFD, etc. could interact with the foreseen agricultural climate risks	s-m	x		UNFCCC (EU, ME), White Paper EU, ADAGIO

	• Implementation of rural development funding, provided under the second pillar of the CAP, could be used to directly support measures aimed at adaptation, such as the development of water efficient technologies or the production of water-extensive crops				
	Consideration of the current agricultural development programme in the development of a national adaptation strategy for the agricultural sector	s-m		x	NAS (MD)
	Adaptation of agricultural policies to new climate scenarios (moving towards the cultivation of more 'adapted' crops to the prevailing water availability scenario) including reforms	s-m		x	NAS (MD), ClimateWater, UNFCCC (RS), NAS (MD), CLAVIER
	Adaptation of insurance systems • Introduce new insurance mechanism like "multiple risk insurance" • Improve the existing agricultural insurance system to assist farmers to cover costs of bad weather insurance policies	s-m		x	UNFCCC (BA, RS), CC (DE)
	Implementation of Best Agricultural Practice (BAP), e.g. organization of a workshop focussing on the relevant instruments of the EU Common Agricultural Policy and Best Agricultural Practices for ensuring reduction of agricultural pollution by the ICPDR in close cooperation with the European Commission and involving both the agricultural and water management ministries of the countries	s-m	x		RBMP (DRB), DRPC
	Adaptation of water conservation technology policies • Implementation and enforcement of water saving regulations and a changing subsidies system related to irrigated crops • Definition of standards applying at farm level for compliance with existing national authorisation procedures when using water for irrigation • Implementation of obligations related to cross compliance to help raise farmers' awareness of the authorisation procedures, particularly through the provision of better information to farmers and the perspective to reduce CAP payments in case of infringement	s-m	x	x	ClimateWater, EU COM

5.11 Irrigation

Irrigation for agricultural purposes is likely to increase in the entire DRB, which will especially occur in the south-eastern parts due to an expected expansion of droughts during the growing season in the future. However, changes in irrigation are rather uncertain and are also regulated by managerial and political measures.

Danube River Basin (DRB) [51, 57, 18, 56]

- Withdrawals for irrigation may increase in the south-eastern parts; however, the development of quantity and seasonality remains unclear
- Reasons for an increase: warmer and drier climate and expansion of the irrigation area
- An increase may deteriorate the ecological and chemical balance of freshwater bodies and could lead to an increase of contaminated surface and groundwater bodies after enhanced agricultural use
- High anthropogenic and political impacts

Upper Danube River Basin (UDRB) [21, 25]

- Possible increase of irrigation for agricultural purposes

Middle Danube River Basin (MDRB) [71]

- Increment of irrigation is likely to occur

Lower Danube River Basin (LDRB) [10, 11] [104]

- Increasing needs for irrigation in agriculture

Commonalities

- Possible increase in irrigation for agricultural purposes, especially in the south-eastern parts

Challenges / Knowledge gaps

- Only few concrete findings for all regions
- The present projects and studies indicate tendencies; changes in quantity and seasonality are rather unclear

Adaptation measures

Irrigation is a commonly applied technique in growing crops with an increasing tendency of application due to a likely decrease in summer precipitation in large areas of the DRB. However, water might be scarce in the future, so that this resource is even more required by many different users. In this respect, challenges in the application of irrigation are not the costs, but mainly the availability of water. Therefore not only an expansion of irrigation is suggested in adaptation strategies, but also changing crops patterns and land use. Further commonly mentioned adaptation measures are an improved management of water during irrigation, the development and application of new technological irrigation systems, which should be more efficient and water saving.

*Table 12: Suggested adaptation measures for impacts on irrigation (*Time horizon of the effects of the measures: short-time (s), medium-term (m), long-term (l); abbreviations of the sources can be found in Appendix 5; [47, 119]).*

Type	Possible adaptation measures	Time horizon*	Options for cooperation	Challenges	Source (Countries)
Preparation measures	**Monitoring** • Observation of water quantity used for irrigation • Use of more monitoring mechanisms for irrigation planning, e.g. soil humidity measurements, observation of the plant condition and checking the drain tubes after the irrigation in order to perform necessary modifications for the next watering • Monitoring of all the aspects related to the organization before applying irrigation during and after the management of the irrigation rate, respectively the choice of the application moment	s-m			NAS (AT), UNFCCC (RO)
	Research • On the impact of climate change and droughts on the quantity and quality of water resources used in irrigated agriculture • On the effect of irrigation and sustainability of yields under various water saving methods and irrigation technologies • On the cultivation of halophytic crops (can be irrigated with brackish water) • Assessment of the needs of water for irrigation of agricultural crops under climate change • Preparation of long term projections for the required water resources to be used in agriculture • Estimation of the capability of irrigation and drainage systems • Elaboration of a complex study on prioritizing the redevelopment of the irrigation sector • Assessment of the net effects of more effective irrigation on the GHG budget	m	x		UNFCCC (RO, BG, RS), ClimateWater, ST_IPCC
	Adaptation and introduction of information and advisory system for the need of irrigation (forecast)	s-m	x		UNFCCC (BG)
	Assessment of the energy demand of irrigation systems	s			UNFCCC (BG)
General measures	**Application and expansion of irrigation** for agriculture: choose the most suitable irrigation method considering type of crop, soil type, technology, costs and benefits. *Challenges: to expand irrigation systems is today one of the most frequently discussed adaptation measures (the use of irrigation systems requires sufficient water supplies and probably the needs of plants will be satisfied only partially, but interactive impact of irrigation and fertilization on yield is more intensive than the impact of one of the factors)*	m		x	UNFCCC (RO, SK), NP (CZ), VAHAVA

Behavioural /managerial measures	**Implement a cooperation with hydrologists** in selecting locations where the construction of irrigation systems has been shown to be effective	s-m			UNFCCC (CZ)
	Raising public awareness by preparing information material for water users on the benefits of and good practices in agricultural crop irrigation	s			UNFCCC (BG)
	Completion of the implementation of "The Irrigation Sector Reform and Rehabilitation Project" financed by the World Bank and measures on irrigation from the SAPHARD programme				UNFCCC (RO, BG)
	Changing crops varieties • Growing more resistant crop varieties to reduce dependence on irrigation • Growing crops which withstand drought • Using new cultivars and hybrids that adapt better to water deficit • Changing from irrigated to non-irrigated crops	s-m		x	UNFCCC (BG), White Paper EU, EEA Alps 2009
	Improvement of management, use and protection of water resources in irrigated agriculture • Improvement of the efficiency of the management and use of existing irrigation facilities and elaboration of the technological and technical facilities for irrigation • Preparation of up-to-date strategies and new programs for the redevelopment and restructuring of irrigation management • More efficient water use and reduced water loss may be achieved by appropriate/sustainable land use (for example conservation tillage, mulching) and irrigation management (for example adjust time and amount of water according to plant needs) • Use night-time irrigation	s-m	x	x	UNFCCC (BG), EEA Alps 2009, ClimateWater, EEA Alps 2009
	Construction of irrigation and drainage systems • Reconstruction and reorganization of existing irrigation systems considering climate change in order to increase the efficient use of water, aimed at their use in the condition of water deficit • Implementation of proper models in representative regions in the country • Adaptation of irrigation systems to the cultivated surface and the financial resources	s-m		x	UNFCCC (RS, BA, MD, BG, RO), NAS (RO, BG, DE, MD), CC (DE), WFD 24, EEA 2007
	Development and application of optimized irrigation regimes for major agricultural crops for various agro-climatic regions and new zoning for the irrigated crops in the country	s-m	x		UNFCCC (BG)
	Creation and application of mineral fertilization systems and integrated weed fight during cultivation of agricultural crops under irrigation conditions	s-m	x		UNFCCC (BG)
	Application of treated, microbiologically pure wastewater for irrigating agricultural land	s		x	UNFCCC (DE)
Technologica l measures	**Develop and construction of new systems for irrigation** based on the best available technologies	m		x	UNFCCC (BA, SK, MD, RS), NAS (RO), EEA 2007
	Elaboration of the present irrigation technologies and equipment, aimed at compliance with new needs of the irrigated cultivars and increasing their efficiency	s-m	x		UNFCCC (BG)

	Development / adaptation of irrigation infrastructure • Improvement of the efficiency of use of the existing irrigation infrastructure • Changing technology for irrigated crop cultivation in various agro-climatic regions under water shortage conditions • Building reservoirs in order to secure enough water for irrigation and other needs • Using local water reserves by constructing farm ponds for catching precipitation runoff • Rehabilitation of pump stations within the irrigation facilities declared by the public utility • Development and use of new water saving and energy saving technologies and equipment • Increase cleaning of dirty/ saline water pipes	m	x	x	UNFCCC (DE, BA, RS, RO, BG), ClimateWater, EEA Alps 2009
	Implementation of more efficient and water saving irrigation technologies • Moving towards precision irrigation such as remotely managed sub-surface drip irrigation (with irrigation efficiencies of the order of 98%) • Technical improvement of varieties • Switching irrigation technologies from gravity to drip or sprinkler-feed systems • Application of proper moisture preserving technologies and techniques for soil treatment in irrigated lands	s-m	x	x	UNFCCC (BA, CZ), CC (DE), RBMP (AT), ClimateWater, EEA Alps 2009
	Development and application of technologies and systems for regulation and control of technological processes for the distribution and use of water for irrigation	m	x	x	UNFCCC (BG)
	Development of deficit irrigation techniques in identifying the optimum balance between crop-production and irrigation requirements	s-m	x		ClimateWater
Policy approaches	**Adaptation of the instruments of licensing, control and funding** in order to mitigate negative impacts of irrigation measures on the water table and ecosystems/biotopes	s-m	x	x	BAYKLAS
	Changing legislation and regulation in the irrigation sector taking into consideration the altered agricultural conditions, the experience from the reforms carried out so far and to ask for free use of the technologically established hydromeliorative infrastructure and service facilities on the territory of the associations	s-m	x	x	UNFCCC (BG)
	Establishment or continuing the irrigations subsidy to support the operation of the irrigation facilities which provide a great economic potential	s			UNFCCC (RO)
	Defining standards applied at the farm level for compliance with existing national authorisation procedures when using water for irrigation	s-m	x	x	EU COM
	Projection of wastewater discharge through proper norms for irrigation during drought events	s-m	x	x	RBMP (DRB)
	Development and application of proper irrigation investment programs with state subsidies aimed at the most efficient regions and such with active or to be soon established irrigation associations	s-m		x	UNFCCC (BA, BG), NAS (RO)
	Determination of an irrigation control programme	s-m	x	x	UNFCCC(RO)
	Implementing national actions including "set time-bound targets" to increase the efficiency of water use and irrigation systems in areas experiencing moderate or high water stress	s-m	x	x	OECD

5.12 Forestry

Climate change impacts in the field of forestry are likely to cause a south-west to north-eastern shift of different forest zones and an upward shift of the tree line. A lower productivity and health status of forests due to an increase in droughts is possible, especially in the southeast. However, due to higher annual temperatures, the length of the growing season will be extended and elevated atmospheric CO_2 concentrations can have a fertilising effect. Changes in the distribution, density and biodiversity of forests are also assumed under future climate conditions. Additionally, forests might be impacted by an increasing risk of damages by forest-weakening pests (e.g. bark beetle), storms and forest fires. Contrary, cold and snow-related damages are likely to become less common, but otherwise an increase in spring frost damages is possible.

Danube River Basin (DRB) [14, 18]

- Shift in vegetation distribution; south-west to north-eastern shift of forest zones
- In mountain areas: upward shift of the tree line
- Higher vulnerability
  - periods of droughts and warm winters can weaken forests
  - increase in pest population which can weaken forests
  - increased danger of forest fires
  - more damages due to severe storms are possible
  - possible increase in spring frost damage (earlier leafing)
  - cold and snow-related damage in winter is likely to become less common
- Length of growing season is extending
- Elevated atmospheric CO_2 concentrations can have a fertilising effect

Upper Danube River Basin (UDRB) [21, 64, 79, 128]

- Possible disappearance/replacement of existing or appearance of new types (adapted to dry and warmer conditions)
- Higher vulnerability
  - drought stress might increase
  - heightened stress exacerbates the risk of losses via pests (e.g. bark beetle)
  - more damages due to extreme events (snow, storm) are expected
  - increased danger of forest fires, especially in the inner-alpine dry valleys and the outer-alpine areas; increase especially in summer
- Possible changes in forest density

Middle Danube River Basin (MDRB) [136, 14]

- Many forest areas could be endangered
- Shift and migration of species and current life zones towards higher altitudes and latitudes
- Different composition of certain plant communities; possible expansion of xerothermic shrub and steppe vegetation due to a decrease in air humidity

- Possible changes in forest density
- Lower productivity and health status of forests is possible; however, increased atmospheric CO_2 concentrations can have an effect on individual tree productivity, but can also alter leaf chemical composition, affecting herbivore fitness
- Beech and spruce production will decline at the species receding edge; significant increase in production is projected at the leading edge in the higher elevations
- Higher vulnerability
  - danger of increased vector activity and occurrence of plant diseases
  - increased danger of forest fires (intensity and extent)
  - highest vulnerability to storms at higher altitudes
- High pressure especially on oak tree forests
- Loss of biodiversity; possible disappearance of existing or appearance of new plants

Lower Danube River Basin (LDRB) [27, 136]

- Forests will dry out intensively with an increasing trend
- Increase in water scarcity and aridity in regions up to 800m
- Higher vulnerability especially of hornbeam and ash tree
- Due to an increased CO_2 absorption, possibly higher biomass productivity in lowlands and mountains
- Changes in vegetation distribution and reduction of biodiversity especially in lowlands; some current species might completely disappear

Commonalities

- Altitudinal (upward) and longitudinal (north-east) shift of forest zones
- Possible changes in distribution and density; loss of biodiversity
- Increasing vulnerability and risk of damages (impacts: droughts, pests, fires, storms, snow, spring frost), causing a weakening of forests

Challenges / Knowledge gaps

- On the one side increase in productivity and higher fertility due to a longer growing season, less severe winters and elevated atmospheric CO_2 concentrations; on the other side decrease in productivity due to more damages and increase in drought periods

Adaptation measures

Ecosystem-based as well as managerial measures agree on a promotion of the diversification and the restoration of forest stands together with afforestation activities in order to be prepared for climate changes impacts. Additionally, forest protection and forest safeguarding measures should be adopted.

*Table 13: Suggested adaptation measures for impacts on foresstry (*Time horizon of the effects of the measures: short-time (s), medium-term (m), long-term (l); abbreviations of the sources can be found in Appendix 5; [47, 119]).*

Type	Possible adaptation measures	Time horizon*	Options for cooperation	Challenges	Source (Countries)
Preparation measures for adaptation	**Monitoring** • Implementation of coordinated observation methods and implementation of remote sensing technology on the effects of climate change and air, water and soil pollution on forests • Assessment of correlation between annual forest growth and climate parameters • Conducting a detailed mapping of forests • Assessment of the real consumption of wood products, including illegal logging • Development of and submitting periodic reports on the consumption of wood products	m	x		Alpine Convention UNFCCC (HU, BG, BA, RS, MD, ME, DE), ST_CEU
	Risk assessment for forest health, diseases and pests	s-m	x		UNFCCC (HU, ME)
	Definition of quantitative and qualitative conditions of forestry products to aid climate friendly product penetration on the market	s	x		UNFCCC (HU)
	Implementation of common European methods for evaluation of non-wood forest functions and services and their future financial and functional support	s	x		UNFCCC (BG)
	Research • Expansion of the scientific basis for decisions relative to climate-adapted forest conversion • Establishment and operation of experimental plots • Definition of the effect of climate zone shifts • Forest-plant breeding • Provenance research; using regional cultivation recommendations • Studying wood-harvesting techniques • Exploration of possible wood uses under new climate conditions • Intensification of multidisciplinary research of climate change impacts on forests	m	x		UNFCCC (DE,HU, RS), ST_IPCC
	Identification of difficulties and potential congestions in local industries exploiting and transforming wood in order to implement adapted solutions	s-m	x	x	Alpine Convention
	Increasing prevention of forest fires through **early warning systems** and improvement of the f**orest fire protection system**	s-m	x		CC (DE), UNFCCC (BA,RS)

General measures	Development and application of measures for strengthening the resilience of forests to climate change	s-m	x		UNFCCC (RS)
	Improvement of the water balance in the affected territories	m			UNFCCC (BG)
Ecosystem-based measures	Encouraging the **diversification** of forest stands by favouring autochthonous species that are ecologically resistant; increasing the tree species diversity through transformation of the coniferous ecosystems in mixed forest or broadleaved ecosystems, increasing the proportion of locally indigenous tree species and diversification of the vertical structure; mixed stands and forests with high genetic diversity are less sensitive than coniferous forests (maximally stable, are better able to withstand widespread calamities)	l	x		Alpine Convention, UNFCCC BG,DE), EEA Alps 2009, CC (DE)
	Development and adoption of updated close to nature regimes for forest management in the protected areas and NATURA 2000 sites	m	x	x	UNFCCC (BG,ME,BA)
	Restoration of the forests, damaged by forest fires or other natural disasters, using native tree species, where possible (natural regeneration should be prioritized)	m-l		x	UNFCCC (BG,ME, RS,MD)
	Application of climate change oriented forest research results in the renewal of forests	l	x	x	VAHAVA
	Implementation of measures to protect and / or enhance **biodiversity** (for example restore swamps and alluvial forests; natural forest reserves)	m		x	BAYKLAS, UNFCCC (ME)
	Increasing the forest cover with the aim to contribute to climate change mitigation and increasing the biodiversity	m-l		x	UNFCCC (BG,MD
	Stimulating the **biological production** of products and extension of ecological services in forests	m-l		x	UNFCCC (BG)
	Promote silviculture, which is based on the natural processes of succession, avoiding rough intrusion to nature in all such sites where the ecological conditions allow this approach	m-l		x	VAHAVA
	Maintenance of non-closed canopy in the forest steppe zone	m			VAHAVA
	Sustainable land use management to secure water retention	m	x		CC in DE
	The creation of habitat networks	m-l	x	x	White Paper EU
	Planting of forests in the vicinity of cities (urban forestry)	m		x	UNFCCC (ME)
	Implementation of sustainable management of forest ecosystems, adjusted to changes, for the provision of their environmental function as well as being a source of biomass, wood for products for the conservation of carbon, and carbon sinks	m-l	x		UNFCCC (SI)
Behavioral /managerial measures	Encourage the **diversification** of forest stands by favouring autochthonous species that are ecologically resistant, convert forests from single-species stands into locally adapted mixed stands that face smaller risks	m-l	x		Alpine Convention, UNFCCC (DE,CZ), CC (DE), White Paper EU, ST_CEU
	Changing **water management plans**	m	x	x	CC (DE)
	Capacity building in institutions responsible for forest management to reinforce training, knowledge and adoption of new technologies that facilitate adaptation	s-m			UNFCCC (RS,EU)
	Educating rangers	m			UNFCCC (RS)

	Rising **public awareness** for forest benefits and the ways of their protection, on climate change impacts and possible adaptation measures	s-m	x		UNFCCC (BG,RS), Alpine Convention
	Reassessment of **cultivation recommendations** for all tree species (in an approach that differentiates by locations and that takes into account aspects of climate change, long production periods involved and related uncertainties and risks)	m	x	x	UNFCCC (DE)
	Formation of inter-institutional scientific board, participation in realization and implementation of European and world projects and initiatives, regarding prevention and adaptation of forest to climate change	m	X		UNFCCC (BG), White Paper EU
	Coordination of the implementation of the principle “The user pays” for forest resources, together with all stakeholders	m-l		x	UNFCCC (BG)
	Development and implementation of projects aimed at planting protection forestry strips (**buffer zones**) for agricultural lands protection, antierosional, for waters protection	m	x	x	UNFCCC (MD), VAHAVA
	Caring for and protection of existing forests (in terms of the landscape, habitat type, succession, species and gene), along with the preservation of natural values and processes; conversion of forests that are not suiting to the given habitat and contain non native species	m-l	x	x	VAHAVA, UNFCCC (ME,BA,SK)
	Afforestation of large areas using suitable native species	l	x		VAHAVA, UNFCCC (BA, ME), White Paper EU
	Reduction of areas where clear cutting is allowed	m-l		x	VAHAVA
	Distinction in regulation between natural (semi natural) forests and tree plantations	m-l			VAHAVA
	Establishment of plantation forests for the needs of industry and energy; planting of energy forests to satisfy the needs of population in fuel wood for heating, cooking, etc.	m		x	UNFCCC (MD,BA), VAHAVA
	Sanitary felling and reconstruction of degraded forests	l			UNFCCC (ME)
	Intensive forestation	m-l		x	UNFCCC (RS)
	Application of **forest management** based on natural processes; implementing forest management systems that support and protect sustainable forest management mainly in utilizing natural processes with minimization of energy inputs, natural regeneration of forests, increasing forest area, care and protection of existing forests, conversion of coppice forests into high forests	m-l	x	x	UNFCCC (ME,CZ), VAHAVA
	Plantation of non-native tree species to adapt to new climatic conditions	l	x	x	CC (DE)
	Increased **protection of forests** against pests and plant diseases	m	x		UNFCCC (BA,RS)
	Thinning out of the young stands to increase water and light availability	s			Bulgarian National Action Plan on CC
Techno-logical measures	Agrotechnical analysis, selection and public production of plant types capable to adapt to different climatic conditions, research, development and application of production technologies for such plants	m	x		UNFCCC (HU,RO)
	Adapted cultivation techniques in agriculture and forestry to be prepared for water shortages, e.g. modern water	m	x		CC (DE)

	saving irrigation devices				
	Improvement in technical infrastructure	m			CC (DE)
	Use technology and means in the felling and transportation of wood products, resulting in minimal damage to the forest	s-m			UNFCCC (ME)
Policy approaches	Adoption of measures for **forest protection and forest safeguarding** (e.g. natural regeneration of mountain forests by limiting populations of hoofed animals, reduction of areas where clear cutting is allowed) together with police services, NGO's, municipalities, etc.	m	x	x	UNFCCC (BG,MD), Alpine Convention, VAHAVA
	Statutory prohibition for forest land exchange and the change of the purpose of forest land for the period of 20 years except for important public services	m		x	UNFCCC (BG)
	Update forestry strategy and launch debate on options for an **EC approach** on forest protection and forest information systems	m	x		UNFCCC (EU)
	Development of a new version of the **Environment Protection Law**	m	x	x	UNFCCC (MD)
	Revise regulations and directives in forest management, including climate change impacts	m-l	x	x	UNFCCC (RS)
	Ensure **eco-certification** of all forest parts of the public right of each member state	s-m	x		Alpine Convention
	Development and implementation of projects aimed at planting protection forestry strips for agricultural land and water protection	m		x	UNFCCC (MD)
	Strengthen the role of local communities in sustainable forest management	m			UNFCCC (RS)
	Revision and development of (new) important components of the **forestry regulatory basis**, as integral parts of the forestry regime, focusing on the following areas: maintenance and conservation of forestry stations; conservation of forestry genetic resources; ecological reconstruction of forests; certification of forests, forest products and management systems;	m	x	x	UNFCCC (MD)
	Revision of the regulatory framework pertaining to develop an appropriate **financial mechanism** in **conservation and development of forestry resources**, by imposing mandatory allocations from some extra budgetary funds (ecological, roads, etc.) and taxes (ecological tax on import of oil products, for landscaping , etc.) needed for expansion of lands covered with forestry vegetation , etc	m	x	x	UNFCCC (MD)
	Development and approval of the regulation on implementation and assuring functionality of the principles of **participatory management** of public forest resources	m			UNFCCC (MD)
	Updating national plans for **forest fire prevention and protection**, improvement of the control of activities against forest fires	s	x		UNFCCC (BG)

5.13 Land use

On the one side, drastic land use changes like deforestation or urban sprawl have impacts on climate change. On the other side, climate change might also affect all types of land use. An intensification of extreme events like floods and droughts lead to a higher vulnerability of land use including impacts on agriculture, forestry, industry as well as built environment and infrastructure.

Danube River Basin (DRB) [53, 54]

- Higher occurrence of extreme events might increase the vulnerability of different types of land use (e.g. concerning built environment and infrastructure)
- Increasing conflicting demand between different water and land users (agriculture, industry and human consumption)
- Shift in forest and vegetation distribution may impact land use changes
- Example: flood plains might lose their buffering effect due to an increase in flood events

Upper Danube River Basin (UDRB) [21, 116]

- Land use can be highly vulnerable because of slow adaptation processes
- Climate change might affect many types of land use (e.g. buildings, transportation systems, vegetation cover...)

Lower Danube River Basin (LDRB) [104]

- Higher vulnerability due to more extreme events

Commonalities

- Increasing vulnerability and possible land use changes due to climate change

Challenges / Knowledge gaps

- Only few projects and studies in this field
- Most projects and studies consider land use changes for different fields separately (e.g. agriculture, industry)

Adaptation measures

Adaptation measures in the sector of land-use changes are mainly connected to changes in agricultural land-use, afforestation and generation of flood retention areas. Furthermore, there seems to be a common understanding to consider climate change in urban planning, e.g. the creation of more spaces for ecosystems and water retention areas.

*Table 14: Suggested adaptation measures for impacts on land use (*Time horizon of the effects of the measures: short-time (s), medium-term (m), long-term (l); abbreviations of the sources can be found in Appendix 5; [47, 119]).*

Type	Possible adaptation measures	Time horizon*	Options for cooperation	Challenges	Source (Countries)
Preparation measures for adaptation	**Provision of information about monitoring systems and guidelines** as an important basis for adaptation and climate protection measures	s			NAS (DE)
	Further assessment of the inter-linkages between biofuel development and water availability	s-m	x	x	EU COM
	Quantifying and Monitoring Land Use • Mapping landuse (ensure the technical (e.g., GIS) and human resources are available) • Documenting existing and historic land uses (typology and quantification of change) • Using multi-side palaeoecological studies to broadly map historic and prehistoric patterns of landuse • Understanding the origins and impacts of landuse • Development of consistent quantitative methods to model land use change • Incorporation of biophysical parameters (including those deriving from climate change) and appropriate driving factors such as population growth and economic change	s-m	x		GLOCHAMORE
General measures	**Application of sustainable land use practices**				WWF-DCP
Ecosystem-based measures	**"Making space for water"** through managed retreat option and altering land use at the coast in order to bring benefits to biodiversity, e.g. creation of new saline habitats to replace existing inter-tidal habitats currently at risk due to sea-level rise	m	x	x	White Paper EU
Behavioral /managerial measures	Promotion of collection of rainwater for local use to enhance gardening water supplies	s			ClimateWater
	Consideration of climate change in urban planning • In the way that public areas in towns are used • In their shaping • Creation of green islands with water surfaces in order to decrease temperatures • Prohibition of building in flooding areas • Creation of more space for ecosystems and water retention to reduce flash flooding • Creation of green spaces for passive shading • Using new materials and construction methods, which are more stress resistance in relation to extreme events	m		x	UNFCCC (BA), White Paper EU, NAS (DE)

Technological measures	**Resizing the sanitation system** in order to take over the water excess got from heavy rain falls in the city	m			UNFCCC (RO), ClimateWater
	Reshaping river banks and sea coasts with special care in order to be prepared for floods and flash floods, storms	m	x		UNFCCC (BA)
Policy approaches	Prohibition of settlements or their extension in risk zones	s-m		x	WWF-DCP
	Ensuring the stringent implementation of the Directive on Strategic Environment Assessment in all economic sectors; Member States still need to strengthen their national procedures and ensure that the conditions attached to the final decisions adequately prevent any environmental impact	s-m	x	x	EU COM
	Revision of infrastructure regulations such as the drainage of rain water	m		x	UNFCCC (RO)

5.14 Soils / Erosion

Nearly all regions of the DRB show a possible decrease of soil water content. Longer dry soil periods are predicted especially for the MDRB and LDRB regions during summer droughts. Thereafter, in these regions soil degradation is also possible. Changes in precipitation patterns and an increase in torrential rain and flash flood events can lead to more intense soil erosion. An increase in soil temperature affects especially physical, chemical and biological processes of the top soil layers. Consequently, changes in soil quality regarding biodiversity, nutrient and water cycles and soil forming processes are possible. Moreover, sedimentation in river system is likely to increase due to more extreme events and thawing permafrost.

Danube River Basin (DRB) [14, 56, 89]

Soil water

- Decrease of soil water content / soil moisture

Soil quality, erosion and sedimentation

- Decrease of soil matter
- Changes of soil quality, due to changes in habitat of soil biota and soil chemistry
- Increase in soil erosion, e.g. due to higher winter rainfall
- Increase in CO_2 emissions due to changes in the bio-physical soil conditions
- Baring and remobilisation of sediment-associated contamination due to climate-induced changes in extreme weather conditions; high-energy mass flow of eroded soil or remobilised sediment impacting aquatic ecosystems
- Possible impacts on structure and operation of dams and hydroelectric structures due to more sedimentation, silitation and slippage

Upper Danube River Basin (UDRB)[64, 25, 21]

Soil water

- Slight soil water deficit because of precipitation and evapotranspiration changes
- Decrease of soil water content in summer, but no influence on plants in regions with high precipitation
- Changes in the filter and puffer capacity of soil, the leachate rate / groundwater recharge and the water storage capacity

Soil quality, erosion and sedimentation

- Climate change could affect the soil fauna and biodiversity as well as nutrient and water cycles and soil-formation processes (humus formation / carbon binding, groundwater formation, nutrient cycles / growth conditions)
- Increase of soil temperature in the top layer (0-5cm) with spatial differences
- Increase of soil erosion is possible; local increase of debris flow near the permafrost borderline
- Increase in erosion intensity due to the strengthened occurrence of extreme events
- Higher sedimentation rates due to permafrost thawing and heavy precipitation events
- Increasing discharge of nutrients in winter

- Changes in runoff regimes can affect sedimentation in river systems
- Additional transport of sediments is expected to occur in river systems originating in mountain regions

Middle Danube River Basin (MDRB)[61] [71]

Soil water

- Longer dry soil periods
- Possible seasonal shifts of precipitation patterns; soil moisture will decline in some mid-latitude continental regions during summer
- Soil moisture will be affected by changing precipitation patterns

Soil quality, erosion and sedimentation

- Increase in soil degradation is possible
- Possible increase in soil acidification

Lower Danube River Basin (LDRB) [14, 5]

Soil water

- Longer dry soil periods
- Decrease in soil humidity leads to the less leachate (esp. in summer and autumn)

Soil quality, erosion and sedimentation

- Droughts intensify the soil salinisation processes
- Less soil humidity contributes to an increase of pollution frequency and of water supply restrictions

Commonalities

- *Soil water*: decrease of soil water content, especially in the MDRB and LDRB regions during summer droughts
- *Soil quality, erosion and sedimentation*: changes in soil quality regarding biodiversity, nutrient and water cycles and soil forming processes are possible; possible increase in erosion and sedimentation due to more extreme events and thawing permafrost

Challenges / Knowledge gaps

- Only few projects/studies considering the DRB as a whole and its bigger (sub)catchments

Adaptation measures

Besides the demand for further monitoring to build a reliable basis for adaptation to climate change impacts, changes in the agricultural practice (e.g. ploughing), the creation of buffering systems and afforestation and the implementation of an improved soil moisture management system are suggested.

*Table 15: Suggested adaptation measures for impacts on soils / erosion (*Time horizon of the effects of the measures: short-time (s), medium-term (m), long-term (l); abbreviations of the sources can be found in Appendix 5; [47, 119]).*

Type	Possible adaptation measures	Time horizon*	Options for cooperation	Challenges	Source (Countries)
Preparation measures for adaptation	**Monitoring and mapping** • Adaptation, optimisation and expansion of existing monitoring systems for soil and soil erosion (permanent soil observation program, soil conditions survey) • Drawing up maps that indicate levels of soil risk • Development of hazards maps for geological risk areas in the Alps • Determination of soil properties and water storage capacity and the depth reached by plants roots (the amount of water that is potentially available for plants, the risk for acidification and erosion, content of humus) in areas, which are mostly affected by climate change • Monitoring of organic matter decline due to increased erosion of peat by raising the ground water table • Monitoring and prevention of salinization resulting from irrigation by optimizing irrigation techniques	s-m	x		BAYKLAS, NAS (DE, MD), UNFCCC (RO), EU White Paper
	Detailed **research** on key control factors' impacts on soil functions (functions such as C and N cycles, soil biology)	m	x		UNFCCC (DE), NAS (DE)
Ecosystem-based measures	Mitigating salinization by changing to more halophytic crops	m			EU White Paper
	Considering the spatial and functional arrangement of the landscape in using anti-erosion measures to reach a positive effect on its ecological stability -> should be implemented in all landscape measures	m-l			UNFCCC CZ
	Wetlands management: keep rainwater in places where it falls and improve infiltration of water into the soil and progress towards soil saturation (particularly in hot spots like highly cultivated areas and highly populated areas)	m	x		White Paper EU
Behavioral /managerial measures	Discussing and co-ordinating relevant soil protection aims and mitigation strategies in an interdepartmental approach involving all relevant stakeholders (agriculture, forestry, water-resources management, nature conservation, atmospheric and climate research)	m	x		UNFCCC (DE), NAS MD
	Better education of individual farmers and managers of big agricultural entities	m			NAS MD
	Increasing awareness of farmers	m			UNFCCC (BG)
	Implementation of improved soil moisture management systems involving farmers (inform and fund them). The main objective of an efficient soil moisture management is to increase the water storage within the soil in plant available form without any unfavourable environmental consequences:	m	x		UNFCCC (BA), VAHAVA

	• to reduce evaporation, surface runoff and filtration losses • to increase the available moisture content of the soil: to help infiltration into the soil, increase the water storage capacity, reduce the immobile moisture content • to improve the vertical and horizontal drainage condition of the soil profile or the given area (prevention of over-saturation and water logging)				
	Changing location of economic activities: Relocate human activities in areas with a high flood risk by moving them to higher ground	l		x	EU White Paper
	Reduction/avoidance of the loss of soil organic matter by adapting existing cultivation practices (e.g. ploughing in crop residues, using "green manure")	m			EU White Paper
	Application of organic fertilizers	s-m		x	UNFCCC (BG)
	Covering the soil surface (mulching) in periods out of the growing season in order to avoid erosion, maintain the soil texture and preserve soil properties that enhance cultivation	s		x	VAHAVA
	Application of soil cultivation techniques, which enhance the infiltration of precipitation water into the soil	s-m			VAHAVA
Techno-logical measures	Provision of obstacles to surface runoff to keep precipitation where it falls in a growing season, with various tillage techniques and soil formations (ridges and protective strips formed with stubble worked into the soil)	s-m		x	VAHAVA
	Implementation of new irrigation techniques; better use of efficient irrigation	s-m	x		UNFCCC (BG), NAS MD
	Afforestation as one of the most cost-effective methods for preventing soil erosion	m-l	x	x	UNFCCC (BG), NAS MD
	Creation of terraces, windbreaks, anti-erosion reservoirs, etc.	m		x	UNFCCC CZ
Policy approaches	Share losses: Repay damage caused by flooding (directly or through insurance)	s	x	x	EU White Paper
	Supporting the use of soil improvers and organic fertilisers (e.g. compost and manure)	s-m	x		EU White Paper

5.15 Biodiversity / Ecosystems

An increase in air and water temperature as well as changes in precipitation, water availability, water quality and extreme events like floods, low flows and droughts, might lead to a decrease in biodiversity and changes in ecosystems in the DRB in the long term. Especially the habitats and ecosystems in the south-eastern region of the Danube River Basin and in the Hungarian Great Plain area are likely to become dryer and more fire accidents might occur. Climate change is likely to comprise a shift and changes of aquatic and terrestrial flora and fauna. Moreover, migration patterns are expected to expand north-eastwards and to higher altitudes, whereby a rearrangement of biotic communities and food webs and an earlier onset of lifecycles could take place. Certain species will likely face extinction. While mainly native species are expected to disappear, invasive species might increase. Some studies regarding aquatic systems show a higher risk of algal blooms and eutrophication indicating an endangerment of lakes and wetlands.

Danube River Basin (DRB)[18, 3]

- Decrease in biodiversity
- Changes and expansion of migration patterns; northwards shift of ecosystems and upwards shift in mountain areas with important changes in snow cover and frost/thaw periods; shift in vegetation distribution; potential habitat transformation
- Changes in length of growing season; earlier onset of lifecycles
- Impact on ecosystem productivity; changing metabolic rates of organisms; slower natural regeneration
- Increase in pest population
- More frequent changes of dehydration and rewetting with highly variable redox potential
- Possibly also indirect impacts from land use practices and agriculture

Upper Danube River Basin (UDRB) [78, 25]

- Impacts on flora and fauna, due to an increase in low flows and droughts
- Possible shift and invasion of thermophilic plants from the lower to the upper Danube parts
- Changes of domestic biodiversity and effects on fish and evertebraten-fauna; endangerment of domestic macrophyts especially in low flowing river parts and stagnant water
- Shift of regional fish types adapted to colder water temperatures in higher altitudes and latitudes and replacement with fish types adapted to warmer water temperatures (e.g. in Austria: force back of salmons)

Middle Danube River Basin (MDRB) [123, 112, 29]

- Decrease in biodiversity in a long term
- Rearrangement of biotic communities and food webs; shift and changes in habitats of individual plant and animal types (in latitude and altitude); shifting of the border of vegetation zones
- Changes in ecosystem functions and in quality and quantity of the composition of bioscenosis

- Species with narrow adaptation ability might disappear; species with wide adaptation ability might become dominant; possible disappearance of native species, especially isolated habitats as well as spreading / appearance of invasive species as well as pests, insects, weeds
- Functions of ecosystems could be damaged; plants are increasingly exposed to stress and attacks of pests and plant diseases; slower natural regeneration
- Possible eutrophication of lakes and wetlands (enhanced nutrient loss from cultivated fields; higher risk of algal blooms)
- Possible impacts due to an increase in droughts (esp. Hungarian Great Plain area)
  - lower precipitation might endanger wetlands (e.g. important bird habitats)
  - drying of soils and habitats; wetland habitats might disappear
  - sandy-dune habitats may become desertificated
  - damage to biological processes of the soil; higher risk of salinization
- More forest fires and fire accidents in ecosystems might occur
- Anthropogenic effects play an important role; e.g. phytoplancton biomass is not expected to increase notably and depends more on the degree of nutrient load; however, in case of high nutrient load, increased phytoplankton abundance

Lower Danube River Basin (LDRB) [136, 26]

- Decrease in biodiversity; many species of flora and fauna will likely face extinction
- Changes in the distribution of flora and fauna; regression of the range of some species; possible increase of invasive species
- Disconnection of functional habitats could harm the biodiversity and overall river integrity

Commonalities

- Decrease in biodiversity of flora and fauna; less native species, more invasive species
- Changes in ecosystems; shift of plant growing seasons and life-cycles of organisms
- Latitudinal (northwards) and altitudinal (upwards) shift of flora and fauna
- More problems may occur (e.g. increase in pests, algal blooms and eutrophication)
- Higher risk of drying and forest fires due to an increase in drought events

Challenges / Knowledge gaps

- No clear quantitative, regional and temporal assumptions

Adaptation measures

Protecting endangered species and communities and the extension of natural and/or protected areas are measures, which are often addressed by the analysed adaptation activities. The development of green infrastructure to connect different bio-geographic regions and habitats in order to improve migration options provides an option for transboundary cooperation in the DRB, but also includes challenges such as the different use of land for ecology or agriculture. This is also the case with the suggested restoration of ecosystems and habitats as well as changes in agricultural practice.

*Table 16: Suggested adaptation measures for impacts on biodiversity / ecosystems (*Time horizon of the effects of the measures: short-time (s), medium-term (m), long-term (l); abbreviations of the sources can be found in Appendix 5; [47, 119]).*

Type	Possible adaptation measures	Time horizon*	Options for cooperation	Challenges	Source (Countries)
Preparation measures for adaptation	Establishment of a new systemic inventory	m	x		UNFCCC (SK)
	Monitoring • of endangered species and ecosystems and their stability under the new climate change conditions • of new aquatic species' expansion, their connection to original communities and potential risks • of changes in the structure of communities in aquatic ecosystems • the impacts of climate change on species and biotopes, including the impacts of climate protection • of relevant parameters within protected areas • of the processes that cause the impacts	s-m	x		UNFCCC (SK, RS, MD), NAS (MD), BAYKLAS, VAHAVA,
	Development of a biodiversity indicator system	s	x		UNFCCC (RS)
	Research • on the possibilities to improve policies and develop measures which address biodiversity loss and climate change in an integrated manner to fully exploit co-benefits and avoid ecosystem feedbacks that accelerate global warming • on the potential for policies and measures to boost ecosystem storage capacity for water in Europe • on the vulnerability to climate change, on necessary data to assess the impacts of climate change on terrestrial ecosystems, the sea and biodiversity • support and promote, acknowledge and implement interdisciplinary climate change research agendas	s-m	x		UNFCCC (EU, RS), (ME), NAS (MD)
	Establishment of a priority list of habitats and species, which are sensitive to climate changes	s	x	x	VAHAVA
	Establishment of a scientific infrastructure • for the purpose of investigation of the impact of climate change on biodiversity, terrestrial ecosystems and the sea • for training experts on the issues of climate change and implementation of modern technologies • establishing a data base	s-m	x		UNFCCC (ME, RS)

	• strengthening the scientific and research capacity • appointing an intersectoral group which will deal with the issues of water resources management and protection of biodiversity				
	Preparation of assessments • assessment of the effects of climate change on terrestrial ecosystems, sea and biodiversity • of options for the protection of biodiversity (species) under ex situ conditions • of the importance of different biotope elements for the river in ecology • for proposing measures for improving the aquatic and littoral ecological conditions	s-m	x		UNFCCC (ME), Declaration (DRB)
	Investigate synergistic effects of climate change and other pressures on biodiversity and ecosystems and integrate measures that utilise these synergies between nature conservation, climate protection and adaptation (e.g. where measures make use of the carbon storage function of wetlands)	s-m	x	x	White Paper EU, NAS (DE)
General measures	**Supporting autonomous adaptation of the organisms and ecosystems**, for example by maintaining genetic diversity				EEA Alps 2009
	Decreasing the pressure of other anthropogenic factors to biodiversity				UNFCCC (RS)
Ecosystem-based measures	**Protect extra endangered species and communities** by adopting protection plans, establishing a gene bank of endemic, threatened and endangered species as well as reintroducing native species	m	x		UNFCCC (SK, SI), (RS), (ME), SDR, ClimateWater
	Development of green infrastructure in order to connect different bio-geographic regions and habitats and to improve migration options for species • implmentation of measures to connect biotopes of different scales • removing migration barriers or at least alleviate the impact of anthropogenic constructions on ecosystems (like traffic routes, settlement area and construction works on flowing waters) • designing a national environmental network map • elaborating and ensuring dispersal corridors/biocorridors and migratory routes of various species under the conditions of climate change • completion of the **Lower Danube Green Corridor** (Europe’s most ambitious wetland protection and restoration project, supported by Romania, Bulgaria, Moldova and Ukraine, activities include enhancing the protected area management, preparation and implementation of wetland restoration, consultations with local stakeholders and measures to reconnect floodplains to the river system)	m	x	x	CC (DE), UNFCCC (RS), (ME), BAYKLAS, EEA Alps 2009, ClimateWater, NAS (RS), SDR
	Extension of natural areas to maintain original habitat and ecosystem function/ services • protecting upper-catchment forests and restoring wetlands in order to reduce the risks from climate-related floods and droughts	m-l	x	x	UNFCCC (MD), (SK), White Paper EU, EEA Alps 2009,

	• development and implementation of forests and other green areas extension programs • maintaining and increasing green spaces and fresh-air corridors in urban areas to improve microclimate • creation of a network of environmentally significant areas • strengthening the protection of water related ecosystems • in mountains payment of subsidies to upland farmers in order to maintain traditional pastures • reestablishment of riparian forests to buffer runoff extremes and maintain a unique landscape • preservation and restoration of floodplains, including reversion of arable land to flood meadows *These investments are likely to be highly cost-effective relative to structural alternatives such as dams and dykes*				NAS (RS)
	Increasing protected areas • Implement enhanced protection of the remaining natural ecosystems, such as the Danube Delta or the Carpathians • Adoption of a plan for increasing protected areas • Creation of networks of protected areas, the protected areas should be large and environmentally heterogeneous • Strengthening the capacity of personnel in protected natural resources • Implementation of the Danube River Network of Protected Areas (DANUBEPARKS) • Full establishment of the Mura-Drava-Danube Biosphere Reserve • Maintainance and further development of the Drava River as an "ecological backbone"	m-l	x	x	UNFCCC (RS), (ME), SDR, ClimateWater, NAS (RS), Declaration (DRRB)
	Restoration of most valuable ecosystems/habitats • Restoration of the natural environment, wildlife and vegetation along the Danube • Afforestation of non-arable land and protection of marginal forests • Identification and protection of old growth forests of the Danube Basin • Bioremediation of highly impacted areas, supported by environmental research • Promotion of the conservation of the genetic pool and gene bank cooperation along the Danube • Wetlands restoration, preserving existing peatlands and re-naturalisation where it is possible • Reestablishment of brooks, creeks, rivers and streams with an eye to using river branches and abolishing or circumventing any barriers • Renaturation of rivers and riparian systems in order to buffer run-off peaks, offer additional flood plains and habitat for rare ecological communities	m-l	x	x	SDR, ClimateWater, Alpine Convention, EEA Alps 2009, UNFCCC (MD)
	Promotion of sustainable/climate-friendly agriculture • Implementation of integrated agricultural systems with a diversity of crops and surrounding ecological zones to	m		x	NAS (MD), White Paper EU,

	provide strong defences in the face of weather extremes, pest infestations and invasive species • Promotion of mountain farming based on small structures and maintaining quality farming work • Promotion of climate-friendly agricultural use of peatlands and moorlands				Alpine Convention
	Reduction of existing water continuity interruption for fish migration in the Danube river basin	m-l	x	x	SDR, Declaration (DRRB), DRBMP
Behavioural /managerial measures	**Managing Natura 2000 sites and other protected areas effectively**: establish and exploit the links and synergies between the DANUBEPARKS project and Bavarian projects such as "Green Danube"; provide expertise related to the Danube Delta and similar protected areas to develop knowledge, models and simulation processes related to the Danube Delta phenomena, as well as the Black Sea interface phenomena, including training activities and supporting doctoral and post-doctoral studies	m	x	x	SDR
	Increasing public awareness about the importance and impact of climate change on biodiversity to protect environment and natural ecosystem, and on possible adaptation options	m	x		NAS (MD), White Paper EU, UNFCCC (ME), (SR)
	Improvement of informing of professionals on climate change impacts and possible adaptation options	s			UNFCCC (RS)
	Strengthen private and public sector capacity	s			UNFCCC (RS)
	Adapting management at cross sectoral level • Intensification and implementation of the cooperation between land users and the competent authorities for nature conservation, agriculture and water management • Including climate change in sector strategy and planning • Developing tools to facilitate communication within and between sectors, ministries and institutions, and especially between climate change and biodiversity research and policy communities	s-m	x		NAS (DE), (MD), UNFCCC (RS)
	Adapting management of agriculture in limiting overgrazing of steppe pastures and river valleys which are more vulnerable to the increasing occurrence of droughts	s-m		x	NAS (MD)
	Introduction of efficient forest management	m			UNFCCC (MD)
	Adapting water management • Considering biodiversity in measures of flood protection and river basin management • Establishment of water balance management concepts to maintain or revive natural water logging, in order to protect wetlands; including concepts to revive water logging and dams that are adapted to the needs of nature conservation • Nature-oriented management of surface waters, and if necessary reconstruct them (e.g. through the creation of flood plains or the revival of bayous), to sustain the natural capacity of ecosystems • Development of plans for existing dams for excess water to be released in times of need	m	x	x	CC (DE), BAYKLAS, UNFCCC (MD), EEA Alps 2009

	Introduction of management methods, which will decrease the expectable danger of invasive species, aiming at management means that enhance the acceptable (least worse) colonisation processes	m			VAHAVA
	Improvement of the protected areas management system • Management of the matrix between protected areas • Adaptation of maintenance, development and management plans for large protected spaces in order to take into account expected climate change and adapt them according to the results of monitoring programmes implemented for this purpose (e.g. adaptation and management of leisure activities, maintenance measures for infrastructures)	m	x	x	ClimateWater, Alpine Convention, BAYKLAS, UNFCCC (BA)
	Introduction of a biodiversity/ecosystems compliance check in a reinforced spatial planning to increase flexibility of managed and natural systems to accommodate and adapt to climate change including by reducing other pressures on biodiversity/ecosystems arising from habitat conversion, over- harvesting, pollution and invasive alien species and by developing appropriate management and structure of the wider landscape and seascape;	s		x	White Paper EU
Policy approaches	**Making more money available for environment services** in order to adequately finance the required measures for conservation and restoration of biological diversity, and introduce payments for environmental services to protect biodiversity and carbon in agricultural landscapes	s		x	NAS (MD)
	Transfer of rights to own and manage ecosystem services to private individuals	m		x	NAS (MD)
	Improvements in the legislative system and in enforcement in the area of nature protection • Increasing the amount of territory designated as protected areas by law • Establishment of new policies based on an integrated landscape approach to biodiversity protection • Limitation of all activities in protected wetlands and marshes • Adoption of the Nature Protection Law and ratification of international agreements	m		x	UNFCCC (BA), NAS (MD), (RS)
	Implement national and international environmental legislation efforts to reduce pollutant and nutrient inputs into ecosystems and also support the conservation of habitats and biodiversity	m		x	NAS (DE)
	Drafting guidelines on dealing with the impact of climate change on the management of Natura 2000 sites	m	x	x	UNFCCC (EU)
	Stopping the biodiversity loss in line with the Kiev Declaration	m	x	x	NAS (RS)
	Implementation of the water framework directive	s-m	x	x	BAYKLAS
	Possibly reviewing the Convention Concerning Fishing in the Waters of the Danube	m	x	x	SDR

5.16 Limnology

According to warmer air temperatures due to climate change, the water temperature of the top lake layer will increase remarkably. This could lead to changes of the lake stratification and its energy balance. Moreover, the probability of later freezing and earlier ice melting in the year is higher. It is likely that in future the redox potentials will change and the water quality of lakes could be reduced by showing eutrophic conditions and a possible increase in blue-green algae. Especially in summer, a decrease in lake levels is possible.

Danube River Basin (DRB) [3]

- Water temperature of lakes will increase
- Stronger thermal stratification
- High probability for an earlier melting of lake ice
- Reduction of lake soil suspension because of a decreasing redox potential; increase of mobile heavy metals within the soil suspension
- Frequent changes of dehydration and rewetting lead to a highly variable redox potential
- Anticipated changes in the chemical regime of lakes (e.g. accelerated eutrophication, decrease in oxygen)
- Sinks react most sensitive due to a high carbon content

Upper Danube River Basin (UDRB) [21]

- Water temperature of lakes will increase
- Possible decrease in water levels in summer
- Changes of the energy balance of the layered surface water; however, predictions considering the mixing process are uncertain
- Temporal extension of the productive phase
- Climate change might cause a reduced water quality and an increase in blue-green algae

Middle Danube River Basin (MDRB) [27]

- Decrease in water level
- Decrease in water circulation, which could lead to higher saline concentrations and eutrophication levels

Commonalities

- Increase in water temperature; decrease in lake levels
- Changes of stratification, water layers and energy balance
- Possible decrease of water quality

Challenges / Knowledge gaps

- Only few findings about limnology for the MDRB and the LDRB
- Results of different lakes are not necessarily comparable
-

Adaptation measures

The field of limnology is rarely addressed by adaptation activities. Only the common measures of further monitoring are mentioned, but no other specific adaptation measures can be found.

*Table 17: Suggested adaptation measures for impacts on limnology (*Time horizon of the effects of the measures: short-time (s), medium-term (m), long-term (l); abbreviations of the sources can be found in Appendix 5; [47, 119]).*

Type	**Possible adaptation measures**	**Time horizon***	**Options for cooperation**	**Challenges**	**Source (Countries)**
Preparation measures for adaptation	**Improvement / adaptation of monitoring** • Including potential impacts of climate change on circulation of water • Implementation of regular depth profile, temperature and oxygen measurements • Consideration of nutrient situation	m	x		NAS (AT), ST_BLOESCHL_AT
Behavioural /managerial measures	**Adaptation of operation rules** of reservoirs due to hydroclimatic circumstances	s-m		x	ST_BLOESCHL_AT

5.17 Coastal zones

Coastal systems are quite vulnerable to climate change impacts. Rising sea surface temperatures and sea levels as well as changes in frequency and intensity of extreme weather events might impact fisheries, agriculture, tourism, marine freshwater resources, health infrastructure, municipal health infrastructure, water supply and sanitation systems [119]. An increase in sea surface temperature could lead e.g. to re-distribution and losses of marine organisms and an increase of invasive species as well as an increase in toxic bloom events. Rising sea levels could trigger coastal erosion with damages of buildings and a retreat of inland coast as already monitored in the Danube Delta and the Romanian coastline to the Black Sea. Moreover, higher sea levels will likely increase salinization of estuaries and land aquifers with saltwater intrusions and will reduce coastal protection of dams and quay walls.

Danube River Basin (DRB) [119, 53, 56]

- Possible impacts of sea level rise; increase in coastal erosion, flooding, salinization of estuaries and land aquifers, decrease of fresh-water availability due to saltwater intrusion
- Possible impacts of higher sea surface temperature: re-distribution and loss of marine organisms, higher frequency of anomalous and toxic bloom events, enhancement of hypoxia at depth, increase of invasive species
- Variations in the frequency and intensity of extreme weather events could change management of unique coastal ecological and cultural systems

Lower Danube River Basin (LDRB) [104]

- Increase of the sea level of the Black Sea; possible retreat of inland coast (Danube Delta)
- Possible increase in damage of buildings because of increased coast erosion
- Rising sea level will reduce protection effects of the dams and of the quay walls

Commonalities

- Impacts due to an increase in sea surface temperature (biodiversity)
- Impacts due to rising sea levels (erosion, protection)

Challenges / Knowledge gaps

- No clear quantitative and temporal assumptions; rather presumptions than scenario simulations

Adaptation measures

Romania, Bulgaria and the Ukraine have coastal zones within the DRB. Additionally, the EU White Paper [53] as well as outcomes of the project Climate Water [37] suggest adaptation measures in this sector. The agreement among them is low, but the implementation of measures against storm surges and an integrated coastal zone management is addressed by some of them.

*Table 18: Suggested adaptation measures for impacts on coastal zones (*Time horizon of the effects of the measures: short-time (s), medium-term (m), long-term (l); abbreviations of the sources can be found in Appendix 5; [47, 119]).*

Type	Possible adaptation measures	Time horizon*	Options for cooperation	Challenges	Source (Countries)
Preparation measures for adaptation	Improving the **monitoring system** for the Danube Delta eco-systems	s-m	x		DD (RO)
	Vulnerability assessments or risk mapping: Plans should be readily available for disastrous events	s-m	x		ClimateWater
	Implement a **forecasting-warning system**	s-m	x		ClimateWater
General measures	Reduction of anthropogenic impacts on coastal and sea areas	m			UNFCCC (BA)
	Improving public utilities infrastructure, transport and communication to reduce pollution, the isolation of human communities and to raise living standards	m			DD (RO)
	Limit all factors which result in warming and/or acidification	l	x		NAS (DE)
Ecosystem-based measures	Force **afforestation** as a very effective and natural way of protecting the biodiversity, especially against sea intrusion	m		x	ClimateWater
	Establish well managed and sufficiently large **protected areas** (to ensure that species which suffer from climate-induced stress factors are protected at least from certain anthropogenic stress factors)	l	x	x	NAS (DE)
	Restore the natural eco-system functions and natural habitats of endangered species in the Danube Delta	m-l	x	x	DD (RO)
Behavioral /managerial measures	**Management** (planning instruments to allocate the spatial and temporal distribution of human activities in coastal and marine areas) • Integrated coastal zone management (ICZM) (is an approach to resolve conflicts in between use claims) • Maritime Spatial Planning (MSP)	m	x		NAS (DE), White Paper EU, SDR
	Awareness raising, training and education • for those people who are living in the hazard zone of flooding and also for those who are responsible for decisions regarding any aspect of adaptation • Engineers, architects should have trainings about foreseeable impacts of climate change, as they are responsible for many of the most expensive investments affecting lots of people, e.g. bridges with a design life of 100 years, in which time sea level might rise	m	x		ClimateWater
	Change the landuse on sea coasts to alternative uses, which fits better with the new environmental conditions on the shorelines	m-l	x	x	ClimateWater
	Changing the cropping pattern or the use of new salt tolerant species on sea-shores	s-m	x		ClimateWater

	Inundation: large scale relocation of certain areas, where the risk posed by the inundation of the area will be too high	l		x	ClimateWater
	Development of new forms of safety precautions (especially passive ones)	m	x		NAS (DE)
Techno-logical measures	Implement measures against **storm surges**, e.g. the building of new protective structures, such as sea walls, embankments, breakwaters, barriers etc.; at places often hit by storms, cyclone shelters should be built, which proved to be very efficient in protecting people; reinforcement of the harbour structure in order to face heavier storms	m		x	ClimateWater, UNFCCC (RO)
	Implement **beach nourishment** techniques against storm surges and sea level rise, which could actually mean a further space for use by the community	m			ClimateWater
	Development of **water desalinating technologies**	m	x		UNECE 2010
	Building engineering structures that **prevent saltwater intrusion** into aquifers	m-l	x		UNECE 2010
	Dyke building and refurbishment measures	m		x	NAS (DE)
Policy approaches	Ensure that adaptation in coastal and marine areas is taken into account in the framework of the Integrated Maritime Policy, in the implementation of the Marine Strategy Framework Directive and in the reform of the Common Fisheries Policy	m	x		UNFCCC (EU)
	Development of European guidelines on adaptation in coastal and marine areas	m	x		UNFCCC (EU)
	International cooperation: development of integrated strategies for coastal ecosystems (including river estuaries) which facilitate the establishment of alternative habitats for communities affected by the rise in sea level and make use of synergies between nature conservation and coastal protection	m	x		NAS (DE)
	Implement the Floods Directive (provides the legal instrument on flood risk management, requiring Member States to carry out certain measures such as risk assessment, mapping, risk reduction measures etc, including coastal floods.)	m			White Paper EU
	Consideration of maximum protection from increasing storm surge and flood risks in coastal areas and on islands in regional planning	m	x		NAS (DE)

5.18 Water related energy production

Climate change impacts on water dependent energy production are largely connected to changes in water availability and hydrological extreme events. Hydropower for example is strongly related to changes in mean annual discharge as well as flood and low flow events. Thereafter, future mean annual hydroelectric power generation is likely to decrease in the DRB. The mean hydroelectric power generation will decrease in summer; it will increase in winter mostly due to changes in water availability. However, the dimension will differ regionally and locally, and depends e.g. on the type and strategy plans of each hydropower station. The decline of the mean annual and mean summer production values will be especially pronounced in the south-eastern parts. Particularly in mountain areas, there will be a possible seasonal shift due to changes in precipitation and snow cover with a more balanced production over the year. Cooling of thermal power plants will be affected by climate change as well, because this process is largely related to future changes in water temperature and low flow conditions. Most studies show thereafter also a decrease in energy production of thermal power in summer. In general, extremes events may impair the whole energy production and transport infrastructure and may have negative effects e.g. on energy pricing and can lead to energy shortages.

Danube River Basin (DRB)[18, 51]

Hydropower

- Future hydropower is dependent on changes in water availability
- The European hydropower potential declines in future; high decrease in the southern parts, stable predictions in Central and Western Europe and an increase in Northern Europe [18]; the DRB lies in between in the transitional zone

Thermal electricity production

- Possible temperature load is problematic in the future; power stations may have to be shut down more often, especially in summer
- Climate policies will lead to lower water use in the electricity production sector, especially the need of cooling water for thermal power plants (more non-thermal renewable energy)

Upper Danube River Basin (UDRB) [64, 21, 128, 76, 77]

General

- Extremes such as storms, floods, low flows and droughts may impair the operation of installations and equipment for energy conversion, transport and supply (possible results: shortages, rising energy prices, supply disruptions)

Hydropower

- Mean annual hydroelectric power generation: high decrease to stable conditions
- Increase in winter and decrease in summer; in some regions equalisation of the mean annual production cycle
- Energy losses due to a decrease in runoff and more low flow and flood events
- In high Alpine areas compensation of low flows with glacier melt-water in the near future; however, the glacier melt has nearly no influence outside the Alpine headwatersheds

Thermal electricity production

- Insecure availability of cooling water for power generation in thermal power stations
- Higher vulnerability due to higher water temperatures and lower water levels, especially in summer

Lower Danube River Basin (LDRB) [29, 57, 100]

General

- Energy distribution infrastructure, patterns and energy production capacities will be affected

Hydropower

- Most of the potential for future hydropower expansion lies in Albania, Bulgaria and Romania, as well as in the former Yugoslav republics; problem: financing
- Example Arges river basin, Romania: rather low economic implications in terms of future estimated hydropower production

Commonalities

- *General*: climate change impacts on energy infrastructure, transport, operational systems and pricing
- *Hydropower*: decrease (more or less) of mean annual hydroelectric power generation; Increase in winter and decrease in summer
- *Thermal electricity production*: possible temperature load problematic in the future. Power stations may have to be shut down more often due to low water levels and high water temperatures

Challenges / Knowledge gaps

- Only few findings about water related energy production for the MDRB and LDRB
- Only few projects/studies considering the DRB as a whole and its bigger (sub)catchments
- Only few quantitative assumptions about changes in the energy sector due to climate change

Adaptation measures

In the impact field of hydropower and water related energy production, technological measures are important, e.g. the investment in energy storage technology or the implementation of technological solutions for low flow / drought situations. A common agreement on increasing water storage capacity can also be found in the analysed adaptation activities.

*Table 19: Suggested adaptation measures for impacts on water related energy production (*Time horizon of the effects of the measures: short-time (s), medium-term (m), long-term (l); abbreviations of the sources can be found in Appendix 5; [47, 119]).*

Type	Possible adaptation measures	Time horizon*	Options for cooperation	Challenges	Source (Countries)
Preparation measures for adaptation	**Research** • on parameters of the hydrologic cycle: on water reservoir, water demand and water supply trends, on their impact on the resource, the adaptation to climate change, the conflicts which may result • on energy storage • on sources of renewable energy in agriculture and forestry and on the development of a strategy for the use of such sources in the same field • on the discharge of warm waste water from power plants (cooling water) into rivers and the higher concentrations of pollutants in summer because of low flow • conducting studies to reform the design criteria of the spillways of existing dams and, where necessary, works must be scheduled and launched to increase their capacity accordingly • on the hydro-energetic potential of rivers	s-m	x		NAS (AT, HU, RS, MD), ST_BONACCI_HR, WASKLIM, UNFCCC (BA), ClimateWater
	Monitoring • to reassess thermal discharge • of the aquatic environment				NAS (AT), ST_BLOESCHL_AT, ClimateWater
	Risk assessment concerning climate change effects for the hydroelectric sector • identification and evaluation of potential supply risks • identification of impacts on hydropower production • evaluation of dam safety • evaluation of other infrastructure in the energy system such as transportation and distribution systems (including potential future changes in plant production, peak supply, and plant margins, at the cross sectoral level)	s-m	x		UNFCCC (RO), NAS (DE), WFD 24, White Paper EU
	Establishment of crisis task force to permit rapid response in the case of damage and failure due to extreme weather events	s	x		NAS (DE), White Paper EU
General measures	**Assessment and optimisation of the energy grid** • creation of "smart grids" to support decentralised energy production • consider the option for a decentralised electricity production and/or an interconnected “European Grid”	m	x	x	NAS (AT), ClimateWater

Ecosystem-based measures	Consideration of consequences for the ecology of rivers in the field of storage management	s-m	x	x	NAS (AT)
	Reduction of the impact of hydro-electric plants on the environment by improving the efficiency of existing artificial lakes and electricity plants and deciding on common guidelines for the construction of small power stations	m		x	Alpine Convention
	Implement ecologically sound hydropower systems	m		x	WWF-DCP
	Find the right balance between use, protection and support of innovative technology in order to avoid new dams and empower existing facilities	m	x	x	WWF-DCP
Behavioural /managerial measures	**Improvement of the effectiveness of the management** of water-powered structures under non-stationary conditions and for decision-making processes in dangerous or uncertain situations	s-m	x		UNFCCC (CZ), NP (CZ)
	Introduction of integrated water resource management	s-m	x		UNFCCC (BA)
	Shift towards less water consumptive energy sources: solar or wind power in order to reduce the sensitivity of the energy sector to diminished water availability	m	x	x	EEA Alps 2009
	Paying attention to the location of power plants • Using different locations for power plants (because of cooling water) • Promotion of decentralised sustainable energy generation where appropriate to local conditions to reduce risk	s-m	x	x	WFD 24, White Paper EU
	Implement an effective load management, such as reducing peak demand in periods of short supply by e.g. applying both load and climate condition forecasting models	s	x	x	EEA Alps 2009
	Exchange Information • coordination and information exchange about new modifications to water bodies (hydropower dams for instance) between WFD and FD management since water bodies influence flood risks • storage of monitoring data concerning hydropower and thermal power generation in shared data bases available to scientists and water users	s	x	x	WFD 24, ClimateWater
	Risk management • Recognition of existing dams in flood risk assessment and management, because they contribute to flood risk management • Including climate change into current risk management strategies as part of a larger planning process concerning hydropower and thermal power generation	s	x		WFD 24, ClimateWater
	Studying / assessment of structural measures before implementation • Consideration all uses of the reservoir (e.g. hydroelectricity, irrigation, drinkable water supply, tourism, fire fight, ecology of water systems) before the enlargement of existing reservoirs and/or the creation of new reservoirs • Consideration of ecological aspects, because they are known to generate significant impacts on the water	s-m		x	ClimateWater

	courses (morphological changes, barriers to fish migration, etc.)				
	Reduce energy demand by public campaigns and training on energy efficiency	s-m		x	UNFCCC (BA), EEA Alps 2009, White Paper EU
	Compensation of bottlenecks in summer (just for countries with access to the sea): thermal power stations in coastal areas do not have to cope with water temperature restrictions and are thus less sensitive to droughts than stations dependent on river water, to a certain extent they could thus alleviate the impact of summer droughts, when plants along rivers are at risk of shutting	m	x	x	EEA Alps 2009
	Optimization of storage management: Altered influx conditions in the annual reservoir balancing, which do not exceed a certain limit, might be balanced by means of a changed strategy regarding reservoir management. If the reservoir management allows for a certain degree of freedom, an adjustment based on the demand is possible. Should not only the seasonal distribution of the reservoir influx change, but also the overall water volume, this would naturally have an impact on the annual production capacity	s		x	UNFCCC (AT), NAS (AT), WASKLIM
	Optimization of sediment management to reduce time demand for preventive maintenance and reach higher storage capacity for flood events	s			WASKLIM
	Optimisation of the management of cooling water demand as part of the river basin management plans, including hydro peaking, minimum flow, and reservoir management (in particular under low flow conditions)	s-m	x		ClimateWater
	Increasing the consideration of water temperature in water management, e.g. in heat load discharge	m	x	x	NAS (AT), ST_BLOESCHL_AT
	Updating of **heat load** and **cooling water quantity / low flow management plans**	s	x	x	WASKLIM
	Raise low water by means of adaptive control of reservoirs	s	x	x	WASKLIM
	Decrease the heat load in water bodies e.g. caused by cooling water	m	x	x	BAYKLAS, RBMP (Bavaria)
Technological measures	**Development of hydro power plants** to reduce emissions	m		x	NAS Bulgaria
	Increase and invest in energy storage technology using pump hydropower storage systems like pump -turbines with two reservoirs at different altitudes in order to match the energy offered by the renewable sources to the needs of the consumers (e.g. to reduce the asynchrony) and in order to cover the peak load	m		x	BAYKLAS, VAHAVA, ClimateWater
	Increase security of water-powered structures against overflowing, e.g. by storage power plants optimization or development of the wastewater systems in central energy industry plants to ensure better removal of rainwater	s			NAS (AT, DE), NP (CZ)
	Re-commissioning of small and medium hydro power plants	s		x	NAS (RS)
	Implement technological solutions for low flow/drought • Apply turbines that use lower nominal power to reduce the impact of low water supply on hydropower plants • Establish emergency water connections for power plants in case cooling with river water becomes impossible	m	x	x	EEA Alps 2009, NAS (DE)

	due to summer drought				
	Development of closed systems in which process water is re-used, if necessary after treatment	m-l	x	x	UNECE 2010
	Increasing water storage capacity • in investing and enlarging the existing reservoirs and/or creation of new reservoirs to make it possible in summer to keep on hydropower production • in supporting low flow in particular for thermal power plant cooling • creation of multifunctional dams in order to contribute to water storage (utilizations: flood protection, hydropower, stabilisation of discharge downstream in times of drought for ecological purposes, maintenance of water abstraction and discharge for power plants, navigation, recreation, fishery and nature protection)	m-l	x	x	EEA 2007, ClimateWater, WFD 24
	Promotion of efficient cooling systems	s-m			UNFCCC (DE), White Paper EU
	Increasing the transfer of water	s-m	x	x	EEA 2007
	Consideration of potential changed flood patterns in the regulation of run-off-river power plants in order to have a positive effect reducing local floods, especially on smaller and medium flood events	m		x	WFD 24
	Development of alternatives for cooling, e.g. using cooling towers or cell cooling techniques which need less cooling water	m			WASKLIM, NAS (AT)
	Implementation of new technology gaining **better efficiency coefficients** *Challenges: higher costs*	m-l	x	x	WASKLIM
Policy approaches	**Revision of manipulating and operating regulations** in water works to increase safety against overflowing	s	x	x	UNFCCC (CZ)
	Carrying out regular reviews of the permitting regime of impoundments: multifunctional dams are subject to operation licenses for hydropower schemes (in which the regulating national authorities establish the conditions under which a power plant shall be operated at different moments of the year and sometimes even of the day). This license/permit contains detailed conditions for river flow regimes and minimum and maximum water levels to respect according to the season, so that for example enough storage space is in the reservoir to absorb the spring flood	s-m	x	x	WFD 24
	Incorporating climate change into existing codes and guidelines concerning hydropower and thermal power generation	s-m	x	x	ClimateWater
	Development of guiding principles on integrating environmental aspects in the use of existing hydropower plants: the ICPDR should organize in close cooperation with the hydropower sector and all relevant stakeholders a broad discussion process about this topic; the guiding principles should including a possible increase of hydropower plants efficiency, as well as in the planning and construction of new hydropower plants	s-m	x	x	DRPC
	Investment and installation in the energy infrastructure such as in extreme peak load facilities, or alternatives (like storage) and in relocation and reinforcement of the Energy Grid and connections	m		x	White Paper EU, ClimateWater

	Implementation of special regulations for thermal discharge during extreme events	s	x	x	NAS (AT)
	Development / implementation of strict rules for discharge of water into rivers and for water withdrawal	s	x	x	WASKLIM

5.19 Navigation

There are only several statements for the entire Danube catchment. Most of the projects investigate the German parts of the rivers Rhine, Elbe, Oder, and Danube [80, 128, 64, 63]. For the UDRB a significant reduction of the minimal low water is projected [64]. Due to future high water projections, only minimal influence for shipping is expected. These trends are also described in the project [128].
In general there is an agreement in limited or impassable navigation due to more frequent extreme water levels and unstable conditions, especially on routes using free-flowing waterways. Higher future temperatures in winter have a positive effect because of less frost and icing.
Low water levels, also often in combination with a reduced flow velocity, lead to reduced cargo and limited navigability. This is stressed for the MDRB countries Slovakia and Hungary, especially in summer for the hot lowlands with less precipitation in future. The development of the navigability in the MDRB is also depending on climate change impacts in the upper area (esp. in the Alps). Improving the channel conditions to ensure navigability at lower water levels could partly alleviate the expected problems but can lead to ecological conflicts [65].

Upper Danube River Basin (UDRB) [64, 128]

- Different scenarios show for the upper part of the Danube (gauge Achleiten) for the periods 2012-2041 and 2030-2059 a significant reduction of the minimal low water up to 50%; this reduction is more distinct in the second period; the minimal low water is expected to increase from 22 to 36-100 days/year, when shipping is not possible
- low flow could impair the supply with resources by shipping

Middle Danube River Basin (MDRB) [123, 122, 128, 126, 80]

- Development of the navigability in the MDB is depending on the Climate Change impact in the headwatersheds, esp. the right tributaries of the Alps
- Inland water transport on the Danube, the Morava and lower part of the Váh will be affected negatively by the decrease in flows during summer, but also by heavy rains in summer along with a steep increase in water level up to flooding activity level
- The shifting of the hydraulic regime of rivers towards the extremes hinders navigation and contributes to the increase of ship accidents
- Increase in air humidity in colder seasons may have negative impacts due to more frequent creation of fog, icing and black ice
- Less ice cover on water ways

Lower Danube River Basin (LDRB) [1]

- Forecasted sea-level rises can be expected to affect ports and other maritime infrastructure
- For the water level in the Dniester and Prut rivers a reduction is projected, but it is not clear to what extent this might be counterbalanced by rising sea levels expected in the next 50-100 years
- Rehabilitation of the river transportation system may be completely undermined by decreasing rainfall

Commonalities

- Expected reduction of minimal low water leads to more days per year without possibility of shipping
- For high water only minimal influence for shipping is expected
- More unstable conditions in runoff
- Less icing in winter

Challenges / Knowledge gaps

- Only few finding about navigation
- Only few projects / studies considering the entire DRB and its bigger (sub-)catchments
- Need for a study on long-term changes in water availability

Adaptation measures

The implementation of forecast / river information systems is suggested as an adaptation measure. In order to eliminate existing navigation bottlenecks, environmentally sustainable solutions should be found. The adaptation / creation / modernisation of infrastructure can be challenging but also provides an option for cooperation among the DRB countries.

*Table 20: Suggested adaptation measures for impacts on navigation (*Time horizon of the effects of the measures: short-time (s), medium-term (m), long-term (l); abbreviations of the sources can be found in Appendix 5; [47, 119]).*

Type	Possible adaptation measures	Time horizon*	Options for cooperation	Challenges	Source (Countries)
Preparation measures for adaptation	Better **monitoring** of water levels	s-m	x		WASKLIM
	Research • Initiating research programmes with the view to develop reliable adaptation strategies and measures for shipping and the waterway network (e.g. KLIWAS in DE) • A more detailed and scientifically-sound assessment is necessary for deepening traffic routes	s-m	x		NAS (MD, DE) UNFCCC (DE)
	Examine whether climate-induced changes create a need for adaptation of monitoring and advisory services, forecasting and warning services, risk management, emergency and rescue services	s	x		NAS (DE)
	Forecast / River Information Systems • Better seasonal discharge predictions at waterway level could help to adjust in short term • Improvement of methods in forecasting water levels • Implementation of harmonised River Information Services (RIS) (aim: increasing the safety, efficiency and environmental-friendliness of inland navigation, important is an implementation along the entire Danube and its main navigable tributaries and canals)	s-m	x		EEA 2007, EEA Alps 2009, SDR, ECCONET, NAS RS, WWW-DCP
General measures	Promotion of transport on interior waterways will enhance the competitiveness of river transport relative to other modes	s-m	x	x	NAS (RO)
	Reducting of environmental impacts	s-m	x	x	NAS (RO)
	Providing sufficient water depth in times of low water flow	s-m	x	x	WFD 24
Ecosystem-based measures	Combination of any requirement for increased water storage to support navigation infrastructure with habitat creation initiatives	m	x	x	WFD 24
	Integrated sediment management planning could aim to offset any potential new dredging requirements by identifying measures, such as buffer strips, which aim to prevent additional sediment (and associated nutrients, pesticides, etc.) entering the watercourse	m	x	x	WFD 24
	Establishment of a sustainable, environmentally sound and transnationally coordinated approach in ship waste management along the Danube by (1) elaborating national ship waste management concepts, (2) implementing pilot actions and (3) developing a financing model for the operating system based on the polluter-pays principle	m	x		SDR, NAS (RS)

	Identification of environmentally sustainable solutions for improved navigability in order to eliminate existing navigation bottlenecks taking into account likely impacts of climate change, the preservation of functioning ecosystems and planning guidelines	s-m	x	x	SDR, WWW-DCP, DRPC
	Definition of navigation fairway conditions according to ecological needs				WWW-DCP
Behavioral /managerial measures	Investment in education in the Danube navigation sector	m	x		SDR
	Re-launching maritime transport through the Romanian Black Sea and Danube ports by expanding their functional structures to serve as logistical centres integrated in the inter-modal transport system	m-l		x	NAS (RO)
	Waterway management • Find and coordinate ways of using new routes optimally • Improvement of comprehensive and standard waterway management of the Danube and its tributaries in more cooperation and coordination among national authorities (Build on the network of Danube Waterway Administrations (NEWADA) project) • better reservoir management in low-flow cases	s-m	x	x	UNFCCC (DE), SDR, WASKLIM
	Support transport on waterways • Shifting from other transport modes that are potentially more harmful to the climate, such as road transport • offer competitive alternatives in the ‘door-to-door’ logistical chain • Increasing the share of intramodal transport in the total transport of goods by increasing the use of inland waterways and railroad transport	s-m	x	x	EEA 2007, EEA Alps, NAS (RO, RS), CC (DE)
	Support the follow up process preparing a “Manual on Good Practices in Sustainable Waterway Planning”	s-m	x		DRPC
	Avoidance of redundant transportation, changes in industrial production leading to lower transport requirements or shifting transport towards the season with high river discharges, if possible, could reduce the pressure on the navigation sector during months of low water flows	m	x	x	EEA 2007, EEA Alps
Techno-logical measures	**Adaptation / creation / modernisation of infrastructure** • Adaptation /modernisation of infrastructure water to increase the average speed and fluidity of traffic • Deepening of the traffic routes in the lower Dniester and Prut rivers and make corresponding improvements to the existing ports • Completion of the Váh transport route and making navigable the Bodrog, the Laborec and the Latorica is the priority in water transportation due to the cross connection of the Baltic Sea and the Balkan • Harmonization and adaptation of the construction of new corridors to actual commercial and transport in Europe and the orientation to the construction of multi-modals corridors	m-l	x	x	NAS (RO, RS, MD) UNFCCC (SK), ECCONET
	Low flow measures • Expansion of the shipping routes and management of water levels considering ecological interests,	s-m	x	x	BAYKLAS, CC (DE), EEA 2007, EEA Alps

	• Support the container shipping with shallow draft (national-wide) • Buffering water level fluctuations by damming • Altering ship design (e.g. ships with less draught because of lightweight material, and improved manoeuvrability (for example the 'Futura carrier' funded by the BMU or 'INBAT', an EU 5th FP project)				
	Improving the Operation Parameters of Hydro-Technical Installations	m	x		UNFCCC (MD)
	Modernisation of the Danube fleet • Innovation, dedicated fleet modernisation and optimised waste management measures, in order to improve environmental and economic performance of Danube navigation • Establishment of a common approach for the modernisation of inland vessels • Technological developments in terms of innovative vessels, engines and optimised fuel consumption (e.g.: retrofitting with particle filter, using low emission fuel, using onshore power while docking)	m	x		SDR, WWF_DCP, WASKLIM, ECCONET
Policy approaches	Providing a balanced framework for fair competition among ports	s-m	x		NAS (RO)
	Gradual development of shipping on interior waterways through upgrading and expansion of port infrastructure, providing continuous access for vessels up to 2,000 tdw on the Romanian sector of the Danube and fluent navigation along the whole length of the Rhine- Main-Danube corridor	s-m	x	x	NAS (RO)
	Implementation of the Short Term Internal Navigable Waterways Rehabilitation Plan	s	x	x	UNFCCC (MD)

5.20 Health

Milder climate and an increase in extreme events like floods, droughts and hot air temperatures will also impact human health, either directly through physiological effects or indirectly through the spread of pathogens. In the DRB a remarkable increase in diseases, injuries and deaths is possible. Furthermore, a decrease in water quality may affect skin irritations in bathing areas. Climate change will have an influence on disease carriers and may expand their seasonal and regional occurrence. Vector-borne diseases, like malaria may even arise in the UDRB. The transmission could be, however, due to adequate health services and management systems quite low.

Danube River Basin (DRB) [54, 53, 4, 32, 18, 119, 56]

- Higher death rates related to an increase in heat waves are likely to occur, especially in the south-eastern parts
- Reduction of water quality may lead to an increase in contamination, especially during extended drought periods as well as severe flood events
- An increase in heavy rainfall could overburden water treatment facilities and sewage systems, which could release high levels of enteric pathogens and could cause potential disease outbreaks
- Increasing sea level could lead a higher amount of deaths by drowning in floods
- Higher economic costs due to more health effects caused by climate change
- Possible influence on disease carriers
  - Vector-borne diseases are expected to increase as insects move to higher altitudes and latitudes; however, if there are adequate health services and management, the risk of transmission of malaria is very small
  - Water-borne diseases are likely to increase due to more flood events; this could affect water quality and water quantity
  - Food-borne diseases (e.g. salmonella) might increase under changing climate
- Changes of different environments could cause changes of associated diseases, e.g.:
  - Wetlands: encephalitis, malaria, schistosomiasis
  - Permanent water: filariasis, malaria, schistosomiasis, onchocerciasis
  - Ocean (sea surface temperature and height): cholera

Upper Danube River Basin (UDRB) [19, 25, 116]

- Increase in extreme weather and hydrological events can lead to more injuries and deaths
- Decrease in water quality (e.g. increase in blue-green algal blooms) can trigger irritations of the skin
- Milder climate favours the propagation of native and non-native pathogens
- Possible increase in the propagation of disease carrier animals
- Seasonal malaria occurrence is possible
- Rising temperatures may affect the storage life of food causing a rise in gastro-intestinal infections
- Water supply shortages could impact health

Middle Danube River Basin (MDRB) [120, 121]

- Higher possibility of heat strokes and mortalities during periods with extremely high temperatures
- Possible spread of vectors and exotic diseases and increase of infections transmitted through food and water (e.g. diarrhoea and dysentery)

Lower Danube River Basin (LDRB)[100, 1]

- Possible increase of diseases associated to water
- Increase in floods, low and high temperatures can lead to more deaths
- A lack of good-quality drinking water could increase the risk of infections spreading
- Numbers of infection bearers such as mosquitoes, which swarm near flooded land, could rise (possible increase of encephalitis and Lyme disease)

Commonalities

- Increase in diseases, injuries and deaths triggered by climate change might occur
- Milder climate and increase in extreme weather and hydrological events impact
  - direct impacts through physiological effects (e.g. heat victims)
  - indirect impacts through increase in disease spread (e.g. vector-borne pathogens)

Challenges / Knowledge gaps

- Only few findings about climate change impacts on health for the MDRB and LDRB
- The present projects and studies indicate tendencies; quantitative changes are mostly unclear; rather presumptions than scenario simulations

Adaptation measures

There seems to be a common understanding on strengthening or improving the public health monitoring system and emergency medical services and infrastructure together with protecting the water quality to be prepared for climate change impacts in the field of health. Raising public awareness and the appropriate human behaviour to reduce increasing risks are behavioural measures.

*Table 21: Suggested adaptation measures for impacts on health (*Time horizon of the effects of the measures: short-time (s), medium-term (m), long-term (l); abbreviations of the sources can be found in Appendix 5; [47, 119]).*

Type	Possible adaptation measures	Time horizon*	Options for cooperation	Challenges	Source (Countries)
Preparation measures for adaptation	**Introduction / improvement of early warning systems** in regard to extreme weather events, e.g. floods, heat waves	s-m	x		UNFCCC (RS), NAS (MD, DE), CC (DE), UNECE 2009
	Establishment / improvement / strengthening of public health monitoring of vectors, transmitted and infective diseases and pathogens (including changes in vector-borne disease distribution) and permanent surveillance of drinking water quality	m	x		UNFCCC (RS, MD, ME), NAS (DE), UNECE 2009, White Paper EU
	Ensuring / protecting water quality • Improvement of permanent water quality controls • Moving polluting facilities away from labour and recreation zones • Protecting water quality in water catchments by decreasing contamination of source water, reduction of the amount of treatment and quantity of chemicals in order to increase health benefits • Development of water safety plans	s-m	x	x	UNFCCC (ME, MD), ClimateWater, White Paper EU, UNECE 2009
	Research • Improvement of research of climate change impacts on health • Development of strategies concerning pathogens • Strengthening research capacity • Performance of epidemiological studies concerning the influence of the climate change effects on health	m	x		UNFCCC (RS), NAS (DE)
General measures	**Strengthening capacity for long-term preparation and planning,** especially to identify, address and remedy the underlying social and environmental determinants that increase health vulnerability	m	x		UNECE 2009
	Increasing accessibility to key determinants of health, such as clean water, energy and sanitation	s			White Paper EU
	Modification / adaptation of coastal protection and flood control	m	x		UNFCCC (DE), NAS (DE)
Behavioural	**Raise appropriate human behaviour to reduce** health risks from extreme events (such as storms or floods)	m	x		UNFCCC (DE), NAS

/managerial measures					(DE), JRC 2005
	Public education and awareness-raising: promote appropriate targeted information for the general public and individual risk groups	m	x		NAS (DE), CC (DE), UNECE 2009
	Strengthening emergency medical services: ensure well-equipped health stations (e.g. the availability of medications, vaccines equipment and diagnostic tests) and availability of communication and transportation facilities and extend the program of public health care in order to contain the spread of disease vectors	m	x		UNFCCC (RS), White Paper EU, UNECE 2009, BAYKLAS
	Strengthening professional capacity e.g. in instructing the health professionals concerning new diseases and carrier of diseases	m			UNFCCC (RS), BAYKLAS
	Implementation of regular vector control and vaccination programmes	m			UNECE 2009
	Ensuring effective communication services for use by health officials	s-m	x		UNECE 2009
	Strengthening of the public health infrastructure • Strengthening capacity of health protection institutions and institutions responsible for prevention and control programmes • Implement precautionary measures in municipal infrastructure • Placement of critical activities for public health (water treatment works, energy supply, hospitals) in locations with less risk for extreme weather events	m	x		UNFCCC (BA, RS, DE), White Paper EU
	Development of emergency response plans in using existing systems and links to general and emergency response systems, e.g. for the case of floods or heat waves	s-m	x		UNFCCC (DE), NAS (DE) UNECE 2009, White Paper EU
	Construction of water services for multiple use and functions, socially, economically and ecologically costly to increase positive effects on health	m	x	x	ClimateWater
	Implement risk and crisis management by infrastructure operators	m	x		UNFCCC (DE), NAS (DE)
Technological measures	**Using rapid molecular methods** for detection of infectious agents and a new group of models that include climate information	m			JRC 2005
	Maintaining and improving water and sewer infrastructure with special emphasis on the coastal part and implementation of sanitation and water treatment projects to ensure access to qualitative good water for rural communities and social institutions	m			UNFCCC (MD), NAS (MD)
	Implementing precautionary measures in the construction/building sector to linki health care with appropriate architecture, urban and landscape planning, e.g. through physical modification of building environment and improved housing and building standards	m-l		x	UNFCCC (DE), NAS (DE), UNECE 2009
Policy	**Including climate change in spatial and urban planning** to reduce risks of heat islands, air pollution and heat waves	s-m		x	UNFCCC (RS)

approaches	**Ensuring cooperation between the competent authorities** in order to promote certain operative intervention programmes in case of the manifestation of certain extreme weather events	s-m			UNFCCC (RO)
	Implementation of a health policy concept including recommendations on prevention of heat-related health problems and other health risks associated with climate change, and also proposals for action on coping with weather extremes and natural disasters from a health point of view				NAS (DE)
	Development of guidelines on health impacts of climate change	s	x		UNFCCC (EU)

5.21 Tourism

Climate change has besides socio-economical developments an impact on tourism with a potential regional and seasonal shift. Winter tourism in all mountain regions of the DRB may suffer from milder winters with less snow cover and a shorter snow seasons, especially in lower altitudes. An increase in water and energy demand for artificial snow production might be a potential conflict. The summer season will be extended, however, an increase in droughts and water scarcity could lead to extended water shortages and potential conflicts between different water users, especially in the south-eastern regions of the DRB. This would be exacerbated by a general increase in tourist numbers. On the one side, lake tourism in the UDRB and sea side tourism in the LDRB could benefit from an extended season. On the other side, in some areas like in the Hungarian Balaton region, lower lake levels, extreme hot temperatures and drought events could have negative effects with a decrease in water quality and water supply in the peak summer season. In the future, alternative activities at tourist destinations as well as off-season tourism could increase.

Danube River Basin (DRB)[53, 46, 18, 52]

- Potential shift in major flows of tourism within the EU from southern to northern regions and in seasonal distribution
  - increase in hot summer temperatures in the southern regions may lead to a redistribution or seasonal shift away from the current summer peak
  - reduction in snow-cover will affect winter tourism and the sports industry
- Peak season water demand could cause severe constraints on local water supply, especially in drought prone areas
- Further installation of more golf courses, swimming pools and aqua parks lead to higher water demand → potential conflicts with other water users

Upper Danube River Basin (UDRB) [65, 64, 83, 19, 116, 95]

- In general, development of summer and winter tourism is highly influenced by anthropogenic effects (socio-economic development)
- In the UDRB, especially the winter tourism is vulnerable to climate change
  - shorter winter tourism season; possible concentration to midwinter months
  - skiing might not be possible at lower altitudes; this could cause a higher concentration on higher altitudes
  - increase of local conflicts because of increasing demand for artificial snow production and energy are expected
  - reduced winter tourism will have a negative impact on winter tourism; important consequences for the winter tourism industry (e.g. Austria)
- Development of summer tourism might be positive; however possible problems with water supply and hot temperatures
  - positive effects for lake tourism (e.g. Austria)
  - more tourists are expected, which will increase water demand, particularly during summer → potential conflicts with other water users

    - recreation season might shift due to hot temperatures from summer to spring and autumn
    - in the lowlands of the European Alps especially city tourism will gain attractiveness due to a prolonged season and an increase in summer days
- Alternative activities will play an important role; numbers of off-season visitors could increase
- Competition between alternative mountain land use is likely to increase in the future (might be offset by new opportunities in summer and new technologies)

Middle Danube River Basin (MDRB) [33, 122, 123, 94, 24, 23, 26, 136]

- Decrease in the potential of winter tourism; radical decrease of winter sport opportunities (e.g. Carpathian area)
    - irregular occurrence of snow cover and shorter skiing season
    - skiing might not be possible at lower altitudes; however, possibly more snow at higher elevations
- Longer summer period; climate change impacts on summer tourism could be negative
    - higher intensity of extreme meteorological events
    - due to water restrictions, tourism facilities might remain empty during drought periods
    - maintenance of golf courses may become more expensive
    - example Lake Balaton: increasing number of uncomfortable days due to hot temperatures and less water in summer; extension to spring and autumn
- Higher number of tourists causes increased water consumption and higher sewage loads and solid waste
- Further problems like increased rockfalls, enhanced erosion and landslides might affect tourism

Lower Danube River Basin (LDRB) [100, 1]

- The effects of water-related aspects of climate change on tourism could be positive or negative; summer tourism in summer is strongly influenced by climate change
    - extended summer season
    - influence on national seaside tourism warmer summer might encourage national tourists to make more frequent trips on the seaside
    - problems due to more extreme weather events affecting the infrastructure and the tourists and local communities safety and health
    - high stress on water reserves during the peak tourism season
- Climate change might increase the percentage of local people involved in tourism

Commonalities

- Winter tourism: shorter winter season and unstable occurrence of snow, especially in lower altitudes; possible conflicts caused by higher water and energy demand (e.g. for artificial snow)
- Summer tourism: seasonal expansion; however, possible conflicts caused by a decrease in water availability and an increase in water shortages

Challenges / Knowledge gaps

- The present projects and studies indicate tendencies; quantitative changes are mostly unclear; rather presumptions than scenario simulations
- Besides climate change, high anthropogenic factor in tourism development

Adaptation measures

The creation of additional tourist attraction, alternative activities and an economic diversification are identified as adaptation measures in the field of tourism. Sustainability and local tourism concepts considering climate change are commonly mentioned in adaptation activities, including water saving concepts, which should be supported by the investment in new infrastructures.

*Table 22: Suggested adaptation measures for impacts on tourism (*Time horizon of the effects of the measures: short-time (s), medium-term (m), long-term (l); abbreviations of the sources can be found in Appendix 5; [47, 119]).*

Type	Possible adaptation measures	Time horizon*	Options for cooperation	Challenges	Source (Countries)
Preparation measures for adaptation	Implementation of observation of water consumption of tourism, e.g. for skiing areas	s-m			NAS (AT)
	Identification of current and potential conflicts between tourism and other activities related to the use of resources	s		x	NAS (RS)
General measures	**Shifting the touristic seasons:** extension of the summer tourism season, creation of tourism packages for people who can take holidays in the after season, making efforts to prolong winter season	m			UNFCCC (RO, SK), White Paper EU
	Development of year-round tourism	m			UNFCCC (BA)
	Creation of additional tourist attractions, alternative activities and economic diversification • Development of new tourism offers (also involving other economic sectors such as agriculture) • Support alternatives to winter sports in the cold season, which are not affected by the lack of snow (in the mountain resorts), e.g. walking, cultural tours, wellness, culinary holidays, congresses • Offer more activities, which do not depend on weather conditions • Offer activities that are less dependent on water resources	s-m			UNFCCC (RO), NAS (DE), EEA Alps 2009, Alpine Convention, BAYKLAS
	Development of new climate-appropriate concepts in supporting this concepts by regional planning projects	m			NAS (DE)
Ecosystem-based measures	**Evaluation of every new snowmaking facility for its impact on the environment**, in this context note legal obligations and standards in terms of nature conservation sites *Challenges: environmental regulations in this respect differ from country to country and even within countries*	s	x	x	Alpine Convention
	Prevention of artificial snowmaking (particular) in ecologically sensitive and endangered habitats	s	x	x	Alpine Convention
	Rehabilitation of beaches affected by the coast erosion	m			UNFCCC (RO)
	Development/Promotion of sustainable and local tourism concepts considering climate change • Promotion of the idea of sustainable tourism development to reduce conflicts between different users • Development of a tourism development program based on principles of sustainable development • Cooperation in nature friendly tourism development, e.g. in the Danube-Carpathian region	m	x		UNFCCC (DE), NAS (RS), BAYKLAS, EEA Alps 2009, ST_CEU

Behavioural /managerial measures	**Reduction of water demand in the peak season and minimisation of resource use** to reduce the ecological footprint and stress on water, e.g. by raising public awareness	s-m		x	EU COM, EEA Alps 2009
	Contribution of tourists operators to mitigating negative impacts by, for example, introducing water-saving strategies and techniques, water recycling (in accommodation, catering facilities, golf courses, etc.) and staff training	s-m		x	EEA Alps 2009
	Creation of an information and communication platform which e.g. could also include a further training module for sustainable tourism development	s-m			UNFCCC (DE), NAS (DE), NAS (RS)
	Avoidance of the construction of new ski centres or the investments in existing ski centres				UNFCCC (SK)
	Changing /reorientation to activities that are less vulnerable to expected climate change: reorienting ski centres in lower mountains to the activities that are less vulnerable e.g. cycling and walking, staying and relaxation at water, water sports, cycling tourism, water tourism, staying and relaxation at thermal water or at spa	m		x	UNFCCC (SK)
	Abandonment of a number of ski locations	m		x	White Paper EU
	Envisage investments into alternatives to the application of artificial snow: considering a continued rise in temperatures, snowmaking may cease to be economically attractive	m-l		x	Alpine Convention
	Establishment of the Drava River area as a cross-border recreation area in considering sustainability and environmental issues	m-l	x		Declaration (DRRB)
	Using alternative environmentally friendly sources of energy in tourism	m			NAS (RS)
	Introducing waste collection and recycling systems and building a system for control of illegal waste dumpsites	m			NAS (RS)
	Combination of investment of public funds in snow-making equipment with the assessment of the consequences of such techniques on the environment and direct public funds towards other alternatives	m		x	Alpine Convention
	Improvement of regional water resources management plans contributing towards balancing the interests of different water users like mountain railways (operators of snowmaking facilities), households and other water demand stakeholders	s-m		x	Alpine Convention
Techno-logical measures	**Investment in/creation of new infrastructures** • additional investments for water supply and sanitation • increase reservoir capacity and transfer of water • establish retention and storage of water in ponds to contribute towards mitigation of temporal water stress due to snowmaking • weather independent infrastructure	m		x	NAS (DE), EEA 2007, White Paper EU Alpine Convention, CECILIA
Policy approaches	Integration of climate change considerations into national tourism strategies	s-m		x	ST_CEU
	Implement regulation mechanisms for artificial snow production to not further reduce low flow	s-m		x	RBMP (AT)

6. Conclusion

The analysis of research and development projects and studies as well as the adaptation activities dealing with climate change impacts, show that changes in climate are expected in the DRB due to increasing air temperatures and seasonal changes in precipitation with a decrease in summer. These changes are likely to impact on the future water availability and quality, and consequently on water dependent sectors as presented before. In order to be prepared for the future development, adaptation measures of different categories are suggested in the analysed sectors, which offer several options for transboundary cooperation in the DRB within the ICPDR. However, challenges to bring the different interests to a common approach may arise.

The presented results are all based on the analysed research and development projects and studies and adaptation activities as well as the discussions during meetings and the stakeholder workshop. Based on these discussions, the following conclusions are drawn, which are already discussed during the 34th RBM EG in Belgrade:

- Climate change impacts will be of different magnitude in the Danube River Basin regions and the water related sectors are triggered by a north-west to south-eastern gradient of temperature increase and the north-southern transitions zone of precipitation changes.

- Uncertainty is not a reason for doing nothing. Win-win / no-regret adaptation measures should be considered. The implementation of well established WFD PoMs is a step towards adapting to climate change.

- The study already identified a preliminary set of measures with options for a basin-wide / transboundary coordination (focus of ICPDR Adaptation Strategy).

- There is a challenging interdependency among impacts, adaptation measures, different interests and also human impacts in water use (hydropower, agriculture, water supply, water quality (WFD!)).

- Building on the "Danube Study - Climate Change Adaptation", the ICPDR Adaptation Strategy will define next steps towards the integration of climate adaptation issues in the DRBM Plan 2015 and beyond. The ICPDR Strategy should identify main impacts for individual sectors, address remaining uncertainties and propose and prioritise possible adaptation measures.

- With regard to the preparation of the DRBM Plan 2015 and due to the broad and cross-sectoral nature of climate change impacts, the involvement of other ICPDR expert groups will be needed.

- The ICPDR Adaptation Strategy should be based on existing information, mainly in the CIS Guidance No. 24 [55], information in RBMPs and existing national and regional adaptation strategies.

In order to develop an Adaptation Strategy for the entire DRB until the end of 2012, this study provides the basis and will be discussed during upcoming meetings and workshops, e.g. during the *Danube Climate Adaptation Workshop* from 29-30 March 2012 in Munich, Germany.

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