Revision and Update of the Danube Study

"Integrating and editing new scientific results in climate change research and the resulting impacts on water availability to revise the existing adaptation strategies in the Danube River basin"

Danube River Basin
Climate Change Adaptation

on behalf of:

Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety

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List of Acronyms

DRB	Danube River Basin
DRBM	Danube Flood Risk Management Plan
EC	European Community
EEA	European Environment Agency
EU	European Union
FD	(EU) Flood Directive
GCM	Global Circulation (Climate) Model
GHG	Greenhouse gas
ICPDR	International Commission for the Protection of the Danube River
IPCC	Intergovernmental Panel on Climate Change
LDRB	Lower Danube River Basin
MDRB	Middle Danube River Basin
NAS	National Adaptation Strategy
NC	National Communications under the United Nations Framework Convention on Climate Change
RCM	Regional Circulation (Climate) Model
RCP	Representative Concentration Pathways
SRES	Special Report on Emissions Scenarios
UDRB	Upper Danube River Basin
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
UNIGE	University of Geneva
WFD	(European) Water Framework Directive

Summary

The *Revision and* U*pdate of the Danube Study* was initiated by the ICPDR and supported by the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety to revise the findings of the first Danube study conducted 2010-2011 (report January 2012). The new study will support a Danube wide understanding of the impact of climate change on hydrology and water availability in the light of the new IPCC report AR5 and improved regional climate models. The outcomes of the study should provide an analysis of projects conducted between 2012 and 2017 and a comparison to the findings of the first Danube study. The work on the second study started in January 2017 and was finished in February 2018.

A close collaboration with experts in the Danube River Basin (DRB) was intended within the Study. Therefore several meetings, workshops and conferences were attended to present and discuss the outcomes of the study.

In order to identify new scientific results and the resulting impacts on water sectors in the DRB, ongoing and finalized research and development projects and studies as well as actual 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. Only documents, reports and papers which have been published and are accessible through libraries or internet in English, German or French could have been taken into account.

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 analysed scenarios.

The applied models and scenarios of different projects and studies were analysed with regard to future temperature and precipitation development and the projected extreme weather events. With the publication of the 5th IPCC Assessment Report (AR5), a new scenario framework using representative concentration pathways (RCPs) replace the SRES scenarios [65]. In contrast to SRES-emission scenarios of the 3rd and 4th IPCC assessment reports, RCPs are no longer based on potential global developments and the resulting GHG emissions but on defined radiative forcing (radiative forcing pathways), which are caused by changes in the atmospheric constituents, such as carbon dioxide [65,73].

In contrast to the first Danube study, research projects and recently updated or finalized National Adaptation Strategies deal with different scenarios and especially different reference periods and model periods for the near future, which hinder the comparison of the results (see section 3). To summarize the results it can be pointed out that compared to the first study the results show slightly different, but nevertheless significant temperature differences for the far future. As already documented in the first study, there is a high agreement that air temperature is likely to increase in the future with a gradient from northwest to southeast, both annually and in all seasons. For the future period from 2021 to 2050 an increase in annual mean temperature between 0.5°C in the upper basin parts and up to 4°C in the lower basin parts of the DRB are projected. For the far future 2071 to 2100, an increase between 1°C in some parts of the Upper DRB and 5°C in the middle and lower DRB are projected. Studies using recent and high resolution regional climate models, show that also within the countries of the DRB large differences are projected for the different landscape units

[47,58]. This is especially true for countries with large mountain ranges like Austria, Croatia or Romania. To use just the mean temperature value for the entire country does not seem appropriate.

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 in comparison to the first study models show a much higher significance that there will be intensification in seasonal changes. A strong decrease in summer precipitation and an increase in winter precipitation will be most likely. Particularly in the south-eastern parts a reduction of about 25 and 45 % is shown in the scenario results.

As a second step, climate change impacts on water related issues and possible adaptation measures were compiled for different fields. To enable the comparison between both studies and to evaluate the developments and changes of climate change impacts on the water issues within the last 5 years, the same categories as in the first Danube study were selected. This includes impacts on water availability considering runoff and evapotranspiration, extreme hydrological events like floods, droughts and low flows as well water quality. Moreover, impacts on different water uses are focused. This encompasses impacts on agriculture, irrigation, forestry, biodiversity and ecosystems, water related energy production and navigation. Other categories analysed in the first study could not be regarded due to reduced project capacity. If statements make it possible, impacts on the entire DRB, the Upper (UDRB), Middle (MDRB) and Lower Danube River Basin (LDRB) have been analysed 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, strong seasonality of precipitation 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 extreme events, droughts and low flow are likely to become more intense, longer and more frequent in the DRB, just as already pointed out in the first study. Significantly different are the findings concerning flood events. Whereas in the first study no clear picture could be drawn, the actual studies predict an increase in floods regarding to an increase in heavy rain fall events. However, these events are difficult to project and have a high spatial variability. Water dependent sectors such as agriculture (irrigation), forestry, navigation and water related energy production will suffer under these projected future conditions, but the impacts differ between Upper, Middle and Lower DRB. This is especially true for navigation in the UDRB where the low flow conditions show a significant impact, whereas in the lower DRB navigation is hardly affected.

Especially the decrease in precipitation during the vegetation period and the higher temperatures lead to a general increase in water demand for agriculture and forestry in the MDRB, the LDRB and some areas of the UDRB during summer. Consequently without additional irrigation the elongation of the vegetation period has no positive effect on agriculture. The reduction in stream flows together with an expected increase in water temperature, good water quality might be endangered. 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. Besides the already mentioned longer vegetation period, a reduction of the ice days on rivers has a positive impact on navigation.

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, as well as the strong seasonality of precipitation with a significant decrease in summer can be seen as hard facts. The increase of extreme events, the impacts on agriculture and ecosystem can be seen as highly certain, whereas other impacts are quite uncertain.

The strong impacts of climate change necessitate the development of adaptation measures. Climate change impacts will pose an increasingly significant threat if the reduction of greenhouse gas emissions is not complemented by climate change adaptation measures [43,128,129].

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. Any adaptation measures pointed out in reports and studies before 2012 still keep their validity [40]. The now applied evaluation analyses whether in new strategies, studies or projects additional adaptation measures are enclosed. 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. It is also indicated whether the measures have any relevance to the European Water Framework Directive (WFD) or the Flood Directive (FD). New measures concentrate on agriculture, floods and droughts and ecosystems. 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.

The activities seem to agree on the demand for forecasting and warning services, e.g. for extreme events as floods and droughts. In some adaptation strategies options for cooperation among the DRB countries within the ICPDR are identified in the measures, but mostly measures concentrate on the national level. In some of the in the last five years developed or updated National Adaptation Strategies (NAS) and National Communications under the UNFCCC (NCs), the ICPDR Strategy on Adaptation to climate change is taken into account, but not for all areas of adaptation transboundary approaches to understand the interconnections of regional impacts are considered.

In order to update the ICPDR strategy on adaptation to climate change by 2018, this study provides an overview on new scientific results and the development of impacts on water related fields. Thus 5 years is in relation to developments in nature a short time, and not in all fields there are new results. But the changes which could be addressed are of significance and an update of the ICPDR strategy should be regarded.

1 Project Overview: Objectives of the Study

The *Revision and* U*pdate of the Danube Study* was initiated by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety to revise the findings of the first Danube study conducted 2010-2011. The new study supports a Danube wide understanding of the impact of climate change on hydrology and water availability in the light of the new IPCC report AR5. The outcomes of the study provide an analysis of projects conducted between 2012 and 2017 and a comparison between the findings of the two projects.

It started in January 2017 and continued for 13.5 month. A close collaboration with experts in the Danube River Basin is intended within this study.

The study is divided into the following four work packages.

1. Compilation of results and data of research and development projects, conducted between 2012 and August 2017, 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) communalities, contradictions in results and approaches
   b) dependencies, competing interests and possible conflicts
   c) deficits of knowledge
3. Comparison of the results with the findings of the study from 2011.
4. Analysis of the effectivity of adaptation measures and / or the definition of necessary measure adjustments. Suggestions as basis for an adjustment of the basin-wide adaptation strategy to climate change in water related issues in the Danube River Basin with / for the ICPDR team of experts.

Neither further model calculations were carried out nor adaptation activities will be suggested.

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.

- **44th River Basin Management Expert Group Meeting** 25-26 October 2016 in Budapest, (R. Stolz)
  The required steps for the update of the Climate Change Adaptation Strategy and its knowledge base were discussed
- **45th River Basin Management Expert Group Meeting** 3-4 May in Brussels (R. Stolz)
  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.
- **Project meeting** 4th July in Munich (R. Stolz, W. Mauser, M. Weber, M. Ebner)

  The state of the project and the structure of the upcoming report were discussed.
- **XXVII Conference of the Danubian countries**, 26-28 September in Golden Sands (Bulgaria (R. Stolz, W. Mauser)
  Presentation of results
- **46th River Basin Management Expert Group Meeting** 14-15 November 2017, Bucharest
  A draft of the preliminary final report was presented for discussion

- **21st Ordinary Meeting of the ICPDR,** 20 December 2017, Vienna
  The main outcomes of the study were presented
- **ICPDR Climate Change Adaptation Workshop,** 27th/28th March 2018, Belgrade
  The final report was presented

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) (fig. 1), which are based on ten sub-catchments (fig.2). 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 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.

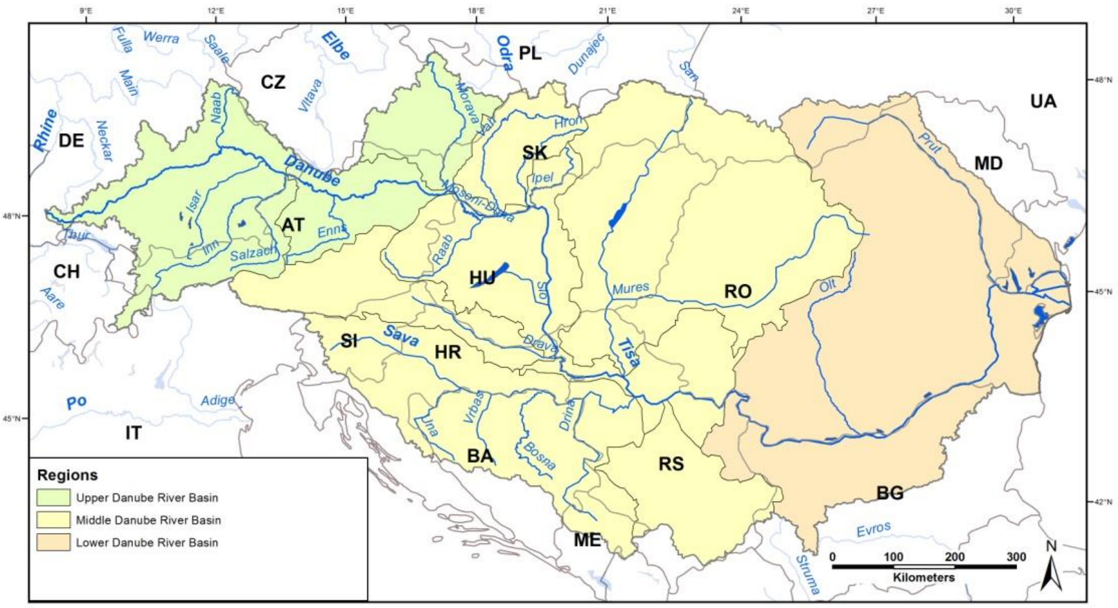

Figure 1: Main regions of the Danube River Basin

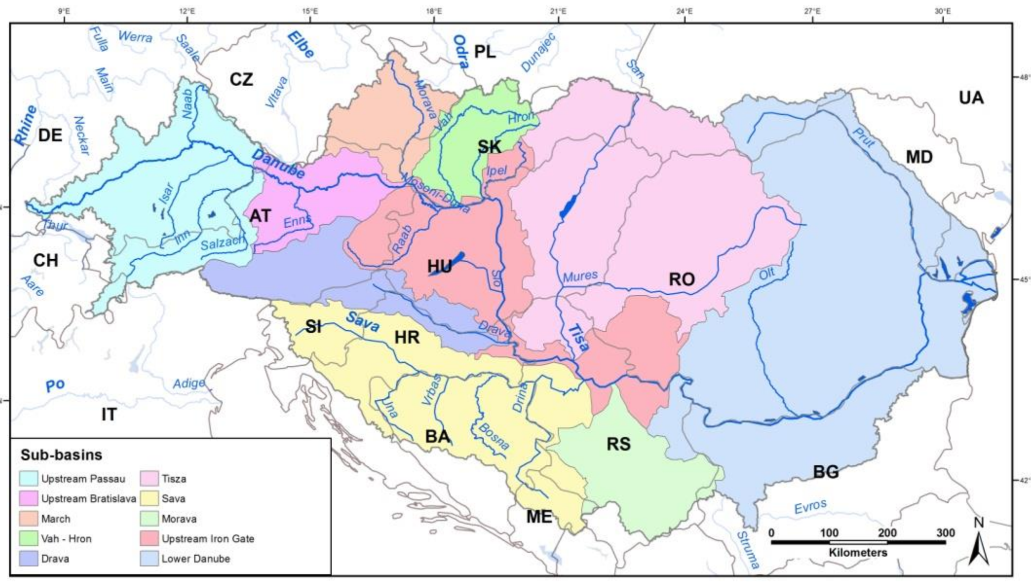

Figure 2: Main sub-basins of the Danube River Basin

2 Data Compilation and Analysis

The presented results are solely based on the analysed studies, projects and adaptation activities. Only documents, reports and papers which have been published and are accessible through libraries or internet in English, German or French could have been taken into account.

The methodology of the analysis and the zoning of the DRB had been adopted from the first study to secure the comparability. Main focus of the analysis of 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.

Results and findings from the first study remain valid. No contradictory conclusion was examined. The development and improvement of the knowledge base mainly refer to improved climate scenarios and models. The conclusions related to the expected changes in climate can now be stated more precisely. The increase of the level of knowledge for the impacts of climate change is mainly due to additional data, longer monitoring periods and improved regional models. In several categories the uncertainty of conclusions could be reduced.

2.1 Research and development projects

In total, 73 research and development projects and studies are included in this analysis. Only projects which a) started before 2012 and finished after 2012 (date of the final report), b) started and finished after 2012, and c) started after 2012 and yet ongoing were taken into account. Studies and reviewed papers published after 2012, but using data which are older were not taken into account. Nevertheless also these documents had to be reviewed. So overall many more studies and projects had to be analysed. 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)
- Impacts on: agriculture, irrigation, forestry, land use, biodiversity / ecosystems, water related energy production and navigation

To classify the reliability of the content, the documents are grouped in

- Reviewed: peer-reviewed papers in scientific journals, books
- "Grey" literature: Reports, fact sheets, non-reviewed papers etc.
- Internet documents

Besides the development projects and studies, 37 National Adaptation Strategies, the [h]National Communications under the UNFCCC (6th UNFCCC), conventions, strategies and guidances all published, updated or reviewed between 2012 and August 2017 were analysed as well.

The majority of projects are funded by EU programmes, namely the 7th framework programmes, the INTERREG programmes Alpine Space as well as the South East Europe Transnational Cooperation Programme or other EU programmes. 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.

To facilitate the comparison of findings between the first and the updated study, the information gathered by the analysis of the research and development projects and studies is stored in a database within 17 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.

2.2 Adaptation 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 (e.g. BAYKLAS, BayKliZ) [8] and the national (e.g. German Adaptation Strategy) [126] level are collected and integrated in the data base, if available.

Figure 3: Countries with National Adaptation Strategies in the DRB

The NAS and NCs focus on the assessment of the present situation and of the requirements for adaptation to climate change on a national level. 12 of the 15 DRB countries (except Montenegro and Moldova) have contributed to the UNFCCC (Ukraine only in Russian). Since 2011 in six more countries National Adaptation Strategies are meanwhile adopted (fig. 3) and National Action Plans are installed and all countries established the 6th NC.

Comparing the 6th and 5th National Communications under the UNFCCC for each country referring to the climate change knowledge base, the chapters to climate change and adaptation to climate change vary significantly. For some countries both NC do not show any differences (e.g. Bulgaria, Croatia, Bosnia, Slovenia), or the 6th NC has even less information and is referring the NAS (e.g. Germany, Austria). The 6th NC of Romania and Czech Republic contain significantly more and updated information. To sum up, it can be pointed out most of the 6th NC do not show much differences or new information compared to the 5th NCs.

The recently adopted and updated NAS and Action Plans were analysed with regard to impacts of climate change, and for which issues adaptation measures are suggested. Fig. 4 shows the percentage of both, addressed issues and suggested adaptation measures for the different impact fields according to the analysed activities. Unfortunately for 4 countries (Czech Republic, Romania, Slovenia, Ukraine) the NAS and Action Plans are only available in the local language, with short executive summaries in English for Czech Republic and Romania and no summaries for Ukraine and Slovenia. In Serbia no NAS is available yet and the update of the German NAS is a progress report, not addressing climate change issues.

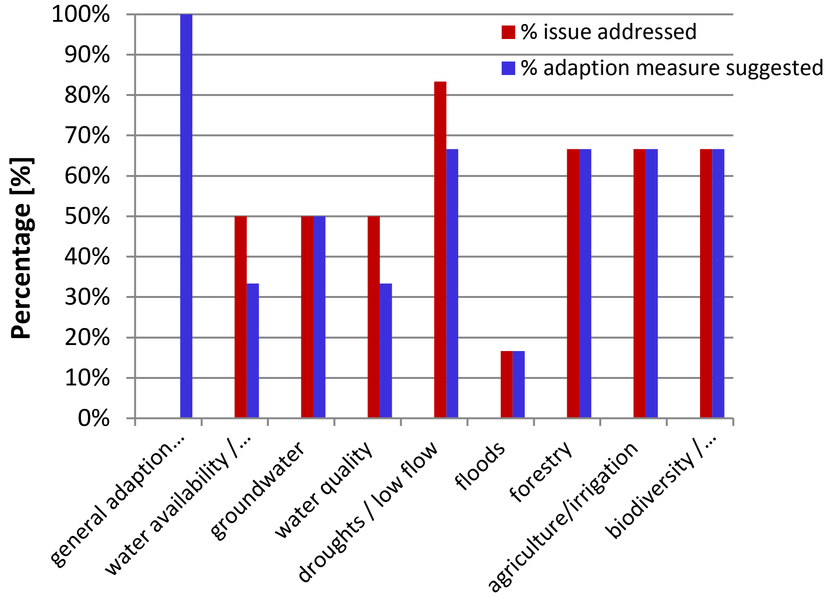

Figure 4: Percentage of addressed climate change issues (red) and suggested adaptation strategies (blue) in National Adaptation Strategies (adopted or updated 2012-2017)

Additionally, relevant reports and further activities on the administrative level in relation to climate change impacts are considered (fig. 5) as for example the EEA report "Climate change, impacts and vulnerability in Europe 2016" [40]. Administrative regulations, such as the EU White Paper, the Water Framework Directive, and other related directives or River Basin Management Plans [63] and conventions are collected to cover the political background of the study [38,44,129].

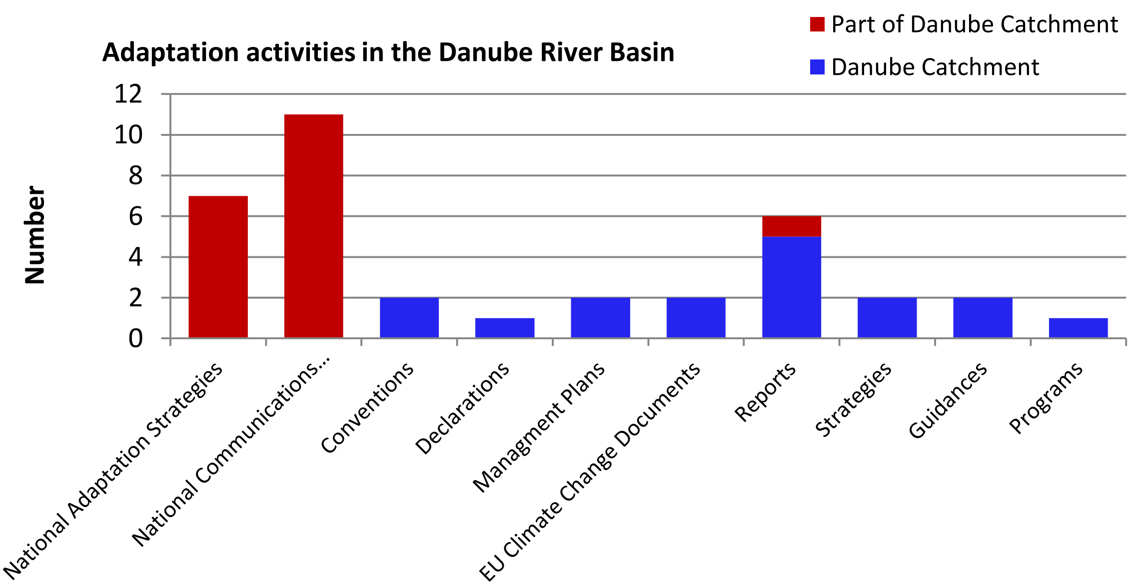

Figure 5: Overview of analysed adaptation activities, covering parts of (red) or the entire DRB (blue)

Besides general, water related adaptation measures, hydrological extreme events (droughts and floods) are mostly addressed by the adaptation activities, followed by the agricultural sector and biodiversity. Besides the water related issues, in all NAS socio-economic issues and their adaptation play an important role.

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) [74]. 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 [14].

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.

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.

Besides the amount of statements of all projects and studies, the amounts of statements of all adaptation strategies are listed for each impact in the first study. For an update of the certainty, only statements of papers, reports and adaptation strategies since beginning of 2012 were taken into account. Because for this period less material is available than for the first study, the problem occur that not all impacts were investigated by a larger number of projects. The certainty cannot be increased, if just two statements are available, although they have a high agreement. The certainty was only taken into account, if four or more statements are available. Fig. 6 gives an overview about the degree of uncertainty of the climate elements and the main impacts considered in this study and the changes in uncertainty, indicated by the arrows and a change in colour, in comparison to the first study. The impacts are assigned to the impact areas climate elements, water availability, extreme hydrological events, water use and ecosystems.

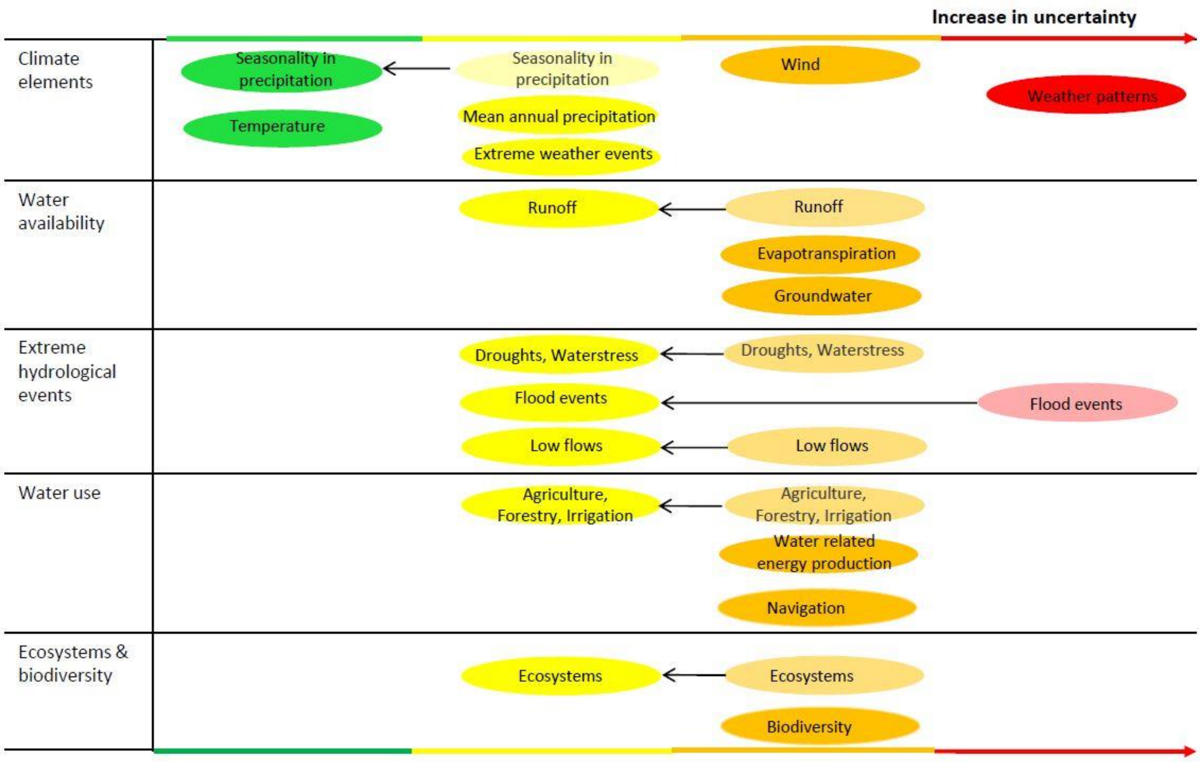

Figure 6: Uncertainty and changes in uncertainty of climate elements and main impacts due to the four certainty-categories: very high (green), high (yellow), medium (orange) and low (red).

Climate elements: According to Fig. 6 changes in temperature are classified with very high certainty. Thereby, future development of both, the mean annual and seasonal temperature, is a hard fact. The certainty of the future development of annual mean precipitation is high, however, less reliable than temperature changes, mainly for spring and autumn. But meanwhile all analysed projects agree with very high certainty that the seasonal distribution will change to higher precipitation in winter and less in summer. This can be taken now as a hard fact as well. In future, extreme weather events, classified with a high certainty, will show higher variabilities in quantity, seasonality and space [54].

Water availability: The impacts on evapotranspiration and groundwater are all rather uncertain and classified with a medium certainty. Changes in water availability largely depend on precipitation, where a shift in seasonality is expected with very high certainty. Subsequently changes in runoff and in particular its seasonality are marked as highly certain. The largest and most certain changes are expected for the LDRB.

Extreme hydrological events: The strongest increase in certainty since the first Danube study can be seen for extreme events [51,59]. The new, high resolution RCMs give projections with a higher significance. Due to the high certainty of extreme weather events and the more reliable projections of heavy rainfall events, the certainty increased for all hydrological extreme events. Flood events show the strongest increase. There is high certainty that flood events will become more frequent in all regions [49,54,75,100]. However, no conclusion about the severity of the events can be drawn. It is expected, that smaller rivers and creeks are stronger affected than larger ones. The general tenor in the statements is that due to the increase in heavy precipitation events, the flood events will increase as well.

Water use: Regarding the impacts on different fields of water use, water related energy production and navigation are classified with a medium certainty. There is no agreement within the DRB, although for some parts of the basin the agreement is high. Navigation might benefit in winter due higher runoff in the upper DRB and to less icing but in summer shipping will be restricted in the UDRB due to more days with low water conditions. Low water conditions in the MDRB and LDRB seems not to affect the navigation too much, because the discharge seems still sufficient enough in the lower river valley [50,72,109]. The impacts on agriculture are investigated to a high degree, especially the water availability in summer for irrigation. Statements highly agree that irrigation has to be increased, but that there will be a lack of water in the MDRB and LDRB. For water related energy production, e.g. hydroelectric power generation might possibly increase in winter and decrease in summer. There is no general agreement to which extent hydropower and also thermal power stations will be influenced. The statements differ depending on the region investigated, but they all agree that in summer there will be negative impact [106, 133].

Ecosystems and biodiversity: With a high certainty, climate change could lead to the fact that water quality deteriorates and water temperature increases which will have a strong effect on aquatic ecosystems. Moreover, vulnerability due to climate change might increase for aquatic ecosystems with high certainty and biodiversity might decrease with medium certainty.

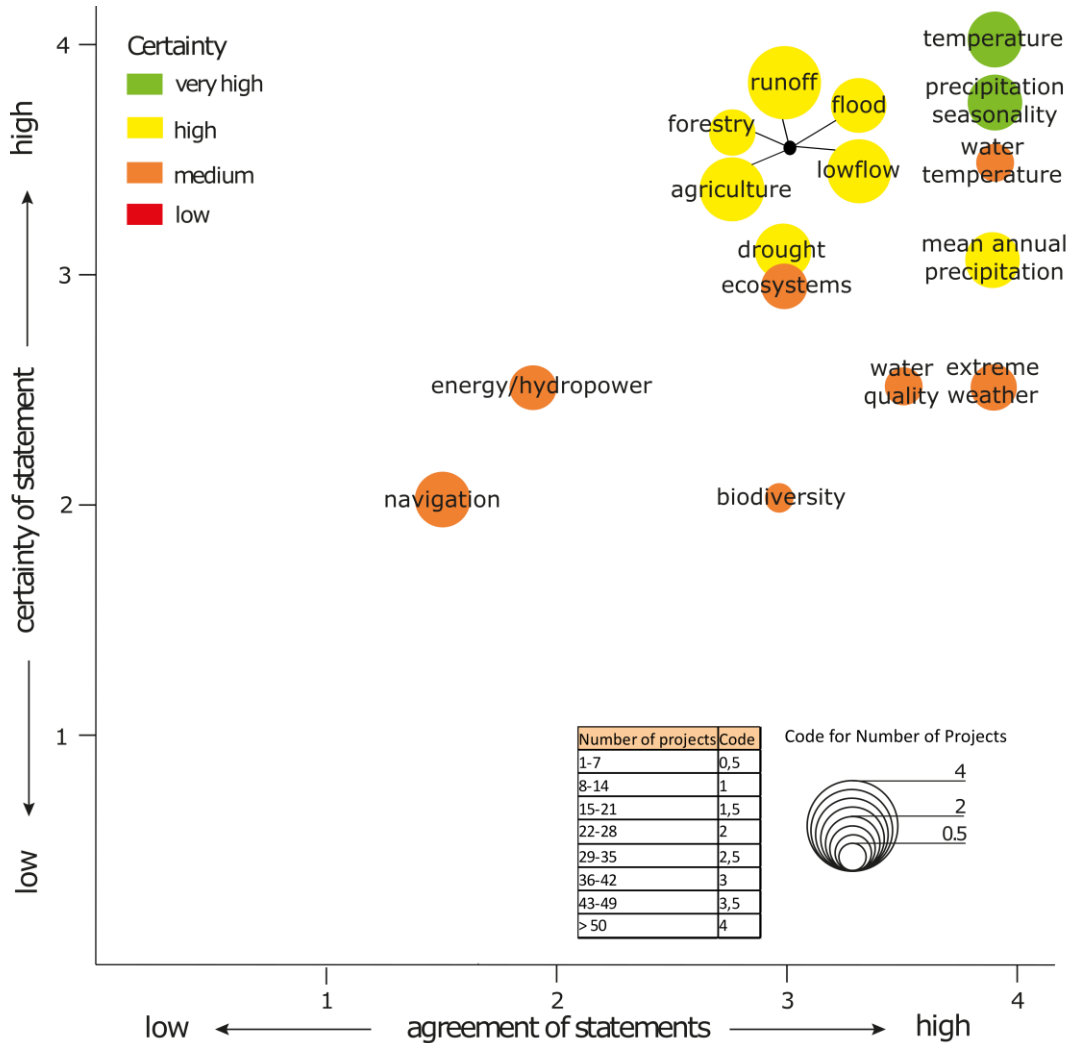

Figure 7: Revised and updated overview of certainty for projected climate change impacts in the DRB.

Figure 7 presents the revised and updated overview for projected climate change impacts of the analysed sectors in the DRB. In addition to Figure 6 it gives information about the certainty of statements, the agreement of statements and the amount of studies, which were analysed. It has to be noted that forestry, agriculture, flood, low flow and runoff are located at the same place, which is represented by the black dot. However, they differ in the amount of analysed documents. It can also be seen that impacts on water temperature are classified with medium certainty, despite the agreement and certainty of statements is high. Due to the low amount of studies a higher classification is not possible and compared to the results of the first Danube study (Figure 8) a shift to higher agreement of statements is made. Results for energy/hydropower remained the same, which is due to little availability of studies in that sector. In contrast to the first study, a higher agreement and certainty on the impact on water quality becomes clear. When it comes to precipitation, it has to be noted that the updated study distinguishes between mean annual precipitation and precipitation seasonality. It is highly certain, that seasonality changes, whereas the development of mean annual precipitation is unclear for the near future and reliable statements are only made for the far future. Due to contradictory and vague statements the certainty of impacts on navigation did not improve in comparison to the first Danube study. However, certainty for climate change impacts on forestry, agriculture, flood, low flow and runoff certainty significantly improved. Also certainty of impacts on ecosystem and biodiversity is not higher. This is mainly due to the fact, that changes in ecosystems and biodiversity are highly influenced by reciprocal effects and indirect climate change impacts, which are not studied in detail until now. Moreover, impacts greatly vary and are not clearly understood so far. It highly depends on which aspects are focused, e.g. terrestrial ecosystems, aquatic ecosystems or species composition. Thus it is difficult to draw a consistent picture of climate change impact on biodiversity and ecosystems.

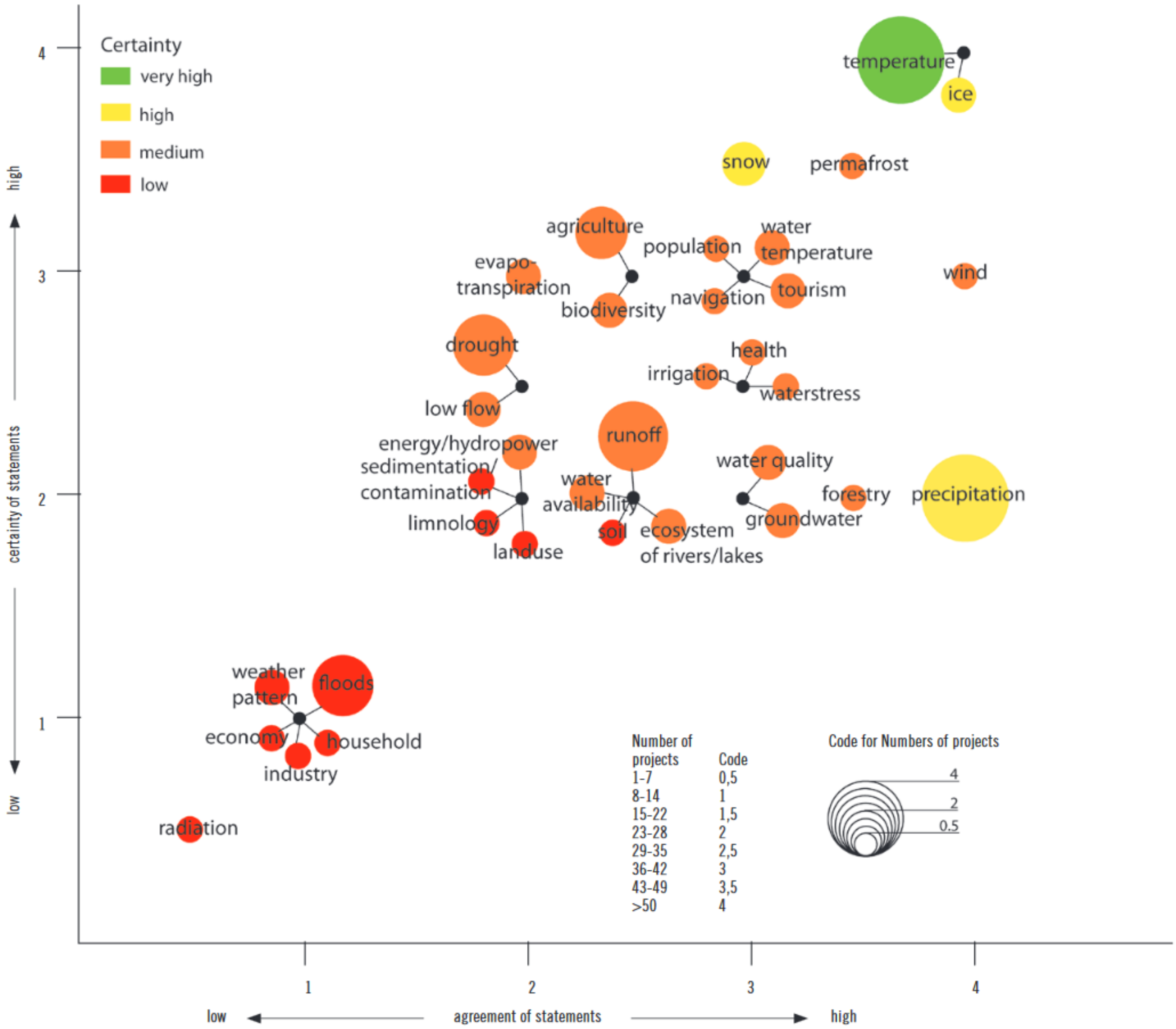

Figure 8: Overview of certainty for projected climate change impacts in the DRB [62].

Key findings and comparison to the previous study

Not for all impacts a sufficient amount of statements could be analysed to define a certainty level and compare it to the results from the first study. Nevertheless it appears that especially for climate elements, extreme hydrological events, changes in runoff regimes, agriculture, forestry and irrigation the certainty of the actual statements is higher than in the first study. For water related energy production and navigation, statements are highly contradictory. Thus no increase in certainty compared to the first study can be achieved.

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, studies and National Adaptation Strategies use the IPCC emission scenarios A1B, A2, B1 and B2 [90]. Most of the projects started before the IPCC AR5 was published and the model results of the new RCP scenarios were available. During a term of a research project models and scenarios were not changed. However, other emission scenarios are also applied in a projects and studies, which mainly started after 2013. 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 50 km (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.

The National Adaptation Strategies and National Communications often include the model results. The targeted measures and proposed action described in the strategies are based on IPCC climate scenarios and global and regional climate models (GCM, RCM). But the use of different scenarios hinders the comparability of climate change model results within the DRB. Moreover not only different scenarios and global and regional climate models are in usage, the reference and modelling periods differ significantly as well. Tab.1 & 2 show the analysis of the NAS and NC concerning the IPCC scenarios, reference and modelling periods.

Table 1: Applied climate scenarios in National and Regional Adaptation Strategies and the 6th National Communications. In three countries no specifications about climate scenarios can be found in the reports.

	SRES				RCPs				
	A1B	A2	B1	B2	8.5	6.0	4.5	2.6/3-PD	n.i.
Germany	blue	blue	blue		red	red	red		
Bavaria (regional)	blue/red	blue	blue						
Austria	blue				red		red		
Czech Rep.	red								
Slovakia		blue	blue						
Swizzerland	blue	blue						blue	
Slovenia									green
Croatia		blue							
Serbia	blue/red	blue/red							
Bosnia-Herz.	blue	blue		blue					
Montenegro									green
Bulgaria	blue								
Romania									green
Hungary	blue	blue			red		red		
Moldovia		blue		blue					
Ukraine	blue	blue			red		red		

NAS / reports/ NC 2012-2017	red
NAS or/and NC until end 2011	blue
no information	green
scenarios utilized in both time periods	blue/red

Table 2: Modelling periods used for the projection of future climates in the DRB

Referenz period	Bavaria / Germany	Austria	Czech Rep.	Slovakia	Swizzerl.	Slovenia	Croatia	Serbia	Bosnia-Herz.	Montenegro	Bulgaria	Romania	Hungary	Moldova	Ukraine
2001 - 2011											■				
1991 - 2010															■
1980 - 2009					■										
1986 - 2005															
1971 - 2000	■	■										■	■		
1961 - 1990				■		■	■	■	■						
no information			■							■				■	
Near future															
1991-2020				■											
2001 - 2030								■	■						
2010-2039			■								■			■	
2011-30															■
2011-40							■								
2021-2050	■	■										■	■		
2020-2045					■										
no information						■				■					
Far future															
2071-2100	■			■	■	■	■	■	■			■	■		■
2065-2094											■				
2070-2099														■	
no information		■	■							■					

The scientific basis of projects which not have been finished by the end of 2011 has been examined regarding the field of modelling, projection period/horizon, regional coverage, models (-ensembles), scenarios and databases. The focus is on the identification of projects that take the RCP scenarios, evolved from the Fifth Assessment Report of the IPCC, into account. The RCP scenarios replaced the SRES-scenarios and thus prevail in actuality [65,90]. A comparison between scenario specific results is crucial for the future course of the project, since recent studies on climate change impacts predominantly use RCP scenarios. Succeeding work packages aim at quantifying reference values and analysing differences in model outputs of the common climate and hydrological parameters within a meta-analytical approach.

Global climate models (GCM) in projects involving climate modelling

A high variety of GCMs are used in all considered projects. Unspecified model-member of the ENSEMBLES project are found in five projects, specific members of ENSEMBLES (e.g. ARPEGE, HadCM3 and ECHAM5, further description in van der Linden & Mitchell (2009) [132]) are most commonly used, while the main GCM in the CORDEX project [52] is considered in three projects. A high number of other GCMs are used but cover merely single projects (fig.9). It must be noted that in most of the projects model-ensembles generate the resulting projections. Members of these ensembles differ by specifications of the projects.

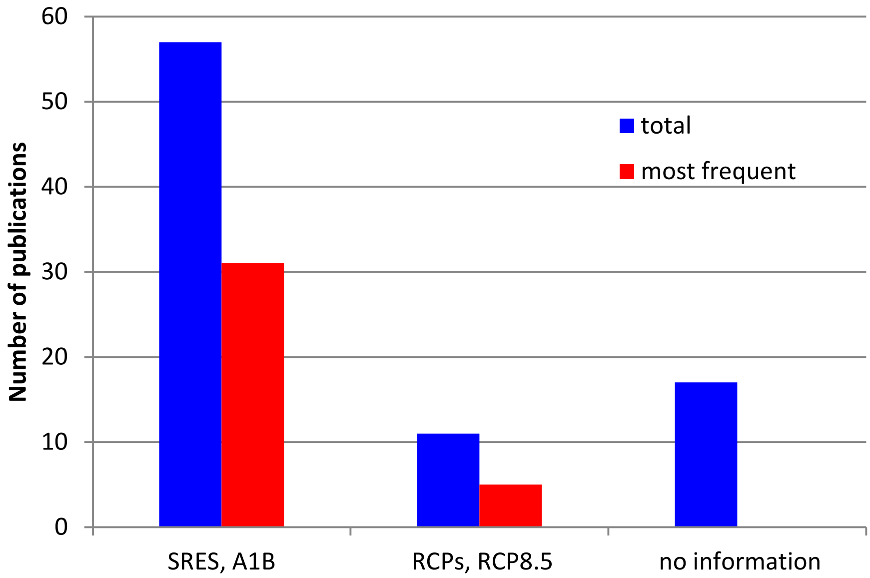

Figure 9: Scenarios used in analysed studies and research projects

4.2 Air temperature

At the end of the research period of the first Danube Study, in total 18 of the projects and studies that have not been completed or their final report has not been published (in the following referred to as "projects") now provide climate projections and resultant air temperature and precipitation trends. An overview of the considered projects and their simulation horizon as well as projected scenarios are given in table 3. It must be noted that nine projects refer to data that were produced within the ENSEMBLES project whereas two revert to the PRECIS project. Additional literature, National Adaptation Strategies (NAS), National Communications (NC) and published papers were reviewed as well but are cited separately.

Table 3: Timescales and scenarios of ongoing studies that provide climate projections and related studies.

Project name	Date of report	Timescale reference	Timescale near	Timescale mid	Timescale far	Scenarios/ Pathways
Bartholy et al. 2014 [6]	2014	1961-1990	2021-2050		2071-2100	A1B, A2, B1, B2 (PRECIS)
CC-WATERS [21]	2012	1961-1990	2021-2050		2071-2100	A1B (ENSEMBLES)
CLIMATECOST [28]	2011	1961-1990	2011-2040	2041-2070	2071-2100	A1B, E1 (ENSEMBLES)
CLIMSAVE[29]	2013	1961-1990	2025	2055		A1B, B1, B2
Hlásny et al. 2016 [58]	2016	1961-1990	2021-2050		2071-2100	A1B (ENSEMBLES)
Jacob et al. 2014 [66]	2014	1971-2000	2021-2050		2071-2100	A1B, RCP4.5, RCP8.5 (ENSEMBLES)
KLIWA [70]	2012	1971-2000	2021-2050		2071-2100	A1B, B2
KLIWAS [71]	2014	1951-2006	2021-2050		2071-2100	A1B
Laaha et al. 2016[77]	2016	1976-2008	2021-2050	2051–2080		A1B, B1, A2
Lobanova et al 2015 [80]	2015	1971-2000	2021–2050		2071-2100	A1B (ENSEMBLES)
Madsen et al. 2014 [81]	2014					Review paper
MANFRED [82]	2013	1961-1990		2051-2080	-2100	A1B (ENSEMBLES)
Pieczka et al. 2011[97]	2011	1961-1990			2071-2100	A1B, A2, B2 (PRECIS)
PESETA-II	2014	1961-1990			2071-2100	A1B, RCP8.5
SILMAS [113]	2012	1961-2000	2001-2050			A1B (ENSEMBLES)
Schneider et al. 2013 [109]	2013	1971-2000		2041–2070		A2 (WATCH)
Stagl et al. 2015 [123]	2015	1971-2000	2031–2060		2071-2100	A1B, RCP8.5, RCP6, RCP2.6 (ENSEMBLES, ISI-MIP)
WATCH [134]	2011	1971-2000	2021-2050		2071-2100	A2, B1
WEATHER [135]	2012	1961-1990	2021-2050		2071-2099	A1B (ENSEMBLES)

Following, a generalized simulation horizon is chosen where timescales until 2050 are defined as near future period and beyond 2050 as far/distant future period. Soft definitions (e.g. “mid-century”) are classified in the respective project context.

Danube River Basin (DRB) [26,28,29,66,71,109,119,134,135]

- **Projects**

Climate projection results considering the DRB in particular are given by three projects [71,119,134]. A further constraint is the lack of explicit data within the WATCH [134] project, thus the here presented projections are estimations derived from included graphs. Studies regarding Europe are presented as well but should be contemplated carefully due to a lack of concrete DRB context.

Mean annual air temperature

Stagl & Hattermann 2015 [119] state there is a “clear warming trend for the Danube towards the middle of the 21th century”, which is most pronounced in the southern parts of the LDRB with more than 2 °C (A1B) and less distinct in the UDRB. KLIWAS [71] anticipates an increase of 0.5 °C to 2.5 °C For the SRES A2 an increase lower than 2.0 °C for the near future period and more than 4.0 °C for the distant future is projected, whereas respectively in the B2 scenario an increase lower than 2.0 °C and lower than 3.0 °C is expected [134].

Europe:

The WEATHER-project [135] simulates an increase of 0.5 °C to 2.0 °C (SRES A1B) for the near future period and 3.5 °C to 4.0 °C for the distant future. The study of Jacob et al. 2014 [66] reveals statistically robust trends implying a mean annual temperature increase of 1°C to 4.5°C for RCP4.5, 2.5°C to 5.5°C for RCP8.5 and 3 °C to 4.5 °C for SRES A1B. Furthermore “the projected spatial patterns are very similar in all scenarios with greater annual mean warming in Southern Europe and towards the northeast” [66]. Nevertheless, regional heterogeneity becomes apparent by comparing the spatial patterns of RCP4.5 and SRES A1B. Considering temperature projections realized for RCP4.5 and A1B in a regional context, a slightly higher temperature increment can be seen compared to the RCP4.5 in DRB relevant sub regions of Europe. For continental Europe the projections range from +1.6 °C to +3.2 °C for RCP4.5 and +2.8 °C to +4.5 °C for SRES A1B and SRES A2 [66,109]. For RCP8.5 and the distant future trends are more pronounced (see figure 10 & 11). Trends for the alpine space vary between +1.9 °C to +3.4°C and +3.1 °C to +4.5 °C respectively. Trends for Southern Europe are determined consistent in range of +1.9 °C to +2.7 °C for RCP4.5 and +3.3 °C to +4.1 °C for SRES A1B. While the mean trends in Europe are similar, still significant regional heterogeneity between modelling outcomes can be detected.

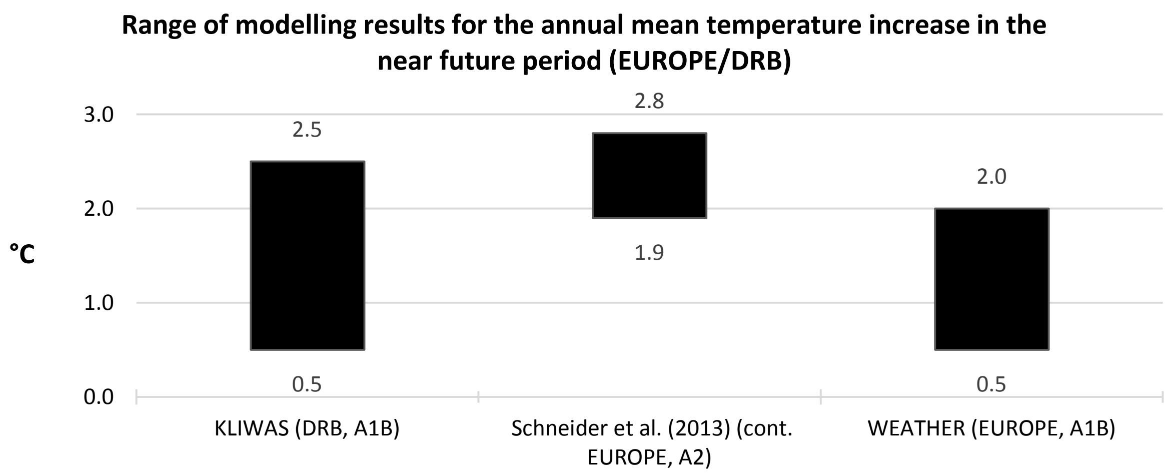

Figure 10: Summary of modelling results for the annual mean temperature increase in the near future period for Europe and the DRB.

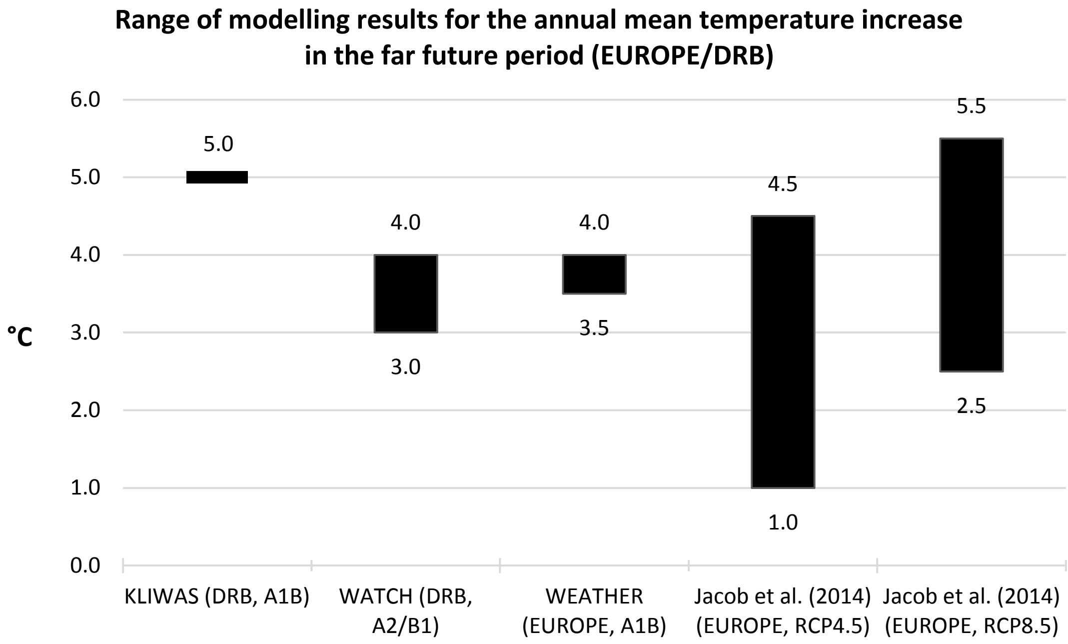

Figure 11: Summary of modelling results for the annual mean temperature increase in the far future period for Europe and the DRB.

Mean summer air temperature

KLIWAS [71] anticipates a mean summer air temperature increase of 1.0 °C to 2.0 °C for the near future period.

Europe:

For the near future period a temperature increase of 1.0 °C to 3.6 °C (SRES A1B, B1 and B2) is projected [29]. CLIMATECOST [28] simulates an increase of 3.5 °C for the A1B scenario in the distant future. For RCP4.5 and RCP8.5 a north-south gradient with the strongest warming in the Mediterranean and Black Sea region is projected by Jacob et al. (2014) [66].

Mean winter air temperature

KLIWAS [71] anticipates a mean winter temperature increase of 0.5 °C to 2.5 °C for the near future period.

Europe:

CLIMSAVE [29] projects an increase of 1.1 °C to 4.9 °C for the near future period. The largest changes are projected in winter for northern (partially Eastern) Europe. CLIMATECOST [28] simulates an increase of 3.6 °C under the SRES A1B scenario for the far future period. In winter, positive trends in temperature are less pronounced in Western Europe though showing a strong increasing gradient towards the north east under RCP 4.5 and RCP 8.5.

Findings for the near future period are summarized in figure 12.

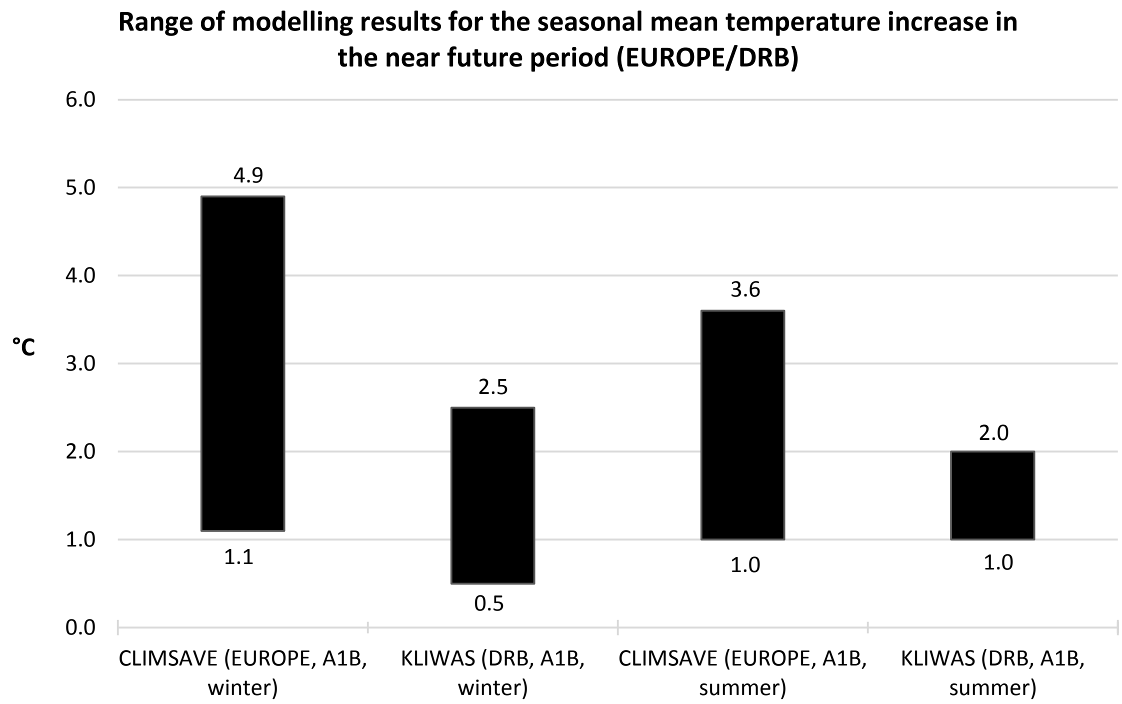

Figure 12: Summary of modelling results for the seasonal mean temperature increase in the near future period for Europe and the DRB.

- **National Adaptation Strategies (NAS) and National Communications under the UNFCCC (NC)**

No model results are given for the entire DRB and Europe. A summary of projections for the sub-catchments is given in figure 13 & 14.

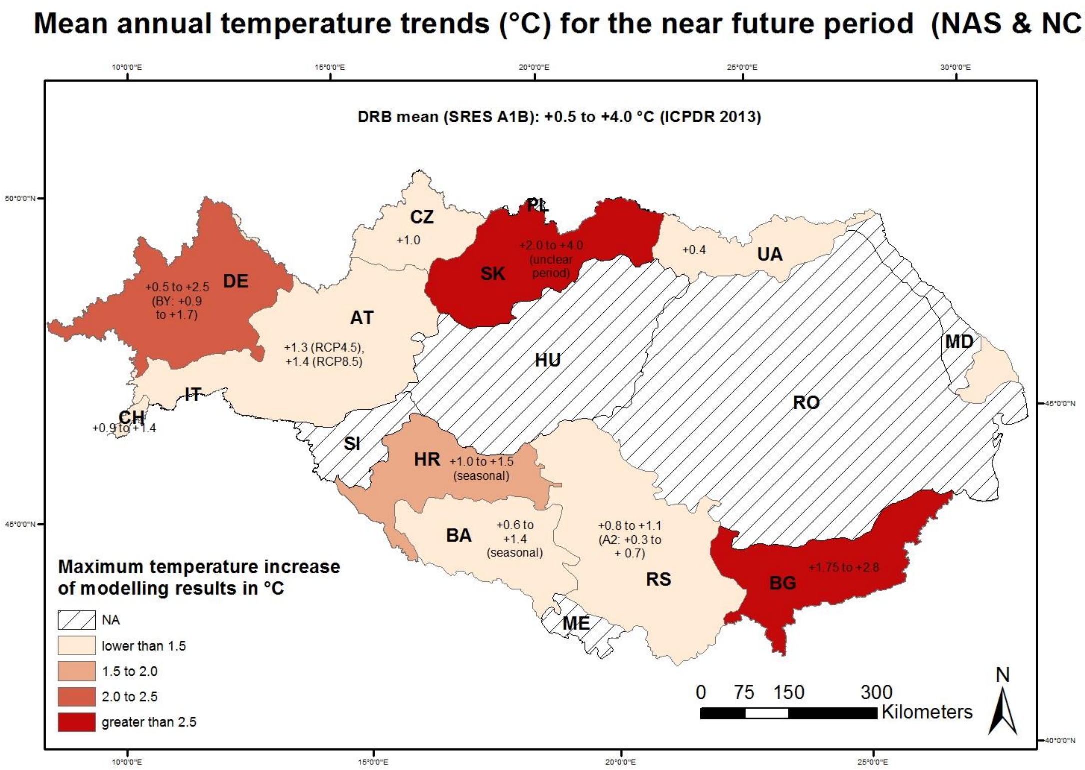

Figure 13: Mean annual temperature trends (°C) for the NAS and NCs in the near future period. Unless otherwise stated, the applied scenario is SRES A1B.

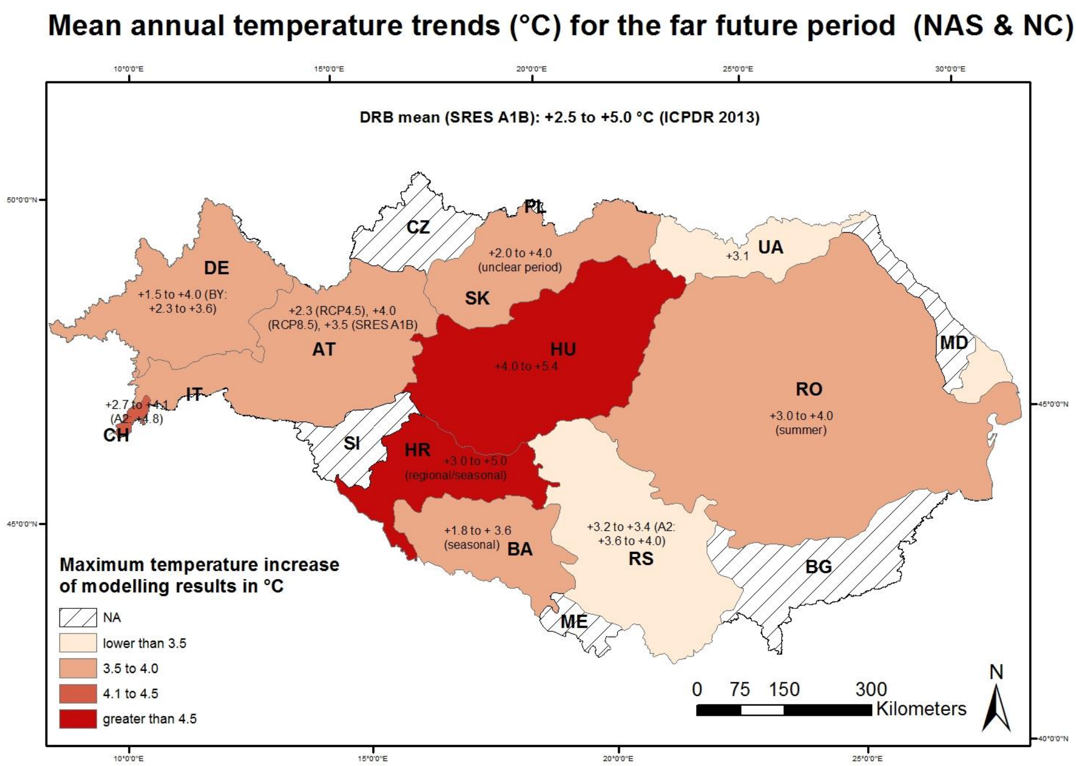

Figure 14: Mean annual temperature trends (°C) for the NAS and NCs in the far future period. Unless otherwise stated, the applied scenario is SRES A1B.

Key findings and comparison to the previous study

The temperature projections for the near and far future period of the ongoing projects predominantly resemble the outcomes of the first Danube Study. Minor differences in temperature value ranges become apparent but considering varying scenarios and projection horizons within the projects they are insignificant. Due to the ENSEMBLES project as a major data provider for various projects in the first Danube Study as well as in the Update Danube Study, this was an expected outcome in terms of temperature trends.

Considering modelling results of RCPs and the SRES Scenarios it becomes obvious that these are similar in temperature ranges, but in terms of spatial heterogeneity the RCPs offer a more differentiated view with pronounced warming hotspots in the alpine space and southeast Europe especially for the RCP8.5. Spatial correlation between RCP8.5 and SRES A1B ranges between 0.82 to 0.97 for the near future with a stronger correlation in the far future period [66].

Upper Danube River Basin (UDRB) [47,70,71,76,82,113]

- **Projects**

Mean annual air temperature

For the near future period in the SRES A1B projections vary between an increase of 0.5 °C to 2.5 °C and up to 5°C for the far future maximum with a more pronounced warming in winter [70,71]. For alpine regions temperature projections are similar but with seasonal differences depending on considered study. For RCP4.5 an increase of 1.3 °C for the near future and 2.3 °C for the distant future is anticipated. Respectively, for RCP8.5 an increase of 1.4 °C and 4.0 °C is simulated.

Mean winter temperature

Winter temperature ranges between an increase of 2.4 °C (RCP4.5) and 4.4 °C (RCP8.5) [47].

- **National Adaptation Strategies (NAS) and National Communications under the UNFCCC (NC)** [4,9,46,125]

Mean annual air temperature

For the near future period an increase of 0.9 °C to 2.0 °C with seasonal and spatial differences is projected by NAS and NC for the UDRB, whereas a more severe change of mean annual temperature of 2.0 °C to 4.8 °C is simulated for the distant future. The predominantly applied scenarios are SRES A1B and furthermore A2, RCP4.5, RCP8.5, RCP3PD.

Key findings and comparison to the previous study

See section Danube River Basin (DRB) in Chapter 4.2

Middle Danube River Basin (MDRB) [6,21,58,97,136]

- **Projects**

Mean annual air temperature

An increase of 1.3 °C to 2.6 °C is projected for the mean annual temperature in the MDRB for the near future period. In the far future period temperature trends vary between an increase of 3.1 °C to 5.4 °C for SRES A1B. Further, a great variation in time and space becomes evident.
Hlásny et al. (2016) [58] simulated an increase of 3.2 °C to 3.8 °C for the far future period in the Carpathians, with a heterogeneous pattern including regional hotspots showing an increment up to 5.1 °C.

Mean summer air temperature

The mean summer air temperature for the near future period is projected to increase 1.5 °C to 3.7 °C for SRES A1B [6,21]. The far future period temperature is projected to increase 3.4 °C to 6.7 °C. SRES A2 and B2 were applied as well, resulting in a maximum increase of 8.0 °C and 6.0 °C for the near future period.

Mean winter air temperature

The mean winter air temperature for the near future period is anticipated to increase 1.0 °C to 2.5 °C under SRES A1B [6,21]. The far future period temperature is projected to increase 2.5 °C to 4.1 °C. Further SRES A2 and B2 were applied resulting in a maximum increase of 4.2 °C and 3.2 C for the near future period, respectively. Pieczka et al. (2011) [97] stated that the projected increase shifts towards the larger temperature values.

- **National Adaptation Strategies (NAS) and National Communications under the UNFCCC (NC) [27,85,86,88,89,102–104,111]**

Mean seasonal air temperature

Statements regarding the near future period vary from an increment of 0.2 °C to 1.5 °C. Far future temperature change is projected to be in a range of 2.4 °C to 5.4 °C. However, this data refers to mean seasonal temperature changes instead of the annual mean. Applied scenarios and RCPs are mostly SRES A1B and A2 as well as B1 and B2.

Considering the NAS and NC, it must be noted that it is complex to draw consistent statements of temperature development for the entire catchment of the MDRB since projection periods, reference periods and the temperature indices are different and often not clearly defined.

Key findings and comparison to the previous study

See section Danube River Basin (DRB) in chapter 4.2.

Temperature projections tend towards the greater changes in comparison to the first Danube Study. The temperature is projected to be significantly higher in the distant future. Additionally, spatial variability of projections becomes apparent. However, due to an inconsistent modelling base of the considered projects distinct statements are challenging to provide.

Lower Danube River Basin (LDRB) [33,119]

- **Projects**

An increase of 1 °C to 2.5 °C (A1B) in annual mean temperature until the mid of the century is projected, most pronounced in the southern parts of the LDRB [119]. For the distant future the temperature increment ranges from 1.8 °C to 5 °C.

- **NAS + NC**

It is impossible to find a consistent statement for the entire LDRB since countries do not have similar reference or projection periods, and due to a lack of definite values.

Key findings and comparison to the previous study
A comparison is not possible due to a lack of data.

4.3 Precipitation

See chapter 4.2.

Danube River Basin (DRB) [28,29,66,71,109,119,134,135]

- **Projects**

Annual mean precipitation

For the DRB a decrease of lower than 5 % is projected for the near future period under SRES A2 and SRES B2. In the far future the projections vary between a decrease of 5 % to 10 %.

Europe:

The WEATHER-project [135] provides more general statements which can be summarized as a possible increase of annual amount in northern Europe and a decrease of precipitation in the south of Europe for the near future period. The far future period is characterized by the same configuration of change but more pronounced (up to -20%). Jacob et al. (2014) [66] state that "the ensemble mean projects a statistically significant increase in large parts of Central Europe and Northern Europe of up to about 25 % and a decrease in Southern Europe. […] The pattern of the changes is very similar for RCP4.5, but less pronounced. The spatial pattern for A1B precipitation changes qualitatively agrees with the described changes for RCP4.5 and RCP8.5, and the magnitude of the changes mostly lies in-between the two RCPs".

Considering the spatial distribution of precipitation trends, the far future simulation for continental Europe and RCP4.5 is +1 % to 13 % and -1 % to 5 % for SRES A1B. This accounts for the alpine space +4 % to 8 % and +5 % to +12 %, respectively. For southern Europe trends of -10 % to 0 % for RCP4.5 and -12 % to -18 % for SRES A1B were found. Results for RCP8.5 are more pronounced than the ones of RCP4.5.

Summer/Winter mean precipitation

KLIWAS [71] projects precipitation changes from -10 % to +5 % in summer and -10 % to +10 % in winter for the near future period.

Europe:

Since it is hard to give exact values of precipitation trends due to an inconsistent database and especially the heterogeneous reference areas, rather generalized statements can be drawn. The considered studies reveal seasonal and spatial differences across Europe. Thus, a spatial gradient is obvious with an increasing trend in the north and decrease in the south for winter while precipitation in eastern Europe might increase slightly (+7.70 mm; SRES A1B [28]). In summer, the largest drying trends are projected in southern (-26.40 mm; SRES A1B [28]) and eastern Europe (-28.46 mm; SRES A1B [28]). Considering Europe-mean CLIMSAVE [29] projects a decrease of -2.0 % to -29.5 % for the near future period in summer and +1.1 % to +12.5 % in winter for SRES A1B, B1 and B2. More pronounced trends are expected for the far future period. Nevertheless, most projects agree that in winter precipitation is likely to increase in the northern parts of Europe.

Jacob et al. (2014) [66] state that "in winter, only the most southern parts of Spain, Italy, Greece, and Turkey experience a decrease, while there is an increase for the rest of Europe. The separation band moves northward in spring, until in summer an increase is only seen in Scandinavia and North-Eastern Europe, while there is a drying in Western, South-Eastern, and parts of Central Europe". For RCP8.5 spatial patterns are similar but larger in magnitude.

- **NAS + NC**

A summary of projections for the sub-catchments is given in figure 15, 16 and 17.

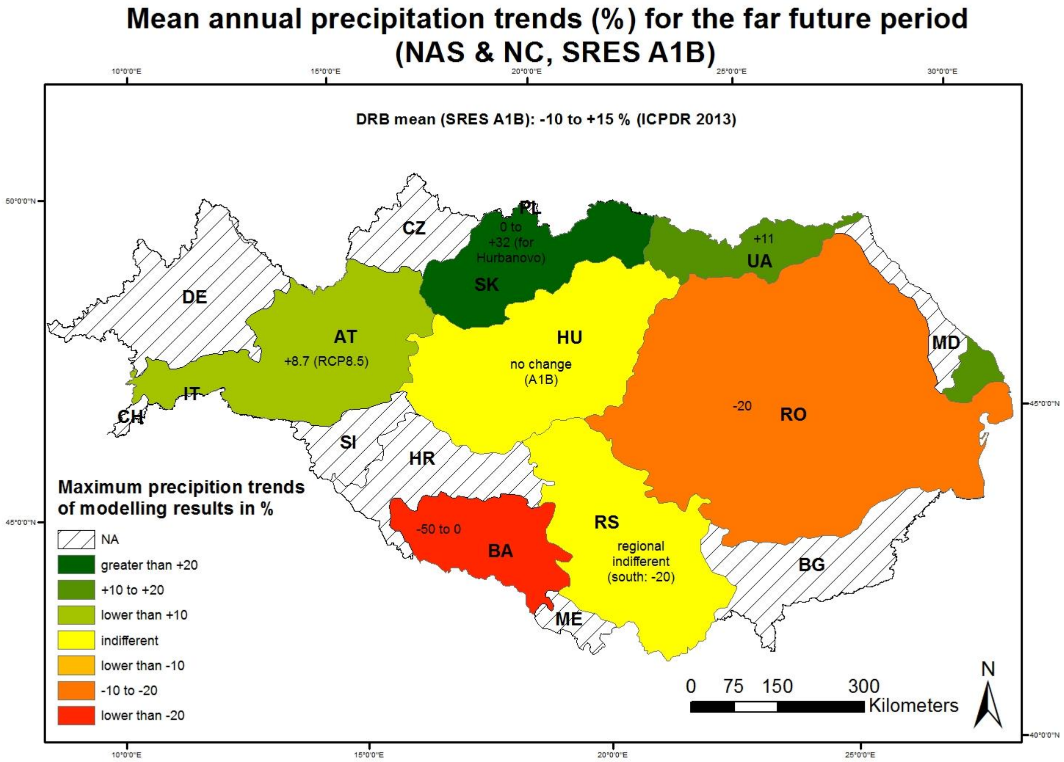

Figure 15: Mean annual precipitation trends (%) for the NAS and NCs in the far future period. Unless otherwise stated, the applied scenario is SRES A1B.

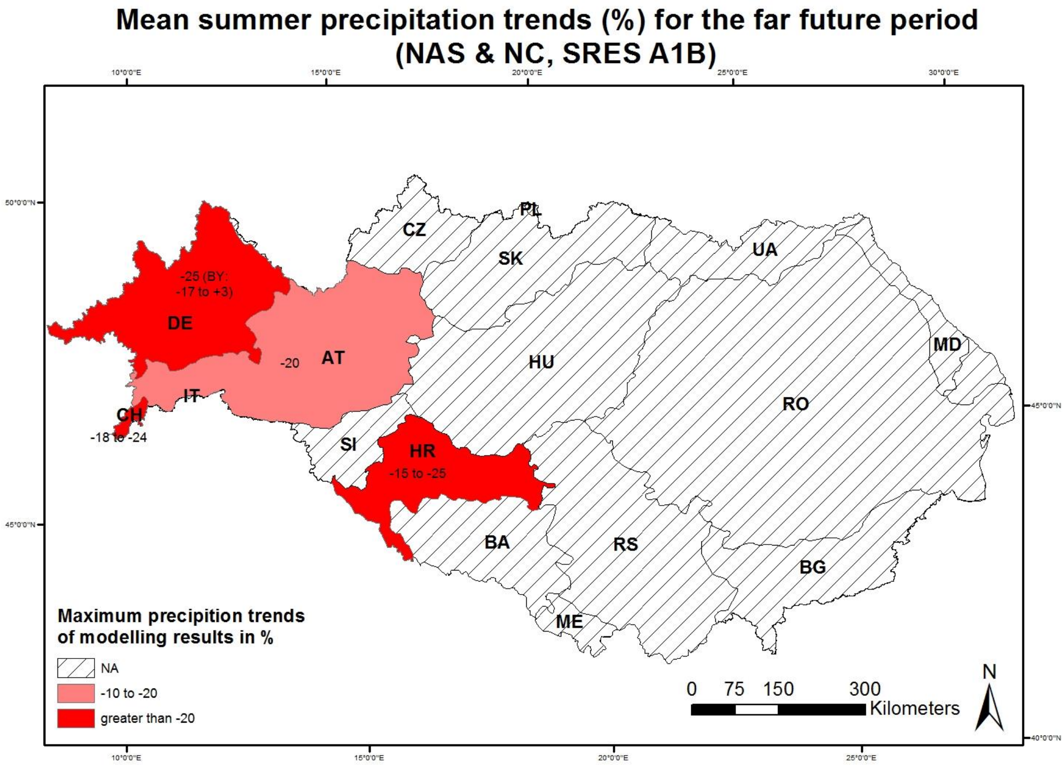

Figure 16: Mean summer precipitation trends (%) for the NAS and NCs in the far future period. Unless otherwise stated, the applied scenario is SRES A1B.

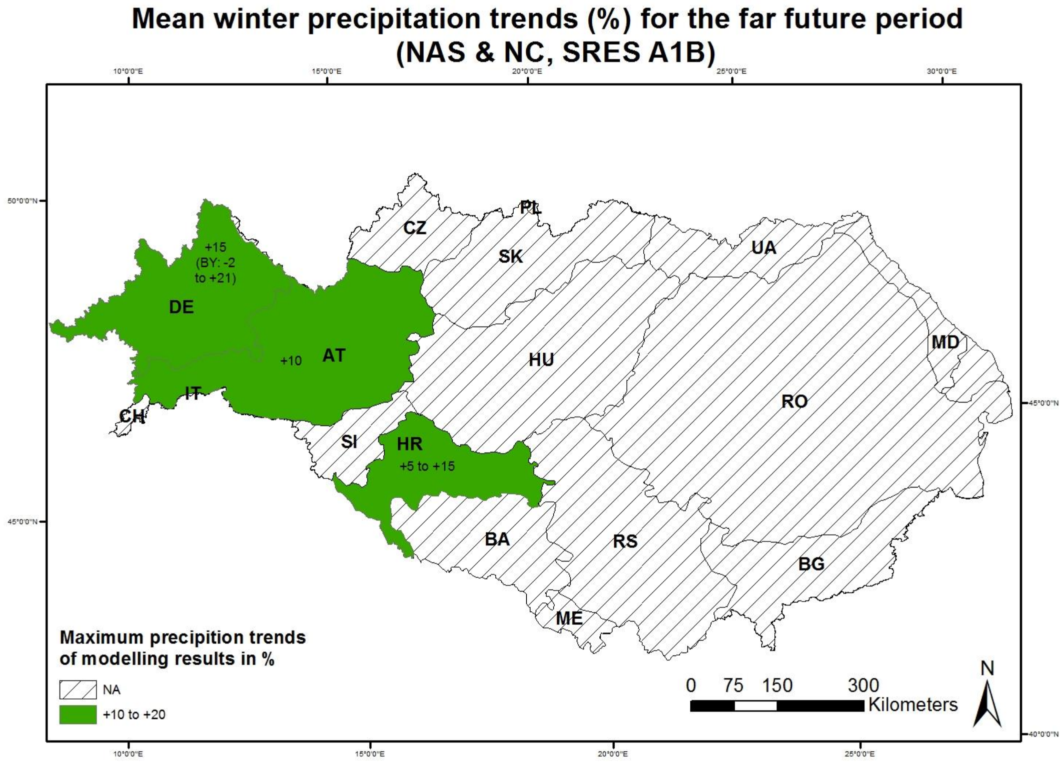

Figure 17: Mean winter precipitation trends (%) for the NAS and NCs in the far future period. Unless otherwise stated, the applied scenario is SRES A1B.

Key findings and comparison to the previous study

The precipitation projections for the near and far future period of the ongoing projects predominantly resemble the outcomes of the first Danube Study. Minor differences in temperature value ranges become obvious, but considering varying scenarios and projection horizons within the projects these can be referred to as insignificant. Since the ENSEMBLES project is a major data provider for various projects in the first Danube Study and in the Update Danube Study, this was an expected outcome in terms of precipitation projections.

It must be emphasized that the projects show regional and seasonal patterns which show a decrease of precipitation in the south/east, a slight or inconclusive increase in the north/west, a decrease in summer and an increase in winter precipitation.

Considering modelling results of RCPs and the older SRES Scenarios, it becomes apparent that these generally resemble but in terms of spatial heterogeneity the RCPs offer a more differentiated resolution. Thus, spatial correlation between RCP8.5 and SRES A1B ranges from 0.59 to 0.92 for the near future depending on the considered region. Stronger correlation is calculated for the far future period [66].

Upper Danube River Basin (UDRB) [47,70,71,76,82,113,119]

- **Projects**

Summer/Winter mean precipitation

The situation in the UDRB is characterized by regional inconsistent projections which show seasonal trends. In the alpine space, projects indicate that summer precipitation is likely to decrease until the near future period (up to 30 %) with a more pronounced negative trend for the distant future. A spatial gradient is projected for the SRES A1B, ranging from a stronger drying trend in the western and central parts up to values like those of today in the eastern parts. Winter precipitation is expected to increase in most of the regions (+30 % in the eastern Alps [76]). Projections for other parts of the UDBR vary; however, an increasing trend in winter precipitation can be detected with values of +15 mm for the near future period and SRES A1B and additionally a decreasing trend of -35 mm in summer. For RCP8.5, an increase of 18 % to 30 % in the distant future is simulated. It must be noted that some studies detect only slightly distinct or even inconclusive trends and high temporal and spatial variability.

- **NAS + NC [4,9,46,125]**

No clear trend for the near future period becomes obvious considering NAS and NC. For the far future period, a change in precipitation distribution is projected which is more dominant than a change in the annual precipitation sum. Thus, an increase in winter precipitation is projected with values up to +25 % while summer precipitation decreases by -30 % with an increasing variability in the latter case. Moreover, spatial heterogeneities aggravate solid statements. The applied scenario is mostly SRES A1B but also include A2, RCP4.5, RCP8.5 and RCP3PD.

Key findings and comparison to the previous study

Precipitation trends and findings concur, although, summer precipitation decrease in the Alps is projected to be more pronounced.

Middle Danube River Basin (MDRB) [6,21,58,97,119,136]

- **Projects**

Annual mean precipitation

Annual mean precipitation is projected to decrease about 20 % by the far future period for the SRES A2 and B2, with the largest change in summer (34 % SRES A1B, 43 % SRES B2, 58% SRES A2). Projections indicate that a seasonal shift of the driest months from winter to summer might occur in the far future period [97]. Another Study [21] reveals a precipitation gradient between north and south (of 44°), indicating no difference in the north in contrast to a precipitation decrease between -60 to 0 mm in the south for the near future period, whereas for the far future period -30 mm to -10 for the north and -140 mm to -50 mm for the south are shown.

Summer/Winter mean precipitation

Considering seasonality, the projects show a decreasing trend in summer precipitation in the near as well as the far future period. Respectively, a decrease of -17 % and -33 % is projected for the SRES A1B. For SRES A2 a maximum decrease of -58 % is projected in summer. In contrast, the winter precipitation shows a positive trend with values ranging from +13 % for the near future period to +34 % for the far future period and SRES A1B. [21] reveals a spatial gradient besides the seasonality of projected precipitation trends. Thus, the summer precipitation north of 44° is projected to show a less pronounced drying trend than the south (Summer North to 44°: near future period: -15 mm to 0 mm; far future period: -40 mm to -20 mm. Summer South to 44°: near future period: -30 mm to 0 mm; far future period: -80 mm to -40 mm). The Mediterranean parts are characterized by more pronounced drying trends in summer [119].

The winter precipitation trends feature a clear spatial disparity, with the near and far future period in the North experiencing a positive trend from +10 mm to +30 mm while precipitation in south is simulated to decrease in the range of -40 mm to 0 mm for the near future and -100 mm to 0 mm in the distant future. Considering these values some uncertainty is introduced to the projections.

In the western Carpathians, the total precipitation during the growing season show a decrease up to -10 % for the far future period while for the rest of the Carpathians a decreasing trend of -15 % to -27 % is projected [58].

- **NAS + NC [27,85,86,88,89,102,102–104,111]**

There is no clear trend identifiable for the near future precipitation change. Documents considering the far future precipitation change, state minor variation in the annual amount but a change in seasonal amount with a decline in summer and increase in winter. However, the amount of change greatly depends on the region.

Key findings and comparison to the previous study

The precipitation projections for the near and far future period of the ongoing projects, NAS and NC, predominantly resemble the outcome of the first Danube Study. Minor differences in precipitation value ranges are evident, but considering varying scenarios and projection horizons within the projects, these are insignificant. Nevertheless, a significant spatial variability becomes apparent as well as concordant changes contemplating the increment of precipitation in winter and the opposing decrease in summer.

Lower Danube River Basin (LDRB) [33,119]

- **Projects**

Diakov et al. (2012) [33] state a very uncertain range of -15 % to + 6%.

“A small reduction in winter precipitation is projected for the Romanian lowlands” [119].

- **NAS + NC**

No documents considering LDRB in general are available. It is impossible to make a consistent statement for the entire LDRB since countries do not have similar reference or projection periods, and further due to a lack of solid data.

Key findings and comparison to the previous study

A comparison is not possible due to a lack of data.

4.4 Extreme weather events

Danube River Basin (DRB) [66,81,124,135,137]

- **Projects**

The considered studies are consistent in increasing extreme winter precipitation events over Europe for the far future period and SRES A1B, with a more pronounced trend over north-east Europe (between 60 % to 80 % for the 90th percentile of precipitation [135]). Zolina (2012) [137] states an increase in extreme summer precipitation in eastern Europe.

Generalized Stahl et al. (2012) [124] indicate a positive trend in extreme precipitation in rain-dominated regimes and inconsistent or decreasing trends in snow dominated regimes. Negative trends in Southern and Eastern Europe are projected, while for other parts trends are positive.

Jacob et al. (2014) [66] state that "for winter, RCP8.5 projects strongest increases in heavy precipitation (up to 35 %) in Central and Eastern Europe, whereas A1B projects changes up to 25 % only in this region". Comparing RCP4.5 and RCP8.5, the seasonal patterns of change are similar but less pronounced (15 % to 25 %). Thus, "besides isolated regions in Southern Europe (mostly along coastlines)—no decrease in heavy precipitation is indicated" [66].

Considering the mean length of dry spells "for RCP4.5 and A1B, a small increase in the length of extended dry spells is projected for Central Europe, which is more pronounced in A1B. A decrease in the length of extended dry spells is calculated in A1B for parts of Scandinavia. This feature is extended towards the Alps in the RCP8.5, in which the number of dry spells increases […]. This means that under RCP8.5 more but shorter dry spells are projected in the alpine region. For regions with a large increase in the length of extended dry spells, the number of dry spells is decreasing […]" [66].

Key findings and comparison to the previous study

While the first Danube Study provides more general statements considering extreme weather events, the projects in this study identify a seasonal behaviour in climate projections. Therefore, the accordance in an increasing number of extreme winter precipitation events over Europe and especially in the North-East for the far future period must be emphasized. Statements regarding extreme summer precipitation especially in Eastern Europe are inconsistent.

Summarized, project outcomes cannot be considered as uniform, thus statements of the first Danube Study cannot be confirmed nor contradicted.

Considering RCP4.5, RCP8.5 and SRES A1B, it has to be noted that "the annual cycle of changes in heavy precipitation is similar in all three scenarios, but the amplitude of the change is stronger in RCP8.5 than in A1B in several regions" [66].

Upper Danube River Basin (UDRB) [1,47,71,81,137]

- **Projects**

Considered projects indicate an increasing trend in extreme precipitation events especially in winter. In general, extreme precipitation events are projected to increase about 20 % to 30 % in the far future period [81]. In summer, a decrease of extreme precipitation is simulated with regional exceptions (South-Eastern Germany). Heat days (T > 30°C) show an increasing frequency with +10 d to +15 d in the near future period and +30 d to +35 d in the distant future for SRES A1B, A2, B2.

Under RCP4.5 and RCP8.5, the occurrence of mean heat days increases between +7 d to +17.4 d in the distant future. Mean maximum daily precipitation is simulated to increase 16.2 % (RCP4.5) to 23.5 % (RCP8.5).

Key findings and comparison to the previous study

Findings resemble section 4.4 Danube River Basin (DRB).

Middle Danube River Basin (MDRB) [6,16,17,22,51,58]

- **Projects**

More frequent warm and hot events as well as greater record hot conditions are projected with an increment proportional to scenarios and time horizon. Hlásny et al. (2016) [58] stated that temperature exceeding 30 °C "in the Western and Eastern Carpathians was projected to increase by 18–30 days in the period 2071–2100, the projected increase in the Transylvanian Plateau, Serbian, and Western Romanian Carpathians was 33–48 days". The projections of a consecutive quantity of dry days show a decrease in the outer Western parts of the Carpathians, while in the Serbian part it increases from 18 d to 21 d. The rest of the Carpathian region shows unclear patterns [58]. For Hungary the number of hot days (T > 30°C) is projected to increase up to 65 d in the distant future and for SRES A1B. The number of extreme hot days (T_{max} > 35 °C) show an increasing trend up to 34 d and further the number of heat wave days (T_{mean} > 25 °C) increase up to 59 d [6].

Simulations for extreme precipitation in the distant future show an increase of 95th percentile of daily precipitation in spring of around +15 % in the north-western part of the basin and in central Bosnia. In summer, a less certain signal of-10 % to +10 % in the eastern parts is projected. In autumn and winter an increase of +30 % is expected in the Eastern and Northern parts.

The maximum 24- and 48-h precipitation is expected to increase throughout the twenty-first century in spring, autumn, and winter. Changes of summer maxima are spatially highly variable. In the western part of Croatia and also Bosnia and Herzegovina, a decrease of up to -20 % is expected, whereas a slight increase (approximately +5 %) is estimated in the north-western part of the basin.

Key findings and comparison to the previous study
Findings resemble the first Danube Study. Precipitation extremes tend to be more pronounced. Furthermore, a significant spatial variability in future trends becomes evident.

Lower Danube River Basin (LDRB)

- Projects

None

Key findings and comparison to the previous study
A comparison is not possible due to a lack of data.

4.5 Deficits

Inconsistency in spatial coverage of scientific basis
In view of the available literature for this study it becomes clear that there is a pronounced inconsistency with regards to the spatial coverage of the analyzed documents. While for the UDRB and MDBR adequate and reliable literature was accessible, the whole DRB and LDRB are under-represented. For these regions, analysis and revision of adaptation measures provided by the first Danube Study is difficult or even impossible due to this lack of information.

Inconsistency in modelling approaches of scientific basis
Modelling approaches in climatology and hydrology significantly differ in terms of reference periods, modelling horizon, used models, model input and applied scenarios. This aggravates the comparison of modelled future conditions in the investigated region and makes a consistent conclusion rather difficult. Considering the reviewed literature, it is apparent that some data sets (ENSEMBLES & PRECIS; see table 3) are used more frequently, but are not consistent in modelling configurations, which are applied in the considered studies. For robust statements regarding climate change trends and their impacts on the DRB a harmonized and consistent model-base, which draws on integrative and joint functioning of the EU's corresponding countries, is strongly required.

Implications of inconsistency
In general it must be noted that even small variations of climatic conditions can lead to severe changes in the hydrologic cycle [80]. This needs to be considered for the development of climate change adaptation measures. Induced by heterogeneous data, different modelling approaches and further the intrinsic model uncertainties, resulting errors must be assessed. It is crucial for the development of feasible adaptation measures to minimize these uncertainty factors.

Conclusion
Hydrological processes are sensitive to minor climatic variations [80]. However, for the DRB the data basis of possible future climate change effects on which conclusions for vulnerabilities and adaptation measures should be drawn, is very inconsistent (see table 3). This leads to high uncertainties in these conclusions and precise statements of climate change effects on hydrology are

hardly possible. Therefore, a harmonized and consistent modelling basis of climate change effects on hydrology is crucial within the DRB. Based on this, robust conclusions on topics such as water availability, runoff and extreme events can be drawn, which serve as foundation for the development of feasible adaptation measures. The constraints stated in this section must be taken in into account when adaptation measures in this or the first Danube Study are considered.

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 and extreme hydrological events like floods, droughts and low flows. Moreover, impacts on water uses are focused on. This encompasses impacts on agriculture, irrigation, forestry, land use, biodiversity and ecosystems, as well as water related energy production and navigation.

In difference to the first study the fields

- Water supply and demand
- Health
- Tourism
- Snow and ice
- Soils
- Limnology
- Water quality
- Coastal areas

are not addressed for several reasons. On one hand there is a lack of new projects and data dealing with these topics, on the other hand due to short project capacities, not all topics can be evaluated.

Firstly, for each impact, the main outcomes of the research and development projects and studies conducted in the considered space of time (between 2012 and end of 2016) are described (see section 2). After a short summary, details of the main findings for the entire DRB and for the regions UDRB, MDRB and LDRB (see fig. 1) 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. Uncertainties, contradictory or significantly different results are highlighted. Besides the application of locally known hydrological models, several studies refer to LISFLOOD, WaSIM-ETH, and WaterGAP [108,131].

If the analysis of projects and studies show differences in the impacts due to the application of different climate change scenarios and high resolution RCM between the two studies, these findings are displayed in a separate paragraph.

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. Following the approach from the first report, 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 [128,129]. 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 [128], EEA [39,40] and the UNFCCC [http://unfccc.int/focus/adaptation/items/6999.php]. However, there is no sharp separation possible between these categories.

Adaptation is a rather new approach to the problems the impacts of climate change are causing. The development and application of adaptation measures are directed at long sight and measurable results are slowly coming up. Therefore any adaptation measures pointed out in reports and studies before 2012 still keep their validity [40]. To keep the clarity, these measures are no more displayed.
The tables on suggested adaptation measures include therefore only the adaptation measures analysed from studies and projects after 2012. To illustrate commonalities and differences, a colour code was selected:

- Measures written in black are relevant in both studies
- Measures written in red are new compared to the first study
- Measures written in green are often addressed

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 relevance to the European Water Framework Directive (WFD) and the European Flood Directive (FD) 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. A short comment is given, if contradictory measures are identified or gaps are addressed in reports, studies or strategies.
Before describing the climate change impacts and the related adaptation measures for the different analysed sectors, 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

Adaptation to climate change is thus now considered essential in order to reduce the impacts of climate change that are already happening and to increase resilience to future impacts, some of which cannot be reversed. The shift from a focus primarily on mitigation towards embracing adaptation too can also be observed in the scientific literature, where adaptation meanwhile get more attention than mitigation. Adaptation refers to adjustments in ecology, social or economic systems in response to actual or expected climate change and their impacts. It refers to changes in processes, practices and structures to moderate potential damages or to benefit from opportunities associated with climate change. Building resilience is in general a robust approach to adaptation and is closely related to the vulnerability approach because the aim of building resilience is to reduce vulnerability. It is not dependent on detailed climate projections and can handle the daunting uncertainties associated with local-scale projections.
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. It is important to build a basin-wide evaluation system and to interact in multi-level governance systems. Long-term outputs have to be identified and a shared understanding about the objectives is of importance to succeed in identifying adaptation measures on different levels.

The implementation of integrated river basin management plans is supposed to involve coordinated 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 behavioral measures and the construction or modification of infrastructure, e.g. dams, reservoirs, river beds, retention areas, as technological measures are commonly addressed by the analyzed 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.

Overall the suggested general adaptation measures have not significantly changed compared to the previous Danube study (see table 4). Some are more specified, others emerged as important for a wider area. As rather new and important measures, an increased knowledge transfer, the raise of public awareness and the reinforcement of individual responsibility are seen.

Table 4: Suggested general adaptation measures for water related climate change impacts (*Time horizon of the effects of the measures: short-term (s), medium-term (m), long-term (l); (Measures shown in green=mostly addressed, red = new compared to the first study; ǂ = in contradiction to WFD). Abbreviations see Appendix.

Type	Possible adaptation measures	Time horizon*	Relevance to WFD	Relevance to FD	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 • Determination of the limits to adaptation (time of implementation, space limit the action will be helpful)	m			UNFCCC (RS, RO, HU, ME, EU), NAS (HU, DE), RBMP (DRB) EEA 2016
	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, • Establish a **centralized database** to monitor the direct socioeconomic impacts of extremes in a distinct region	m	Y y		NAS (AT, RO, DE), UNFCCC (BIH, ME, RS, HR), SDR, UNECE 2015, RBMP, 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		y	UNFCCC (RS, BIH, SI, CZ, HU), , EEA 2013, 2016, CC (DE), UNECE 2015
	Risk mapping: identification of potential risk areas (areas, infrastructures and utilities)	m		y	JRC 2016, UNECE 2015, NAS (AT, DE)
	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 • Ensuring that monitoring systems used in the DRB have the ability to detect climate change impacts on	s-m	Y Y		UNFCCC (DE, RS, BIH, EU, HU,RO, AT), ICPDR RBMP (DRB), UNECE 2015, RBM (AT), WFD 24, Declaration (DRB),

	ecological and chemical water status as well as the effects of climate change adaptation measures • 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 • Review of the monitoring programmes under the WFD for their adequacy in reliably detecting and assessing such impacts • Development of vulnerability maps		Y Y Y Y		NAS (AT, BIH) ICPDR DRBMP Network Vulnerability (DE)
	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**) • 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 • 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)	m	y	y	ICPDR RBMP (DRB), UNFCCC (BIH, HR, EU, DE, MD, RS, AT), JRC 2013, , BAYKLAS 2016, WFD 24, NAS (AT, DE, RO)
	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			RBMP (DRB), UNFCCC (AT, HU)
General measures	**Development of inter-regional adaption strategy:** different regions are interconnected and dependent	m	y		EEA 2016
	Prevention, control and reduction of transboundary impact: develop, adopt and implement relevant legal,	m			Declaration (DRB)

	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				
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	y	y	UNFCCC (DE), NAS (DE), ICPDR DRMP
	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			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			UNFCCC (DE), NAS (MD)
	Expansion of water conservation areas	m	y	y	CC (DE), NAS (CZ)
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			UNFCCC (CZ), UNECE 2015, White Paper EU, NAS (AT), EEA 2013
	Dialogue, participation, information exchange, social networking • Better communication among institutions • Collaborative and partnership strengthening, building of networks • 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			UNFCCC (ME, MD, EU), EEA Alps 2009, UNECE 2015, Declaration (DRRB), NAS (DE, AT), EEA 2012, CC (DE)
	Sustainable and integrated management • Creation of new alliances and ways of working for innovative solutions, e.g. catchment management, source	m			NAS (AT, DE, MD), UNFCCC (ME, SI)

	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 • Ensuring sustainable management of natural resources and integration of climate change issues • Consolidation of a water saving 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)				
	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 • Promotion of the exchange of knowledge and experiences between politics, administrations, science, and the concerned actors **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			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 • Reinforcement of individual responsibility in the population through awareness-raising and information • 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			UNFCCC (RS, SI, BIH, CZ, SK, HU, MD, ME, AT, RS), NAS (MD, AT, DE, RO, RS), BAYKLAS 2016, EEA 2012, 2016, UNECE 2015
	Capacity building and strengthening among institutions on local, regional and transboundary levels	m			RBMP (AT), RBMP
Techno-logical measures	Determination of the need for **widening and deepening riverbeds** and their additional cleaning	m-l	y	y	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	y		UNFCCC (BA, RO), UNECE 2015, 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			UNFCCC (RO)

	Increase of energy efficiency by 20% by 2020	s-m			UNFCCC (SK)
Policy approaches	**Administration** • 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 **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	m			UNFCCC (SK), NAS (RS), SDR, UNECE 2015, Declaration (DRRB)
	Creating a **supportive institutional framework** (changing standards, legislation, and best practice guidance, and developing appropriate policies, plans and strategies) • New regulations and standard criteria for options/measures • Guidelines, governance and co-ordination – price signals, market -based instruments and private financing – EU Financing schemes	m			Network Vulnerability (DE) White Paper EU BAYKLAS 2016
	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			NAS (DE, RO),
	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			NAS (DE, RO)
	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			NAS (RS), UNFCCC (RO, HU, DE, AT)
	Increasing public acceptance	s-m			Bayklas 2016
Challenges	• Finding a proper way to deal with uncertainties • Cross-cutting issue: multitude of actions and stakeholder from various fields • Close relationship between climate change mitigation and adaptation: Adaptation cannot replace climate change mitigation; achievement in mitigation efforts can help to reduce costs of adaptation	s-m			NAS (AT), EEA 2016, UNECE 2015
External Conditions	**Consideration of variable global conditions**: e.g. long-term rising prices for energy, resources, etc. and demographic trends.	s			NAS (AT), UNECE 2015

5.2 Water availability

When assessing the water availability it is necessary to have a look at the equation of the water balance $P = R + E + \Delta S$, where P is precipitation, R is runoff, E is evaporation and ΔS are changes in water storage. Every term of the equation is largely controlled by temperature, precipitation, changes in snow cover and glacier melt, of which the future development has been described in the previous sections. In the following, the main focus is on runoff, since data availability for this term is sufficient. Regarding evaporation and evapotranspiration, findings of the first Danube study [32] can be confirmed and there are no additional findings which make a revision necessary. The same applies for the storage term S, which encompasses groundwater, soil water, snow, glaciers, and permafrost. In general, the magnitude of changes in discharge depends strongly on the selected climate scenario or RCP. Furthermore there will be a considerable time shift of the annual peak flow. This is mostly related to reduced storage of winter runoff due to changes in the snow regime and/or in the precipitation pattern [120].

Danube River Basin (DRB)

Runoff [34,50,56,109,119–121,134]

- Changes in mean annual runoff
  - Decrease of runoff in particular at the end of the 21st century
- Seasonal changes
  - Decrease of discharge in summer
  - No change or a slight increase of discharge in winter in some river sections
  - Flow regime modification in particular in mountain regions: shift of runoff peaks towards earlier in the year

Upper Danube River Basin (UDRB)

Runoff [*4,23,30,46,70,120,125*]

- In general, there will be enough water available for consumption in future. However, already existing shortages in summer in unfavourable areas could worsen and a general decrease of water resources is expected. In contrast, for the Alpine area a positive change for the meteorological water balance is expected until the middle of the 21st century.
- Changes in mean annual runoff
  - No clear trend, however a slight decrease of 4-6% until the middle of the 21st century is expected
  - The Alpine rivers (Inn, Lech, Isar) show in all RCP projections no changes or a slightly higher discharge for the near future (until 2050). For the far future (2071-2100) a significant increase using RCP2.6 and 4.5 projections, decrease for RCP8.5.
  - For the far future, the modelled discharge in the upper Danube differs significantly depending on the RCP. From no change or only a slight increase in the RCP2.6 to significant decrease of 10-20% for RCP8.5
- Seasonal changes
  - A clear shift in the runoff regime is projected

- More runoff in winter, less runoff in summer
- Higher evaporation and higher water demand in summer lead to less runoff
- In glaciated areas a short-to-mid-term increase in summer runoff is projected; long-term decrease
- Annual peak flow will occur slightly earlier in the year

Middle Danube River Basin (MDRB)

Runoff [*4,16,34,46,50,56,60,83–85,89,99,107,109,120,134,136]*

- Changes in mean annual runoff
  - General decrease in runoff in the far future between 10-20% (RCP2.6) and up 40% (RCP8.5)
  - No agreement of studies in the trend concerning the discharge until the middle of the 21st century. Varying from no trend to a decrease of 5-20% in the Danube and all tributaries
  - South and south-east of the MDRB is subject to significantly higher changes than the north and west (decrease of 20-60% until the end of the 21st century).
- Seasonal changes
  - Slight increase in winter runoff and a decrease in summer runoff
  - Flow regime modifications in particular in mountain regions (shorter snow cover period)
  - Annual peak flow will occur about 20 days earlier in the far future

Lower Danube River Basin (LDRB)

Runoff [*37,83–87,92,120*]

- Changes in mean annual runoff
  - Decrease of runoff in the near future of 10-40% depending on the RCP
  - In particular strong decrease of even >40% in the distant future.
  - No clear statements for the Ukrainian, Moldavian and Bulgarian part
  - For the Danube in the Danube Delta an insignificant decrease in runoff until 2050 is expected
- Seasonal changes
  - Smaller tributary rivers in the Danube Delta are projected to face a significant reduction in runoff in summer (5 –30%)
  - Lower runoff is expected in particular during the summer month
  - Annual peak flow will occur about 30 days earlier in the far future

Commonalities

Runoff

- Although for the middle of the 21st century little change in mean annual runoff is expected, for the distant future a decrease in runoff is expected in every region.
- A change in runoff regimes to increasing winter runoff and decreasing summer runoff is expected

Challenges / Knowledge gaps

Generally, statements for the south eastern part of the MDRB and LDRB are often very vague and of doubtful reliability. Despite there are more documents and case studies available for the LDRB than in the first Danube study, their significance is often limited. There is only one study where the impact of climate change on the river discharge is modelled using the different RCP projections. Moreover, there is no study, which addresses the entire DRB from a hydrological perspective.

Key findings and comparison to the previous study

In contrast to the previous study, most of the documents expect insignificant changes in mean annual runoff until the middle of the 21st century. However, they confirm a significant decrease in mean annual runoff until the end of the 21st century. This is valid for the entire DRB, also for the UDRB. Even this is the area with the highest water availability, water shortages are expected in unfavorable areas in the far future, which has not been reported in the first study. The most crucial aspect regarding runoff is the change in seasonality, which applies to all of the regions in the DRB. Here, a decrease in summer runoff and an increase in winter runoff are expected, which stresses the findings from the previous study.

Adaptation measures

The adaptation measures in this field mainly address reduced water availability in future.

A strong emphasis in all countries lies on preparation measures such as installing monitoring systems, mapping and data exchange. Measures for the risk of reduced water availability ranges from the improvement of water retention in the landscape to technical water saving methods and polity measures to improve water management, especially in low water situations. Accordingly, behavioural and technological water saving measures are mentioned in many studies (see table 5).

Table 5: Suggested adaptation measures for reduced water availability (*Time horizon of the effects of the measures: short-term (s), medium-term (m), long-term (l); (Measures shown in black = relevant in both studies, green=most often suggested, red = new compared to the first study; ǂ = in contradiction to WFD). Abbreviations see Appendix.

Type	Possible adaptation measures	Time horizon*	Related to WFD	Related to FD	Source (Countries)
Preparation measures for adaptation	**Monitoring** to determine changes, resp. assessment of CC impacts on volume and quality of water bodies, water use etc.	s-m	y		NAS (HR, ME, RS), ClimWatAdapt
	Identification and **mapping** of potential risk areas (lacking water resources, floods…)	s	y	y	UNFCCC (ME, SK)
	Forecasting and warning service	s-m	y	y	UNFCCC (ME)
	Identification of the area with high potential risks of flood and deficit of water	s		y	UNFCCC (RO) AT-Actionplan
	Increasing knowledge: Research on future water quantity under different research scenarios and on mechanisms behind the changes	s-m			AT-Actionplan
	Development and validation of **new models**	m			GLOCHAMORE
General measures	Consideration of the impacts of climate change in integrated river-basin management	m	y		UNFCCC (DE, RO)
Ecosystem-based measures	• Increase **water retention properties** of the landscape, e.g. by restoring bogs/swamps and wetlands • Renaturation of riparian areas and wetlands • Limitations of activities in flood plains	s-m	y	y	NAS (CZ), BAYKLAS
Behavioral /managerial measures	Efficient use of water to ensure sustainability	s			NAS (SK, 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)
	Minimize the pollution of water resources by discharges of untreated or insufficiently treated municipal waste water	s	y		NAS (SK)
	Use of purified and microbiologically safe wastewater for watering farmland Improvement of the treatment of the residual and domestic water	m	y		NAS (DE) UNFCCC (RO)
	Transferring inter-basins of water for the compensation of the deficits in some basins	m-l	y		UNFCCC (RO)
	Low-loss irrigation of agricultural land	s-m			NAS (MD, DE)
	Review the sustainable exploitation of water resources	s	y		UNFCCC (SK)
	Extension of the water recharge solutions of the phreatic layers				UNFCCC (RO)
	Better communication among institutions, forecasting and warning service	s-m			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. • Increase storage capacities	m, l	y	y	Bayklas
	Adapting the infrastructure	m-l			NAS (DE), UNFCCC (RO)
	Precautions against water losses in distribution networks	m			UNFCCC (DE,), Bayklas
	Collection of rainwater	s-m	y		UNFCCC (RO)
	Further development of water-saving methods, especially in manufacturing processes in trade and industry	m			NAS (DE), UNFCCC (RO)
	More efficient water use and conservation by the rehabilitation of the transportation and distribution installations and also through technological modifications (the promotion of the technologies with low water consumption, etc.)	s			UNFCCC (RO)
	More efficient cooling of power stations	m			NAS (DE)
Policy approaches	Restrictions on developing activities in water shortage areas	s-m			NAS (DE)
	Referring to WFD and FD as guidances	s	y	y	BAYKLAS 2016
	Update the guiding schemes of arrangement and management to take into consideration the effects of climate change				UNFCCC (RO)
	Water protection against pollution and depletion caused by anthropogenic activities (both groundwater and surface water)	m	y		BAYKLAS 2016,WFD 24, DRPC, Declaration (DRB)
	Expansion of Low water information services	s			BAYKLAS 2016
	Putting in place requirements for prior authorization of abstractions	m			DRPC

5.3 Droughts / Low flows

In the following subsections drought and low flows are analysed in detail for the entire DRB and the sub regions. Results emphasize the differences in the DRB. Despite the general intensification of the drought and low flow situation all over the DRB, the southern and eastern region will be affected most. In mountain regions a strong shift in seasonality is expected, which results in an increasing risk of low flows during summer and a decreasing risk during winter. The most affected rivers will be smaller tributary rivers in the South and East. The fact, that for the Danube River no critical intensification is projected in the South and East, hints at the importance of alpine and mountain head watersheds, which contribute a vast amount to the overall runoff. This should be taken into consideration when developing adaptation strategies, since transboundary collaboration is indispensable for effective measures.

Danube River Basin (DRB)

Drought [50,109,117,118,134]

- Generally the DRB will face more, more intense and longer drought situations in the future
- The South and East is stronger affected than the North, however areas negatively affected will expand further north

Low flow [50,109,119,120,134]

- Decrease in low flow runoff in particular in the South and East
- In mountain regions decrease of summer low flow and increase of winter low flow

Upper Danube River Basin (UDRB)

Drought [18,18,23,46,125]

- More and longer summer droughts, in particular in the distant future

Low flow [4,9,10,46,76,,95,125]

- Generally an increase in low flow events, a longer duration and a decrease of flow in such events is expected
- Until the middle of the century, no significant changes in the lowlands, with a weak tendency to a decrease in low flow
- Until the end of the century, decrease of low flow of up to 30%
- In the Alpine region a significant increase of low flows is expected until the middle of the century and until the end of the century which can be in the range of 15% to more than 60% (Q95)
- In the Alpine region decrease of low water runoff in summer and increase in winter
- Decrease of low water runoff in the more continental east in every season

Middle Danube River Basin (MDRB)

Drought [31,31,50,85,86,88,89,91,134]

- More, more intense and more harmful droughts are expected, in particular in summer and autumn
- strongly amplified water scarcity problems in the Balkan region in particular in the south

- New areas might be affected by droughts, which have not been affected so far
- Mixed pattern in the transition zone (central Europe and the Carpathians)

Low flow [16,16,50,84,85,107,109,134,136]

- Increase in low flow conditions in duration and intensity
- In the Balkan region a reduction of low river flows by 25 – 50% until the middle and more than 50% until the end of the 21st century is expected
- In contrast for the near future little change is projected for the Sava river basin

Lower Danube River Basin (LDRB)

Drought [31,50,50,86,87,92,102,134]

- In Bulgaria a shift from mild to severe droughts within less than 60 years is expected
- More frequent droughts events in the Budjak steppe
- General statements for the MDRB also apply for the LDRB.

Low flow [50,84,92,109,134]

- Increase in low flow conditions in duration and intensity
- In particular small rivers are affected by the intensification of low flow events
- A complete dry-out of small rivers, which are subject to extreme low flow is expected

Commonalities

- In all sub regions an intensification of drought and low flow situations is expected
- Mountain areas will experience an increase of drought an low flow events in summer and a decrease in winter

Challenges / Knowledge gaps

- Information scarcity for the LDRB
- It is frequently stated, in particular in the LDRB, that small rivers are strongest affected by droughts and low flows. However, information/data is mostly not available for these small rivers.
- Regions and terms like Balkan, South, low flow, minimum flow, and drought are not clearly defined and have not always the same meaning in the analysed documents. This complicates comparisons or makes it even impossible!
- Contradictory statements for the MDRB

Key findings and comparison to the previous study

Statements of the previous Danube study are confirmed. The newly available information emphasizes the differences in future drought and low flow development in the DRB – intensification of drought and low flow situations in the south and east and a shift of the affected areas to the north. Data/Information basis for the LDRD did slightly improve in comparison to the first Danube study. However, their significance is often very limited.

Adaptation measures

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 low water and droughts, there seems to be a common understanding to create early warning systems and action plans. Adaptation measures addressed in the evaluated documents do not significantly differ from the measures described in the first Danube study. A further adaptation measure to the increase of soil-water holding capacity is mentioned in projects. Drought and low flow are addressed in more detail in the 6th NC under the UNFCCC from Romania, in the compendium of the Global Water Partnership, the JRC technical report on meteorological droughts in Europe as well in the Climate change adaptation strategy and action Plan for the Danube Delta Region [53,86,118].

Droughts also differ in terms of their spatial characteristics. Drought impacts are closely related not only to the magnitude of the event, but also to the timing of the onset, duration and spatial extent. As vulnerability to drought has increased globally, greater attention has been directed to reducing risks associated with its occurrence through the introduction of planning to improve operational capabilities. Adaptation measures which are mostly addressed are preparation measures. The installation of early warning systems seems to be very important, thus this is not an adaptation (see table 6).

Table 6: Suggested adaptation measures for impacts on droughts / low flows (*Time horizon of the effects of the measures: short-term (s), medium-term (m), long-term (l); (Measures shown in green=mostly addressed, red = new compared to the first study; ⱡ = in contradiction to WFD). Abbreviations see Appendix.

Type	Possible adaptation measures	Time horizon*	Related to WFD	Related to FD	Source (Countries)
Preparation measures for adaptation	**Monitoring systems** • Establishment of new and maintenance, optimization and extension of existing monitoring systems • 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 • Monitor water demand closely and forecast it, based on improved knowledge about demands and trends.	s- m	y		NAS (AT, CZ), WFD 24, EU COM, BAYKLAS 2016, JRC 2013, UNFCCC (RO)
	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 • Monitoring and the advertising about the decreasing of debits/drought at national level	s-m	y		EU COM, NAS (AT), UNECE 2009, ADAM, JRC 2013, EEA 2016, UNFCCC(RO)
	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			NAS (CZ), WFD 24, UNECE 2009, EU COM, UNFCCC (RO, BA), NAS (MD)
	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	s-m	Y y		NAS (AT, CZ,RS), OECD, WFD 24, EEA 2012,2016, UNFCCC (SK), BAYKLAS, KLIWAS

	• Fostering exchanges of information and best practices on drought risk management				
	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 • Involvement of stakeholders for engagement to realise decisive measures to tackle water scarcity	s-m			WFD 24, EEA 2012,2016, 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 into the risk management aspects of drought management • 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	s-m			UNFCCC (HR, AT), EEA 2012,2016
General measures	Taking additional efforts to prevent water scarcity and be better prepared to tackle the impacts of droughts	m			WFD 24
	Following an integrated approach based on a combination of measures (compared to alternatives based on water supply or economic instruments only)	m			WFD 24
	Incorporation of climate change adaptation in water management by continuing the focus on sustainability (sustainable balance between water availability and demand)	m			WFD 24
Ecosystem-based measures	Investigation of droughts and their impacts on ecological conditions of water bodies	m			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	y		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 • Reviewing the local governments and water supply providers' conservation and drought contingency plans	m	y	y	UNECE 2015, ADAM, EEA 2012,2016, WFD 24,
	Increase of soil-water holding capacity		y		EC (2014), NAS (Ro)
Behavioral /managerial measures	Implementation of **water use restriction** and limitations in water abstraction and pumping during drought events.	s-m			SDR, EEA 2016
	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)	s-m			CC (DE), WFD 24, RBMP (AT), UNECE

					2015, UNFCCC (BA)
	Raising public awareness of water-saving behaviour	m			CC (DE), WFD 24, RBMP (AT), UNFCCC (BIH)
	Managing urban water demand through the right mix of restrictions, pricing and water efficiency for ensuring safe 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 • Managed Aquifer Recharge • Water wise rebate scheme • Water allocation and planning including making new housing development water neutral	s-m	y		WFD 24, EEA 2012, UNECE 2015,
	Creation of a **hierarchy of water supply restrictions** applied during the drought event and coordination of communities among institutions involved in water management	s			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 • 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)	m-l			NAS (MD), UNFCCC (BIH), JRC, UNECE 2015,
Techno-logical measures	**Increasing water storage** • 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	m			NAS (AT), UNFCCC (BIH), BAYKLAS, CC (DE), WFD 24, RBMP (AT), EEA 2016,

	• Use of local water reserves by constructing farm ponds for catching precipitation runoff				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			UNECE 2015, EC, BAYKLAS 2016,
	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 • Creation of alternative technological solutions like desalinization and reuse of wastewater • Measures of the saving and the efficient utilization of water(irrigation, industry) • Deceasing of the losses in the distribution system of the water	m-l			EU COM, CC (DE) UNFCCC(RO)
	Leakage reduction of reservoirs and water distribution networks	m			EC, UNECE 2015, GWP 2013
	Improvement of **infrastructure resilience**	m			EU COM, UNECE 2010, UNECE 2009
	Special construction for the attenuation of the high flood				UNFCCC (RO)
	Increase in **water retention** properties	m-l			UNFCCC (HR), NAS (HU), RBMP (AT)
Policy approaches	Improvement of the **linkages** between European policymakers, operational water management agencies and researchers to ensure current operational best practice is shared Better transboundary cooperation: between local catchments as well as between states	s			UNFCCC UNECE 2015, NAS (AT)
	Cooperation with other countries to exchange experiences in combating droughts	s			UNFCCC (HR, AT), UNECE 2015
	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			JRC
	Implementation of a clear definition and methodology for estimating economic, social and environmental cost of droughts	m			JRC

5.4 Floods

The projection of the future development of floods with regard to their intensity, timing and frequency is considered to be a challenging and uncertainty afflicted task. This can be traced back to various factors. The origin of floods can be very diverse: long and persistent rainfall events, storm precipitation, and rain on snow events. Another crucial factor is the terrain characteristics: mountains and lowlands, small and big catchments, geological conditions, soil properties. Moreover, there is great human influence on the surface which can contribute to flood development: agriculture, forestry, soil sealing, and river regulation. Despite these factors, which influence flood intensity, timing and frequency, the analysed documents coincide with an increase in future flood risk and intensity, mainly in small and mountain catchments.

Danube River Basin (DRB) [*98*]

- More frequent high/extreme floods
- Increasing flood risk
- Low certainty

Upper Danube River Basin (UDRB) [*4,8,10,18,46,125]*

- General increase in flood risk and floods is projected
- Particular increase in winter and possible increase in spring and early summer
- A decrease in summer is highly uncertain
- Forecasts of floods are accompanied by high uncertainty since knowledge of the future development of meteorological extremes, in particular precipitation, is insufficient.

Middle Danube River Basin (MDRB) [*16,17,24,27,85,86,88,89,107,109,111,134,136*]

- Increase in flood risk, intensity and duration
- In particular an increase in flood risk in rivers originating from mountains and in mountain headwater catchments
- Shift of flood peaks to earlier month
- Higher possibility of flood events during dry periods due to storm precipitation during droughts

Lower Danube River Basin (LDRB) [*24,86,87,92,109,134*]

- Generally statements are the same as for MDRB
- Less early spring floods due to reduced snow cover

Commonalities

- In all regions of the DRB an increase in flood risk, duration and intensity is expected
- The most affected areas are assumed to be mountain catchments
- There is considerable uncertainty in the quantification of future flood events due to shortcomings in future precipitation estimation

Challenges / Knowledge gaps

- Quantification of flood intensity, frequency, and seasonality
- Partly contradictory findings
- Lack of consideration of the anthropogenic influence on flood events (e.g. land use change)

Key findings and comparison to the previous study

Generally, statements of the previous Danube study are confirmed. Despite in both studies a high uncertainty in future flood estimation can be noticed, every analysed document in the new study agrees in a general intensification of flood events all over the DRB. Small and mountain catchments appear to be the most affected ones.

Adaptation measures

Flooding is expected to become more frequent due to an increase in extreme events, although uncertainty is significant due to the high variability in precipitation. Similar to the previous study, for adaption measures mainly 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 (see table 7).

Table 7: Suggested adaptation measures for impacts on floods (*Time horizon of the effects of the measures: short-term (s), medium-term (m), long-term (l); (Measures shown in black = relevant in both studies, in green=mostly addressed, red = new compared to the first study; ǂ = in contradiction to WFD). Abbreviations see APPENDIX

Type	Possible adaptation measures	Time horizon*	Relevant to WFD	Relevant to FD	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	s-m	y	y	NAS (RS, AT, CZ), , RBMP (TRB), Water Act (CZ), , ICPDR FD, WFD 24, Declaration (DRRB), BAYKLAS, CLIMALP
	Implementation of a **flood risk assessment** for the identification of areas exposed to floods	s-m		y	UNFCCC (DE, CZ), NAS (DE, RS, RO), BAYKLAS, Floods Directive, Water Act (CZ), ICPDR FAP RBMP (TRB)
	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		y	UNFCCC (RS, DE), NAS (RS), BAYKLAS,, WFD 24, JRC, Flood Directive, RBMP, ICPDR FRMP, UNFCCC (BIH),
	Development of Strategies and Plans • Contingency, confinement and possibly evacuation plans of trans-national flood areas (floodplain basins) should be worked out jointly by the interested countries	s-m	y	y	NAS (RS), BAYKLAS, RBMP , Water Act (CZ), SDR, ICPDR FRMP

	• 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 • Integration of preventive flood protection in regional planning				
	Monitoring • 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 • Improvement of gauging and monitoring in small catchments	m	y	y	UNFCCC (ME), NAS (RS), WFD 24, RBMP (TRB), Water Act (CZ), Action Plan AT 2012
	Improvement of information systems • Organisation of flood and reporting services, flood recording and documentation • 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 • Improvement and increase of information exchange	s-m		y	Declaration (DRRB), Water Act (CZ), ICPDR FAP, RBMP (TRB), WFD 24, RBMP (TRB), BAYKLAS, Floods Directive, EEA 2012, 2016
	Re- evaluation of flood protection and water structures taking into account climate change impacts	s-m		y	UNFCCC (RS, SK), BAYKLAS, WFD 24, Water Act (CZ)
	Updating flood design values	s-m			NAS (AT), ST_BLOESCHL_AT
General measures	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		y	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	s-m		y	UNFCCC (RS), NAS (RS), WFD 24, RBMP (TRB), ICPDR FAP, UNFCCC (RO), NAS (RS), CC (DE), EEA

	• 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				2012,2016, Water Act (CZ)
	Prevention of accidental pollution during floods affecting the storage facilities of dangerous substances	s			RBMP (DRB)
Ecosystem-based measures	**Protection and restoration of water retention areas, including natural reservoirs** • Creation or restoration of retention areas to increase water retention properties of the landscape • Increase 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 vegetation, soil, ground and wetlands has an important mitigating effect particularly in minor or medium-scale floods;	m-l	y	y	UNFCCC (CZ), NAS (DE), NP (CZ), UNECE 2015, EEA 2012, ICPDR FRMP, Declaration (DRRB), RBMP (AT), , WFD 24, CC (DE), NAS (DE), RBMP (TRB), Declaration (DRRB), UNFCCC (DE), NAS (HU,DE,AT), BAYKLAS 2016
	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 • Correlation of the territorial development and improvement plans with the strategy and the risk management plans	m			NAS (DE), WFD 24, SDR UNFCCC (RO)
	Improvement of forest management in high altitudes and better management of protective mountain forests	l			Action plan AT 2012
	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	y	y	RBMP (DRB), BAYKLAS
Behavioural /managerial	**Awareness raising, training and education of the general public**	m			UNFCCC (DE, RO), CC (DE), WFD 24,

measures	• 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 • 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 • 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 • Emergency planning and training				BAYKLAS, RBMP (TRB), ICPDR FRMP, Water Act (CZ), BAYKLAS 2016, RBMP (TRB)
	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	s-m	y	y	NAS (HU), UNECE 2015, RBMP Declaration (DRRB), SDR, CC (DE), ICPDR FRMP, ADAPTALP, UNFCCC (CZ, AT), Action plan AT 2012
	Adaptation of flood management • Implementation of proper flood control practice • Implementation of appropriate floodplain management to explore the benefits of flooding • 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 • Integration of flood risk management into land use planning	s		y	UNFCCC (RO), NAS (AT, HU, DE), RBMP, ICPDR FRMP
	Sustainable agricultural practices	M			NAS (AT), BAYKLAS,

	• 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 • Close co-operation with agriculture to reach a more sustainable agricultural practise	s-m s m s			Action Plan _AT 2012
	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 basins 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 • Reduction of impermeable areas and improvement of soil storage	m-l			NAS (DE, MD, AT), CC (DE), , White Paper EU, RBMP, UNFCCC (RO, H, AT,DE),BAYKLAS
	Capacity building: raising preparedness of the organisations responsible for flood mitigation	s			NAS (RS), RBMP
	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 • Change the operation of reservoirs and lakes • Creation of accumulation polders for capturing flood waves instead of permanent reservoirs	s-m			UNFCCC (CZ), Water Act (CZ),
Techno-logical measures	**Structural flood protection / adaptation of urban infrastructure** • Adaptation of stream canalization • Improvement of existing drainage systems and capacity, including the separation of sewage, sewer relief from	m-l			UNFCCC (DE, RO, CZ), NAS (DE, MD), ADAM,

	flood waters by offsite pumping and other solutions • Implementation of artificial infiltration and retardation to reduce impermeable areas • Creation of local storages (ponds, building storages, groundwater cisterns) • Construction of new protection structures e.g. tidal barriers • Construction and renewal of polders • Permanent maintenance of technical protection structures				ClimateWater, BAYKLAS, UNECE 2009, RBMP (TRB), ADAM, SDR, ICPDR FAP, WFD 24, EEA 2012, 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 • Widening the area between dikes • Construction of temporary dams • Implementation of measures to maintaining dam safety	m-l		y	UNFCCC (CZ, BA), NAS (AT, DE, HU), UNECE 2015, 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	m			UNFCCC (RO), EEA 2012, WFD 24, CC (DE),
	Introduction of a climate change adaptation factor on dams and dykes (example Bavaria)				KLIWA, RBM (Bavaria), NAS (AT),
	Creation / adaptation of reservoirs • Building new reservoirs like emergency flood reservoirs and multi-purpose reservoirs, which serve as an 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	m	y	y	UNFCCC (CZ), WFD 24, ST_IPCC BAYKLAS
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		y	UNFCCC (EU),NAS (DE), BAYKLAS
	Legal legitimating the creation of retention areas	s-m			NAS (AT)
	Development of a strategy for flood protection	s-m		y	NAS (CZ)
	Use the EU Floods Directive as a legal framework for a coordinated approach to assess and manage flood risks	s-m		y	SDR, BAYKLAS,

					Action-Plan AT 2012
	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			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			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	s-m			UNFCCC (HR, RS) NAS (RS)
	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	y	y	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			NAS (HU), CC (DE), BAYKLAS, RBMP (TRB),

5.5 Agriculture

The cultivation of crops, their productivity and their quality are directly dependent on different climatic factors. Livestock, another important part of the agricultural system in the DRB are affected by climate change directly through changes in temperature and humidity affecting animal performance and indirectly through effects on feed production and availability, as well as through livestock disease prevalence. Of all factors, water availability is the most crucial one for agriculture [40]. Since water availability will be strongly influenced by future climate change huge consequences are expected for farming activities in the DRB. As described in previous sections effects of climate change vary in the DRB. Besides generally growing water demand and a shift of species, impacts of climate change vary significantly. In the UDRB water availability will be high enough for productive farming, apart from some unfavourable areas. Main threats for agriculture in the UDRB are extreme events like floods, hailstorms, heavy precipitation, and damage from invasive species and pests. In contrast the amount of water available for agriculture will significantly decrease in the southern and eastern parts of the DRB leading to increasing damages from droughts and heatwaves as well as, accompanied by rising temperatures, to a reduction of the vegetation period in some areas. Here, also socio economic effects are expected, because employment is depending directly on agriculture to a great proportion. All over the DRB there will be an increasing demand of irrigation. However, in the dry regions of the MDRB and LDRB there will not be enough freshwater to meet the requirements.

Danube River Basin (DRB) [*40*]

- Longer thermal growing season:
    - An advantage for plants and livestock
    - Leads o the northwards expansion of areas that are suitable for several crops
    - May increase the spread of weeds, insect pests and diseases
    - Allows introduction of new crops
- Increased crop water demand
- CO_2 fertilisation effect

Upper Danube River Basin (UDRB) [*3,4,9–11,18,23,41,46,48,50,125*]

- Reduced number of frost days
- Date of the late frost advances significantly (5-15 days)
- Increasing risk of damages from extreme events (floods, heat waves, droughts, hailstorms, heavy precipitation, etc.)
- Higher variability in occurrence of extreme events may lead to less reliable production
- Invasive species and pests are expected to reduce yields
- Increasing water demand during the growing season
- Increasing irrigation amount by the middle of the 21st century

Middle Danube River Basin (MDRB) [*27,60,85,86,88,89,91,99,103,107,111,114*]

- Less phytopathogenic fungi due to drier conditions

- Damage due to extreme events (floods, heat waves, droughts, hailstorms, heavy precipitation, etc.)
- Shift of cultivation zones to the north and to higher elevated areas
- Change in suitable crops
- Change in natural species → reduced diversity → higher susceptibility to disturbances of the ecological balance
- Impacts on productivity of crops in terms of quality and quantity (negative impacts are expected to exceed positive impacts)
- Increasing soil water stress → increasing demand for irrigation
- Insufficient irrigation infrastructure
- Invasive species, pests and diseases
- More frequently used pesticides or herbicides may have a negative impact on the quality of water resources
- Intensified soil erosion
- In Slovakia an extension of the irrigation period is expected
- Too little freshwater available for irrigation of all maize plants
- Yields of several rainfed crops (maize, wheat) are decreasing

Lower Danube River Basin (LDRB) [*33,86,87,92,102,130*]

- In Bulgaria negative impacts due to droughts are expected (within less than 60 years a shift from mild to severe droughts)
- In Ukraine a general increase in yields and increased frequency and severity of droughts and extreme weather events is expected
- Water stress increases in every scenario. Long term crop water demand is expected to be higher than rainfall
- Yields of several rainfed crops (maize, wheat) are decreasing, while others are increasing
- Regions with increase in plant growth days as well as regions with a decrease in plant growth days
- In the Danube Delta negative impacts are also expected for the employment rate and for fishing and fish farming
- Increasing water demand
- Shortening of the vegetation period in some areas due to water scarcity
- Desertification possible in some areas
- Decreasing irrigation potential
- Higher temperatures and the increasing drought risk are expected to reduce livestock production through negative impacts

Commonalities

- In every region of the DRB negative impacts on agriculture are expected in the future

- Increased water demand
- Shift in species
- Invasive species and pests
- Increasing risk of damages from extreme events

Challenges / Knowledge gaps

- Information scarcity for the LDRB
- Information from NAS and NCs of the LDRB countries are frequently not specific for the LDRB
- Spatial heterogeneity of the DRB is insufficiently taken into consideration in the statements of the documents.
- Quantification of the effects of climate change on agriculture
- Quantification of water needed for irrigation
- High uncertainty about the response of livestock production to climate change

Key findings and comparison to the previous study
The most remarkable difference in comparison to the previous Danube study is that now negative impacts of climate change on agriculture are expected to exceed positive impacts in every sub region. Positive impacts like higher yields due to a longer vegetation period are largely limited to the short and medium term future. However, like in the previous study, there are large regional differences shown by the fact that negative impacts are more severe in the drier southern and eastern regions than in the north. Unlike in the previous study, a higher water demand is also expected in relatively wetter areas. When it comes to irrigation, both studies show an increasing demand but new findings show that the freshwater availability is too little to meet the requirements. Moreover, a higher atmospheric CO_2 content is no longer mentioned as a positive factor for agriculture. Due to the greater information basis of the first Danube study more specific statements were possible in the first study, which remain still valid. Both studies highlight the risk of increasing yield variability and further negative aspects due to extreme events.

Adaptation activities

Food security will be negatively affected by climate change in the coming decades. Adaptation strategies that minimize expected impacts s involve largely local- to regional-scale actions. 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. A crucial point to adaptation will be the increasing demand of water due to irrigation. Sophisticated irrigation schemes, water saving techniques and drought prone crop seem to be an adequate adaptation especially in the lower Danube River Basin. 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 (see table 8).

Table 8: Suggested adaptation measures for impacts on agriculture (*Time horizon of the effects of the measures: short-term (s), medium-term (m), long-term (l); (Measures shown in black = relevant in both studies, green=most often suggested, red = new compared to the first study; ǂ = in contradiction to WFD)

Type	Possible adaptation measures	Time horizon*	Relevant to WFD	Relevant to FD	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 • Observation of water consumption of plants • Observation of water quantity used for irrigation • Better integration of risk and impact data	m	y		UNFCCC (BG), NAS (SK, AT), BAYKLAS, UNFCCC (RO), FAO DRIDANUBE
	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 • 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	m			UNFCCC (RS, HU), NAS (RS), 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	s-m			UNFCCC (BG, HU, EU),BAYKLAS

	precipitation and temperature changes				
	Development / enhancement of models for • Climate: Elaboration of regional models and climate scenarios for each agro-pedoclimatic 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			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 agro-climatic 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			UNFCCC (BG, RS, ME, RS), BAYKLAS, White Paper EU, DRIDANUBE
	Establishment / enhancement of early warning systems of droughts and other extreme climate episodes of importance to agriculture	s-m			UNFCCC (RS)
	Examination of the capacity of the Farm Advisory System to reinforce training, knowledge and adoption of new technologies that facilitate adaptation	s			UNFCCC (EU)
	Development and application of indicators in agro-climate and agro-ecological zoning to connect indicator analysis to modelling techniques in order to create model based indicators	s			UNFCCC (RS, HU)
General measures	**Development / adaptation of the agricultural infrastructure** • 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 • Elaboration and implementation of hydro- and agro-technical 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	y		UNFCCC (BIH, CZ, MD, DE), NAS (MD, DE), CC (DE), EEA 2012,2016, ClimateWater
	Expansion of agriculture to new regions characterized by improved thermal and moisture conditions	m			UNFCCC (BG), LULUCF Actions Austria(2015)
	Application and expansion of irrigation for agriculture: choose the most suitable irrigation method considering type of crop, soil type, technology, costs and benefits.		y		BAYKLAS, UNFCCC

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			NAS (RO)
	Protection of biotopes Protection of the integrated production and ecological stability	s-l			NAS (SK)
	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), LULUCF Actions Austria(2015)
	Promotion of less intensive land management techniques in sensitive areas and also in other places, in order to reduce environmental pressure	s-m			LULUCF Actions Austria(2015), DRIDANUBE
	Avoidance of a distinct expansion of arable farming in traditional grassland farming areas due to ecological and aesthetic reasons	m			NAS (SK, RO)
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 variability with specific short- and long-term strategies with respect to crop protection, watering, fertilisation, plant breeding, production, site selection, etc. • Integrated landscaping for soil protection • Preservation of existing pastures and revitalisation of abandoned pastures	m			UNFCCC (RS, BG), NAS (MD), NP (CZ), LULUCF Actions Austria (2015), BAYKLAS, Action Plan AT-2012
	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 • 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.)	m	y		UNFCCC (AT, RS, RO, SK, MD, ME) NAS (), CC (DE), WFD 24, BAYKLAS, White Paper EU, LULUCF Actions Austria(2015)

	• 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 • Protection of natural soil functions • Prevention of damage (erosion) and conservation				
	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			UNFCCC (HU, BG), NAS (BG), White Paper EU
	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 • Altering inputs, varieties and species for increased resistance to heat shock and drought, flooding and salinization				FAO (2014) LULUCF Actions Austria(2015), BAYKLAS, UNFCCC (RO,RS,AT)
	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 irrigation with emphasis on irrigation efficiency and water saving	m	y		NAS (BG), CC (DE), RBMP (Bavaria), WFD 24, BAYKLAS,

	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 • Ensure the traditional Slovak species breeding, to support the domestic species and help adapt them to the present-day conditions with the purpose of more stable productivity	s-m			UNFCCC (RO, HU, ME, BG), NAS (RO), CC (DE), White Paper EU, WWF-DCP NAS(SK)
	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 • Altering the timing or location of cropping activities.	s-m			UNFCCC (RO, AT, BG, RS), CC (DE), BAYKLAS, FAO (2014)
	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, BAYKLAS
	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 • Use nitrogen fertilizers more efficient • Reduction of nitrification by draining agricultural areas • Application of integrated pest management	s-m			UNFCCC (BG, RO, RS), NAS (RS), CC (DE), RBMP (Bavaria), WFD 24, BAYKLAS, OECD,
	Improvement of water management to prevent water logging, erosion and leaching, e.g. including agriculture in water management programmes	s-m			UNFCCC (BIH, RO, AT), BAYKLAS

	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 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			UNFCCC (BIH, AT, RO, SK, BG, ME, MD), NAS (BG), NP (CZ), CC (DE), White Paper EU, BAYKLAS, EEA 2012,
	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			UNFCCC (BA, AT), BAYKLAS,
	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			UNFCCC (RS), NAS (DE), SDR
	Education and awareness raising	m			UNFCCC (RS), NAS (RS,), ADAGIO
	Reinvention and maintenance of traditional elements of land use and landscape management, e.g. cutting and 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)	s-m			FAO, Action-Plan AT 2012
	Changing management intensity in the species mix, rotation periods, adjusting to altered wood size and quality, and adjusting fire management systems				Action-Plan AT 2012
Technological measures	**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)
	Development and application of new, water-use efficiency related techniques • Efficiency improvement in irrigation and water use through the introduction of modern technological developments • Application of technological measures to increase the efficiencies of irrigation systems • Adoption of water-efficient technologies to 'harvest' water, conserve soil moisture (e.g. crop residue retention), and reduce siltation and saltwater intrusion	m	y		LULUCF Actions Austria(2015)UNFCCC (BG, BIH)

Policy approaches	**Review the WFD River Basin Management Plans** by the Member States including their technical, financial and social dimension	s			EU COM, Action-Plan AT, 2012
	Increase the co-ordination between water and agricultural policies	s			EU COM
	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			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			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 • 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	s-m			UNFCCC (EU, ME), White Paper EU, DRIDANUBE
	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			RBMP (DRB), DRPC, BAYKLAS
	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	s-m			FAO, BAYKLAS, LULUCF Actions Austria(2015), EU COM, DRIDANUBE

5.6 Forestry

Forestry shares much of the climate change impact with agriculture like the shift in species to the north and to higher elevated areas as well as increasing risks of damages from pests, water stress or storms. In particular alpine forests are vulnerable to the climate change induced shift in species. As for agriculture, the negative impacts of climate change exceed the positive impacts, which especially apply for some south eastern regions, where even desertification is expected.

Upper Danube River Basin (UDRB) [*2,9–11,18,23,41,46,48,125*]

- Destabilisation of forest ecosystems because of multiple climate stresses like pests, invasive species, water stress and other extreme events
- Shift in tree species and loss of species
- In particular the Alpine region is vulnerable when it comes to a shift in species
- Increasing risk of forest fires
- Positive effect: Longer growing season
- Higher earlier spring temperatures increase the danger of damages by late frosts
- Reduced snowfall: positive effect is a reduction in snow damage

Middle Danube River Basin (MDRB) [*27,85,86,88,103,111*]

- Positive effects due to a longer growing season only in areas with enough water
- Shift and change of species, accompanied by the intrusion of invasive species and pests
- More wildfires and increasing water stress
- Desertification processes in the south of Romania are expected
- Negative effects are predominant in areas with low water storing capacities
- Considerable decrease of forest productivity from 2040 due to higher temperatures and lower precipitation

Lower Danube River Basin (LDRB) [*86,92,102*]

- Shift and change of species suitability due to higher temperatures and increase in water stress
- Decline in structure and stability of forest ecosystems
- Worsening soil characteristics in Bulgaria
- For the Ukraine is expected that in areas with sufficient water forest productivity might increase
- Considerable decrease of forest productivity from 2040 due to higher temperatures and lower precipitation
- Desertification processes in the south of Romania are expected
- Loss of native tree species

Commonalities

- Shift and change of species
- Increasing water stress
- Increasing risk of forest fires
- Winds throws due to an increase in storm events

Challenges / Knowledge gaps

- Too little information for the LDRB draw a consistent picture of the development of forestry

Key findings and comparison to the previous study

Findings from the previous Danube study can be largely confirmed. However, it became more certain that negative impacts of climate change exceed positive impacts. Like at agriculture, a higher atmospheric CO_2 concentration is no longer regarded as a positive effect in forestry.

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 (see table 9).

Table 9: Suggested adaptation measures for impacts on forestry (*Time horizon of the effects of the measures: short-term (s), medium-term (m), long-term (l); (Measures shown in black = relevant in both studies, green=most often suggested, red = new compared to the first study; ǂ = in contradiction to WFD)

Type	Possible adaptation measures	Time horizon*	Relevant to WFD	Relevant to FD	Source (Countries)
Preparation measures for adaptation	**Monitoring** • 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 • Continuation of inventory of private forests • Monitoring the health of forests • Assessment of the damage caused by climate change	m			UNFCCC (HU, BG, BIH, RS, MD, ME, DE), UNFCCC(RS), BAYKLAS, LULUCF Actions Austria (2015),
	Risk assessment for forest health, diseases and pests	s-m			UNFCCC (HU, ME)
	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 • Additional research and monitoring in the field of climate change impacts on forests, vulnerability and Adaptation • Experience and knowledge exchange between science and practice	m			UNFCCC (DE,HU, RS), ST_IPCC (2013) UNFCCC (RS) BAYKLAS
	Increasing prevention of forest fires through **early warning systems** and improvement of the **forest fire protection system**	s-m			CC (DE), UNFCCC (RS), NAS (AT)

General measures	Development and application of measures for strengthening the resilience of forests to climate change	s-m			UNFCCC (RS, AT,DE), FAO, BAYKLAS
	Pre-cautionary measures				NAS (AT)
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			BAYKLAS, LULUCF Actions Austria(2015),
	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			UNFCCC (BG,AT , RS,MD)
	Creating a system of "protecting forest strips"				Monitoringbericht (D)
	Application of climate change oriented forest research results in the renewal of forests	l			NAS (H), BAYKLAS
	Implementation of measures to protect and / or enhance **biodiversity** (for example restore swamps and alluvial forests; natural forest reserves)	m			BAYKLAS, UNFCCC (ME)
	Increasing the forest cover with the aim to contribute to climate change mitigation and increasing the biodiversity	m-l			UNFCCC (BG,MD, H, RO), BAYKLAS
	Strengthening of the natural regeneration of natural forests and their sustainable use	m			NAS (SK)
	Maintenance of non-closed canopy in the forest steppe zone	m			NAS (H)
	The creation of habitat networks	m-l			White Paper EU
	Planting of forests in the vicinity of cities (urban forestry)	m			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			UNFCCC (SI)
	Biodiversity • Reduction of biotic and abiotic disturbances through strengthening adaptive capacity of forests • Measures supporting biodiversity, ecological stability and community service of the forest	s-m			UNFCCC (RS) NAS(SK)
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			Alpine Convention, UNFCCC (DE,CZ),
	Adapting/ Changing **water management plans**	m			UNFCCC(RS), CC (DE)
	Improvement of the forest management (objectives, framework, principles) regarding to the adaptation to the climate change (according to the latest research)				NAS (SK), BAYKLAS

	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			UNFCCC (BG,RS), Alpine Convention, Monitoringbericht D)
	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			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			UNFCCC (BG), White Paper EU
	Coordination of the implementation of the principle "The user pays" for forest resources, together with all stakeholders	m-l			UNFCCC (BG)
	Development and implementation of projects aimed at planting protection forestry strips (**buffer zones**) for agricultural lands protection, anti-erosional, for waters protection	m			UNFCCC (MD)
	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			UNFCCC (ME,BIH,SK)
	Afforestation of large areas using suitable native species Choice of adequate tree species, provenances, population and genotypes, which are more tolerant on altered climate conditions or specialized for potential climate conditions in future	l			UNFCCC (RS), Monitoringbericht D)
	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			UNFCCC (MD,BIH),
	Sanitary felling and reconstruction of degraded forests	l			UNFCCC (ME)
	Intensive reforestation	m-l			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			UNFCCC (ME,CZ, AT),BAYKLAS
	Plantation of non-native tree species to adapt to new climatic conditions	l			CC (DE), BAYKLAS, NAS (AT), LULUCF Actions Austria(2015)
	Increased **protection of forests** against pests and plant diseases	m			UNFCCC (BIH,RS, D, AT)
	Thinning out of the young stands to increase water and light availability	s			UNFCCC (RS),

	Reduction of spruce stands vulnerable to drier conditions				Monitoringbericht (D)
Techno-logical measures	Agro-technical 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			UNFCCC (HU,RO)
	Adapted cultivation techniques in forestry to be prepared for water shortages	m			CC (DE)
	Improvement in technical infrastructure	m			CC (DE)
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			UNFCCC (BG,MD), Alpine Convention
	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			UNFCCC (BG)
	Update forestry strategy and launch debate on options for an **EC approach** on forest protection and forest information systems	m			UNFCCC (EU)
	Development of a new version of the **Environment Protection Law**	m			UNFCCC (MD)
	Revise regulations and directives in forest management, including climate change impacts	m-l			UNFCCC (RS)
	Ensure **eco-certification** of all forest parts of the public right of each member state	s-m			Alpine Convention
	Development and implementation of projects aimed at planting protection forestry strips for agricultural land and water protection	m			UNFCCC (MD)
	Strengthen the role of local communities in sustainable forest management	m			UNFCCC (RS), BAYKLAS
	"Future Forests Programme": Reconstruction of forests from spruce to mixed forests				BAYKLAS
	Updating national plans for **forest fire prevention and protection**, improvement of the control of activities against forest fires	s			UNFCCC (BG)

5.7 Biodiversity / Ecosystems

Climate change impacts biota from an individual, population, species and community level to whole ecosystems or biogeographic regions. If abiotic factors like regional climate conditions are changing, the individuals can be more prone to catastrophic disturbances like disease, insects or fires [12].

Many of the since 2012 published studies and projects refer not only to the DRB, but more to Europe or Middle Europe [40,55,78,94,96]. They also rely often on data and research results acquired prior to 2012. The main findings are comparable to those mentioned in the first Danube study. 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. Hydrological variations control key habitat conditions within the river channels, floodplains and stream-influenced ground water zones. Many of the natural factors are interdependent and anthropogenic factors, such as land use change and agricultural practices often co-vary [78,79,118,122] [see fig. 18].

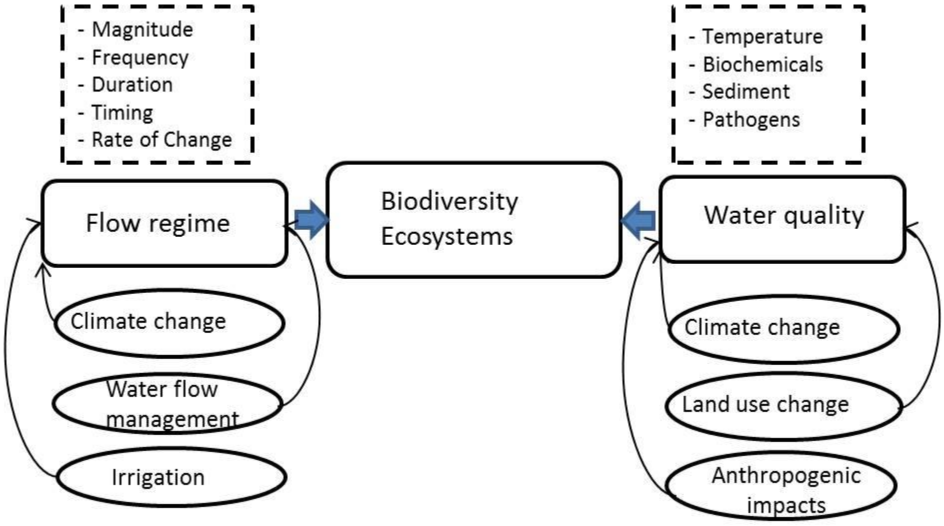

Figure 18: Linkage between hydrology, water quality and biodiversity (adapted from: RICHTER 1996)

The most commonly applied indicators for the climate impact assessments are eco-hydrological indicators, such as mean annual discharge, seasonal discharge (based on four seasons), monthly discharge, low flows (Q90% as an index for minimum flow levels for ecosystems) and mean annual flooding. These indicators play an important role for the entire Danube River and its tributaries.

Only few of the recent publications focus on sub-catchment or geographic regions of the DRB [80]. Statements made for the entire DRB are mostly relevant for the sub-catchments as well. With respect to surface water temperature and water quality the "ICPDR review on impacts of climate change on surface water temperature and quality (2017)" refers to the changes in the different sub-catchment. The KLIWA project (2014) on surface water ecology deals with climate change impacts in Bavaria, the European funded HABIT-CHANGE project with climate induced changes in protected areas. Six of the investigated examples are located within the DRB. Recent observations indicate changes in the long-term quasi-equilibrium of diverse physical and biological systems in the Carpathians and show that the impacts of climate change on ecosystems are in mountainous areas in general more severe than in lowlands. Table 10 summarises the impacts of flow changes.

Table 10: Eco-hydrological indicators and their impacts on ecosystems and biodiversity [119,122]

Eco-hydrological indicator	Impacts
Changes in mean annual flow	Floodplain vegetation Number of endemic fish species
Changes in seasonal mean flow	Habitat availability for aquatic organism Changes in soil moisture of floodplains
Changes in flow velocity	Changes in sediment transport
Changes in seasonality (timing of the annual maximum flow)	Spawning cues for migratory fish Behavioral mechanism
Low flows: Changes in Q90%	Changes in habitat conditions (temperature, oxygen conditions) Changes in soil moisture Water stress for plants
High flows (changes in Q2%)	Disruption of spawning Food availability Access to special habitats can be blocked Benefits of more frequent high flows: restoration of river-floodplain connectivity; increasing biomass

Danube River Basin (DRB) [*5,64,78,116,122*]

Compared to other large European rivers, the Danube still holds relatively large near-natural river sections with intact ecological functions. Considerable pressure on the river's native biodiversity comes from the invasion of non-native species which threaten native species. Additional pressure comes from land use change, water stress, pollution, habitat fragmentation, flow regulations.

Impacts on aquatic and riverine ecosystems and biodiversity are:

- Seasonal flow regimes are projected to change significantly with increasing global temperatures.
- Except in the alpine and dinaric tributaries for the winter months, the seasonal discharge of the rivers in the Danube basin is projected to decline progressively with global warming. The decrease in summer discharge is more severe, as it aggravates existing low flow periods.
- Changes in timing and magnitude of low flow and flood events impact fish migration, spawning and the macrozoobenthos (food resources)
- Changes in the hydrological regime may create new conditions to which native biota may be poorly adapted and exceed the tolerances of some aquatic biota and riparian plants
- The increase of mean summer temperatures leads to an increase of the water temperatures, which again increases the pressure on the native species in rivers and riverine habitats.
- 40% of the species are already invasive. The number will increase
- Earlier snowmelt or no snow cover during winter may lead to an earlier and longer rise in water temperature, impacting species which are sensitive to changes in this variable.
- The increase of water temperature leads to
  - Reduced oxygen and CO_2 solubility.
  - A changing in timing of algae blooms and thus food availability
  - An impact on the fish spawning and migration
  - An impact on phytoplankton and macrozoobenthos
- Increase of heavy rain fall events lead to an increase in sediment input
- Other impacting factors on water quality are indirectly related to climate change, such as land use change which can lead to an increase of anthropogenic impacts (e.g. fertilizer).

Impacts on terrestrial ecosystems:

- Longer growing season length causes a change in species structure within an ecosystem
- Redistribution of species on land across latitude and elevation influences food webs, biotic communities and migration patterns
- Mainly native species are expected to disappear
- Genetic changes, followed by extinction of species unable to adjust to climate change.
- Increase of the exotic species at the level of the actual natural habitats and the increase of their potential to become invasive

Upper Danube River Basin (UDRB) [*5,122]*

- Redistribution of terrestrial species especially in alpine areas
- Changes of domestic biodiversity and effects on fish and invertebrate-fauna
- Decrease in native and increase in alien species
- Endangerment of domestic macrophyts especially in low flowing river parts and stagnant water.
- Changes in flow regimes (higher discharge in winter, less discharge in summer in alpine rivers).
- Increase of heavy rain events will lead to higher erosion and sediment input thus influencing spawning areas and feeding grounds
- Increase of sediment input towards the end of the century due to diminishing glaciers changes river habitats
- Positive effect: many fish species (e.g. carps) can benefit from an increase in flooding and high flow events in spring that restore river-floodplain connectivity, thus leading to an increase in abundance/biomass or enhancing recruitment
- Earlier snowmelt or no snow cover during winter may lead to an earlier and longer rise in water temperature, impacting species which are sensitive to changes in this variable

Middle Danube River Basin (MDRB) [*25,64,115,122*]

- Modification of the habitats distribution and composition as a result of the change in the species structure.
- Decrease in native and increase in alien species.
- The surface area of several smaller lakes will significantly decrease (especially in the Hungarian Plains).
- Decrease of the extent of wetland habitats due to smaller magnitude of low flows and increasing number of low flow days.
- Loss of existing habitats due to alterations in discharge and decrease in water quality.
- Higher stress on aquatic ecosystems.
- More forest fires and fire accidents in ecosystems might occur.

Lower Danube River Basin (LDRB) [*35,64,79*]

- An increase of droughts might endanger wetlands
- Disconnection of functional habitats could harm the biodiversity especially in the Danube Delta
- Decrease in water quality and an increase in eutrophication due to rising water temperatures
- Changes in the freshwater and marine aquatic ecosystems generated by water warming and sea level rise

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
- Modification and losses of habitats due to changes in magnitude, frequency and timing of discharges

Challenges / Knowledge gaps

- Deficits in quantitative, regional and temporal assumption for losses of native species and threatened ecosystems
- Deficits in assessing impact of river flow changes
- Upstream – downstream connections
- Definition of hot spots and key catchments
- Evaluation of ecosystem services

Key findings and comparison to the previous study

Statements of the previous Danube study are confirmed. The changes of abiotic conditions threatening ecosystems and the increase of alien and invasive species are confirmed in the new studies, as well as the changes in distribution and migration patterns. Confirmed is also that the expected increase in water temperature and the following decrease of water quality will harm ecosystems and biodiversity significantly. New findings are that the changes in flow conditions will be besides the water temperature the most significant impact on aquatic and wetland.

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.

Concerning the 6th UNFCCC only minor changes or additional measures in comparison with the 5th UNFCCC could be detected. Not in all countries adaptation policy and measures for ecosystems in general are adopted. Some are only concentrating on forest ecosystems or wetland systems (6th UNFCCC Bulgaria)(see table 11).

Table 11: Suggested adaptation measures for impacts on water related energy production (*Time horizon of the effects of the measures: short-term (s), medium-term (m), long-term (l); (Measures shown in black = relevant in both studies, green=most often suggested, red = new compared to the first study; ǂ = in contradiction to WFD)

Type	Possible adaptation measures	Time horizon*	Relevant to WFD	Relevant to FD	Source (Countries)
Preparation measures for adaptation	**Establishment of a new systemic inventory**	m			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 • Evaluation of areas of various level of protection, and of the National Ecological Network, from the point of view of the changing climate and for identifying points of conflicts • Systematic long-term mapping, monitoring of occurrence of populations of invasive species	s-m			UNFCCC (SK, RS, MD), BAYKLAS, KLIWA NAS (H, SK,RO)
	Development of a biodiversity indicator system Determine the need for indicators, information and equipment, as well as priorities for long-term monitoring of climate change impacts on biodiversity	s			UNFCCC (RS)
	Research • on the vulnerability to climate change, on necessary data to assess the impacts of climate change on terrestrial ecosystems, the sea and biodiversity	s-m			UNFCCC (EU, RS),
	Establishment of a priority list of habitats and species, which are sensitive to climate changes	s			NAS (H,AT), KLIWA, ST_Laize
	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			UNFCCC (RS)

	• strengthening the scientific and research capacity				
	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			White Paper EU, KLIWA NAS (DE)
General measures	Supporting autonomous adaptation of the organisms and ecosystems, for example by maintaining genetic diversity				EEA Alps 2009, EEA 2016
	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			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 • designing a national environmental network map • increase of the landscape connectivity: elimination of barrier effect of roads and railways, elimination of barrier on water streams	m	y		CC (DE), UNFCCC (RS), BAYKLAS, KLIWA, NAS (SK SL, RS),
	Diversification of landscape and landscape structures – ensuring the heterogenic ecosystems, increased diversity of vegetation and of morphology, ensuring the dynamic natural processes	m-l			NAS (SK)
	Extension of natural areas to maintain original habitat and ecosystem function/ services • Restoring wetlands in order to reduce the risks from climate-related floods and droughts • Strengthening the protection of water related ecosystems • Preservation and restoration of floodplains, including reversion of arable land to flood meadows • Maintenance of non-closed canopy in the forest steppe zone. Moving or translocating protected areas: if a habitat moves in response to changing conditions (e.g. to higher elevations), it may be necessary to extend the boundaries or even translocate animals and plants	m-l	Y Y y		UNFCCC White Paper EU, NAS (H, RS) IUCN, WWF
	Increasing protected areas • Securing options for the migration of species between sites of natural fauna and flora • Strengthening the capacity of personnel in protected natural resources • Implementation of the Danube River Network of Protected Areas (DANUBEPARKS) • Implementation of the reconstruction of the needed habitats and the continuation of these efforts	m-l			NAS (D,H)
	Restoration of most valuable ecosystems/habitats • Restoration of the natural environment, wildlife and vegetation along the Danube	m-l			EEA (2012, 2016), NAS (D),

	• Identification and protection of old growth forests of the Danube Basin • Wetlands restoration, preserving existing peatlands and re-naturalisation where it is possible • Renaturation of rivers and riparian systems in order to buffer run-off peaks, offer additional flood plains and habitat for rare ecological communities				
	Promotion of sustainable/climate-friendly agriculture and forestry • The conversion of forests that do not suit the given habitats and contain non-native tree species • Assurance of buffer zones around the sensitive habitats	m			NAS (H), Alpine Convention
Behavioural /managerial measures	**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			NAS (AT,), UNFCCC (RS)
	Improvement of informing of professionals on climate change impacts and possible adaptation options	s			UNFCCC
	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 • 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			NAS (D), UNFCCC (RS)
	Adapting management of agriculture • limiting overgrazing of steppe pastures and river valleys which are more vulnerable to the increasing occurrence of droughts • sustainable use of grasslands	s-m			NAS (H, SK)
	Introduction of efficient forest management	m			UNFCCC (MD)
	Adapting water management • Considering biodiversity in measures of flood protection and river basin management • 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 • Ecologically concerned water management following the requirements of the Water Framework Directive of the EU • Operation of reservoirs in such a way as to consider ecological aspects	m	Y Y Y y		UNFCCC, NAS (H,AT)
	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			
	Improvement of the protected areas management system	m			KLIWA

	• 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)				Alpine Convention, BAYKLAS, UNFCCC (BIH)
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			NAS (MD,RO,H)
	Including knowledge about impacts of climate change in landscape planning				NAS(D)
	Conduct regular evaluation and improvement of strategies and adaptation measures				UNFCCC (RS)
	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 • Adoption of the Nature Protection Law and ratification of international agreements	m			UNFCCC (BIH), 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			NAS (DE)
	Implementation of the water framework directive	s-m	y		BAYKLAS, KLIWA

5.8 Water related energy production

In the Danube Basin Hydropower has a long tradition and it dominates the Renewable Electricity sectors (RES-E) of all but three countries (Germany, Czech Republic and Hungary) [101]. The long tradition together with the requirement of increased generation and use of energy from renewable sources represents a significant goal for the development of hydropower generation in the countries of the DRB [42]. The Danube countries are obliged to implement water, nature and other environmental legislation by following the EU Water Framework Directive as key tool for water policy [45]. In order to support the countries in the DRB ICPDR has developed an Assessment Report on Hydropower Generation in the DRB where important key information on hydropower generation in the context of water management, flood protection, biodiversity and nature protection on a basin wide level are represented [61]. Under this aspect the energy discussion should also be linked to the debate on adaptation to climate change.

Hydropower is on one hand a positive contribution to climate change mitigation through the avoidance of burning fossil fuels [61]. On the other hand it must take into account that climate change can have impacts on hydropower generation also, e.g. resilience of river habitats, quantity of flow, seasonal changes of flow, higher water levels.

Electricity supply from hydropower and thermal production is depending on water volume. Climate change impacts on water dependent energy production are largely connected to changes in water availability and hydrological extreme events [46]. Hydropower for example is strongly related to changes in mean annual discharge as well as flood and low flow events. Climate projections indicate only a small change in annual runoff; hence the seasonal pattern will significantly change, causing a decrease in runoff in summer. This will impact the energy production. Moreover, a possible increase in sediment loading would perturb the functioning of power-generating infrastructure [46].

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 [86]. 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. Due to increased runoff in winter, the vulnerability for power shortage for heating is low [46], but most studies show a decrease in energy production of thermal power in summer, which may coincide with an increased demand for cooling in households. 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)

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 [7]; 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) [*46,133*]

Hydropower

- In the Alpine regions a general warming trend will cause a seasonal shift towards earlier runoff. However more diverse changes in precipitation for the different climate scenarios and time periods result in diverging hydrological projections. A decrease in runoff is found in some models, but the generally shift of runoff towards winter suggests that the overall impact for the electricity sector tends to be positive rather than negative [133]. This is also shown in the estimated changes in average annual electricity generation by runoff power plants that are always in the one digit percentage but either positive or negative depending on the climate scenario.
- Mean annual hydroelectric power generation: more or less stable conditions in the near future, a decrease may appear in the far future.
- Energy losses due to a decrease in runoff and more low flow and flood events in the far future
- In high Alpine areas compensation of low flows with glacier melt-water in the near future; In the long term, however, the accelerated retreat of the glaciers is expected to result in decreasing water supply
- In glaciated areas the possible increases in sediment loading would perturb the functioning of power-generating infrastructure. This may cause a significant reduction in energy production in the large storage power plants in the UDRB (e.g. Kaprun) [46]

Middle Danube River Basin (MDRB) / Lower Danube River Basin (LDRB) [*15,105–107*]

General

- More information is available from the MDRB [106,107]. There is a lack in research results for the LDRB
- 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 Croatia and Serbia
- Investigations at the Vidraru hydropower development on the Arges River south of the Carpathians show the influence of climate change on hydropower electricity production for the period of 2071-2099. It is shown that almost every model gives as a result a reduction in flow

values especially in summer (June-August). The energy production of Vidraru Hydropower station shows a reduction of 4- 14% for the investigated period

- In the SAVA River Basin the mean discharge is projected to change only a little until 2040, but will decrease by 20% end of the century. Ecological flow (e-flow) shows no significant change till 2030, but to the end of the period a decrease of 11% (RCP4.5) or 14% (RCP8.5) in e-flow may result.
- Due to an increase in flood events, flood related damages of runoff power plants may increase [15]

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

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

Key findings and comparison to the previous study

- Both study show similar results in case of thermal power plants
- There is agreement that end of the century due to reduced discharge , hydropower generation will decrease as well
- New studies show that the change in sedimentation could have also a significant influence. This is subject to research
- Hydropower generation in rivers may also face a problem of increasing flood events and possible damages

Adaptation measures

The adaptation to climate change of the water related energy sectors is often seen as a secondary problem compared to other challenges such as the impacts of storms [127]. Adaptation measures proposed in the 6th National Communications under the UNFCCC refer frequently to the measures already proposed in the 5th NC. Most studies are concerned about the increase of energy demand in summer due to an increasing in cooling systems. The energy demand will exceed the energy demand in winter due to heating. As adaptation measures more research and studies are promoted to determine bottle necks. In the impact field of hydropower and water related energy production, technological measures are seen as the most 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. The elaboration of strategies to save energy, as well as the concerns about power plant safety in case of extreme events can be seen as a fairly new adaptation approach [86, 89](see table 12).

Table 12: Suggested adaptation measures for impacts on water related energy production (*Time horizon of the effects of the measures: short-term (s), medium-term (m), long-term (l); (Measures shown in black = relevant in both studies, green=most often suggested, red = new compared to the first study; ɫ = in contradiction to WFD)

Type	Possible adaptation measures	Time horizon*	Relevance to WFD	Relevance to FD	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 the hydro-energetic potential of rivers • 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	s-m	y y		NAS (AT, HU, RS,D), WASKLIM, UNFCCC ClimateWater Climate-ADAPT
	Monitoring • of the aquatic environment				NAS (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	y	y	UNFCCC (RO), NAS (DE, SK), WFD 24, White Paper EU,
General measures					
Ecosystem-based measures	Consideration of consequences for the ecology of rivers in the field of storage management	s-m	y		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			Alpine Convention, NC (RO, BUL, RS)
	Implement ecologically sound hydropower systems	m	y		WWF-DCP
Behavioural /managerial	Introduction of integrated water resource management	s-m	y		UNFCCC, NAS, EEA
	Paying attention to the location of power plants	s-m	y		WFD 24, White Paper

measures	• Using different locations for power plants (because of cooling water) • Promotion of decentralised sustainable energy generation where appropriate to local conditions to reduce risk				EU, UNFCCC, EEA 2016
	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			EEA Alps 2009, EEA 2012
	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			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 • Managing flood pathways for dams • Taking actions to determine the critical infrastructure in the energy system (hydroelectric dams) in order to determine the measures required in case of extreme weather phenomena	s		y y y	WFD 24, ClimateWater EEA 2012, 2016, UNFCCC
	Studying / assessment of structural measures before implementation • Consideration of ecological aspects, because they are known to generate significant impacts on the water courses (morphological changes, barriers to fish migration, etc.)	s-m			ClimateWater, Global Water Partnership
	Reduce energy demand by public campaigns and training on energy efficiency	s-m			UNFCCC EEA 2012,
	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			ClimateWater, EEA 2016
	Increasing the consideration of water temperature in water management, e.g. in heat load discharge	m	y		NAS (AT),
	Updating of heat load and cooling water quantity / low flow management plans	s			WASKLIM, NC (AT,RO,RS)
	Raise low water by means of adaptive control of reservoirs	s			WASKLIM
	Decrease the heat load in water bodies e.g. caused by cooling water	m	y		BAYKLAS, RBMP
Technological	Increase of power plant safety	m			NAS (SK)

measures	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), UNFCCC (CZ)
	Re-commissioning of small and medium hydro power plants	s			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 due to summer drought	m			ECCONET, NAS (DE)
	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	m-l			EEA 2012,2016, WFD 24
	Promotion of efficient cooling systems	s-m			UNFCCC (DE,RO), White Paper EU
	Increasing the transfer of water	s-m	ǂ		EEA 2012
	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	y		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)
	Elaboration of strategies by the local public administration authorities in order to use energy sources which should comply with the European environment and efficiency norms	m-l			UNFCCC(RO)
Policy approaches	Development of guiding principles on integrating environmental aspects in the use of existing hydropower plants	s-m			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			White Paper EU,
	Implementation of special regulations for thermal discharge during extreme events	s	y	y	NAS (AT)

5.9 Navigation

Transport and navigation on inland waterways are just as water related energy production very much linked to the river discharge and therefore to low flows and floods. Compared to the first study more projects are dealing with the impact of climate change on transport / navigation, whereas most projects are not focusing solely on the Danube, but on the European waterway corridors where the Danube is the south-east part. ECCONET and KLIWAS are the most comprehensive projects [19,36], but they are dealing only with the German and Austrian part of the Danube. There is still need in research for the MDRB and LDRB [57]. However, available assessments of climate change impacts on transport, including the costs from extremes, do not give a comprehensive overview of climate-related risks for transport across Europe owing to their widely different methodological approaches [40].

The impact of climate change is addressed more or less in all the projects, but model calculations were carried out mainly in KLIWAS. Other projects rely on these model calculations. Schweighofer (2014) [110] stated that for a proper evaluation of the future navigation conditions on the European waterways, the usage of a multi-model approach, using an ensemble of global and regional climate models, combined with the application of hydrological models (transferring the weather related information to discharge) as well as relationships between discharge, water levels and flow velocities is necessary [110]. For the near future there is no agreement between the projects about the significance of influences on the navigation, whereas for the far future there is in general an agreement in limited or impassable navigation due to more frequent extreme water levels and unstable conditions, especially on routes using free-flowing waterways [40]. The focus is set not so much on the fairways as such, but on the bottlenecks as these areas can impact shipping on a long river stretch. 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 [50,93]. Results agree that this is especially true for the UDRB. In contrast to the results of the first study, the newer publications do not see in general a problem for the MDRB and LDRB, because of the in general higher discharge of the Danube in these regions. Only drought situations will cause an impact [69,135].

Upper Danube River Basin (UDRB) [*13,19,67,68,110*]

- No agreement about the impact of the low flow development on navigation in the near future. Some studies see a positive effect on navigation for the nearest future (until 2020) due to higher low water flows in winter
- For the far future agreement about a significant increase in the low flow conditions and a strong impact on navigation
- No new model results (results from KLIWAS and GLOWA Danube 2010).
- Change from snowfall to more rainfall during winter may lead to more balanced navigation conditions in the UDRB
- Increased flooding conditions may cause problems
- Due to increasing winter temperatures, positive development concerning ice conditions

- As critical due to water depth the river stretches between Straubing and Vilshofen and at Wildungsmauer are seen in the near future

Middle / Lower Danube River Basin (MDRB) [*50,110,112*]

- Since the first study no projects were dealing with the development of shipping conditions in the MMDRB and LDRB.
- Only general statements for pluvial regimes are available:
  - The higher winter precipitations will lead to an increase in high water and flood conditions which will hinder navigation
  - The strong decrease in summer precipitation will cause critical low flow conditions
  - A more frequent appearance of dry summers may affect inland waterway transport significantly
  - Less ice in winter has a positive impact on shipping, especially in the MDRB

Commonalities

- Effects on shipping will be significant in the far future
- Both, the increasing low flow conditions in summer and the increasing flood conditions in winter will effect transport

Challenges / Knowledge gaps

- More projects were dealing with shipping, but no new climate and hydrological model results were generated
- Research need for the MDRB and LDRB

Key findings and comparison to the previous study

- More projects were dealing with transport/navigation (in total 10). Most important ECCONET and KLIWAS
- No new model results for the UDRB
- No agreement about the low flow development at the UDRB in the near future
- Increasing flood conditions are now seen more as a problem
- Decreasing flow conditions in summer will cause significant impacts on navigation

Adaptation measures

No extensively different adaptation measures are suggested than in the first study. It may be noticeable that the new suggested measures are only dealing with construction, engineering and fleet adaptation. Improving the channel conditions to ensure navigability at lower water levels is seen as the most necessary measure, although it can lead to ecological conflicts [13,20,112](see table 13).

Table 13: Suggested adaptation measures for impacts on navigation (*Time horizon of the effects of the measures: short-term (s), medium-term (m), long-term (l); (Measures shown in black = relevant in both studies, green=most often suggested, red = new compared to the first study; ǂ = in contradiction to WFD)

Type	Possible adaptation measures	Time horizon*	Relevance to WFD	Relevance to FD	Source (Countries)
Preparation measures for adaptation	Better **monitoring** of water levels	s-m	y		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			NAS (DE) UNFCCC (DE), KLIWAS Actionplan-AT
	Forecast / River Information Systems • Better seasonal discharge predictions at waterway level could help to adjust in short term • Improved prediction of water level situation up to 3 month • 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			EEA, 2012, ECCONET (2014), NAS RS,
General measures	Promotion of transport on interior waterways will enhance the competitiveness of river transport relative to other modes	s-m			NAS (RO, HR, HU),
	Reduction of environmental impacts	s-m	y	y	NAS (RO), EEA 2016
	Providing sufficient water depth in times of low water flow	s-m	y		WFD 24, via Donau
	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	y		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	y		ECCONET, 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			SDR, WWF-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			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			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			UNFCCC (DE, AT, HU), KLIMWAS, ECCONET Via Donau
	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 intermodal transport in the total transport of goods by increasing the use of inland waterways and railroad transport	s-m			NAS (RO, RS), CC (DE)
	Support the follow up process preparing a "Manual on Good Practices in Sustainable Waterway Planning"	s-m			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			EEA 2012, EEA Alps
Techno-logical measures	**Adaptation / creation / modernisation of infrastructure** • Adaptation /modernisation of infrastructure water to increase the average speed and fluidity of traffic • 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 • Engineering and maintaining fairway and channel • Better logistics	m-l s-m	ǂ y	y	NAS (RO, RS, MD) UNFCCC, viaDonau, ECCONET
	Low flow measures • Expansion of the shipping routes and management of water levels considering ecological interests, • Support the container shipping with shallow draft (national-wide) • Buffering water level fluctuations by damming • Remove or reduce bottleneck structures in the channel • 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)	s-m	y y ǂ ǂ		BAYKLAS, CC (DE), EEA 2012, EEA Alps viaDonau, ECCONET

	Improving the operation parameters of hydro-technical installations	m			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	y		WWF, WASKLIM, ECCONET, via Donau
Policy approaches	Providing a balanced framework for fair competition among ports	s-m			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			NAS (RO)

6 Conclusion and Outlook

- Most of the findings and especially the adaptation measures from the first Danube study 2011 are still valid

- New findings in comparison to the first study:

  - Climate change models for the DRB are often not comparable due to difference reference and model periods and different emission scenarios.

  - Since the IPCC AR5 new emission scenarios and high resolution regional climate models are available.

  - Seasonality of precipitation will increase: strong decrease of summer precipitation especially in the SE.

  - Weather and hydrological extremes (droughts, heat, floods) will increase with higher certainty.

  - Frequency and length of heat waves will increase.

  - New models and scenarios have a higher spatial resolution and will give more detailed results → high regional variability of climate change impacts.

  - Increase of energy demand for cooling.

  - Possible damages on runoff power stations due to increased flood events.

  - Climate change is affecting all regions and all fields, but uniform. The differences in impacts between the sub-catchments and the 3 parts of the Danube will increase.

  - Dry regions such as the LDRB will get drier, wet regions, such as the alpine areas will get wetter, but high variability within landscapes.

  - Although there is a positive effect on the duration of the growing season, it might not result in higher yield and harvests in all parts of the DRB. Especially in the eastern and south-eastern parts, the summers will be too hot and with not enough precipitation. Yield may decrease significantly.

  - Changes in the uncertainty of climate change effects: Most of the findings regarding climate change effect have become more certain. This applies in particular for seasonality in precipitation, runoff, droughts, floods, low flows, agriculture, forestry and ecosystems.

- Climate change adaptation strategies have to be applied on different levels. There is still a lack in transboundary coordination.

- The status of implementation of adaptation strategies differs from country to country.

- There seems to be still a lack of monitoring systems especially in the non-EU countries. There are only requests for national monitoring systems. The basin-wide coordination of monitoring systems is not addressed.

- The implementation of adaptation strategies is constrained to a lack of money in many countries.

Table 14 summarises the direction of projected climate change and impacts for the DRB sub-regions in different sectors and was created following [40].

Table 14: Direction of projected climate change impacts for the DRB sub-regions in different sectors. Cells without arrow indicate that there was no information

Direction of projected climate change and impacts for the DRB sub-regions			
Sector	UDRB	MDRB	LDRB
Changes in the climate system			
Mean annual air temperature	↗	↗	↗
Mean summer air temperature	↗	↗	↗
Mean winter air temperature	↗→	↗	
Mean annual precipitation	→	↗↘	→↘
Mean summer precipitation	↗↘	↘	↘
Mean winter precipitation	↗→	↗↘	
Heat extremes	↗	↗↘	
Extreme precipitation	↗	↗→	↗
Changes in discharge / water availability			
Mean annual discharge	↗→	→↘	→↘
Average summer discharge	↘	↘	↘
Average winter discharge	↗	→↘	↘
Timing of the annual peak flow	↘	↘	↘
Changes in droughts and low/flows			
Drought	↗→	↗→	↗
Low flow	↗→	↗→	↗→
Changes in floods			
Floods	↗	↗	↗
Changes in agriculture			
Growing season	↗	↗	↘
Damage from extreme events	↗	↗	↗
Reliable production	→	→↘	
Water demand	↗	↗	↗
Invasive species/pests	↗	↗	↗
New species/shift	↗	↗	
Changes in forestry			
Growing season	↗	↗↘	
Forest fires	↗→	↗→	↗
Structure and stability	↘	↘	
New species/shift	↗	↗	↗
Changes in biodiversity/ecosystems			
Number of native species	↘	↘	↘
Number of invasive species	↗	↗	↗

Water temperature	↗ (red)	↗ (red)	↗ (red)
Shift of habitats	↗→ (black)	↗→ (black)	↗→ (black)
Vulnerability to changes in discharge	→ (black)	↗ (red)	↗ (red)
Changes in water related energy production			
Hydropower potential	→ (red)	→↘ (red)	↘ (red)
Thermal electricity potential	→ (black)	↘ (red)	↘ (red)
Changes in navigation			
Ice cover	↘ (green)	↘ (green)	↘ (green)
Low flow conditions	→ (black)	↗ (red)	↗ (black)

↗	Increase throughout most of a region	Beneficial change (green)
↘	Decrease throughout most of a region	
↗→	Increase in substantial parts of a region	Adverse change (red)
→↘	Decrease in substantial parts of a region	
↗↘	Increase as well as decrease in a region	Change neither beneficial nor adverse/small change (black)
→	Only small changes	

To sum it up, the update and revision of the Danube Study revealed that most of the statements on climate change effects on the hydrology in the DRB from the first Danube Study can be confirmed. However, the analysed documents show that the methods for projecting future climates and their effects significantly improved, which allows for drawing a much clearer picture of climate change effects in the DRB with higher certainty. This applies in particular for the temporal and spatial distribution of climate change effects. Against this background an update of the ICPDR Strategy on Climate Change is highly recommended.

During the project time, a questionnaire about the implementation of climate change adaptation strategies and its challenges and advantages was sent to the national representatives. The preliminary analysis indicates that the ICPDR Strategy on Climate Change influences the development of national, regional and sectoral adaptation strategies. Yet, numerous challenges or even barriers such as the lack of money and knowledge, the infringement of rights or the lack of spatial differentiation of adaptation measures are named, when it comes to the implementation of adaptation measures. Moreover various needs, like hot spot analyses or downscaling of measures are indicated in the responses. The answers to the questionnaire are highly relevant for an update of the ICPDR Strategy on Climate Change and will be taken into consideration and discussed in the [18,38] ICPDR Climate Change Adaptation Workshop in Belgrade in March 2018.

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Annex 1: Terminology

Adaptation	Adaptation refers to actions that people take in response to, or in anticipation of, projected or actual changes in climate, to reduce adverse impacts or take advantage of the opportunities posed by climate change. (ICPDR 2013)
Adaptive capacity	The capabilities, resources or institutional capacities of systems, organisations or (individual) actors that enable them to adapt to climatic conditions that have been altered, or will alter in the future, and their possible impacts. Adaptive capacity includes the capacity to take effective adaptation measures and, by these means, to reduce potential damages, take advantage of opportunities or cope with consequences, mainly by reducing sensitivity by adaptation measures. To estimate adaptive capacity, socio-economic conditions and future developments need to be investigated, which is often performed through scenarios and expert judgment. (ICPDR 2013)
Autumn	September, October, November
Benefit-sharing	The fair and eqitable sharing of benefits arising from the use of water (Definition after the Nagoya-Protocol)
Climate Change Scenario	A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models. (IPCC 2013)
Climate Model	A numerical representation of the climate system based on the physical, chemical, and biological properties of its components, their interactions, and feedback processes, and accounting for some of its known properties (IPCC 2013).
Climate scenarios	Estimates of future climatic conditions generated by modelling approaches with certain underlying pathway.

Climate-proof	Activities to increase the resistance and resilience of the policies, plans and programs that will be directly or indirectly affected by the impacts of climate change, acknowledging the new conditions where the baseline is inherently unstable and changing, and including climate protection aims. (ICPDR 2013)
Data	Analysed documents, projects, adaptation activities, studies and reviewed papers.
Development projects	A project that seeks to integrate organisations, stakeholders and networks to generate a synergetic approach for the development or assessment of a common objective.
Documents	Analysed peer-reviewed papers in scientific journals or books, “Grey” literature: Reports, fact sheets, non-reviewed papers, internet documents, etc..
Exposure	The degree of climate stress upon a particular unit or system; it may be represented as either long-term change in climate conditions, or by changes in climate variability, including the magnitude and frequency of extreme events. (ICPDR 2013)
Extreme precipitation	Event of significantly high rainfall that is defined by a statistical concept.
Far/Distant future period	Future time period beyond the year 2050.
Green infrastructure	Strategically planned network of natural areas that provide an ecological framework for the protection and future development of ecosystems and biodiversity regarding human land use and building activities.
Improvement of resilience	Improvement of resilience involves increasing the ability of a system to withstand shocks and surprises and to revitalize itself if damaged. An integrated adaptive ecosystem management approach that increases ecosystem stability can improve the resilience of the environment and reduce vulnerability to improve the well-being of societies and ecosystems dependent on natural resources. Flexible sustainable decision-making processes that can accept new information, and that can be modified on the basis of this

	information, are also important elements in building and/or improving resilience. (ICPDR 2013)
IPCC report AR5	Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC). The report provides the comprehensive and recent results of the research in climate change.
Landscape units	Areas of catchments with similar characteristics.
Low-regret measures	Adaptation measures where the associated costs are relatively low and where the benefits, although mainly accrued under projected future climate change, may be relatively large. (ICPDR 2013)
Mitigation	Mitigation refers to actions taken to prevent, reduce or slow climate change, through slowing or stopping the build-up of greenhouse gases in the atmosphere.
Near future period	Future time period before the year 2050.
No-regret measures	Cost-effective adaptation measures that are worthwhile (i.e. they bring net socio-economic benefits) whatever the extent of future climate change is; they include measures which are justified (cost-effective) under current climate conditions (including those addressing its variability and extremes) and are also consistent with addressing risks associated with projected climate changes. (ICPDR 2013)
Projection	Future conditions calculated or simulated through trend extrapolation or modelling approaches depending on emission- or radiative forcing scenarios.
Projects	Conventions, strategies and guidances, projects and adaptation activities as well as studies and reviewed papers.
RCP **(Representative Concentration Pathways)**	Scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases (GHGs) and aerosols and chemically active gases, as well as land use /land cover (Moss et al., 2008). The word representative signifies that each RCP provides

	only one of many possible scenarios that would lead to the specific radiative forcing characteristics. The term pathway emphasizes that not only the long-term concentration levels are of interest, but also the trajectory taken over time to reach that outcome (Moss et al., 2010). (IPCC 2013)
Reference period	A certain period that serves as reference for modelling or statistical calculations of future conditions and against which change can be evaluated.
Research projects	Projects that seeks to systematically establish facts and knowledge about a specific topic by scientific methods.
Resilience	The resilience of a natural system is its capacity to tolerate disturbance without collapsing into a qualitatively different state that is controlled by a different set of processes. A resilient system can withstand shocks such as extreme events and rebuild itself. When a system loses resilience, it becomes vulnerable to changes that previously could be absorbed. In a vulnerable system, even small changes may be devastating. Even in the absence of disturbance, gradually changing conditions such as climate, land use and policies can surpass threshold levels, triggering an abrupt system response. Therefore, managing resilience enhances the likelihood of a sustainable generation of ecosystem services benefiting humans in changing environments where the future is unpredictable and changes are likely. (ICPDR 2013)
Scenario	A plausible description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces (e.g., rate of technological change, prices) and relationships. Note that scenarios are neither predictions nor forecasts, but are useful to provide a view of the implications of developments and actions. (IPCC 2013)
Seasonality	Sequence of certain events or climatic conditions at regular intervals within a year.
Sensitivity	The degree to which a system or actor is either

	adversely or positively influenced by climate variability or climate changes. (ICPDR 2013)
Spring	March, April, May
SRES Scenarios	SRES scenarios are emission scenarios with different underlying assumptions for future greenhouse gas emissions (and other driving forces) derived by demographic, societal, economic and technical storylines. (IPCC 2013)
Summer	June, July, August
Vulnerability	The extent to which a system or actor is susceptible to, or incapable of coping with, the detrimental consequences of climate change, including climate variability and extremes. Vulnerability depends on the character, magnitude, pace and variability of the climatic change to which the system is exposed, as well as the sensitivity and adaptive capacity of the system or actor. (ICPDR 2013)
Water stress	Water stress occurs, when the demand for water cannot be covered due to its availability or quality restrictions during a certain period.
Winter	December, January, February
Win-win measures	Cost-effective adaptation measures that minimize climate risks or increase adaptive capacity, and which also have other social, environmental or economic benefits; win-win options are often associated with those measures or activities that address climate impacts and also contribute to climate change mitigation or meet other social and environmental objectives. (ICPDR 2013)

Annex 2: List of projects, studies, conventions, reports, publications and guidances analysed for the scientific data base.

These projects and documents had been analysed, but not all of them have been included in the scientific data base due to redundancies, missing climate change scenarios and model results, not covering significant areas of the DRB, no published results until 1st Sept 2017 or no extended information in English. If several reports of a project were published, they are summarized under the project name.

Projects, reports and publications used for addressing adaptation measures are listed in annex 3. (ST= publication in journals)

Project/Author	Funding	Region	Project title	Date of report
ACQWA	European Commission 7th Framework Programme	UDRB	Assessing Climate impacts on the Quantity and quality of Water. Source: Beniston, M., Stoffel, M. & Hill, M. (2013): Project Science and Policy Brief.	2013
ALPFFIRS	INTERREG III B Alpine Space Programme	UDRB	Alpine Forest Fire waRning System. Source: ALPFFIRS (2012): Die Waldbrände der Alpen. Vorhersage, Kenntnis und Kooperation zum Schutze unserer Wälder.	2012
ALP-WATER-SCARCE	INTERREG III B Alpine Space Programme	UDRB	Water Management Strategies against Water Scarcity in the Alps. Source: ALP-WATER-SCARCE (2011).	2011
APCC		UDRB	APCC: Österreichischer Sachstandsbericht Klimawandel 2014 (Austrian Assessment Report 2014 (AAR14), Austrian Panel on Climate Change (APCC), Verlag der Österreichischen Akademie der Wissenschaften, Wien, Österreich.	2014
BAYERISCHES LANDESAMT FÜR UMWELT		UDRB	BAYERISCHES LANDESAMT FÜR UMWELT (2016): Bayerische Klima-Anpassungsstrategie 2016.	2016
BAYERISCHES STAATSMINISTERIUM FÜR UMWELT UND VERBRAUCHERSCHUTZ		UDRB	BAYERISCHES STAATSMINISTERIUM FÜR UMWELT UND VERBRAUCHERSCHUTZ (2015): Klima-Report Bayern 2015.	2015
BUNDESMINISTERIUM FÜR VERKEHR, INNOVATION UND TECHNOLOGIE		UDRB	BUNDESMINISTERIUM FÜR VERKEHR, INNOVATION UND TECHNOLOGIE (2017): Aktionsprogramm Donau des bmvit bis 2022.	2017
CARPATHCC	European Commission	MDRB, CARPATHIAN	In-depth assessment of vulnerability of environmental resources and ecosystem-based adaptation measures in the Carpathian Region	2014

Project/Author	Funding	Region	Project title	Date of report
CARPIVIA	European Commission	CARPATHIAN MOUNTAINS	CARPIVIA project: Carpathian integrated assessment of vulnerability to climate change and ecosystem-based adaptation measures	2013
CC-WATERS	South East Europe Transnational Cooperation Programme	MDRB	Climate Change and Impacts on Water Supply. Source: Simonffy Z. & CCWATERS (2012): WP4: Availability of Water Resources Final Report.	2012
CH2014-Impacts	Oeschger Centre for Climate Change Research (OCCR, University of Bern), the Federal Office for the Environment (FOEN/BAFU), the Federal Office of Meteorology and Climatology MeteoSwiss National Centre of Competence in Research on Climate (NCCR Climate)	UDRB	CH2014-Impacts (2014): Toward Quantitative Scenarios of Climate Change Impacts in Switzerland, OCCR, FOEN, MeteoSwiss, C2SM, Agroscope, ProClim, Bern, Switzerland.	2014
CLIMATECOST	European Commission 7th Framework Programme	EUROPE, DRB	CLIMATECOST - The Full Cost of Climate Change. Source: Christensen, O.B., Goodess, C.M., Harris, I. & Watkiss, P. (2011): European and Global Climate Change Projections: Discussion of Climate Change Model Outputs, Scenarios and Uncertainty in the EC RTD ClimateCost Project.	2011
CLIMSAVE	European Commission 7th Framework Programme	EUROPE, DRB	Climate Change Integrated Assessment Methodology for Cross-Sectoral Adaptation and Vulnerability in Europe. Source: CLIMSAVE (2013): Climate Change Impacts, Adaptation and Vulnerability in Europe: An integrated approach.	2013
CLIMSAVE	European Commission 7th Framework Programme	EUROPE, DRB	CLIMSAVE-Consortium & Harrison, P. (2013): Climate Change Impacts, Adaptation and Vulnerability in Europe: An integrated approach.	2013

Project/Author	Funding	Region	Project title	Date of report
CLISP	INTERREG IV B Alpine Space Programme	UDRB	Climate Change Adaptation by Spatial Planning in the Alpine Space. Source: CLISP (2009): CLISP - Climate Change Adaptation by Spatial Planning in the Alpine Space.	2009
DRIDANUBE	INTERREG Danube Transitional Programme	DRB	Drought Risk in the Danube Region	2017
ECCONET	European Commission 7th Framework Programme	UDRB, MDRB	Effects of climate change on the inland waterway networks. Source: Heyndrickx, C., Breemersch, T. (2012): ECCONET: climate change and adaptation to inland waterways, Athens.	2012
EEA		EUROPE	EEA - European Environment Agency (2016): Climate change, impacts and vulnerability in Europe 2016.	2016
ENVIROGRIDS		EUROPE	Building Capacity for a Black Sea Catchment Observation and Assessment System supporting Sustainable Development. Source:UNIGE (2013): Deliverable 5.8 Synthesis of vulnerability and adaptation issues.	2013
EURAC		UDRB	EURAC (2011): WP 4 Vulnerability Assessment. SYNTHESIS REPORT.	2011
EUROPEAN COMMISSION		EUROPE	EUROPEAN COMMISSION (2009): Renewable Energy Directive.	2009
EUROPEAN COMMUNITIES		EUROPE	EUROPEAN COMMUNITIES (2009): Common Implementation Strategy for the Water Framework Directive (2000/60/EC). Guidance document No. 24. River Basin Management in an Changing Climate.	2009
FLOODRISK	European Commission	DRB	Stakeholder Oriented Flood Risk Assessment for the Danube Floodplains	2012
GLOBAL WATER PARNERSHIP		EUROPE	GLOBAL WATER PARNERSHIP (2017): Integrated drought management in Central and Eastern Europe.	2017
HABITAT-CHANGE	INTERREG IV B Central Europe programme	EUROPE	LEIBNITZ INSTITUTE OF ECOLOGY AND REGIONAL DEVELOPMENT (2013): HABIT-CHANGE - adaptive management of climate-induced changes of habitat diversity in protected areas, www.habit-change.eu/.	2013

Project/Author	Funding	Region	Project title	Date of report
ICPDR		DRB	ICPDR (2013): Assessment report on Hydropower generation in the Danube Basin.	2013
ICPDR		DRB	ICPDR (2017): Review of impacts of climate change on surface water temperature and quality in the Danube River Basin.	2017
JRC PESETA II		EUROPE	JRC Peseta II. Source: Ciscar J.C., Feyen L., Soria A., Lavalle C., Raes F., Perry M. & Nemry F. et al. (2014): Climate Impacts in Europe. The JRC Peseta II Project.	2014
KLIWA	UVM, STMUG	UDRB	Klimaveränderung und Konsequenzen für die Wasserwirtschaft. Source: Arbeitskreis KLIWA (2016): Ableitung von Temperaturpräferenzen des Makrozoobenthos für die Entwicklung eines Verfahrens zur Indikation biozönotischer Wirkungen des Klimawandels in Fließgewässern. Source: KLIWA (2012): Auswirkungen des Klimawandels auf Bodenwasserhaushalt und Grundwasserneubildung in Baden-Württemberg, Bayern und Rheinland-Pfalz.	2016, 2012
KLIWAS	BMVBS	DRB, UDRB	Auswirkungen des Klimawandels auf Wasserstraßen und Schifffahrt – Entwicklung von Anpassungsoptionen. Source: KLIWAS (2014): Validierung und Bewertung von Klimaprojektionen – Bereitstellung von Klimaszenarien für den Binnenbereich. Source: BUNDESANSTALT FÜR GEWÄSSERKUNDE - KLIWAS Koordination (2013): Auswirkungen des Klimawandels auf Wasserstraßen und Schifffahrt –Entwicklung von Anpassungsoptionen. Source: FEDERAL MINISTRY OF TRANSPORT AND DIGITAL STRUCTURE (2015): KLIWAS-Impacts of Climate Change on Waterways and Navigation in Germany. Concluding Report	2015, 2014,2013
MANFRED	INTERREG IV B Alpine Space Programme	UDRB	Management strategies to adapt Alpine Space forests to climate change risks. Source: MANFRED (2013): The 22nd Century Potential of Alpine Space Forests: An overview of climate change risks for forest practitioners in the Alps based on the EU Alpine Space Programme's MANFRED project results.	2013

Project/Author	Funding	Region	Project title	Date of report
NATIONAL ADAPTATION STRATEGY Austria		AT	FEDERAL MINISTRY OF AGRICULTURE, FORESTRY, ENVIRONMENT AND WATER MANAGEMENT: The Austrian Strategy for Adaptation to Climate Change.	2012
NATIONAL ADAPTATION STRATEGY Bavaria		UDRB, Bavaria	Bayerische Klima-Anpassungsstrategie	2016
NATIONAL ADAPTATION STRATEGY Bosnia-Herzegovina		BA	BOSNIA AND HERZEGOWINA MINISTERY FOR SPATIAL PLANNING, CIVIL ENGINEERING AND ECOLOGY (2013): Climate Change adaptation and low emission development strategy for Bosnia and Herzegowina.	2014
NATIONAL ADAPTATION STRATEGY Czech Republic		CZ	MINISTRY OF ENVIRONMENT - Strategy on Adaptation to Climate Change in the Czech Republic – Executive Summary	2015
NATIONAL ADAPTATION STRATEGY Republic of Slovakia		SK	MINISTRY OF ENVIRONMENT OF THE SLOVAK REPUBLIC: Adaptation Strategy of the Slovak Republic on Adverse Impacts of Climate Change.	2014
NATIONAL ADAPTATION STRATEGY Switzerland		CH	BUNDESAMT FÜR UMWELT: Anpassung an den Klimawandel in der Schweiz.	2014
2nd NC_BOSNIA-HERZEGOWINA		BH	Second National Communication of Bosnia and Herzegovina under the United Nations Framework Convention on Climate Change.	2013
6th NC_SERBIA		RS	MINISTRY OF AGRICULTURE AND ENVIRONMENTAL PROTECTION (2016): Second National Communication of the Republic of Serbia under the United Nations Framework Convention on Climate Change.	2016
6th NC_ROMANIA		RO	Roman, M., Mischie, A., Gheorghe, L., Manea, F., Stănică, C., Deaconu, S. & Smarandache, M. et al. (rou_nc5_resbmit.pdf (Adap-Nation-Romania)): 5th National Communication of Romania.	2010
6th NC_BULGARIA		BG	REPUBLIC OF BULGARIA: Sixth National Communication on Climate Change.	2013

Project/Author	Funding	Region	Project title	Date of report
6th NC_CROATIA		HR	REPUBLIC OF CROATIA, Ministry of Environmental and Nature Projection: Sixth National Communication and First Biennial Report of the Republic of Croatia under the United Nations Framework Convention on Climate Change (UNFCCC).	2014
6th NC_GERMANY		DE	FEDERAL MINISTRY OF THE ENVIRONMENT, NATURE CONSERVATION, BUILDING AND NUCLEAR SAFETY: Sixth National Communication under the United Nations Framework Convention on Climate Change - Report by the German Federal Government.	2013
6th NC_HUNGARY		HU	Hungary (2013): 6th National Communication to the UNFCCC.	2013
6th NC_ROMANIA		RO	MINISTRY OF ENVIRONMENT AND CLIMATE CHANGE: Romania's Sixth National Communication on Climate Change and First Biennial Report.	2013
6th NC_Slovakia		SK	MINISTRY OF ENVIRONMENT OF THE SLOVAK REPUBLIC & Slovak Hydrometeorological Institute: THE SIXTH NATIONAL COMMUNICATION OF THE SLOVAK REPUBLIC ON CLIMATE CHANGE.	2013
6th NC_SLOVENIA		SI	REPUBLIC OF SLOVENIA, Ministry of Agriculture and the Environment (2014): SLOVENIA'S SIXTH NATIONAL COMMUNICATION AND FIRST BIANNUAL REPORT UNDER THE UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE.	2014
6th NC_SWITZERLAND		CH	SWISS CONFEDERATION: Switzerland's Sixth National Communication and First Biennial Report under the UNFCCC.	2013
6th NC_UKRAINE		UA	MINISTRY OF ENVIRONMENT AND NATURAL RESOURCES OF UKRAINE, State Service of Ukraine of Emergencies, National Academy of Sciences of Ukraine, Ukrainian Hydrometeorological Institute (2013): VI National Communication of Ukraine on Climate Change.	2013
NEWADA DUO	EU SEE Transnational Cooperation Programme	DRB	NEWADA DUO (2012-2014): Waterway maintainace and management system for the Danube	2012-2014

Project/Author	Funding	Region	Project title	Date of report
ÖKS15		UDRB	Klimaszenarien für Österreich. Source: FEDERAL MINISTRY OF AGRICULTURE, FORESTRY, ENVIRONMENT AND WATER MANAGEMENT (2015): ÖKS15 Klimaszenarien für Österreich.	2015
REKK	Ministry of Foreign Affairs of Hungary	DRB	REKK - Regional Centre for Energy Policy Research (2013): Renewable Electricity Market Monitoring in the Countries of the Danube Region.	2013
INTERNATIONAL SAVA RIVER BASIN COMMISSION		SAVA	SAVA River Basin Management Plan	2014
SILMAS	INTERREG IV B Alpine Space Programme	UDRB	Sustainable Instruments for Lakes Management in the Alpine Space. Source: SILMAS (2012): Climate Change Impacts on Alpine Lakes.	2012
SOER_I		EUROPE	EEA - European Environment Agency (2010): The European Environment. State and Outlook 2010. Adapting to climate change - SOER 2010 thematic assessment. DOI.	2010
SOER_II		EUROPE	EEA - European Environment Agency (2015): SOER 2015 - The European environment: State and outlook.	2015
ST_BARTHOLY	Hungarian Scientific Research Fund, Swiss-Hungarian Cooperation Programm, European Union and the European Social Fund	MDRB	Bartholy, J., Pongrácz, R. & Pieczka, I. (2014): How the climate will change in this century?, Hungarian Geographical Bulletin, 63, 55–67.	2014
ST_BERGENGREN		EUROPE, WORLD	Bergengren, J.C., Waliser, D.E. & Yung, Y.L. (2011): Ecological sensitivity: a biospheric view of climate change, Climatic change, 107, 433–457.	2011
ST_BEUTHE		UDRB	Beuthe, M., Jourquin,B., Urbain,N., Lingemann,I., Ubbels,B. (2014): Climate change impacts on transport on the Rhine and Danube, Transportation Research Part D, 27, 6–11.	2014

Project/Author	Funding	Region	Project title	Date of report
ST_BLOESCHL		UDRB	Blöschl, G., Schöner, W., Kroiß, H., Blaschke, A.P., Viglione, A., Böhm, R. & Haslinger, K. et al. (2011): Anpassungsstrategien an den Klimawandel für Österreichs Wasserwirtschaft. Studie der Zentralanstalt für Meteorologie und Geodynamik und der Technischen Universität Wien.	2011
ST_BRILLY a		MDRB	Brilly, M., Sraj, M., Vidmar, A., Primožič, M., Koprivšek, M. & Kavcic, K. (2014): Pilot Project On Climate Change: Building The Link Between Flood Risk Management Planning And Climate Change Assessment In The Sava River Basin.	2014
ST_BRILLY b		MDRB	Brilly, M., Šraj, M., Vidmar, A., Primožič, M. & Koprivšek, M.: Climate Change Impact on Flood Hazard in the Sava River Basin, in: A. Adrovič, R. Milačič (Eds.), The Sava River, Springer, Berlin [u.a.], 2015, pp. 27–52.	2015
ST_CEGLAR		MDRB	Ceglar, A. & Rakovec, J.: Climate Projections for the Sava River Basin, in: A. Adrovič, R. Milačič (Eds.), The Sava River, Springer, Berlin [u.a.], 2015, pp. 53–74.	2015
ST_CIORAN		MDRB	Cioran, G.H. (2016): Microbiological and ecological classification of water quality in the Danube River Basin in Romania, Global Science Research Journal, vol.4, 331–340.	2016
ST_DASCALU		LDRB	Dascălu, S.I., Gothard, M., Bojariu, R., Birsan, M.-V. Cică, R., Vintilă, R., Adler, M.-J., Chendeș, V., Mic, R. (2016): Drought-related variables over the Bârlad basin (Eastern Romania) under climate change scenarios, CATENA, 141, 92–99.	2016
ST_DERKNIJFF		WORLD	der Knijff, J.M., Younis, J. & Roo, A.P.J. de (2010): LISFLOOD, International Journal of Geographical Information Science, 24, 189–212.	2012
ST_DIAKOV		LDRB	Diakov, O., Zakorchevnaya, N., Nesterenko, M., Tudor, M., Drumea, D., Kovbasko, O. & Zhmud, M. et al. (2012): Vulnerability of the Danube Delta Region to Climate Change.	2012
ST_DUBROVSKY		EUROPE	Dubrovsky, M., Simon, K.-H., Stuch, B., Kok, K. & Harrison, P. (2013): Report on the European driving force database for use in the Integrated Assessment Platform.	2013

Project/Author	Funding	Region	Project title	Date of report
ST_DUMITRACHE		MDRB	Dumitrache, A., Sandu, C., Elhag, M., Yilmaz, N., Dumitrescu, A. & Cheval, S. (2017): Climate change effect on hydrological and chemical parameters of shallow lakes of the Danube Delta (Romania).	2017
ST_FLOERKE		WORLD	Flörke, M., Wimmer, F. et al (2012): Climate change adaptation - modelling water scenarios and sectoral impacts. CESR.	2012
ST_FORZIERI		EUROPE	Forzieri, G., Feyen, L., Rojas, R., Flörke, M., Wimmer, F. & Bianchi, A. (2014): Ensemble projections of future streamflow droughts in Europe, Hydrology and Earth System Sciences, 81.	2014
ST_GAAL		MDRB	Gaal, L., Beranova, R., Hlavcova, K., Kysely, J. (2014): Climate Change Scenarios of Precipitation Extremes in the Carpathian Region Based on an Ensemble of Regional Climate Models, Advances in Meteorology, 1–14.	2014
ST_GOBIET		UDRB	Gobiet, A., Kotlarski, S., Beniston, M., Heinrich, G., Rajczak, J. & Stoffel, M. (2014): 21st century climate change in the European Alps-a review, The Science of the total environment, 493, 1138–1151.	2014
ST_GOTTFRIED		EUROPE	Gottfried, M., Pauli, H., Futschik, A., Akhalkatsi, M., Barančok, P., Benito Alonso, J. L. (2012): Continent -wide response of mountain vegetation to climate change, Nature Climate Change, 2, 111–115.	2012
ST_HLASNY		MDRB	Hlásny, T., Trombik, J., Dobor, L., Barcza, Z., Barka, I. (2016): Future climate of the Carpathians, Reg Environ Change, 16, 1495–1506.	2016
ST_HUANG		UDRB	Huang, S., Krysanova, V. & Hattermann, F. (2015): Projections of climate change impacts on floods and droughts in Germany using an ensemble of climate change scenarios, Reg Environ Change, 15, 461–473.	2015
ST_JACOB	EU FP6 and FP7	EUROPE	Jacob, D., Petersen, J., Eggert, B., Alias, A., Christensen, O.B., Bouwer, L.M. & Braun, A. et al. (2014): EURO-CORDEX, Reg Environ Change, 14, 563–578.	2014

Project/Author	Funding	Region	Project title	Date of report
ST_KLEIN_I		DRB	Klein, B., Meissner, D. (2016): Navigation on the Danube - Vulnerability of Inland Waterway Transport and Waterway Management on Hydrometeorological Extremes.	2016
ST_KLEIN_II		UDRB, DRB	Klein, B., Nilson, E., Krahe, P., Rachimow, C., Horsten, T., Maurer, T. & Moser, H.: Climate change analyses used for river basin management in the rivers Danube and Elbe, in: German Federal Institute of Hydrology (BfG), Department M2 - Water Balance, Forecasting and Predictions, 2010.	2010
ST_KLEIN_III		UDRB	Klein, B., Krahe, P., Lingemann, I., Nilson, E., Kling, H. & Fuchs, M. (2011): Assessing climate change impacts on water balance in the upper Danube basin based on a 23 member RCM ensemble.	2011
ST_KOLFAK		UDRB	Kolfak, S., Wienhaus, S., Moser, H. et al (2014): Die Auswirkungen des Klimawandels auf Wasserstraßen und Schifffahrt in Deutschland einschätzen: Unterstützung für Entscheidung zur Anpassung, Tagungsband, 121–133.	2014
ST_KYSELI		EUROPE	Kyseli, J., Beranova,R. (2009): Climate-change effects on extreme precipitation in central Europe: uncertainties of scenarios based on regional climate models, Theor Appl Climatology, 95, 361–374.	2009
ST_LAAHA	Klima- und Energiefonds Austria	UDRB	Laaha, G., Parajka, J., Viglione, A., Koffler, D., Haslinger, K., Schöner, W. & Zehetgruber, J. et al. (2016): A three-pillar approach to assessing climate impacts on low flows, Hydrology and Earth System Sciences, 20, 3967.	2016
ST_LAIZE		EUROPE	Laizé, C.L.R., Acreman, M.C., Schneider, C., Dunbar, M.J., Houghton-Carr, H.A., Flörke, M. & Hannah, D.M. (2014): Projected flow alteration and ecological risk for pan-European rivers., River Research and Applications, 30, 299–314.	2014

Project/Author	Funding	Region	Project title	Date of report
ST_LOBANOVA		LDRB	Lobanova, A., Stagl, J., Vetter, T. & Hattermann, F. (2015): Discharge Alterations of the Mures River, Romania under Ensembles of Future Climate Projections and Sequential Threats to Aquatic Ecosystem by the End of the Century, Water, 7, 2753–2770.	2015
ST_MADSEN		EUROPE	Madsen, H., Lawrence, D., Lang, M., Martinkova, M. and Kjeldsen, T. (2014): Review of trend analysis and climate change projections of extreme precipitation and floods in Europe, Journal of Hydrology, 519, 3634–3650.	2014
ST_MIC et al_I		MDRB, LDRB	Mic, R.P., Corbus, C. & Busuioc, A. (2013): Climate Change Impact Upon Water Resources in the Buzau And Ialomita River Basin, Rev. Roum. Géogr./Rom. Journ. Geogr., 2013.	2013
ST_MIC et al_II		MDRB, LDRB	Mic, R.P., Corbus, C. & Metreata, M. (2016): Effects of Climate Change in Extreme Flow in Romanian River Basin Barlad.	2016
ST_NEJEDLIK		MDRB	Nejedlik, P. & Siska, B.: Climate change impacts and the adaptation options in agriculture in Slovakia, in: B. Siska (Ed.), Environmental changes and adaptation strategies, Skalica, Slovakia, 2013.	2013
ST_NESTERENKO		LDRB	Nesterenko, M., Dyakov, O., Drumea, D. & Doroftei, M. (2014?): Adapting To Change - Climate Change Adaptation Strategy and Action Plan for Danube Delta Region.	2014
ST_OSTFELD		DRB	Ostfeld, A., Barchiesi, S. & Bonte, M.E.A. (2012): Climate change impacts on river basin and freshwater ecosystems: some observations on challenges and emerging solutions, Journal of Water and Climate Change, 3, 171–184.	2012
ST_PARAJKA	Klima- und Energiefonds Austria	UDRB	Parajka, J., Blaschke, A.P., Blöschl, G., Haslinger, K., Hepp, G., Laaha, G. & Schöner, W. et al. (2016): Uncertainty contributions to low-flow projections in Austria, Hydrology and Earth System Sciences, 20, 2085–2101.	2016
ST_PECL		WORLD	Pecl, G.E.A.T. (2017): Biodiversity redistribution under climate change: Impacts on ecosystems and human well-being, Science, 355.	2017

Project/Author	Funding	Region	Project title	Date of report
ST_PIECZKA	Hungarian Ministry of Environment and Water, the Hungarian Academy of Sciences, Hungarian National Science Research Foundation, Hungarian National Research Development Program European Union Nr. 6 program, European Union and the European Social Fund	MDRB	Pieczka, I., Pongrácz, R. & Bartholy, J. (2011): Comparison of Simulated Trends of Regional Climate Change in the Carpathian Basin for the 21st Century Using Three Different Emission Scenarios, Acta Silvatica et Lignaria Hungarica, 7, 9–22.	2011
ST_PISTOCCHI		DRB	Pistocchi, A., Beck, H., Bisselink, B., Gelati, E., Lavalle, C. & Feher, J. (2015): Water scenarios for the Danube River Basin: Elements for the assessment of the Danube agriculture-energy-water nexus.	2015
ST_PONGRACZ	Hungarian Scientific Research Fund, European Union, European Social Fund , EU FP6 Integrated Project	MDRB	Pongrácz, R., Bartholy, J. & Kis, A. (2014): Estimation of future precipitation conditions for Hungary with special focus on dry periods, Időjárás, 18.	2014
ST_RAJCZAK		EUROPE, UDRB	Rajczak J, Pall P, Schär C. (2013): Projections of extreme precipitation events in regional climate simulations for Europe and the Alpine Region., J. of Geophysical Research, 118, 3610–3626.	2013
ST_ROMAN		WORLD, EUROPE	Roman R., De Felice M., Popa B. (2014): Influence of climate change on hydropower plants electricity production., U.P.B. Sci. Bull. Series D, 76, 1454–2358.	2014
ST_ROO_I		MDRB	Roo, A. de, Bisselink, B., Beck, H., Bernhard, J., Burek, P., Reynaud, A. & Pastori, M. et al.: Modelling water demand and availability scenarios for current and future land use and climate in the Sava River Basin, in: Publications Office of the European	2016

Project/Author	Funding	Region	Project title	Date of report
			(Ed.), JRC Technical Reports, Luxembourg (Luxembourg).	
ST_ROO_II		MDRB	Roo, A.P.J. de, Wesseling, C.G. & van Deursen, W.P.A. (2000): Physically based river basin modeling with GIS, Hydrological Processes, 14, 1981–1992.	2000
ST_SCHNEIDER		EUROPE	Schneider, C., Laizé, C.L.R., Acreman, M.C. & Florke, M. (2013): How will climate change modify river flow regimes in Europe? Hydrology and Earth System Sciences, 17, 325–339.	2013
ST_SCHWEIGHOFER		EUROPE	Schweighofer, J. (2014): The impact of extreme weather and climate change on inland waterway transport, Natural Hazards, 72, 23–40.	2014
ST_SIEDL		EUROPE	Siedl, N., Schweighofer, J. (2014): Guidebook for enhancing resilience in european inland waterway transport in extreme weather events, Vienna.	2014
ST_SIPKAY_I		MDRB	Sipkay, C., Drégelyi-Kiss, Á., Horváth, L., Garamvölgyi, Á., Kiss, K.T. & Hufnagel, L. (2010): Community ecological effects of climate change, Climate change and variability, 139–162.	2010
ST_SIPKAY_II		MDRB	Slipkay, C., Tihamér, K., Vadadi-Fulop, C. & Hufnagel, L. (2012): Simulation modeling of phytoplankton dynamics in a large eutrophic river, Hungary – Danubian Phytoplankton Growth Model (DPGM), Biologia, 67, 323–337.	2012
ST_SPINONI_I		MDRB	Spinoni, J. & Vogt, J.: Szalai,S. et al (2014): Climate change in the Carpathian Region. CARPATCLIM.	2014
ST_SPINONI_II		EUROPE	Spinoni, J., Naumann, G., Vogt, J. & Barbosa, P. (2016): Meteorological Droughts in Europe: Events and Impacts – Past Trends and Future Projections. CARPATCLIM.	2016
ST_STAGL_I	European Regional Development Fund (ERDF)	DRB	Stagl, J. & Hattermann, F. (2015): Impacts of Climate Change on the Hydrological Regime of the Danube River and Its Tributaries Using an Ensemble of Climate Scenarios, Water, 7, 6139–6172.	2015

Project/Author	Funding	Region	Project title	Date of report
ST_STAGL_II	European Regional Development Fund (ERDF)	DRB	Stagl, J. & Hattermann, F. (2016): Impacts of climate change on riverine ecosystems: Alterations of ecologically relevant flow dynamics in the Danube riber and its major tributaries, Water, 8.	2016
ST_STAGL_III	European Regional Development Fund (ERDF)	DRB	Stagl, J., Hattermann, F. & Koch, H. (2013): Modelling of climate change impacts on river flow regime and discharge of the Danube River considering water management effects, Geophysical Research Abstracts, 15.	2013
ST_STAGL_IV	European Regional Development Fund (ERDF)	EUROPE	Stagl, J., Hattermann, F. & Vohland, K. (2015): Exposure to climate change in Central Europe: What can be gained from regional climate projections for management decisions of protected areas?, Regional environmental change, 15, 1409–1419.	2015
ST_STAHL	EU WATCH project (WATer and global CHange)	EUROPE	Stahl, K., Tallaksen, L.M., Hannaford, J. & van Lanen, H.A.J. (2012): Filling the white space on maps of European runoff trends: estimates from a multi-model ensemble, Hydrology and Earth System Sciences, 16, 2035–2047.	2012
ST_WAGNER		UDRB	Wagner T., Themeßl M., Schüppel A., Gobiet A., Stigler H., Birk S. (2017): Impacts fo climate change on stream flow and hydro-power generation in Alpine region., Environmental Earth Sciences, 76, 1–22.	2017
ST_ZOLINA		EUROPE	Zolina, O.: Changes in Intense Precipitation in Europe, Chapter 6, in: Kundzewicz, Z.W. (Eds.), Changes in Flood Risk (Ed. Z.W. Kundzewicz), 2012, pp. 97–120.	2012
UMWELTBUNDESAMT		UDRB	UMWELTBUNDESAMT (2015): Monitoringbericht 2015 zur Deutschen Anpassungsstrategie an den Klimawandel. (Evaluation of the German Strategy for Adapatation to Climate Change (DAS))	2015
UNECE		EUROPE	UNECE - United Nations Economic Commission for Europe (2015): Water and Climate Change Adaptation in Transboundary Basins.	2015
WATCAP	World Bank	MDRB	Water and Climate Adaptation Plan for the Sava River Basin. Source: WORLD BANK (2015): WATCAP - Water and Climate Adaptation Plan for the Sava River Basin - Final Report.	2015

Project/Author	Funding	Region	Project title	Date of report
WATCH	European Commission 6th Framework Programme	EUROPE, DRB	WATer and global Change. Source: WATCH (2011): Technical Reports.	2011
WEATHER	European Commission 7th Framework Programme	EUROPE, DRB	Weather Extremes: Assessment of Impacts on Transport Systems and Hazards for European Regions. Source: WEATHER (2009-2012): WEATHER - Weather extremes, Impacts on Transport Systems and Hazards for European regions.	2009-2012

Annex 3: List of projects, studies, conventions, reports, publications and guidances analysed for adaptation measures.

Some of the documents and programmes were published before 2012. They have been included, if the programmes/projects are still on-going or other projects are based on the results

	Abbreviation	Titel	Type	Spatial coverage
National adaptation strategies	NAS AT	National Adaptation Strategy to Climate Change Austria	Action Plan	AT
	NAS BIH	Climate Change adaptation and low emission development strategy for Bosnia and Herzegovina.	Action Plan	Bosnia-Herzegovina
	Bayklas	Bayerische Klima-Anpassungsstrategie(BayKLAS) \ Bavarian Climate Adaptation Strategy	Action Plan	Bavaria
	NAS SK	Adaptation Strategy of the Slovak Republic on Adverse Impacts of Climate Change	Action Plan	Slovakia
	NAS DE	German Strategy for Adaptation to Climate Change	Action Plan	Germany
	NAS HU	Hungarian National Climate Change Strategy	Action Plan	Hungary
	NAS CZ	Strategy on Adaptation to Climate Change in the Czech Republic (Executive Summary)	Summary of the Action plan	Czech Republic
National Communications under UNFCCC	UNFCCC BIH, HR, SI, RS,SK, RO, HU, ME, EU, DE, AT, BG, MD	6th National Communication under the United Nations Framework Convention on Climate Change (UNFCCC). The communications of all countries in the DRB had been analysed	Communications	DRB
Conventions & Declarations & Management Plans	ICPDR RBMP (DRB)	Danube River Basin Management Plan 2015 Implementation of the WDF in the Danube Basin	Management Plan	DRB
	Declaration (DRB)	Danube Declaration; overall legal instrument for co-operation on transboundary water management in the Danube River Basin	Declaration	DRB
	FRMP	ICPDR Flood Risk Management Plan	Management Plan	DRB
	Alpine Convention	Platform on Natural Hazards of the Alpine Convention PLANALP		Alpine Areas
Water framework Directive Documents	WFD 24	Water Framework Guidance Document No 24	Guidance	Europe
	FD	European Flood Directive	**Directive**	Europe

	Abbreviation	Titel	Type	Spatial coverage
Documents & Strategies & Guidances	UNECE 2015	United Nations Economic Commission for Europe – Water and Climate Change Adaptation in Transboundary Basins	Guidance	Europe
	White Paper EU	EU White Paper; first published 2009. Still valid for adaptation	Document	Europe
	EC 2013	EU Strategy for the Danube Region	Strategy	DRB
	GWP 2013	Global Water Partnership	Guidance	worldwide
	ICPDR	ICPDR Strategy on Adaptation to Climate Change	Strategy	DRB
	DAS	Evaluation of the German Strategy for Adaptation to Climate Change (DAS)	Strategy	UDRB, Germany
Programmes & Reports dealing with climate change and adaptation in the water sector	EEA 2012, 2016	European Environment agency – Climate Change, impacts and vulnerability in Europe. Reports 2012 & 2016	Report	DRB, Europe
	Network Vulnerability	Climate Change in Germany - vulnerability and adaptation of climate sensitive sectors	Report	UDRB, Germany
	ClimWatAdapt	Climate Adaptation – modelling water scenarios and sectoral impacts	Report	DRB
	ADAPTALP	AdaptAlp (Adaptation to Climate Change in the Alpine Space)	Report	UDRB, Alpine Region
	GLOCHAMORE	Global Change in Mountain Regions	Report	Mountains worldwide
	JRC	JRC Technical Reports	Report	DRB
	ADAM	Adaption and Mitigation Strategies - supporting European climate policy	Report	Europe
	KLIWAS	Impacts of climate change on waterways and navigation	Report	UDRB, Germany
	ST_BLOESCHL_AT	Blöschl, G., Schöner, W., Kroiß, H., Blaschke, A.P., Viglione, A., Böhm, R. & Haslinger, K. et al. (2011): Anpassungsstrategien an den Klimawandel für Österreichs Wasserwirtschaft.	Report	Austria
	WWF-DCP	WWF Danube Carpathian Programme	Report	Carpathian
	KLIWA	Auswirkungen des Klimawandels auf Bodenwasserhaushalt und Grundwasserneubildung in Baden-Württemberg, Bayern und Rheinland-Pfalz	Report	Southern Germany

	Abbreviation	Titel	Type	Spatial coverage
	DRIDANUBE	Drought Risk in the Danube Region	Report	DRB
	FAO	Drought risk	Report	worldwide
	LULUCF Actions Austria(2015)	Land use, land use change and forestry	Report	Austria
	Monitoringbericht	Wald Monitoring Bericht	Report	Germany
	ST_Laize	Laizé, C.L.R., Acreman, M.C., Schneider, C., Dunbar, M.J., Houghton-Carr, H.A., Flörke, M. & Hannah, D.M. (2014): Projected flow alteration and ecological risk for pan-European rivers., River Research and Applications, 30, 299–314	Report	DRB
	IUCN	International Union for Conservation of Nature: water management and stewardship 2016	Report	worldwide
	Climate-ADAPT	Climate Adaptation – modelling water scenarios and sectoral impacts	Report	Europe
	ECCONET	Effects of climate change on the inland waterway networks	Report	UDRB, MDRB,
	Via Donau	Action Programme for the Danube 2022	Report	UDRB, Austria
	WASKLIM	Wasserwirtschaftliche Anpassungsstrategien an den Klimawandel	Report	UDRB, Germany
	CC	CC-waters: Climate Change and Impacts on Water Supply	Report	Germany
	EU-Committee	Climate change adaptation: Empowerment of local and regional authorities, with a focus on their involvement in monitoring and policy design	Report	DRB, Europe