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Assessment of Climate Change Adaptation Policies in the Danube River Basin

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"Master of Science"

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Affidavit

I, **CHRISTINA KAUER**, hereby declare

1. that I am the sole author of the present Master's Thesis, "ASSESSMENT OF CLIMATE CHANGE ADAPTATION POLICIES IN THE DANUBE RIVER BASIN", 63 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

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Abstract

Adaptation to Climate Change is one of the key challenges humankind has to face. In this regard, the management of freshwater resources is vital as water is indispensable for all forms of life. This thesis assesses Climate Change adaptation policies in the Danube River Basin (DRB), the most international river basin in the world. For the purpose of the analysis of policies, a method has been developed to systematically assess and compare various policies on a transboundary and national level. First, the current and future changes attributable to Climate Change on the hydrological cycle and consequently on the anthroposphere are assessed by a comprehensive literature review. Second, measures on adaptation from selected transboundary and national policies are categorized according to the effect and type of measure followed by a comparison to the proposed policy lists by Mauser et al. (2012, 2018) which can be seen as exhaustive. The results regarding the policy development stage are set into relation with the findings from climate science and are examined regarding adequacy. This thesis concludes that policies on Climate Change adaptation are very well developed in the DRB. Despite the complexity arising from different national and transboundary actors, the common framework for the DRB functions well. Hence, concerning the field of Climate Change adaptation, the policy framework of the DRB can serve as a role model for other transboundary river basins. It is crucial that the adaptation policy process remains open and flexible as new scientific evidence will be continuously available. Moreover, there is need for further research on the actual implementation of adaptation policies in the DRB.

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List of Abbreviations

ANAR	Adminstraţia Naţională “Apele Române”
AOSIS	Alliance of Small Island States
BMLFUW	Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft
DFRM	Danube Flood Risk Management
DRB	Danube River Basin
DRBM	Danube River Basin Management
DRPC	Danube River Protection Convention
EU	European Union
EUSDR	EU Strategy for the Danube Region
ICPDR	International Commission for the Protection of the Danube River
LDC	Least Developed Countries
LDRB	Lower Danube River Basin
MDRB	Middle Danube River Basin
MMAP	Ministerul Mediului Apelor și Pădurilor
ORNL DAAC	Oak Ridge National Laboratory Distributed Active Archive Center for Biochemical Dynamics
rkm	river kilometer
UDRB	Upper Danube River Basin
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
WFD	Water Framework Directive

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1 Introduction

One of the most pressing future challenges for mankind is to cope with anthropogenic Climate Change. The United Nations Framework Convention on Climate Change (UNFCCC) is the main international treaty aiming to regulate anthropogenic interference with global climate. Within the UNFCCC, the Paris Agreement was adopted in 2015 laying down provisions of how to keep global temperature well below 2 °C above pre-industrial levels including efforts to limit the increase to 1.5 °C.

Basically, there are two main challenges related to Climate Change: mitigation and adaptation. While mitigation measures aim to limit and stop Climate Change mainly by reducing anthropogenic greenhouse gas emissions and increasing carbon sinks (such as forests), adaptation measures have the objective of minimizing, offsetting or even preventing the effects of Climate Change. Mitigation and adaptation are of course not independent of each other. Greater levels of mitigation actions can reduce needs on the adaptation side (compare also to Paris Agreement Art. 7/4 (UNFCCC 2015)). For successful mitigation actions, it is crucial to reach a common and global effort since it is a case of the tragedy of the commons. Adaptation measures however require mostly action on a regional scale combined with financial mechanisms that are again of global effort. A large amount of Climate Change adaptation policies, measures, action plans, strategies etc. can be found all around the world. In this context, “[t]he ultimate challenge humankind faces right now is not to understand the climate system and project into the future, but to figure out what action would be ‘most desirable’ given considerable residual uncertainty in both the climate as well as the techno-economical system.” (Held 2011, 123). Given this complexity, the question arises whether Climate Change adaptation policies are able to respond adequately to the needs that have been revealed by climate science. As climate projections are linked to uncertainties, adaptation policies need to be flexible and adjustable to updated future scientific findings. Understanding the present and future challenges to Climate Change adaptation is crucial. Therefore, adaptation policies should be regularly assessed and evaluated.

This Master thesis tries to answer the question of adequacy of Climate Change adaptation policies. The author focuses on how the assessment of Climate Change adaptation policies in the Danube River Basin (DRB) is conducted. The research area has been selected because of three main reasons.

First, freshwater is of foremost importance as it is indispensable for all forms of life and provides the basis for human existence. Anthropogenic Climate Change will put additional pressures on water availability and quality. The relationship of Climate Change and freshwater resources is therefore of "primary concern and interest" (Bates et al. 2008, 7), see also chapter 3.

Second, the Danube River is unique in the world, because its river basin is shared by more countries than any other river in the world, namely 19 countries. As transboundary cooperation in river basin management is essential, the DRB is thus an excellent example of a regional but transboundary policy area. Moreover, the management of the DRB is very well embedded in the framework of the International Commission for the Protection of the Danube River (ICPDR) and can serve as an example for other transboundary rivers in many aspects, also regarding Climate Change adaptation policies. Management of transboundary waters can play an important role in international relations, as it can be a tool for "[…] sustainable development, peace building and preventive diplomacy." (Rahaman 2009, 222).

Third, management strategies of water bodies in general have been subject to substantial changes during the last decades, not least because "Climate change increases the complexity […], altering not only the characteristics of the hydrological cycle but also the way that water will be used." (Watts 2010, 86). Future conditions will change and can no longer be extrapolated from the past. This constitutes a major shift for water body management practices and needs to be considered.

This thesis is structured as follows. Introductory chapters narrow down the research area, define research questions and describe the method developed by the author to systematically assess Climate Change adaptation policies in the DRB. The method used has been tailored to the needs of the research area. Subsequently, an outline of general effects of Climate Change on the hydrological cycle and consequently on water bodies is given, outlining once again the urgency of protecting freshwater resources in the face of Climate Change. Moreover, necessary background information on the research area is provided. Various aspects of the DRB are presented with a focus on legal provisions aiming to protect the DRB. These preparatory chapters are followed by a key part of the thesis which summarizes the main scientific findings concerning Climate Change in the DRB including already observed changes and future projections. Furthermore, a more detailed introduction to Climate Change adaptation is given and selected adaptation polices concerning the DRB are presented, followed by an in-depth analysis of Climate Change adaptation measures. Finally, the results of the policy analysis are brought into relation with scientific findings and discussed aiming to assess the adequacy of adaptation policies in the DRB. In the conclusion, lessons learnt are presented and a future outlook is given.

2 Research Questions and Method

Based on the relevance of Climate Change adaptation polices in the Danube River Basin as it has been formulated in the introduction, this Master thesis aims to answer the following research questions:

Question 1 *What are the future challenges in the Danube River Basin regarding Climate Change?*
Question 2 *To what extent do policies in the Danube River Basin include Climate Change adaptation and do they react adequately to the needs revealed by climate science?*

In the following, the author uses the word "Climate Change" (capital letters) to describe anthropogenic global warming observed since the mid-19th century unless taken from a direct quotation where the exact wording remains unchanged.

Question 1 can be considered as the basis to answer Question 2 and will be answered in chapter 5 by a comprehensive literature review on Climate Change effects in the DRB. The most important effects of Climate Change on the DRB are presented considering uncertainty. Uncertainty in this context needs to be understood in a comprehensive manner. First, the uncertainty of occurrence of an effect is considered. Second, the uncertainty of the direction of the effect and its magnitude is taken into account as well, meaning up to what extent researchers agree. The degrees of uncertainty are classified as low, medium, high and very high. The attribution of degrees of uncertainty to the different Climate Change effects is leant on Mauser, Prasch, Koch, & Weidinger (2012) and Mauser, Stolz, Weber, & Ebner (2018).

Question 2 will be answered in chapter 6 by a detailed and systematic analysis of policies in the most important river basin management plans. This policy analysis is conducted as follows. Based on the findings of chapter 5, a list of important Climate Change effects is obtained. For each effect, the questions are answered according to the scheme in figure 1.

1)	2)	3)	4)
Has the issue been mentioned in the respective document? Is there a link to Climate Change?	Are there Climate Change adaptation measures available?	What kind of measures are available? a) Preparation b) Ecosystem c) Behavior and management d) Technology	Assessment of development stage of adaptation policy

Figure 1: Scheme of a systematic policy analysis

First of all, it needs to be clarified whether the respective Climate Change effect is mentioned in the policy document as being a future problem. As certain changes in the DRB cannot be traced back solely to Climate Change, it is possible that the changes are recognized as becoming an issue one needs to address, but that they are not brought into relation with Climate Change. Hence, this question has to be clarified as well. Second, it has to be checked whether a corresponding adaptation measure is mentioned. If yes, the third step is to analyze and classify those measures. This will be based on a classification of Climate Change adaptation measures in water body management (preparation, ecosystem-based, behavior and management-based and technology-based measures) which will be described in detail in chapter 6.2. It is possible that one single measure can be assigned to more than one type of Climate Change effect. As there is the possibility of synergies, one measure may address more than one Climate Change effect. However, besides synergies there can also be measures which have adverse effects on other areas such as flood protection systems on river continuity (ICPDR 2015b, 37). Finally, each policy measure is classified according to a degree of policy development (A, B, C, D). A detailed description of the degrees of policy development can be found in table 1.

Table 1: Description of Policy Development Stages

Development Stage	**Description**	
A	• The policy acknowledges the effect and a need for action. • The effect is set into relation to Climate Change explicitly or implicitly. • Various concrete measures are specified in the policy that aim to adapt to the effect in various ways and/or from different angles.	Measures specified
B	• The policy acknowledges the effect and a need for action. • The effect is set into relation to Climate Change explicitly or implicitly. • There are measures available that aim to adapt to the effect. However, these measures are not as detailed and extensive as in stage A (see below).	
C	• The policy acknowledges the effect and at the best also for a need for action. • The effect may be set into relation to Climate Change explicitly or implicitly. • There are no adaptation measures available.	No measures specified
D	• The policy does not mention the effect at all. • There are no adaptation measures available.	

The classification according to the development stage aims to answer the first part of Question 2, namely to what extent Climate Change adaptation is included in policies concerning the DRB. To be able to differentiate consistently between development stage A and development stage B, the catalogue of possible adaptation measures in Mauser et al. (2012) and Mauser et al. (2018) is considered to be exhaustive and thus seen as a reference catalogue when determining that a set of measures is considered to fall under development stage A or B. The threshold between development stage A and B has been set to be at 50 %, meaning that at least half of the possible adaptation measures are included in the respective policy. This rather low threshold has been selected, because the list of possible measures taken as a reference is very extensive and partly repetitive. Hence, also in policy stage A there is still room for improvement. The results of the above described policy analysis are shown in a table; an exemplary table 2 is presented below.

Table 2: Policy Analysis – exemplary table

Policy Region	1)		2)	3a)	3b)	3c)	3d)	4)
	Mentioned	Relation to Climate Change	Measure	Preparation	Ecosystem	Behavior and management	Technology	Development stage
Effect 1								
Effect 2								
etc.								

The second part of Question 2 regarding the adequacy of measures is answered based on the needs revealed by answering Question 1. For each Climate Change effect, the development stage of policies is set into relation with the findings of Question 1 and presented in a diagram which are the basis for discussion. These diagrams aim to structure the results and visualize them in a comprehensible manner. On the x-axis of each diagram, the level of uncertainty is shown and on the y-axis the policy development stage is displayed. Each point represents a combination of uncertainty and policy development for one or more Climate Change effects. It is important to note that a linear relationship between policy development and uncertainty does not necessarily represent the "optimal" outcome as the analysis is rather qualitative than quantitative. On the one hand, uncertainty can still be seen as an approximation of urgency in the need for action and consequently as a need to have well developed policies in place. Thus, low uncertainties would require immediate action. On the other hand, high degrees of uncertainty can also stand for urgency as policy makers face high planning uncertainties. Consequently, it can be of extreme importance to have well developed and flexible policies in place despite high uncertainties. In those cases, win-win or no regret solutions play a crucial role.

As the DRB is truly international, it is subject to a complex interplay of different policy makers. In this thesis, there is a focus on transboundary activities which are strongly guided by the ICPDR. Moreover, some examples are given for regional and national policies. On a regional, but still transboundary level, the Danube Delta has been chosen. The Delta is a unique and vulnerable ecosystem which requires special attention also on a policy level. On a national level, Romania and Austria are being analyzed. The two countries have been chosen as they are situated in different parts of the DRB. Further, comparing Romania and Austria is of particular interest as they are on the one hand subject to the same policy framework of the European Union (EU) but on the other hand they face different economic, political and cultural situations. With the selection of the above-mentioned policy levels, this thesis aims to cover a representative part of policies in the DRB. Moreover, only documents that have been published, were accessible to the author and available in English, German, or Romanian language were taken into account. A cost-effectiveness analysis and implementation of Climate Change adaptation policies in the DRB are not the focus of this thesis.

3 Climate Change and Rivers

The global climate is changing and is expected to change substantially in the (near) future. There is multiple scientific evidence that the current climatic developments are linked to an increase in greenhouse gases in the atmosphere caused by anthropogenic activities as well as by land use change which is both, a cause and consequence of Climate Change (IPCC 2013). Global mean temperatures are expected to increase – depending on the representative concentration pathway – by 0.3 to 4.8 °C for 2081-2100 relative to 1986-2005 (IPCC 2013, 20). An increase in average temperature has multiple effects on the hydrological cycle and thus on water bodies such as rivers. Therefore, “Climate change is projected to be a powerful stressor on […] freshwater ecosystems in the second half of the 21st century […]” (Settele et al. 2014, 274). The observed and prospective changes in the hydrological cycle cannot only be attributed to Climate Change, but also to non-climatic changes such as land use changes, socio-economic development (e.g. urbanization) and changes in water demand (Jiménez Cisneros et al. 2014, 234) as well as changes in dam constructions, water supply infrastructure and waste water treatment (Bates et al. 2008, 9).

Furthermore, it needs to be mentioned that climate models predicting future changes as well as hydrological models are always closely related to uncertainties. Especially the uncertainty in regional climate models can be considerable (Kling, Fuchs, and Paulin 2012). In its 4th Assessment Report, the IPCC distinguishes three types of uncertainty, namely unpredictability, structural uncertainty and value uncertainty. While unpredictability is closely related to societal evolution and chaotic components of climate systems, structural uncertainty refers to model specific uncertainties and related ambiguousness, lack of agreement and wrongly or not considered relationships and value uncertainty includes lack of data or of data quality (Bizikova et al. 2011, 173). However, there is disagreement about up to which point uncertainties in hydrological models are substantial or can be ignored compared to the large number of different climate scenarios (Jiménez Cisneros et al. 2014, 241).

The effects of Climate Change on the hydrological cycle are very complex not least because of climate feedback mechanisms and other anthropogenic influences on rivers. Therefore, this chapter aims to summarize the most important effects with a focus on rivers.

3.1 Evapotranspiration and Precipitation

Higher temperatures lead to an increase in evapotranspiration. Higher evapotranspiration leads to a higher water vapor content in the atmosphere. Over global oceans, water vapor has increased by around 1.2 % per decade between 1988 and 2004 (Bates et al. 2008, 18). As water vapor is the strongest greenhouse gas, this results in a feedback mechanism amplifying increasing temperatures. The humidity saturation point of the atmosphere depends on the temperature – the warmer the temperature, the more water vapor can be stored. Due to these changes in atmospheric circulation resulting from a global average temperature increase, precipitation patterns alter as well. Zhang et al. (2007) were able to trace back these changes in precipitation patterns over land in the 20th century to anthropogenic influences. Besides evapotranspiration, precipitation is the main climatic driver controlling freshwater resources (Jiménez Cisneros et al. 2014, 240).

Both, evapotranspiration and precipitation have an influence on river runoff and flow speed which has consequences on water quality and therefore on the (aquatic) ecosystem. Greater runoff for example can lead to a dilution of pollution, but also more pollutants from agriculture may be swept from the soil into the river (e.g. Boxall et al. 2009). Further, water supply for households, food production, energy production (hydropower itself and cooling for other types of energy production), industry, transportation, tourism etc. are influenced by an altered river runoff. On a global scale, the hydrological cycle is expected to intensify by 3 % (increase of evaporation and precipitation). However, over land, average precipitation is expected to decrease by 2 % while evaporation will increase which will have substantial impact on freshwater input to oceans (Arora and Boer 2001, 3338).

Precipitation extremes can lead to soil erosion affecting sediment loads of a river and leading to landslides. However, "[i]n most rivers, it is likely to prove difficult to disentangle the impact of Climate Change or variability from changes resulting from other human impacts and existing evidence suggests that, in most cases, these human impacts are at present likely to be more significant." (Walling 2009, 9).

A frequently discussed issue in connection to changes in precipitation patterns are floods and droughts. Kundzewicz et al. (2012) argue that on a global scale, there is only limited evidence that magnitude and frequency of floods have been affected by anthropogenic Climate Change. However, economic losses increase as more assets are exposed to flood risk (Kundzewicz et al. 2012). Jiménez Cisneros et al. (2014) find that there is however a lack of long term data of unmanaged catchments and state with medium confidence that changes in flood trends are expected to take place on a regional scale (Jiménez Cisneros et al. 2014, 239). The same is true for droughts which by the end of the 21st century will intensify in certain regions – e.g., southern and central Europe – depending on evaporation, precipitation and thus soil moisture (Jiménez Cisneros et al. 2014, 247). Regarding future projections, there is high confidence that "[w]et regions and seasons become wetter and dry regions and seasons become drier." (Jiménez Cisneros et al. 2014, 240). Soil moisture itself plays an important role in the hydrological cycle due to its heat capacity.

Precipitation in form of snowfall as well as melting of snow and ice are of major importance when it comes to Climate Change. Rising average global temperatures can lead to a shift in seasonal river runoffs due to increasing rainfalls instead of snowfalls as well as earlier snow melting. Regardless of the Climate Change scenario, a continued mass loss of glaciers is expected (Jiménez Cisneros et al. 2014, 243). Less surface covered with snow and ice again has feedback effects on the climate as the albedo decreases and hence less solar radiation is reflected. On a global scale, besides thermal expansion of water, decreasing masses of ice leads to rising sea level. This is of importance for coastal regions in general and river mouths in particular. Finally, also permafrost regions are expected to decrease in size influencing runoff patterns. In mountainous areas glacial melting can lead to increased erosion.

Furthermore, changing meteorological conditions affect groundwater. Increasing and decreasing precipitation influence total runoff and are consequently recharging groundwater reservoirs. However, it is not possible to solely link changes in groundwater levels to anthropogenic Climate Change as there are other factors such as land use change, pumping activities and feedback mechanisms having substantial impact (Stoll et al. 2011).

3.2 Water Temperature and Atmospheric CO_2 Concentrations

Higher ambient air temperatures not only lead to higher evapotranspiration, but also to higher water temperatures of water bodies itself, especially in the upper layers. Changes in the thermal regime of rivers have substantial effects on the river's ecosystem and are not only caused by changes in ambient air temperatures as well as connected atmospheric conditions but are dependent on many other factors. The river's discharge, topography, streambed conditions, river bank vegetation and anthropogenic thermal pollution (e.g. cooling water) need to be considered as well (Caissie 2006, 1390f). As already mentioned, the ecosystem and biological processes within this system are heavily influenced by water temperature. Higher water temperatures decrease the oxygen saturation of the waterbody and thus lead to a decrease of the oxygen content in water. This can affect for example the fish population and other aquatic organisms which all have specific temperature preferences. The consequences for fishes can be for example a decrease in population, increasing vulnerability to diseases and a migration to upstream parts of the rivers or tributaries where water temperature is cooler (Caissie 2006, 1399ff). However, migrating fish might not be able to adapt to the new habitat upstream as besides water temperature, other factors such as the runoff are decisive (Prinz et al. 2009, 94). Moreover, biological processes such as nitrification and the carbon cycle are temperature dependent (the higher, the faster autotrophic bacteria grow), but strictly limited by oxygen supply.

Rising atmospheric CO_2 concentrations itself have important impacts on water bodies. In oceans, dissolved CO_2 leads to the formation of carbonic acid and thus to an acidification of oceans. Not only oceans, but also freshwater ecosystems are affected by rising CO_2 concentrations. The main carbon input to freshwaters is in the form of dissolved organic carbon (DOC) from terrestrial ecosystems which is mineralized by bacterial activity to CO_2 in freshwater bodies. This process is expected to intensify with rising atmospheric CO_2 levels and thus "may alter the input of DOC into freshwater ecosystems, although the magnitude and direction of these changes will vary regionally" (Van De Waal et al. 2010, 147).

4 The Danube River Basin

4.1 Introduction to the Danube River Basin

The Danube River Basin (DRB) is one of the world's 263 international river basins and is regarded as the most international basin as it is shared by 19 counties. The basin stretches over 801,463 km^2 covering 10 % of continental Europe and being home for more than 80 million people (ICPDR 2009). Table 3 gives an overview of the 19 countries sharing the DRB including the share of DRB territory as well as information on whether they are a contracting party to the ICPDR (see chapter 4.2 3) and whether they are riparian states to the Danube river (ICPDR 2009). Countries are listed in alphabetical order.

Table 3: List of DRB countries (ICPDR 2009)

Country	% of DRB	ICPDR member	Riparian states
Albania	< 0.1		
Austria	10.0	x	x
Bosnia and Herzegovina	4.6	x	
Bulgaria	5.9	x	x
Croatia	4.4	x	x
Czech Republic	2.9	x	
Germany	7.0	x	x
Hungary	11.6	x	x
Italy	< 0.1		
Macedonia	< 0.1		
Moldova	1.6	x	x
Montenegro	0.9	x	
Poland	< 0.1		
Romania	29.0	x	x
Serbia	10.2	x	x
Slovak Republic	5.9	x	
Slovenia	2.0	x	
Switzerland	0.2		
Ukraine	3.8	x	x

Despite the unifying feature of the Danube river, the countries face very different social and economic situations. Historically, some countries have been divided for many years by the Iron Curtain. Today, 11 out of the 19 countries of the DRB are members of the European Union (EU).

The DRB can be divided into three sub-regions: the Upper Danube River Basin (UDRB), the Middle Danube River Basin (MDBR) and the Lower Danube River Basin (LDBR). The UDRB starts at the source of the Danube river in Donaueschingen in Southern Germany where the rivers Brigach and Breg join[1] and ends at the border between Austria and Slovakia at rkm 1,880[2]. The MDRB stretches from rkm 1,880 to rkm 943 where the so-called *Iron Gate* is located at the border between Serbia and Romania. The LDRB continues from rkm 943 to the estuary at rkm 0. Figure 2 shows a map of the DRB divided into its three sub-regions. The DRB consists of 27 large and around 300 small tributaries to the Danube river as well as a number of lakes (ICPDR 2009).

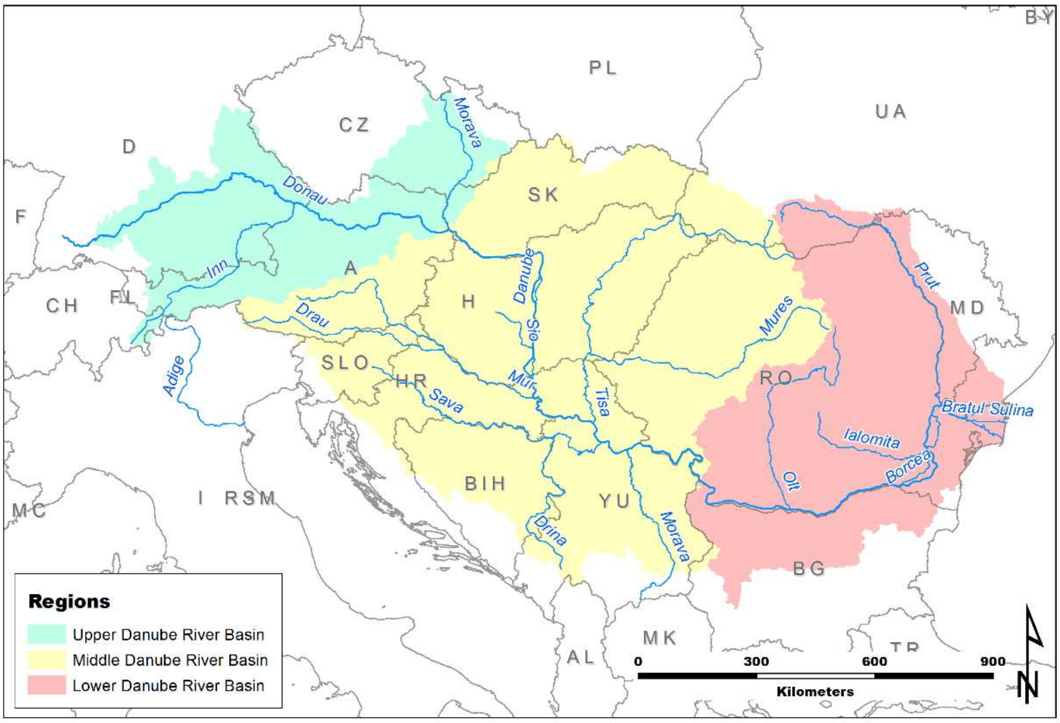

Figure 2: Main regions of the DRB (Mauser et al. 2012; WaterBase n.d.; Natural Earth n.d.)

[1] Also, the source of river Breg is sometimes referred to as the beginning of the Danube.

[2] The river kilometers (rkm) of the Danube river are counted from the estuary in Sulina to the river's source which is an uncommon practice in river kilometrage.

Given the divers geographic situations in the DRB, the basin is situated in various climate zones (compare e.g. Peel, Finlayson, & McMahon, 2007). According to the climate classification of Köppen and Geiger, 11 climate classes are represented in the DRB (see figure 3 and table 4 for explanations).

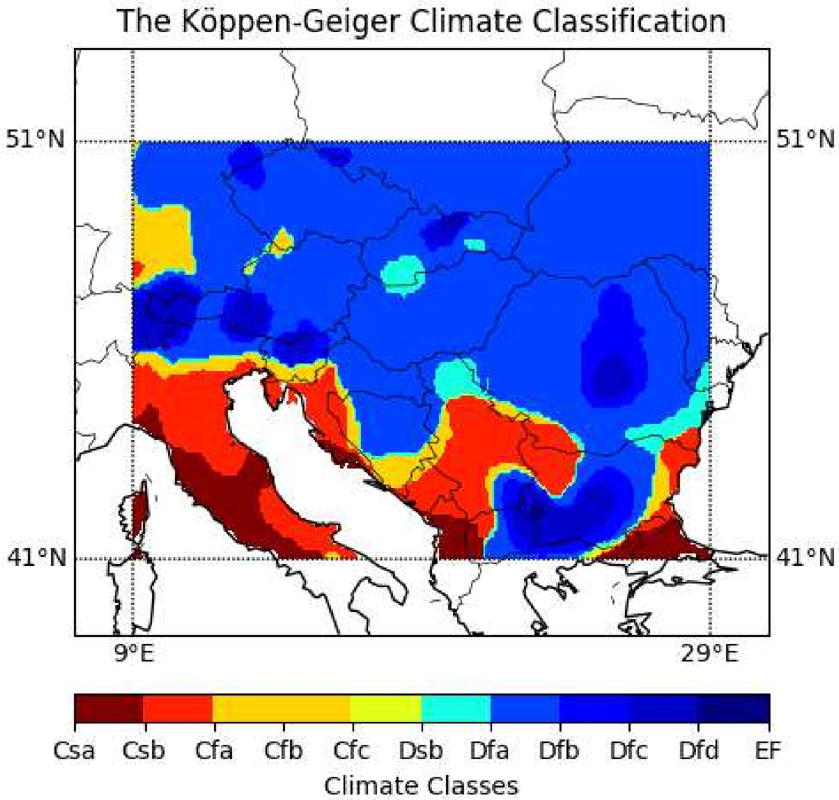

Figure 3: Climatic Classification of the DRB according to Köppen-Geiger (ORNL DAAC 2017)

Table 4: Climate Classes in the DRB according to Köppen-Geiger Classification

Abbreviation	**Climate Class**
Csa	Temperate Dry Summer Hot Summer
Csb	Temperate Dry Summer Warm Summer
Cfa	Temperate Without dry season Hot Summer
Cfb	Temperate Without dry season Warm Summer
Cfc	Temperate Without dry season Cold Summer
Dsb	Cold Dry Summer Warm Summer
Dfa	Cold Without dry season Hot Summer
Dfb	Cold Without dry season Warm Summer
Dfc	Cold Without dry season Cold Summer
Dfd	Cold Without dry season very Cold Winter
EF	Polar Frost

As seen in figure 3, the climate classes range from polar frost region in alpine regions to a climate of dry and hot summers. Given this diversity in climatic situations, it becomes clear that the effects of Climate Change will not necessarily be uniform in the entire basin. Moreover, due to this diversity in climate as well as geographic conditions, the basin is divers in flora and fauna with over 2,000 plant and 5,000 animal species (ICPDR 2009).

Not only today, but also in history, the Danube has been an important economic resource for the riparian states. The river basin "[…] is a vital resource for water supply, sustaining biodiversity, agriculture, industry, fishing, recreation, tourism, power generation and navigation." (ICPDR 2009, 16). Hence, the river is subject to anthropogenic influences including pollution and river bed modifications. The ecological and chemical status of the Danube river is regularly assessed (see chapter 4.2.2). Currently, 48 % of the Danube's morphology are considered to be severely or extensively modified (Liska et al. 2015, 356). According to the Saprobic Index, at 73 % of macrozoobenthic sample sites the "indication of good ecological status" can be found, 15 % are classified as "indication of moderate ecological status" and 4 % even as "high ecological status" according to the *EU Water Framework Directive* (WFD, for details on the directive see chapter 4.2.2) (Liska et al. 2015, 357). Study results regarding the phytobenthos, macrophytes and phytoplankton indicate a decrease of the respective status downstream the Danube (ibid,

p. 368). Fish are exposed to several pressures, such as hydropower, leading to a large number of sites not fulfilling the criteria under the EU WFD (ibid, p. 368). Speaking overall for the DRB, 27 % of the river networks currently do not achieve the good chemical status (ICPDR 2009, 23). Climate Change is expected to put additional pressures on the hydrosphere of the DRB (see chapter 5).

4.2 Legal Provisions Aiming to Protect the Danube River Basin

Being the second largest river of Europe and crossing as many countries as no other river in the world does, the Danube and its river basin are subject to transboundary networks and various legal provisions aiming to protect water bodies in the DRB. First, an overview is given of the main principles in international environmental law regarding transboundary rivers as well as the most important legal provisions on a global and EU level by which the DRB is concerned. Second, legal provisions and transboundary cooperation specifically targeting the Danube River Basin are being presented.

4.2.1 International Level

On an international level, the *Convention on the Law of the Non-navigational Uses of International Watercourses*, hereafter UN Watercourses Convention (United Nations 1997) aims to facilitate the management of transboundary rivers, lakes as well as groundwaters. With the help of this convention, the author aims to summarize the most important principles relevant for transboundary rivers. The following principles are widely accepted in the international community and are acknowledged in many legal texts dealing with international waters (Rahaman 2009, 222). The UN Watercourses Convention was adopted in 1997, but only entered into force in May 2014. 36 countries are contracting parties to the convention of which only three countries are relevant for the DRB. Germany and Hungary are parties to the convention and actually crossed by the Danube river. Montenegro is also party to the UN Watercourses Convention and part of the DRB, even though only minor parts of it belong to this country. One of the main principles of the UN Watercourses Convention and transboundary river basin management in general is the *principle of Equitable and Reasonable Utilization* (United

Nations, 1997, Art. 5) which is based in the theory of limited territorial sovereignty. In order to determine what an equitable and reasonable utilization actually means, exchange of information as well as close international cooperation between the concerning countries is necessary – *principle of Cooperation and Information Exchange* (United Nations, 1997, Art. 8). Further, Article 7 of the UN Watercourses Convention imposes the obligation not to cause significant harm, as the parties shall "take all appropriate measures to prevent the causing of significant harm to other watercourse states" (United Nations, 1997, Art. 7). Equitable utilization and the no-harm obligation however, can be conflicting and do not necessarily lead to the same actions. Nevertheless, the principle of equitable utilization can be seen as prevailing in the UN Watercourse Convention (McCaffrey 1998, 22f). Moreover, the principle of notification, consultation and negotiation are laid down in Article 11 to 18 of the UN Watercourses Convention.

As already mentioned, the above described principles are part of many international agreements, conventions and treaties dealing with transboundary waters as well as with general international environmental issues, such as the *Rio Declaration on Environment and Development (1992)*. Other important legal provisions in this context are the *Helsinki Rules on the Uses of the Waters of International Rivers* (*1966)* which have been suspended by the *Berlin Rules on Water Resources* (*2004)* and the UNECE *Convention on the Protection and Use of Transboundary Watercourses and International Lakes* (*1992)*. Regarding Climate Change, the *Berlin Rules on Water Resources* require the basin states to include the "[p]romotion of appropriate responses by States involved to climate change" (International Law Association, 2004, Art. 66c) in their reviews of implementation and commitments under the agreement. Moreover, the *Convention on Wetlands of International Importance especially as Waterfowl Habitat* (*1971)* (Ramsar Convention) needs to be mentioned in this context. There are numerous so-called Ramsar Sites located in the DRB, such as the Donau-March-Thaya Auen, Gemenc Area and the Danube Delta. Ramsar Sites are wetlands of international importance that require effective management in order to maintain the ecological character.

4.2.2 European Union Level

On a European Union level, the most important pieces of legislation concerning rivers basins are the *Water Framework Directive,* the *Floods Directive,* the *Urban Waste Water Directive,* the *Industrial Emissions Directive,* the *Nitrates Directive* as well as the *Fauna-Flora Habitats Directive and Birds Directive* establishing the Natura 2000 network. According to European law, directives are binding but not directly applicable like EU regulations. The Treaty on the Functioning of the European Union determines that directives need to be implemented into national legislation and they "shall leave to the national authorities the choice of form and methods" (European Union, 2012, Art. 288). In the following, only those directives are discussed in detail which are considered to be of importance for the purpose of this thesis.

The EU *Water Framework Directive* (WFD) was adopted and entered into force in 2000. According to Article 1 of the WFD, "[t]he purpose of this Directive is to establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater […]" (European Union, 2000, Art. 1). Member States shall achieve the good status of surface water and groundwater by 2015 and prevent deterioration of the status. The ecological and chemical status of waters include biological, hydro morphological, physical-chemical and chemical quality criteria. The details of the environmental objectives are laid down in Article 4 of the WFD (ibid, Art. 4). This shall be achieved though the so called combined approach. The combined approach overcomes the historical dichotomy in pollution control as it combines emission limit values and environmental quality standards. In Article 3, a water management system by river basin (instead of e.g. by country) is introduced, overcoming administrative boundaries (ibid, Art. 3). The parties to the WFD have the obligation to formulate river basin management plans which contain a formulation of how the basin specific objectives are to be reached within a certain time frame including a cost-effectiveness analysis of the respective measures. The river basin management plans need to be updated every six years. Currently, the contracting parties are in the second management cycle (2015-2021). Moreover, public participation is a key element to the WFD as laid down in Article 14 (ibid, Art. 14). Arising from the different challenges of the WFD, a common implementation strategy has been developed in order to ensure a coherent and harmonious implementation in the Member States, The EU *Floods Directive* entered into force in 2007 and aims to assess and reduce the flood risk as well as to ameliorate the management of adverse consequences of floods. It shall be coordinated with the WFD (European Union, 2007, Art. 9). Article 6 and 7 of the EU Floods Directive require Member States to prepare flood hazard and flood risk maps as well as flood risk management plans that are to be coordinated with the management plans of the WFD (ibid, Art. 6 & 7). Public participation is also key to the Floods Directive (ibid, Art. 9).

The Natura 2000 network is based on the *Fauna-Flora Habitats Directive (1992)* and the *Birds Directive (1979).* Its aim is to protect natural habitat types and ensure sufficient breeding and resting sites for threatened or rare species. It stretches across all 28 Member States and covers 18 % of the EU's land area as well as 6 % of the marine territory (European Commission n.d.). The Member States are required to manage and monitor the Natura 2000 sites in a sustainable manner. In the DRB, there are 2,860 Natura 2000 sites, of which 230 are located directly along the Danube (ICPDR 2009, 10).

4.2.3 Danube River Basin Level

The history of transboundary cooperation along the Danube river dates back to the *Treaty of Paris* of 1856 which established the *European Commission of the Danube* ensuring free navigation along the lower Danube river. In the aftermath of World War II at the Danube River Conference of 1948, the *Danube Commission* was found which is until today in charge of international navigation in the Danube river. In 1985, countries along the Danube signed a declaration aiming to cooperate in issues regarding water quality and management which eventually lead to the creation of the Environmental Program for the Danube River Basin in 1991 (Shepherd 2014).

Today the *International Commission for the Protection of the Danube River* (ICPDR) is a key player in the DRB as it has been established to implement the *Convention on Cooperation for the Protection and Sustainable use of the Danube River* (Danube River Protection Convention (DRPC)) which is the overall legal instrument for cooperation and transboundary water management in the DRB. The DRPC was signed in 1994 in Sofia and entered into force four years later. The objective is to ensure a sustainable and equitable transboundary management of surface waters and groundwater which includes:

- “the conservation, improvement and rational use of surface waters and groundwater
- preventive measures to control hazards originating from accidents involving floods, ice or hazardous substances
- measures to reduce the pollution loads entering the Black Sea from sources in the Danube River Basin” (ICPDR n.d.)

The ICPDR started operating in 1998 and is today one of the largest and most active transboundary river basin management bodies. 14 counties are contracting parties (see chapter 4.1) as well as the European Union. Out of the 14 contracting state parties, nine are EU Member States and two have official EU candidate status. The key objectives of the ICPDR are to “ensure sustainable water management”, to “ensure conservation, improvement and rational use of surface waters and ground water”, to “control pollution and reduce inputs of nutrients and hazardous substances” and to “control floods and ice hazards” (ICPDR n.d.). The main bodies of the ICPRD are the Ordinary Meeting Group, the Standing Working Group, the Technical Expert Groups and Task Groups. Their work is supported by the Secretariat which is based in Vienna. The annual budget amounts to around € 1 million not including contributions by the contracting parties in staff and material (ICPDR n.d.). According to Article 11 of the DRPC, all contracting parties except the European Union shall contribute to the budget an equal share unless decided otherwise by a unanimous vote. Furthermore, the ICPDR is responsible to coordinate and implement the EU WFD since 2000 and the Floods Directive since 2007 for the DRB. The ICPDR coordinates its activities with the Sava basin, the Tisza Basin and the Prut Basin as well as the Danube Delta. Further, there is a cooperation in place with the *Black Sea Commission*, the *UNECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes*, the *Framework Convention on the Protection and Sustainable Development of the Carpathians* as well as other international river basins. Another important cooperation of the ICPDR is with the EU Strategy for the Danube Region (EUSDR) as laid down in the *Joint Paper on Cooperation and Synergy for the EUSDR Implementation*. The EUSDR is a macro-regional strategy adopted by the European Commission in 2010. The strategy has been defined in the Commission’s Communication COM/2010/0715. In this communication, the strategy’s main priorities are laid down: connecting the Danube Region (including infrastructure, energy, culture and tourism), protecting the environment in the Danube Region, building prosperity in the Danube Region and strengthening the Danube Region including institutional topics and security (European Commission 2010, 6f). Hence, the scope of the strategy is very large and does not only cover environmental issues.

Besides the above mentioned legal provisions aiming to protect the Danube River Basin, national and federal state legislation on environmental protection and river protection are available.

5. Climate Change in the Danube River Basin

This chapter aims to summarize scientific evidence regarding Climate Change effects in the DRB already observed and predicted for the future. As the DRB differs in geography and climate, the effects of Climate Change need to be analyzed for different regions described in chapter 4: Upper Danube River Basin (UDRB), Middle Danube River Basin (MDRB) and Lower Danube River Basin (LDRB). The task of science in regard to Climate Change adaptation policies should be clearly defined as "[s]cience must abstain for giving explicit or hidden normative prescriptions", but should rather "open choices for politics in terms of scientifically sound, self-constrained options." (Held 2011, 124).

The "Danube Study – Climate Change Adaptation" (Mauser et al. 2012) can be regarded as one of the key documents. It was initiated by the German[3] Federal Ministry for the Environment, Nature, Conservation and Nuclear Safety with the objective of providing scientific evidence upon which adaptation policies are to be built on. The study summarizes and analyzes 90 studies regarding Climate Change in the Danube River Basin. It has been updated with the latest scientific findings in 2018 (Mauser et al. 2018). However, this chapter also includes additional studies. Concerning some effects, studies show different results as they depend largely on the underlaying climate scenario (Stagl and Hattermann 2015, 6162). Additionally, in some cases it is hard to attribute the change solely to Climate Change, but also socio-economic models as well as simulation of decision-making need to be taken into account as it is done for example in the multi-actor modelling approach such as DANUBIA (e.g. Barthel et al., 2012).

5.1 Changes in Air Temperature

An increase in air temperature in the DRB can be seen as a hard fact meaning that uncertainty is very low (Mauser et al. 2012, 26). There have been some remarkable changes in temperature already observed. For example in the UDRB, temperature increased between 1960 and 2006 by 0.8°C per decade during summer months (Reiter, Weidinger, and Mauser 2012). Depending on the Climate Change scenario, average

[3] Germany was nominated to take the lead in developing an ICPDR Strategy on Adaptation to Climate Change.

annual temperature is expected to increase between 0.5 - 4°C for the period 2021-2050 and 2.5 - 5°C for 2071-2100 (Mauser et al. 2012, 26). Projections for winter temperatures are not as certain as for summer (Mauser et al. 2012, 27). There are also projections of an increase of even +5°C towards the end of the 21st century in the DRB (Kling, Fuchs, and Paulin 2012). The temperature increase however is not expected to be the same in the whole river basin but will be more pronounced in the southeast than in the northwest (Mauser et al. 2012, 27f). Furthermore, extreme heat waves are expected to occur in summer as well as an increase in hot days (> 30°C) and fewer frost days in winter (ibid). In the LDRB, the amount of tropical nights (> 20°C) is projected to increase by 0.4 - 1 day per decade (ibid, p. 35).

5.2 Changes in the Hydrological Cycle

The above described increase in air temperature has numerous effects on the hydrological cycle in the DRB as shown in chapter 3. While the increase in temperature is certain, effects on mean annual precipitation are slightly less certain. However, changes in seasonality in precipitation can again be seen to happen with very high certainty (Mauser et al. 2018, 17). Mauser et al. (2012) find that "[…] mean annual values will most likely remain almost constant, but seasonally and regionally large changes are projected for the 21st century." (Mauser et al. 2012, 29). While in summer months, 20 % less precipitation is expected, in winter months an increase between 5 % and 20 % are projected. There are no clear trends for spring and winter (ibid). Again, regional variabilities including contradictory findings can be found regarding precipitation changes. Moreover, heavy rain fall events will increase in Northern Europe and decrease in Southern Europe (ibid, p. 33f). An increase in extreme winter precipitation events is expected in the far future, especially in North-East Europe (Mauser et al. 2018, 37f). The Danube Delta – an especially important and vulnerable biosphere – is expected to become drier with regards to precipitation which is correlating "with decreased relative air humidity making the air to be drier and unsuitable for many species that live in the studied area" (Mierla 2016, 81).

The timing of flooding may also be altered by Climate Change. Blöschl et al. (2017) detect a clear shift in the timing of floods in Europe between 1960 and 2010. For the

Danube River Basin, researchers found that the occurrence of floods are expected to shift during the year. In the UDRB, flood risk is expected to increase from autumn to spring and decrease in summer due to changes in snow cover duration. Also, for the MDRB an increase in spring floods is projected. For the LDRB, a lower flood risk in spring may occur as the snow coverage is reduced in general. However, it needs to be mentioned that flood projections are linked with high uncertainty (Mauser et al. 2012, 71ff) and cannot solely be traced back to Climate Change as other factors such as river bed regulation and change of floodplains play a crucial role. More recent studies show a tremendous decrease in uncertainty regarding floods (Mauser et al. 2018, 62). Generally speaking, flood risk is expected to increase in the whole of Europe with strong regional differences and shifts in the point in time of the occurrence of floods. There are no clear trends on extreme flood events in the DRB (ibid). Further, coastal flooding in the Black Sea might become an issue of severe concern due to a possible sea level rise (ibid, p. 72).

Moreover, the counter part of the extreme event of floods namely droughts are also expected to appear in altered patterns in the face of Climate Change. For the DRB "drought and low flow events as well as water scarcity are likely to become more intense, longer and more frequent" (Mauser et al. 2012, 62). Droughts are expected to occur in higher frequency and for a longer period, while the increase of drought risk is especially pronounced in the LDRB (ibid, p. 62f). These results are confirmed in Mauser et al. (2018, p. 54ff). Uncertainties in droughts and water stress are found to have decreased (ibid).

Directly resulting from an increase in air temperature, precipitation in the form of snow is expected to decrease in the whole DRB by the late 21st century and the peak in snow melting will shift from summer to spring (Mauser et al. 2012, 57ff). It can be seen as a hard fact that this shift will happen meaning that uncertainty is very low. However, the extent of this event is subject to uncertainty (ibid, p. 24). In the UDRB and MDRB, there will be a significant retreat in glaciers[4], however, "[…] the Danube is not significantly influenced by ice melt changes." (Mauser et al. 2012, 58). A retreat of permafrost in mountainous regions will lead to a higher sedimentation rate and rock instability (ibid).

[4] On the Balkan Peninsula (MDRB), there are permanent firn-ice patches that can be categorized as glaciers (Gachev, Stoyanov, and Gikov 2016). Moreover, glaciers can be found in the Drava river basin which is part of the MDRB.

As a consequence of the above-mentioned changes in the hydrological balance, river runoff of the Danube as well as of its tributaries alter considerably. By the mid-21st century, only minor changes in runoff are expected in the DRB. However, for the end of the 21st century, "[…] a significant decrease in mean annual runoff […]" (Mauser et al. 2018, 51) is to be expected. Moreover, there are regional and seasonal differences. Stagl & Hattermann (2015) found an overall trend in the DRB towards a decreasing runoff in summer and in most regions and increase in winter. For the UDRB, summer run-offs are expected to decrease by 40 % and during winter an increase is possible (Hattermann, Huang, and Koch 2015, 206). Szépszó, Lingemann, Klein, & Kovács (2014) find only "minor reductions in summer and autumn months" (Szépszó et al. 2014, 260). Annually speaking, decreases in runoff of 15 % for the period 2071-2100 are expected to occur in the UDRB (Kling, Fuchs, and Paulin 2012). Decreases in runoff will be especially pronounced in the Alpine region (Stagl and Hattermann 2015). For the MDRB, a decrease or no trend is expected for annual runoff and there are no clear trends for seasonal changes, with probable increases in winter runoff (Mauser et al. 2012, 48). A decrease discharge will be especially pronounced during summer months in the LDRB having the potential to lead to severe water stress in summer (ibid, p. 48f). A more recent study presented projections for the next 30 years suggesting a decrease in late spring to autumn for the MDRB and the LDRB which would aggravate the existing low flow periods (Stagl and Hattermann 2015).

Regarding the groundwater storage and recharge, a general decline is predicted which can not only be attributed to Climate Change, but also to increased abstraction especially for agricultural purposes. A decline in groundwater quantity may also affect the vulnerability to pollution leading to enhanced transport of pollutants, especially after long droughts. While the decline will be most pronounced in the Hungarian Plain Area, increases in groundwater level are possible in Alpine regions (Mauser et al. 2012, 52).

For nearly all regions, a decrease in soil moisture content is possible. For the UDRB, the filter and puffer capacity of the soil will be changed, however influences on plant growth are not expected due to higher precipitation. In the MDRB and LDRB, especially during summer droughts, soil water content will decrease followed by a degradation in soil quality and soil salination (Mauser et al. 2012, 126f).

The coastal regions in Romania including the Danube Delta are especially vulnerable to Climate Change. A possible increase in the Black Sea level could trigger costal erosion and might lead to salinization of the Danube estuaries as sea water pushes inland having important effects on the ecosystem (Mauser et al. 2012, 140). Past observation of the Black Sea level showed that sea level increased by 1.9 mm per year between 1933 and 2007 (MMAP and ANAR 2016, 311). However, no clear quantitative future assumption or scenario simulations, but rather presumptions can be found (Mauser et al. 2012, 140).

5.3 Changes in Water Temperature

Pekarova et al.(2008) investigated water temperature in the UDRB and were able to show that an increase in air temperature was the main driver for a rise in river water temperatures. However, when considering river runoffs, this trend is not clear indicating that seasonal runoffs have changed which can also be traced back to Climate Change. Thus, "the relationship of increasing air and water temperatures need not to be linear." (Mauser et al. 2012, 83). Furthermore, cooling water releases as well as river bank vegetation have important effects on the river water temperature. Also, "[h]ydroelectric power plants do increase the retention time of river water and reduce the convective heat transfer between air and water by reducing the surface to volume ratio in impoundments." (Zweimüller, Zessner, and Hein 2008, 1023). However, a large part of the long-term temperature increase can be attributed to air temperature and discharge, the rest needs to be attributed to anthropogenic changes (ibid, p. 1035). Speaking for the entire DRB, an increase of 1 °C has already been observed during the last century and an increase of 2 °C is modelled for 2070 (Kristensen 2008, 103). "Projected increases in surface water temperatures are often 50 to 70 % of the projected increases in air temperature." (ibid, p. 103). For the UDRB, between 1950 and 2010 an increase of water temperature of around 0.1 °C per decade has been observed (Zweimüller, Zessner, and Hein 2008). The projected increases in water temperature are more pronounced in autumn and early winter months. During summer, melting water could have even cooling effects on headwaters in the UDRB (Mauser et al. 2012, 83). An increase in water and air temperature may also result in an increase of non-native species (e.g. Nedealcov & Drumea, 2014). Prinz et al. (2009) investigated the effects on rising river water temperature on the fish population in the UDRB. They have found substantial negative effects including a decrease in fish population and recommend on the one hand measures to limit the increase in temperature such as river bank vegetation and on the other hand measures to facilitate fish migration to cooler waters like fish bypasses.

5.4 Effects on Water Availability and Water Quality

Besides other anthropogenic influences, the above described effects of Climate Change have substantial impact on water availability and water quality. A region is defined to be water stressed “if they have either a per capita water availability below 1,000 m^3 per year (based on long-term average runoff) or a ratio of withdrawals to long-term average annual runoff above 0.4.” (Bates et al. 2008, 8). When projecting water stress, not only population projections, but also socio-economic scenarios such as rate of urbanization should be taken into account (Arnell and Lloyd-Hughes 2014, 138).

On the account of the mentioned changes in chapter 5.1, 5.2 and 5.3, water availability will decrease, especially in southeastern regions of the DRB. While in the UDRB no fundamental drinking water supply problems are expected, in the MDRB and LDRB some regions will face difficulties which could eventually lead to an increase in legal and illegal groundwater abstraction (Mauser et al. 2012, 95f). On the water demand side, developments are uncertain and highly dependent on technology, politics, market pricing as well as socio-economic conditions and population growth (ibid).

While water availability is an important aspect, it is crucial to analyze the water quality of the available water. Water quality in the DRB will most likely be reduced by Climate Change due to several reasons. First of all, increased water temperature has fundamental consequences on water quality as it directly leads to lower dissolved oxygen concentrations in the water body and consequently affects biological processes such as the carbon cycle. Further, also the nitrogen cycle is temperature dependent. Therefore, a water temperature increase will lead to increased processing rates of e.g. nitrification and denitrification (Zweimüller, Zessner, and Hein 2008, 1023). While the overall annual nitrogen transport rates are not expected to alter, seasonal changes are expected leading to more transport in winter and less in summer (ibid, p. 1035). Further, it leads to an “[i]ncrease in mineralization and release of nitrogen, phosphorous and carbon from soil organic matter (Mauser et al. 2012, 87). Also, resulting algae flourishing as well as eutrophication affect the river’s ecosystem. Degradation of water quality due to eutrophication has already been observed and traced back to Climate Change, for example in the southern part of the Republic of Moldova (Nedealcov and Drumea 2014, 169).

During low flow conditions and especially during droughts, lower dilution rates of point pollution sources occur decreasing water quality. Increased sedimentation due to low flow conditions may affect the sewage system. Furthermore, vertical transport of pollutants to groundwater may be enhanced (Mauser et al. 2012, 87f). Frequent flooding and flash floods increase particle mobility and thus the release of pollution into the water body (ibid). Moreover, again degradation of water quality due to Climate Change effects may be amplified by other anthropogenic impacts such as the use of fertilizers. However, it needs to be mentioned that human intervention may also increase water quality, such as measures taken regarding waste water treatment.

5.5 Sectors Affected

Climate Change and its consequences touches different areas of the biosphere and anthroposphere in the DRB.

First, the sensible ecosystem itself is affected in many ways. An increase in water temperature with its consequences described in the previous subchapter, changes in air temperature and precipitation patterns, changes in river runoff and accumulation of extreme weather events are expected to contribute to a decrease in biodiversity of flora and fauna in the long term, especially in the south-eastern region of the DRB (Mauser et al. 2012, 130). Water temperature and flow conditions are seen to be the most important pressures on the ecosystem and its biodiversity (Mauser et al. 2018, 89). It is likely that certain species will disappear and will be replaced by non-indigenous species. Also, a shift in food webs and migration patterns is expected (ibid). Moreover, a shift in plant growing seasons as well as increase in pests, algal bloom and eutrophication are to become an issue (ibid, p. 131). Regarding forests, the consequences are not straightforward. On the one hand, higher ambient temperatures, longer growing seasons and a decrease in damages from snow have positive effects on forests. On the other hand, lower productivity and health status during droughts as well as an increasing risk of forest-weakening diseases, storms and frost fires will have negative impacts (ibid, p. 117).

Recent studies show that elevated CO_2 levels can no longer be seen as a positive effect in forestry (Mauser et al. 2018, 80f).

Second, the agricultural sector in the DRB will face difficulties related to Climate Change in the future. In certain regions, one of the limiting factors in agricultural production is the availability of water for irrigation. Extreme weather events and an increase in crop disease risk also need to be mentioned in this context. Due to changes in meteorological conditions,“[t]he UDRB might benefit from a longer growing period, but in the MDRB and especially in the LRDB a shortening of the growing season with yield losses is expected.” (Mauser et al. 2012, 103). However, the final impacts depend also very much on the type of crop. While there can be also positive effects from Climate Change in agriculture, such as extended growing seasons, the “negative impacts of climate change on agriculture are expected to exceed positive impacts in every sub region.” (Mauser et al. 2018, 72).

Third, changes in the river flow influences navigation. The number of days of minimal low water necessary for shipping purposes is expected to decrease. While there is no convincing evidence, that low water events will occur more significantly in the near future in the UDRB, for the LDRB there are concerns for the summer season (Schweighofer 2014, 38). Furthermore, increase in flood risk as well as increase in humidity during cold seasons leading to fog and thus less visibility will have negative effects on navigation. A decrease in ice cover has positive effects (Mauser et al. 2012, 150f).

Forth, variations in river runoffs as well as extreme hydrological events have impacts on water related energy production. Besides hydropower, which will be faced with changed runoff conditions, also thermal power plants or other industrial plants requiring using river cooling are affected by a change in water temperature and run-off and may be faced with insecure availability of cooling water. For the UDRB, hydropower production is expected to increase slightly in the near future (+2 % from 2010 to 2030), but decrease by up to 16 % until 2060 (Koch et al. 2011, 1526). However, this decrease it not distributed evenly across all seasons. While hydro energy production in summer is expected to decrease significantly due to less runoff in the UDRB, in winter, there may be even increases (Koch et al. 2011, 1527f). Koch et al. (2011) consider it as crucial that future hydro power planning in the UDRB takes into account seasonal and regional tendencies such as changed precipitation patterns as well as shifts in timing of snow and ice melting (Koch et al. 2011, 1534). Moreover, changes in sedimentation has the potential to influence hydro power significantly in the future (Mauser et al. 2018, 96).

Fifth, private households in the DRB will also be affected by Climate Change in many ways. As heat waves and extreme weather events are expected to occur more frequently, inhabitants including their private property will be directly affected. Serious health issues may further be aggravated due to decreases in water quality and availability. Moreover, the sewage system and waste water treatment system may be affected during extreme weather events such as floods or droughts.

5.6 Effects and Uncertainties

The figure below (figure 4) aims to summarize the findings of chapters 5.1, 5.2, 5.3 and 5.4 that are of particular importance for chapter 6. The illustration is based on Mauser et al. (2012, p. 24) as well as Mauser et al. (2018 p. 17). It categorizes the different effects of Climate Change on the hydrological cycle and the ecosystem in the DRB according to the uncertainty (low, medium, high and very high) of occurrence as well as direction and magnitude as defined in chapter 2.

Sea level No clear projections available	**Groundwater** Decrease of quantity and quality, especially in MDRB; increases in Alpine region possible	**Snow and ice** Shifts of peak in snow melting, significant retreat in glaciers and permafrost	**Air temperature** Increase more pronounced in southeast than in northwest
Soil Decrease in soil quality and increase erosion, decrease of soil water especially in MDRB & LDRB	**Water temperature** Increase	**Precipitation** Mean annual precipitation; wetter north and drier south; strong regional differences	**Precipitation** Seasonality; decrease in summer, increase in winter
	Water quality Decrease	**Runoff** No clear trend or decrease in summer, increase in winter; strong regional differences	
	Biodiversity Decrease	**Extreme weather events** Increase in frequency and severity	
		Water stress, droughts Longer, more intense & frequent; especially in LDRB	
		Flood events Increase in (winter) floods, strong regional differences	
very high	**high**	**medium**	**low**

← uncertainty

Figure 4: Uncertainties of Climate Change effects in the DRB (Mauser et al. 2012, 2018)

Changes in air temperature as well as precipitation especially seasonal patterns can be seen as future event that will occur with low uncertainty. Regionally, the extent of the change may differ. Shifts in snow and ice melting, changes in runoff, frequency of occurrence of extreme weather events as well as water stress and droughts are expected to occur with medium uncertainty. Moreover, flood events are part of this category. It is very interesting to note, that the uncertainty regarding floods has decreased tremendously. While Mauser et al. (2012) attributed very high levels of uncertainty to the occurrence of flood events, the incorporation of new scientific findings lead to a strong decrease in uncertainty (Mauser et al. 2018). Effects on groundwater can be put together with water temperature, water quality and biodiversity to the group of Climate Change effects expected to occur with high uncertainty. Very high uncertainty remains with rise in sea water level.

In general, it can be said that the effects of Climate Change are not always clear in extent and direction. Many findings are subject to uncertainty, not at least because of inconsistencies in spatial coverage and in modelling approaches. However, what is clear is that Climate Change brings a new and important aspect into river basin management. While certain future changes can be considered as very likely to happen, for other changes flexibility is required due to uncertainty. Uncertainty can be seen as one possible way of describing also the urgency as it does not only include the uncertainty of occurrence but also of the extent of effect.

The above-mentioned Climate Change effects in the DRB are taken as a basis for the following policy analysis. The analysis aims to investigate the policy side of how humans try to adapt to changes in the hydrological cycle and the ecosystem. The adaptation required in sectors of the anthroposphere will only be indirectly included in the analysis.

6 Climate Change Adaptation Policies in the DRB

6.1 Introduction to Climate Change Adaptation Policies

Climate Change adaptation policies aim to anticipate Climate Change and minimize, offset or prevent its effects by setting guidelines to take action. They may also target advantages resulting from Climate Change in order to make efficient use of it. Climate Change adaptation has been high on the agenda of UNFCCC. According to Article 7, paragraph 1 of the Paris Agreement, parties agreed that:

> "the global goal on adaptation of enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change, with a view to contributing to sustainable development and ensuring an adequate adaptation response in the context of the temperature goal".

Adaptation consist of five activities: observation of climatic and non-climatic variables, assessment of impacts and vulnerability, planning, implementation as well as monitoring and evaluation (UNFCCC n.d.). The key milestones in setting up a framework for adaptation are the *Least Developed Countries Work Program (2001),* the *Nairobi Work Program (2006)* and the *Cancun Adaptation Framework (2010)*. As Climate Changes threatens human health, the economy and society in general, adaptation measures can be seen as a moral, economic and social imperative (UNECE 2009).

Funding of adaptation measures is a fundamental part the UNFCCC. For this purpose, financial instruments such as the Adaptation Fund and the Green Climate Fund were established. Priority is given to countries most affected by Climate Change such as AOSIS (Alliance of Small Island States) and LDCs (Least Developed Countries). As those countries are only marginally responsible for Climate Change, international funding of adaptation measures is therefore also a question of equity. In the EU, the multiannual financial framework (2014-2020) includes that 20 % of the EU's budget shall be climate-related. Further, the European Investment Bank and the European Bank for Reconstruction and Development provide further funding opportunities (European Commission n.d.).

It is of foremost importance that decision-making processes in Climate Change adaptation include information on technological and societal developments additionally to climatological projections (e.g. Lopez, Wilby, Fung, & New, 2010). Therefore, Climate

Change policy requires accurate information on Climate Change science and (socio-economic development. However, as both cannot be achieved “climate change policy has to learn decision-making under uncertainty, and climate change science has to base its projections on possible scenarios and storylines.” (Feichter and Gramelsberger 2011, 3). It is important to be aware that the way how policy makers deal with uncertainty is a normative choice (Held 2011, 124). In this context Held (2011) argues that we will witness a rebirth of philosophy in science since “[t]he pressure to distinguish the known, the systemic, the ‘objective’, from the normative, still often entangled scientific […] has never been larger than now, when it comes to negotiate the best climate policy for our future.” (Held 2011, 124). Given the uncertainties adaptation policies have to deal with, they need to be flexible up to a certain extent in order to be adjustable to future scientific findings. Facing these challenges, Ceccato, Giannini, & Giupponi (2011) suggest an idealized decision support system that should “act as mediators between science and policy/decision making and as catalysis of trans-disciplinary research.” (Ceccato, Giannini, and Giupponi 2011, 1164).

Moreover, in order to understand the implications of Climate Change on a local level, participation of local partners is required to integrate information on Climate Change impact with local development issues (Bizikova et al. 2011, 178). Also, the affordability and acceptability of environmental damage through Climate Change are dependent on space and time as well as societal values (Watts 2010, 86). Local Climate Change adaptation plans can sometimes be in conflict with the scale of climate models at which reliable estimates are provided (Lopez et al. 2010, 129).

In the following, more details are provided regarding the development and substance of Climate Change adaptation policies. Such policies should cover “all the steps of the adaptation chain: prevention, improving resilience, preparation, reaction and recovery.” (UNECE 2009, 78). Prevention of negative effects is often long term orientated. Examples for prevention may be the restoration of wetland or relocation of population and assets from flood-prone areas. Improving the resilience of a system (natural, economic or social) and hence the ability to adapt to Climate Change can include for example using less water-demanding crops and conservation of ecosystems. The preparation step is linked to risk assessment and includes early warning systems. Reaction to Climate Change can be an evacuation out of flood zones and establishment of safe drinking water resources in case of an extreme event. Lastly, recovery includes the restauration of a system after an extreme event (UNECE 2009, 79ff). Adaptation measures can further be divided into long-term, medium-term and short-term measures while the focus on medium and long-term measures should be fostered (UNECE 2009, 83).

As the effects of Climate Change are connected to uncertainties especially in the long-term, Climate Change adaptation policies are guided by the precautionary principle which has been laid down for the first time on a global level at the *Rio Conference in 1992* and is laid down as Principle 15 of the *Rio Declaration on Environment and Development* stating that a lack of full scientific certainty shall not be considered as a reason to postpone measures.

It is therefore also crucial that adaptation measures remain flexible to future developments. Besides flexibility, the so called "win-win options", "no-regret options" and "low regret options" are suggested as a way to deal with uncertainties in Climate Change adaptation policies. In its Guidance on Water and Adaptation to Climate Change, the UN Economic Commission for Europe (UNECE) defines these options as follows:

- **Win-win option**: "cost-effective adaptation measures that minimize climate risks or exploit potential opportunities but also have other social, environmental or economic benefits. In this context, win-win options are often associated with those measures or activities that address climate impacts but which also contribute to climate change mitigation or meet other social and environmental objectives." (UNECE 2009, 84).
- **No-regret option**: "cost-effective adaptation measures that are worthwhile (i.e. they bring net socio-economic benefits) whatever the extent of future climate change. These types of measure include those 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." (UNECE 2009, 84).
- **Low regret option**: "adaptation measures where the associated costs are relatively low and where the benefits, although mainly met under projected future climate change, may be relatively large. For example, constructing drainage systems with a higher capacity than required by current climatic conditions often has limited additional costs, but can help to cope with increased run-off as a result of expected climate change impacts." (UNECE 2009, 84f).

When formulating adaptation policies, decision-makers should keep in mind the costs in relation to benefits and effectiveness. Further, the process should be broad including different stakeholders and it should take the feasibility of implementation into account as "[t]here is often a gap between adaptation assessment and planning, on the one hand, and implementation on the other." (UNECE 2009, 88).

In the subsequent subchapters, the author focuses on Climate Change adaptation policies in the DRB on an international and national level followed by a discussion of their implementation.

6.2 Policies on a Transboundary Level in the DRB

On a transboundary level, the ICPDR is playing a key role in Climate Change adaptation policies. Its activities in this field are among others guided by the *EU White Paper on Adapting* to climate change: Towards a European framework for action (COM(2009) 147), by the EU CIS Guidance No. 24, by the Blueprint of Safeguard Europe's Water Resources, by activities of the European Climate Adaptation Platform (Climate-ADAPT) and the UNECE Guidance on Water and Adaptation to Climate Change.

The ICPDR adopted a Climate Change Adaptation Strategy in 2012 as requested by the 2010 Danube Declaration where also the objective of such a strategy is laid down: "This strategy should be based on a step-by-step approach and encompass an overview of relevant research and data collection, a vulnerability assessment, ensure that measures and projects are climate proof respectively 'no regret measures' […]" (ICPDR, 2010, paragraph 30). The objective of this strategy was to illustrate a way of how to successfully implement the topic of Climate Change and its effects into the 2nd Danube River Basin Management Plan (2nd DRBM plan) in 2015 requested by the EU WFD as well as into the 1st Danube Flood Risk Management Plan (1st DFRM plan) requested by the EU Floods Directive. As highly recommended by the updated Danube Study (Mauser et al. 2018, 108), a first revised version of the ICPDR Climate Change Adaptation Strategy is expected to be finalized in December 2018 which will incorporate the latest scientific findings. Updates of the Climate Change adaptation strategy will be in line with the six-year cycle of adapting management cycles in the WFD and Floods Directive. Hence, the process of Climate Change adaptation within ICPRD is not stationary but flexible and subject to updates. In the current version (2012) of the ICPDR Climate Change adaptation strategy, an overview of possible measures is given. The wording remains rather open and general. However, the strategy does not claim to define concrete adaptation measures, but rather to set a framework. Moreover, guiding principles on the adaptation and integration of adaptation into ICPDR activities are presented in the strategy. These principles address the issues of climate modelling and projections of impacts, adaptive capacity of management concepts, adaptation in the WFD, flood risk management and drought risk management. The strategy is not legally binding but shall serve as a common road map for activities on a national and international level.

While not giving concrete policy suggestions, the ICPDR Climate Change adaptation strategy suggests the following classification of adaptation measures following the above-descried steps of adaptation chain (see also chapter 6.1):

- Preparation measures
- Ecosystem-based measures
- Behavior and management-based measures
- Technology-based measures

Preparation measures are intended to support the planning process such as monitoring, evaluation, identification of risks, warning systems, emergency plans and support of further research (ICPDR 2012, 27). In the case of flooding for example, planning means that "there needs to be some kind of response developed a priori so that […] authorities and communities know how to behave during and after the emergency." (Ceccato, Giannini, and Giupponi 2011, 1172). Planning is considered the most needed approach in absolute terms (ibid).

Ecosystem-based measures aim to improve the ability of an ecosystem to adapt to Climate Change. Hence, such measures target the conservation, expansion and restoration of healthy ecosystems and protection areas (ICPDR 2012, 27).

Behavior and management-based measures include awareness raising, education, capacity building, highlighting best practice examples in order to exchange knowledge and the support of sustainable risk management systems such as for water scarcity as well as harmonization of data (ICPDR 2012, 27). Besides planned approaches on Climate Change adaptation, one needs to be aware that in many situations, small actors such as households or businesses will also act autonomously to react to alterations caused by Climate Change. Therefore, educational programs and capacity-building are important in order to improve and to prevent adverse effects of such autonomous adaptation measures (UNECE 2009, 78f).

Technology based measures aim to facilitate the implementation of individual projects and focus on infrastructural projects such as the building of dams, flood retention systems or fish ladders (ICPDR 2012, 27). An important principle in this context, is the best available technology doctrine as laid down in the *EU Directive 84/360/EEC*. The above-mentioned classification can be helpful when analyzing adaptation measures as they demonstrate a comprehensive approach. However, not for every Climate Change effect, the different types of measures are equally possible or important.

Below, the author analyzes, the main approaches to Climate Change Adaptation in the DRB on a transboundary level while focusing on the most important policies. The analysis includes the above mentioned ICPDR Climate Change adaptation strategy and its implementation in the 2nd DRBM Plan and the 1st DFRM Plan. Moreover, an example of a policy on a regional but transboundary level is given, namely the Danube Delta.

The effects of Climate Change on hydrology and ecosystem being analyzed are taken from chapter 5.6 with one exception. Precipitation is not taken into consideration in the policy analysis as it can be seen as a predecessor of other effects and no suitable adaptation measures only addressing changes in precipitation are available or meaningful. However, changes in air temperature – which is also a predecessor for other effects – is taken into consideration here as adaptation measures especially in the field of human health, infrastructure and energy are available.

6.2.1 Second DRBM Plan and First DFRM Plan

Both, the 2nd DRBM plan and the 1st DFRM Plan include a separate chapter on Climate Change which highlight the importance of implementing this topic in the respective management plans as requested by the ICPDR Climate Change adaptation strategy. In the 2nd DRBM plan, it is highlighted once again that Climate Change impacts need to be considered in conjunction with other pressures and hence, adaptation measures “should build on planned or already implemented water management measures." (ICPDR 2015b, 148). Both management plans represent only one level of the water body management strategies. They need to be seen in a framework with national management plans, not least because for certain aspects it may not make sense to adapt a basin wide policy as regions will be affected differently. However, cooperation on a basin wide level is still of great importance, as for droughts and water stress for example (ICPDR 2015b, 93). The aim is to have continuous feedback in place between the different levels of river management.

This subchapter aims to analyze transboundary activities. Two examples of national adaptation plans are being reviewed later in chapter 6.3. As there are several synergies and cooperation between flood management and other aspects of water management (ICPDR 2015b, 83ff), the analysis results of the DRBM plan and DFRM plan are presented in one single table. Table 5 gives an overview of Climate Change adaptation measures in the 2nd DRBM plan and 1st DFRM plan and their development stage. For further details on the measures see Annex Table I and Table II. In figure 5, the findings from the policy analysis of table 5 are set into relation with uncertainties.

Table 5: Policy Analysis DRBM & DFRM plans

DRBM & DFRM	1)		2)	3a)	3b)	3c)	3d)	4)
	Mentioned	Relation to Climate Change	Measure	Preparation	Ecosystem	Behavior and management	Technology	Development stage
Air temperature	(✓)	(✓)						D
Biodiversity	✓	✓	✓	✓	✓	✓	✓	A
Droughts and water stress	✓	✓	✓	✓		✓	✓	B
Extreme weather events	✓	✓	✓	✓		✓		A
Floods	✓	✓	✓	✓	✓	✓	✓	A
Groundwater	✓	✓	✓		✓	✓	✓	A
Runoff	✓		✓	✓	✓	✓	✓	A
Sea level								D
Snow and ice	✓	✓						C
Soil	✓	✓	✓		✓	✓	✓	B
Water quality	✓		✓	✓	✓	✓	✓	A
Water temperature	✓							C

The topics of air temperature (low uncertainty) and sea level (very high uncertainty) are not mentioned in either of the river basin management plans and thus can be attributed to policy development stage D. However, air temperature may be seen as implicitly being acknowledged for as the issue of Climate Change is raised several times. Both river basin management plans strongly focus on hydrology-related questions and hence in this case it might make sense not to emphasize on measures of how to deal with rising air temperatures. Sea level rise only concerns very specific parts of the LDRB. As the DRBM plan and DFRM plan are aiming to formulate basin wide measures, it makes also sense to not include sea level rise (for available measures see chapter 6.2.2).

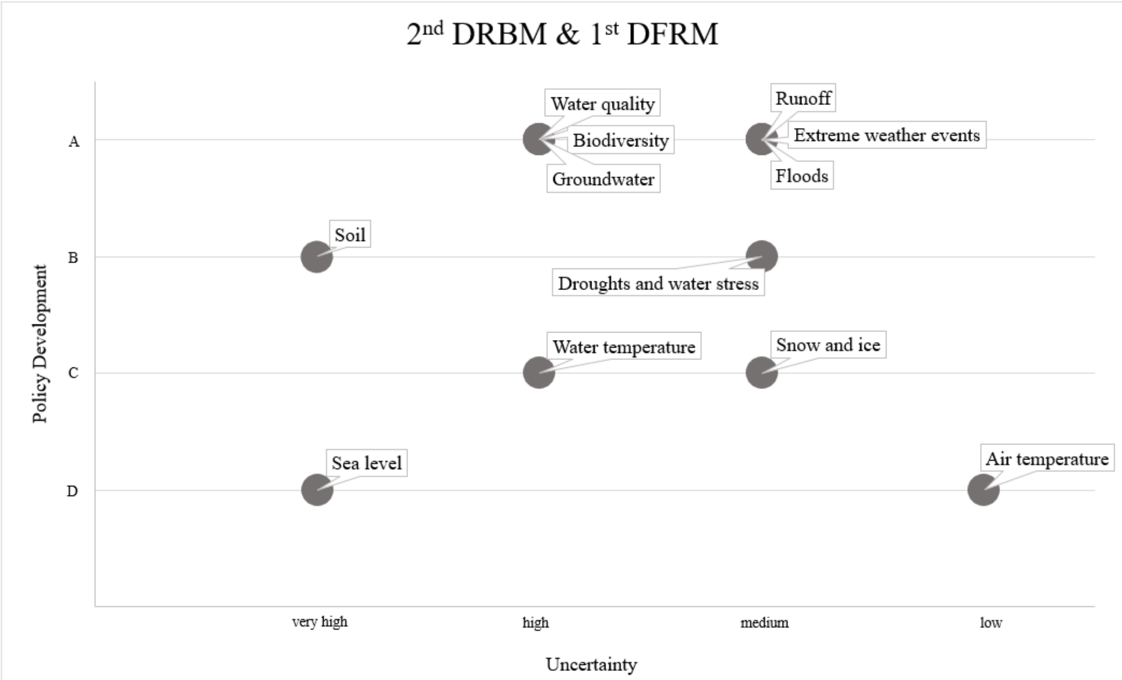

Figure 5: Policy development and uncertainty per effect – 2nd DRBM & 1st DFRM plans

Shifts in snow and ice coverage and melting (medium uncertainty) as well as water temperature (high uncertainty) are mentioned as a future challenge in the DRB, however no concrete measures are given in this regard. Effects on snow and ice are not equally relevant in the DRB depending on geographic conditions. The fields with policies in the development stage B are droughts and water stress (medium uncertainty) and soil (very high uncertainty). Measures in these areas are available, however there is room for improvement. Concerning droughts, the 2nd DRBM plan acknowledges the relevance of the topic and the need for (further) action. However, as there are regional differences in relevance and severity of droughts, especially regional action is of importance (ICPDR 2015b, 93). The remaining possible Climate Change effects are accounted for in several proposed measures with development stage A.

The majority of Climate Change effects of medium uncertainty receive exhaustive echo in policies. The group of effects with high uncertainty is well represented in policies of development stage A with the exception of water temperature for which no direct policies are available. Summarizing, one can say that no clear pattern between policy development and uncertainty can be revealed for DRB wide policies on Climate Change adaptation. Numerous measures are not specifically addressing Climate Change but other anthropogenic pressures such as pollution from agriculture. Nevertheless, the 2nd DRBM plan emphasizes that due to high uncertainties, no measures solely dealing with Climate Change are useful, but measures targeting the improvement of the water status and sustainable water management as those will increase resilience against Climate Change effects (ICPDR 2015b, 148). All in all, it can be said that the management plan includes the topic of Climate Change very well, however there is still room for improvement and the analysis above could serve as a helpful tool when it comes to prioritization.

6.2.2 Danube Delta Strategy and Action Plan

The Danube Delta stretches over Romanian (82 %) and Ukrainian (18 %) territory[5] and is the second largest river Delta in Europe (MMAP and ANAR 2016, 9). With its special ecosystem serving as a place for the development of diverse flora and fauna, the Delta "needs a special planning, management and development approach." (Nesterenko et al. 2014, 53). Therefore, a Climate Change adaptation strategy and action plan has been developed for the Danube Delta by a cooperation of scientists from Romania, the Republic of Moldova and the Ukraine. The strategy includes a very detailed summary of the expected effects of Climate Change in the Delta and proposes an action plan of how to adapt to those changes by making rather specific project proposals and naming different responsible actors. Hence, in contrast to the 2nd DRBM and 1st DFRM plans, this document has the main goal of addressing Climate Change effects and adaptation to them. Table 6 aims to summarize and categorize the topics raised as well as adaptation measures mentioned. Details regarding the different measures are presented in the Annex Table III. Figure 6 displays the results of the analysis of the Danube Delta Climate Change adaptation strategy in relation to uncertainties.

[5] Depending on the definition of the Danube Delta region, the Republic of Moldova may also be included as being part of this region.

Table 6: Policy Analysis of the Danube Delta Strategy and Action Plan

Danube Delta Strategy and Action Plan	1)		2)	3a)	3b)	3c)	3d)	4)
	Mentioned	Relation to Climate Change	Measure	Preparation	Ecosystem	Behavior and management	Technology	Development stage
Air temperature	✓	✓	✓	✓		✓	✓	A
Biodiversity	✓	✓	✓	✓	✓	✓		A
Droughts and water stress	✓	✓	✓	✓	✓	✓	✓	A
Extreme weather events	✓	✓	✓	✓		✓		A
Floods	✓	✓	✓	✓	✓	✓	✓	A
Groundwater	✓	✓	✓		✓	✓	✓	A
Runoff	✓	✓						C
Sea level	✓	✓	✓	✓		✓		A
Snow and ice	✓	✓						C
Soil	✓	✓	✓		✓	✓		B
Water quality	✓	✓	✓		✓		✓	A
Water temperature	✓	✓	✓		✓			B

Policy development stage A can be attributed to air temperature, biodiversity, droughts and water stress as well as extreme weather events, floods, groundwater, sea level and water quality. Policies of development stage B are available for soil and water temperature. The topics of snow and ice as well as runoff are identified as being consequences of Climate Change, but no concrete adaptation measures can be found. However, this does not mean that these topics are not (indirectly) addressed by measures aiming for adaptation regarding another effect as there are interdependencies. Nothing falls into development stage D, meaning that every single issue is addressed and brought into relation with Climate Change.

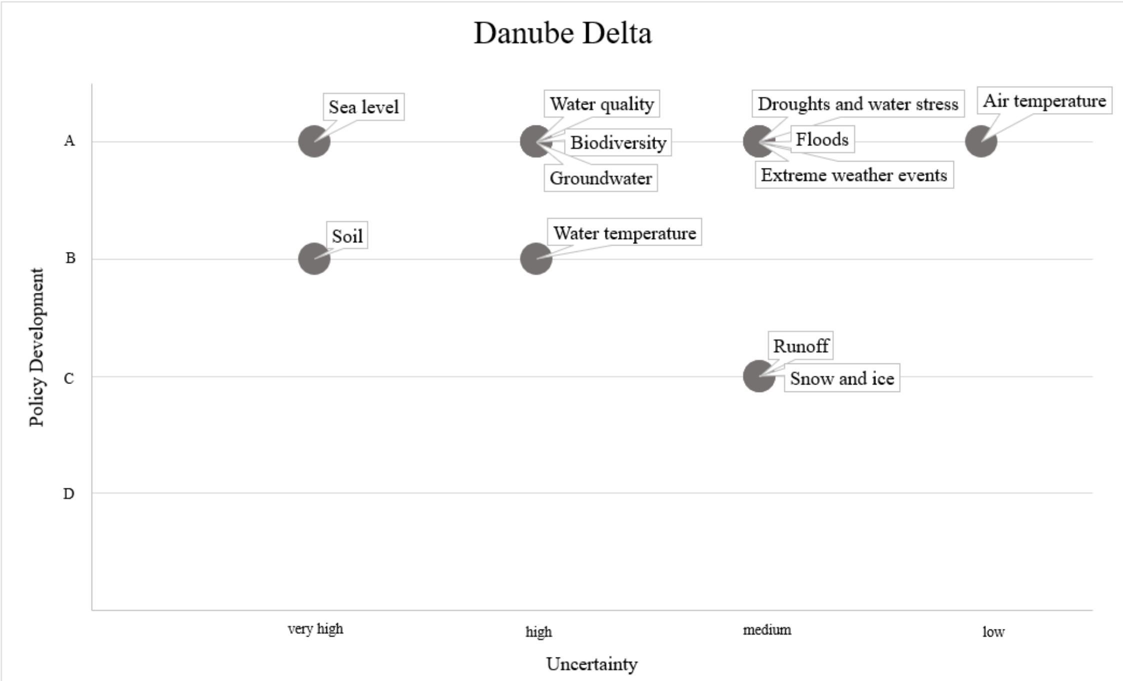

Figure 6: Policy development and uncertainty per effect – Danube Delta

The different effects to which a reaction with policies of development stage A are available range over all levels of uncertainty. Policies of stage B are available for effects of very high or high uncertainty. Again, no clear pattern between policy development and uncertainty can be revealed. All in all, the Danube Delta strategy and action plan is very comprehensive and covers all important areas affected by Climate Change. Concrete adaptation measures are made available and are presented in a very clear way. Furthermore, the transboundary aspect is covered as well.

6.3 Policies on a National Level

As already mentioned, exclusively investigating transboundary and basin wide Climate Change adaptation policies is not sufficient as national river management plans play a crucial role in this regard not least because Climate Change effects are not homogenous in the UDRB, the MDRB and the LDRB. The ICPDR plays a key role in coordinating national, basin wide and sub basin wide policies in the DRB. Their Climate Change adaptation strategy should be seen as a common roadmap guiding the various national polices and activities. In this subchapter, the current national river management plans under the EU WFD of Romania and Austria are being reviewed and checked for the incorporation of Climate Change adaptation measures. Both river management plans include elements of their respective national Climate Change adaptation strategy and make reference to the Danube's basin wide management plan as well as Climate Change adaptation strategy.

While sharing the Danube river and some history, Romania and Austria are two countries with remarkable differences in the economic situation. In 2017, Austria's GDP has been 4.4 times higher than the Romanian GDP (Eurostat n.d.). However, the development of policies happens under a common framework namely of the European Union. For this reason, it is of particular interest to analyze those two countries and to investigate the implementation of Climate Change adaptation measures in river management.

6.3.1 Romania

Romania laid down in its *Planul național de management actualizat aferent porţiunii naţionale a bazinului hidrografic internaţional al fluviuluui Dunărea care este cuprinsă în teritoriul României* (2^{nd} Romanian River Basin Management Plan: 2^{nd} RRBM plan) how the country will meet its requirements under the EU WFD as well as other water body related EU and national legislation. Hence, the document is rather extensive and comprehensive in terms of areas covered. Approximately one third of the DRB is situated in Romania (see chapter 4.1) and the whole Romanian territory is part of the DRB. The 2^{nd} RRBM plan includes a very detailed chapter on Climate Change highlighting among others adaptation measures and referring to various interrelated documents such as the national Climate Change adaptation strategy. Table 7 gives a summary of adaptation measures and their development stage. Details on the Romanian adaptation measures in river management can be found in Annex Table IV. In figure 7, the results of the policy analysis are put in the context of uncertainties.

Table 7: Policy Analysis National Policies Romania

National Policies Romania	1)		2)	3a)	3b)	3c)	3d)	4)
	Mentioned	Relation to Climate Change	Measure	Preparation	Ecosystem	Behavior and management	Technology	Development stage
Air temperature	✓	✓	✓	✓		✓		A
Biodiversity	✓	✓	✓	✓	✓	✓	✓	A
Droughts and water stress	✓	✓	✓	✓	✓	✓	✓	A
Extreme weather events	✓	✓	✓	✓		✓		A
Floods	✓	✓	✓	✓	✓	✓	✓	A
Groundwater	✓	✓	✓	✓	✓	✓	✓	A
Runoff	✓	✓	✓	✓	✓		✓	A
Sea level	✓	✓	✓		✓			B
Snow and ice	✓	✓						C
Soil	✓	✓	✓	✓			✓	B
Water quality	✓	✓	✓	✓	✓	✓	✓	A
Water temperature	✓							C

All of the above-mentioned effects of Climate Change on the Danube river are mentioned in the 2nd RRBM plan. With the exception of water temperature, they are also all brought into relation with Climate Change. Again, the list of policies of development stage A is extensive: air temperature, biodiversity, droughts and water stress, extreme weather events, floods, groundwater, runoff and water quality. Policies addressing these fields are detailed and divers. Development stage B can be attributed to policies regarding the effects on sea level and soil. However, both categories are close in reaching development stage A. Climate Change effects that are mentioned in the management plan, but no corresponding concrete policies are offered for are snow and ice as well as water temperature.

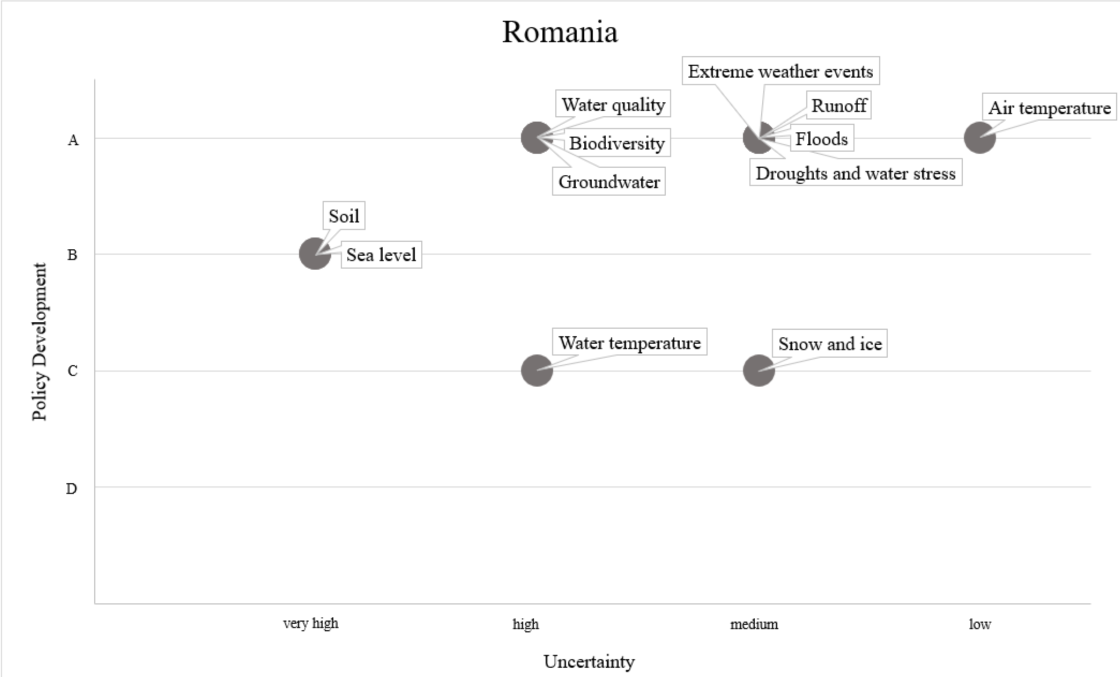

Figure 7: Policy development and uncertainty per effect – Romania

No clear pattern can be found linking policy development to uncertainty. Policy development stage A is available for Climate Change effects associated with high to low uncertainty. Putting changes in water temperature as well as snow and ice cover aside, policies of stage B can be found for effects of very high uncertainty and policies of stage A for every other effect of lower uncertainty.

In summary, it can be said that the 2nd RRBM plan includes Climate Change adaptation well into its river management plan. The chapter on Climate Change is rather extensive and already includes concrete policy measures. In order to identify corresponding measures, one needs to go through a long and sometimes repetitive list of measures. The connection to Climate Change is hardly made in the rest of the document. An important aspect raised at several points in the document is the aspect of financing of various measures. Concrete financial demands are mentioned as well as funding opportunities.

6.3.2 Austria

Austrian territory is part of the Danube River Basin (96 %), the Rhine River Basin (3%) and the Elbe River basin (1 %) (Klaffl et al. 2017, 35). In the Austrian *Nationaler Gewässerbewirtschaftungsplan 2015* (2nd Austrian River Basin Management Plan: 2nd ARBM plan), it is determined how the country will meet its obligation under the EU WFD. Climate Change adaptation as well as mitigation are topics that are specifically addressed in the 2nd ARBM plan. Adaptation measures take into consideration the results of the Austrian Climate Change adaptation strategy. Climate Change adaptation has already been taken into account in the 1st ARBM plan (2009) and experts consider measures as being well implemented (Klaffl et al. 2017, 87). Concrete measures following the 2nd ARBM plan are laid down in a separate non-legally binding action plans for specialized field (urban water management, agriculture and hydro morphology). The action plans are seen as an open list which is to be adapted according to latest scientific findings. A first analysis of these documents showed that the measures are formulated in a very open manner and are not comprehensive. Therefore, as the Romanian version of the river management plan also includes a strategy of how to reach obligations of legislation other than the WFD, the author decided – in order to ensure comparability – to also include relevant parts of the national Climate Change adaptation strategy (*Die Österreichische Strategie zur Anpassung an den Klimawandel*). Table 8 below summarizes and categorizes the Climate Change effects raised as well as adaptation measures taken. Details on the Austrian adaptation measures are presented in the Annex Table V. Like in the previous chapters, the analysis is extended by a diagram in which each point represents a combination between uncertainty and policy development stage (figure 8).

Table 8: Policy Analysis National Policies Austria

National Policies Austria	1)		2)	3a)	3b)	3c)	3d)	4)
	Mentioned	Relation to Climate Change	Measure	Preparation	Ecosystem	Behavior and management	Technology	Development stage
Air temperature	✓	✓	✓	✓		✓	✓	A
Biodiversity	✓	✓	✓		✓		✓	A
Droughts and water stress	✓	✓	✓	✓	✓	✓	✓	A
Extreme weather events	✓	✓	✓	✓		✓		A
Floods	✓	✓	✓	✓	✓	✓	✓	A
Groundwater	✓	✓	✓	✓	✓	✓		A
Runoff	✓	✓	✓	✓	✓	✓	✓	A
Sea level								D
Snow and ice	✓	✓	✓	✓		✓	✓	A
Soil	✓	✓	✓	✓	✓	✓		A
Water quality	✓	✓	✓	✓	✓	✓	✓	A
Water temperature	✓	✓	✓	✓	✓	✓		A

All effects have been raised and have been identified as being influenced or caused by Climate Change and detailed measures of how to deal with these changes have been proposed. Consequently, for all measures policy development stage A can be attributed. One exception is sea level rise which does not have any relevance at all for Austrian territory due to its geographic location. The aspect of financing of measures is not as present as in the Romanian river management plan.

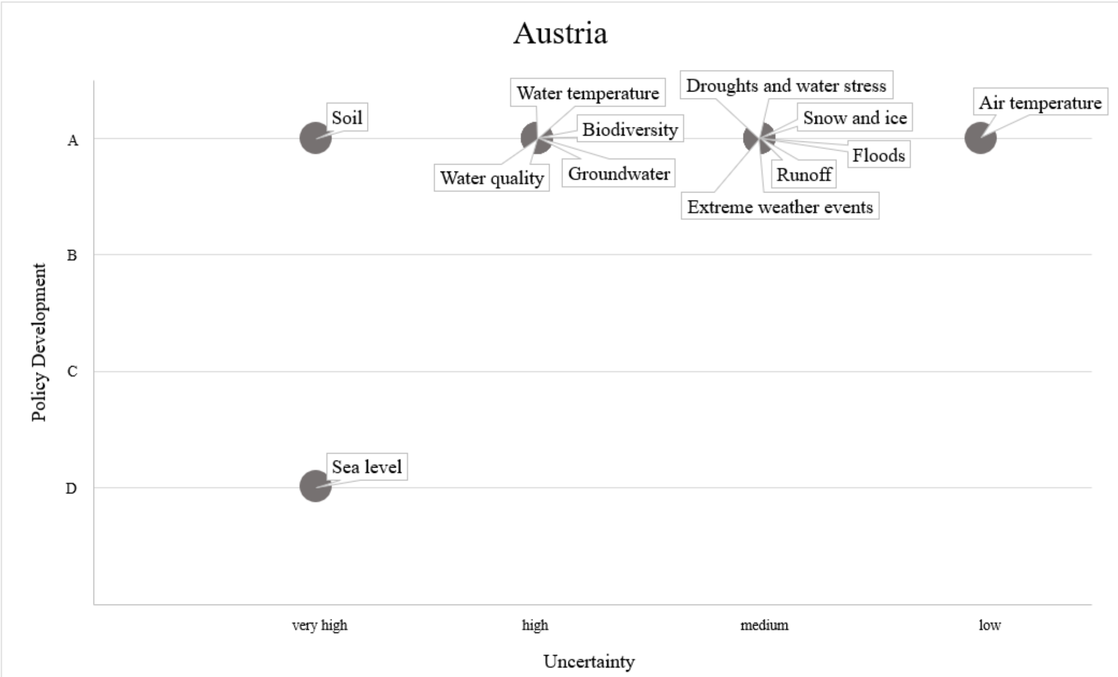

Figure 8: Policy development and uncertainty per effect – Austria

Figure 8 shows that in Austrian adaptation policies, the development stage of policies is high (stage A) for all effects regardless the level of uncertainty they are associated with.

6.4 Comparison

This chapter aims to compare the results of the different adaptation policies presented in the preceding chapters. It is important to be aware of the context of the respective document that has been analyzed. For the Danube Delta, a "pure" Climate Change adaptation strategy has been examined. In all other cases, river basin management plans have been analyzed as the ICPDR Climate Change adaptation strategy requested the implementation of such adaptation in the respective management plans. In the case of Austria, additionally relevant parts of the national adaptation strategy have been implemented. Measures found in river management plans are not solely concerning Climate Change. Furthermore, the policy analysis of this thesis does not claim to be exhaustive in terms of documents analyzed, but representative examples have been chosen (see also chapter 2).

Summarizing the results so far, it can be said that no clear link between uncertainty and policy development can be observed throughout the analyzed documents. The analysis of the current status however may serve as a helpful tool for priority setting when adapting the policies.

Finally, table 9 provides for a comparative overview of uncertainties and policy development stages across the different areas analyzed. Effects on biodiversity, extreme weather events, floods, groundwater and water quality (in grey) are addressed by policies of stage A throughout the analyzed documents. Policies on drought and water stress as well as runoff and air temperature are at stage A in all areas except one. The just mentioned effects are of high or medium uncertainty. Again, also in this comparative analysis of the different types of documents, no clear linkages and dependencies can be revealed.

Table 9: Overview of Uncertainty and Policy Development

	Uncertainty	**DRB**	**Delta**	**Romania**	**Austria**
Air temperature	low	D	A	A	A
Biodiversity	high	A	A	A	A
Droughts and water stress	medium	B	A	A	A
Extreme weather events	medium	A	A	A	A
Floods	medium	A	A	A	A
Groundwater	high	A	A	A	A
Runoff	medium	A	C	A	A
Sea level	very high	D	A	B	D
Snow and ice	medium	C	C	C	A
Soil	very high	B	B	B	A
Water quality	high	A	A	A	A
Water temperature	high	C	B	C	A

7 Conclusion

This Master thesis analyzed the future challenges arising from Climate Change in the Danube River Basins. Based on these findings, the question was answered to what extent policies react adequately. The future challenges have been assessed by a literature review. The most important Climate Change effects in the DRB were identified and classified according to their uncertainty. Uncertainty is to be understood in a broad sense including on the one hand the uncertainty of occurrence and on the other hand the uncertainty related to the agreement in the scientific community regarding the magnitude and direction of the effect. Increases in air temperature are expected to occur with low uncertainty. This raise in air temperature will be more pronounced in the southeast than in the northwest of the DRB. Low uncertainty can be attributed to the seasonality of precipitation. While summer precipitation is expected to decrease, increases are expected in winter time. Further, changes in the annual mean quantity of precipitation will show strong regional differences and extreme weather events will increase in frequency and severity (medium uncertainty). Due to ambient air temperature increases, the peak of snow and ice melting are expected to shift and a retreat in glaciers and permafrost is expected (medium uncertainty). Consequently, also associated with medium uncertainty are alterations in river runoff as well as flood risks and risk of water stress and droughts are expected to increase and shift in the time of occurrence. Strong regional differences are expected. There is high uncertainty regarding the consequences on groundwater quality and quantity, water temperature and quality as well as biodiversity. Water temperatures will increase and consequently water quality will drop. Biodiversity is expected to decrease. Climate Change effects associated with very high uncertainty is a rise of the Black Sea level, decrease in soil quality and increase in erosion. The sectors affected by Climate Change in the DRB are widespread. Besides in agriculture and forestry, adaptation will be required in navigation and water related energy production as well as cooling systems. Moreover, private households will be affected, mainly due to extreme weather events and changes in water availability and quality. Hence, Climate Change affects various aspects of hydrology in the DRB and consequently affects the anthroposphere substantially. Climate Change is expected to have an impact in the near and far future with strong regional differences. There are many research activities going on in the DRB regarding Climate Change, especially in the UDRB.

Based on these findings, Climate Change adaptation policies in the Danube River Basin have been assessed. For this purpose, a method has been developed to systematically analyze and classify policies from different policy documents. As the DRB is subject to a complex interplay of national and transboundary actors, representative documents have been chosen and analyzed. A central transboundary document analyzed was the ICPDR's Climate Change adaptation strategy itself and its implementation into the river basin management plan and the flood risk management plan. The Danube Delta Strategy and Action Plan was chosen as an example of regional but transboundary policy. On a national level, policy regarding Climate Change adaptation in the DRB of Romania and Austria were selected. For each identified effect, the questions were asked whether the effect in general is mentioned in the respective policy document and whether it was brought into relation with Climate Change. Subsequently, the single measures regarding the DRB have been compared to the lists of measures proposed by Mauser et al. (2012, 2018) which are assumed to be exhaustive. In order to illustrate the different angles from which the policies address adaptation, policies were assigned to the categories of preparation, ecosystem-based, behavior and management-based and technology-based measures. As uncertainties play a vital role in Climate Change science, the development stage of a respective policy is set into relation with the degree of uncertainty attributed to the various Climate Change effects by Mauser et al. (2012, 2018).

It can be concluded that Climate Change adaptation policies in the DRB are generally very well developed, based on the latest scientific findings and flexible to future changes. Thus, they can serve as role models for other river basins in an international context. Despite the complexity of international actors involved in this process, the common framework functions very well. The policy analysis does not result in a clear link between policy development stage and uncertainty. However, the analysis could serve as tool to decide on future priorities. While low uncertainties can be an indication for an urge to act, also high uncertainties could result in the need for further policy development as policy makers are faced with high planning uncertainties. Nevertheless, the policy side reacts adequately to needs revealed by science. No-regret and win-win options play a significant role when it comes to uncertainty in Climate Change adaptation. Moreover, it is crucial that the Climate Change adaptation process in the DRB remains open and flexible as new scientific evidence is continuously available and needs to be observed.

Policies are an important basis for Climate Change adaptation, however, the actual implementation of those policies remain the key factor of success. A difficulty, one may be confronted with when analyzing implementation projects is that information on a considerable number of such projects is expected to be not publicly available as many Climate Change adaptation actions take place on a private level (households and business). Currently, the greatest barriers to the implementation of Climate Change adaptation policies in the DRB are lacking financial resources, knowledge, spatial differentiation and infringement of rights (Mauser et al. 2018, 108). A quantitative and qualitative analysis of implementation projects linked to their foundation in policies and science is needed in order to assess the actual action done. This master thesis demonstrated that Climate Change adaptation policies in the Danube River Basin are well developed and can serve as a solid basis for implementation.

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Annex

The tables below summarize Climate Change adaptation measures of the respective documents. Depending on the policy, a considerable amount of measures can be mentioned at several points in the documents. For the purpose of simplicity, sometimes only one reference is given, especially when the measure was mentioned in the context of climate change.

Page numbers in Annex Table I refer to ICPDR (2015a).

Annex Table I: Details of Measures – 1st Danube Flood Risk Management Plan

Extreme weather events	
Preparation	Monitoring, research and forecasting (p. 21ff, p. 44ff)
Floods	
Preparation	Flood risk maps and land use planning (p. 34f) Monitoring, research and forecasting (p. 44ff)
Ecosystem	Restoration of floodplains and wetlands, construction and maintenance of flood retention systems, reduction of soil sealing, enhance capacity of river to channel high flows during flood events (p. 59ff)
Behavior and management	Awareness raising and financial precaution (p. 53ff)
Technology	Maintenance, improvement and enlargement of flood protection services, regular update of flood defense, water retention systems other than ecosystem based/natural (p. 37ff, p. 59ff)

Page numbers in Annex Table II refer to ICPDR (2015b).

Annex Table II: Details of Measures – 2nd Danube River Basin Management Plan

Biodiversity	
Preparation	Monitoring and mapping, including invasive species (p. 47f) and sturgeons (p. 90)
Ecosystem	Restoration, conservation and improvement of river morphology (p. 126), continuity restoration (p. 128ff)
Technology	Fish migration aids (p. 128ff)
Behavior and management	Improvement of management practices (p. 47f) Ex-situ conservation mesures for sturgeons (p. 90)
Droughts and water stress	
Preparation	Information exchange, best practice examples (p. 93)
Behavior and management	Drought risk management tools (p. 93)
Technology	Waste water and sewage systems, pollution source control (p. 111, p. 115f, p. 123f)
Extreme weather events	
Preparation	Monitoring, research and forecasting (p. 44f)
Behavior and management	Land use management (p. 117), risk management (p. 93)
Floods	
Ecosystem	Restoration of floodplains (p. 135)
Groundwater	
Ecosystem	Enhance natural water retention capacity (p. 147f)
Behavior and management	Groundwater quality (p. 146), abstraction management (p. 147f)
Technology	Reduction of pollution e.g. improve sewage system, domestic wells (p. 147f)
Runoff	
Preparation	Harmonizing data on hydro morphology (p. 34)
Ecosystem	Various hydro morphological measures (p. 125, p. 139)
Behavior and management	Measures on water abstraction and hydropeaking (p. 140)
Technology	Various hydro morphological measures (p. 125, p. 139)
Soil	
Ecosystem	Soil conservation & erosion control (p. 117)
Behavior and management	Financing instruments for farmers (p. 117)
Technology	Soil conservation & erosion control (p. 117)
Water quality	
Preparation	Inventory and monitoring tool and early warning system (p. 124), research on effects of nutrients (p. 116), guidance document on good agricultural practices (p. 117)
Ecosystem	Natural water retention measures, soil conservation & erosion control (p. 117)
Technology	Waste water and sewage systems, pollution source control (p. 111, p. 115f, p. 123f)
Behavior and management	Nutrient management, land use management, financing instruments for farmers and other incentives (p. 117)

Page numbers in Annex Table III refer to Nesterenko et al. (2014).

Annex Table III: Details of Measures – Danube Delta Strategy and Action Plan

Air temperature	
Preparation	Early warning systems (p. 45)
Behavior and management	Public awareness, improve access to health care (p. 45)
Technology	Green infrastructure in cities to prevent heat island effect, housing insulation (p. 38), power supply diversification (p. 43)
Biodiversity	
Preparation	Monitoring (p. 35), joint inventory (p. 35), harmonized legislation on fishing (p. 42), define sensitive areas and regulate tourism (p. 44), research (p. 48)
Ecosystem	Restoration of ecosystems (p. 33, p. 43), climate refugia , migration corridors (p. 35), management of invasive species (p. 35), rehabilitation of fishponds, agricultural polders (p. 33)
Behavior and management	crop rotation, forest management (p. 41)
Droughts and water stress	
Preparation	Drought plans (p. 33)
Ecosystem	Restoration of ecosystems (p. 33, p. 43)
Behavior and management	Management in farming (p. 41)
Technology	Technology in farming, irrigation (p. 41), water supply systems, drainage systems and water reuse (p. 37)
Extreme weather events	
Preparation	Early warning systems (p. 45)
Behavior and management	Management in farming (p. 41)
Floods	
Preparation	Identification of risk areas (p. 33)
Ecosystem	Rehabilitation of floodplains (p. 33)
Behavior and management	Public awareness, spatial planning (p. 38)
Technology	Flood retention (p. 37f), green infrastructure (p. 38)
Groundwater	
Behavior and management	water supply, drainage systems, water reuse (p. 37)
Ecosystem	Restoration of ecosystems (p. 33)
Technology	Water reuse (p. 37), improve water quality (p. 33)
Sea level	
Preparation	Identification of risk areas, monitoring (p. 33, p. 39)
Behavior and management	spatial planning (p. 38)
Soil	
Behavior and management	Change of crops, increase soil holding capacity with organic farming (p. 41)
Environment	Restoration of ecosystems (p. 33)
Water quality	
Ecosystem	Restoration of ecosystems (p. 33)
Technology	Update of waste water treatment systems (p. 37), improve water quality (p. 33)

Water temperature	
Ecosystem	Bank vegetation to provide shade (p. 33)

Page numbers in Annex Table IV refer to MMAP & ANAR (2016).

Annex Table IV: Details of Measures – Romanian River Basin Management Plan

Air temperature	
Preparation	Develop plans on how to cope with heat waves (p. 328)
Behavior and management	strengthening local planning capacity (p. 329)
Biodiversity	
Preparation	Regular health checks on fish (p. 245)
Ecosystem	Restoration of wetlands, extend natural habitats (p. 312), ensure fish migration (p. 327)
Behavior and management	Development of traditional fishing and ecotourism activities (p. 312)
Technology	Ensure fish migration (p. 327), eco-friendly technologies in forestry (p. 327), pollution prevention (p. 207)
Droughts and water stress	
Preparation	Identifying drought risk (p. 315), simulations regarding water availability (p. 318), special protection measures for areas at risk (p. 328)
Ecosystem	Adapt crops to become more resistant to low quantities of water taking into account biodiversity (p. 327)
Behavior and management	Management system regarding water abstraction and water use (p. 325), reuse of irrigation water (p. 328), financial support for farmers in case of income loss (p. 280), emergency plans (p. 323)
Technology	Implementation of efficient irrigation systems (p. 251), water reuse (p. 256ff), improvement of sewage system and waste water treatment (p. 253)
Extreme weather events	
Preparation	Identifying risk areas and warning systems (p. 313, p. 315, p. 318)
Behavior and management	emergency plans (p. 323)
Floods	
Preparation	identify risk areas (p. 327, p. 329)
Ecosystem	Restoration of wetlands (p. 312) and natural capacity to deal with floods (p. 314), afforestation of flood risk slopes (p. 327)
Behavior and management	Reducing number of people living in flood risk areas (p. 313)
Technology	Flood defense structures (p. 314, p. 329), pollution prevention (p. 207)
Groundwater	

Preparation	Assessment of groundwater resources (p. 315), identify cases of authorized direct discharge to groundwater (p. 266)
Ecosystem	Restoration of wetlands (p. 312)
Behavior and management	various measures on agricultural practices (p. 217ff), water use management (p. 325)
Technology	Improvement of sewage system and waste water treatment (p. 253)
Runoff	
Preparation	Assessment of Climate Change impact on runoff (p. 315)
Ecosystem	Reduce anthropogenic influences on hydro morphology, preservation of natural flow system (p. 327), various hydro morphological measures, ensure river connectivity (p. 272ff), afforestation (p. 328)
Technology	various hydro morphological measures (p. 272ff)
Sea level	
Ecosystem	Measures to stop coastal erosion and to increase security (p. 289), afforestation (p. 328)
Soil	
Ecosystem	Measures avoiding erosion (p. 314) such as afforestation (p. 328), restoration of wetlands (p. 312)
Technology	Measures avoiding erosion (p. 314)
Water quality	
Preparation	Continuous monitoring of water quality (p. 207), risk management regarding pollution (p. 207), feasibility studies on waste water infrastructure (p. 210), strengthening international cooperation (p. 287)
Behavior and management	Awareness raising regarding anthropogenic pollution of waters (p. 207), staff training (p. 210), various measures on agricultural practices (p. 217ff), promotion of good practice examples (p. 225), water use management (p. 325)
Ecosystem	Protection zones (p. 230)
Technology	Improvement and maintenance of sewage system and of water distribution system (p. 327), pollution control in industry (p. 238ff)

As the policies in the 2nd ARBM plan are spread over several documents, the different sources are given right next to the individual measures (Annex Table V).

Annex Table V: Details of Measures – Austrian River Basin Management Plan

Air temperature	
Perpetration	Continue monitoring and forecast system (BMLFUW 2017, 175f)
Behavior and management	Raising awareness and capacity building (ibid, p. 140f)
Technology	Adapting infrastructure (ibid, p. 140f)
Biodiversity	
Ecosystem	Various measures to ensure river continuity (Fenz et al. 2017, 27), various measures to improve morphology (ibid, p. 30), ensure fish migration (ibid p. 32), restoration of landscape elements such as forests (Schilling, Feichtinger, and Strauss 2015, 13), restoration ecosystems (BMLFUW 2017, 87)
Technology	Various measures to ensure river continuity (Fenz et al. 2017, 27), various measures to improve morphology (ibid, p. 30), ensure fish migration (ibid p. 32), pollution prevention and control (BMLFUW 2017, 87)
Droughts and water stress	
Preparation	Data analysis and further research regarding water as a resource (Klaffl et al. 2017, 194), research on effect of low water on environment (BMLFUW 2017, 85)
Ecosystem	Water protection areas (ibid, p. 82), increase soil water holding capacity (ibid, p. 85)
Behavior and management	Improved management of low water (Klaffl et al. 2017, 193), awareness raising regarding limited resource of water (ibid, p. 194), various measures in agriculture (Schilling, Feichtinger, and Strauss 2015, 29ff), capacity building, water supply system management, adapting water management to low flow (BMLFUW 2017, 76), emergency plans to ensure water supply (ibid, p. 82), water use efficiency (ibid, p. 84), water storage for emergency situations (ibid, p. 85)
Technology	Guarantee water supply incl. groundwater (Klaffl et al. 2017, 194), pollution prevention and control (BMLFUW 2017, 87), water saving technologies (ibid, p. 94)
Extreme weather events	
Preparation	Monitoring, research (ibid, p. 76)
Behavior and management	various measures in agriculture (Schilling, Feichtinger, and Strauss 2015, 29ff), capacity building (BMLFUW 2017, 82), emergency plans to ensure water supply (ibid, p. 82)
Floods	
Preparation	Monitoring, research (ibid, p. 91)
Ecosystem	restoration of landscape elements such as forests (Schilling, Feichtinger, and Strauss 2015, 13), land use

	planning and reduce sealing of surfaces (BMLFUW 2017, 82)
Behavior and management	Adaptive flood management (ibid, p. 76), emergency plans to ensure water supply (ibid, p. 82)
Technology	Flood retention systems (ibid, p. 149f)
Groundwater	
Preparation	Intensify hydrological planning of groundwater (Klaffl et al. 2017, 87), monitoring, research (BMLFUW 2017, 76)
Ecosystem	Measures to insure the good ecological and chemical status (Klaffl et al. 2017, 193), protection of ecosystems important for groundwater (BMLFUW 2017, 89)
Behavior and management	Emission reduction measures to groundwater from agriculture (Schilling, Feichtinger, and Strauss 2015, 5ff, 22f, 24ff), adapting water management to low flow (BMLFUW 2017, 76), emergency plans including usage of deep groundwater (ibid, p. 82f), considering increased use of groundwater for water supply (ibid, p. 89)
Runoff	
Preparation	Monitoring, research (BMLFUW 2017, 76), digitalization of hydrographical data (ibid, p. 79)
Ecosystem	Various measures to ensure river continuity (Fenz et al. 2017, 27), various measures to improve morphology (ibid, p. 30)
Behavior and management	Management of low water (Klaffl et al. 2017, 193), ensure minimum runoff for ecosystem (Fenz et al. 2017, 28), adapting water management to low flow (BMLFUW 2017, 76), strategic planning in industry and energy production (ibid, p. 87)
Technology	various measures to improve morphology (Fenz et al. 2017, 30)
Snow and ice	
Preparation	Monitoring (BMLFUW 2017, 262)
Behavior and management	Change management in sustainable tourism (ibid, p. 109f, p. 313f)
Technology	Adaptation of infrastructure (ibid, p. 180f)
Soil	
Preparation	Monitoring, harmonizing data basis (BMLFUW 2017, 26, 61)
Ecosystem	Measures limiting erosion (Fenz et al. 2017, 31)
Behavior and management	change of crops to reduce emissions and erosion (Schilling, Feichtinger, and Strauss 2015, 29ff), capacity building (BMLFUW 2017, 26f), measures in agriculture (ibid, p. 42ff)
Water quality	
Preparation	Monitoring, research (ibid, p. 76)
Ecosystem	Measures to insure the good ecological and chemical status (Klaffl et al. 2017, 193)

Behavior and management	Emission reduction measures from agriculture (Schilling, Feichtinger, and Strauss 2015, 5ff, 22f, 24ff, 34), training and awareness raising for farmers (Schilling, Feichtinger, and Strauss 2015, 54)
Technology	Measures to insure the good ecological and chemical status (Klaffl et al. 2017, 193), improvement of sewage system and waste water treatment (Lindtner 2007, 9ff), increase efficiency of fertilizer application (Schilling, Feichtinger, and Strauss 2015, 48)
Water temperature	
Preparation	Stronger consideration of water temperature in hydrological planning of (Klaffl et al. 2017, 87), monitoring, research (BMLFUW 2017, 76, 79)
Ecosystem	Restructuring of riparian (Fenz et al. 2017, 34), renaturation of morphology (ibid), river continuity (BMLFUW 2017, 93)
Behavior and management	adapting water management to changes in water temperature (ibid, p. 76), alternative cooling systems, emergency plans (ibid, p. 93)