Climate change risk management in transnational river basins: the Rhine

Saskia van Pelt[1] and Rob Swart[1]

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Abstract

Most adaptive responses to climate change are on national, regional or local scales and currently, many national governments across Europe are developing adaptation programmes without paying much attention to the international dimension. Responsibility and authority for adaptation strategies are distributed over different institutional levels, which includes international actors in the case of transnational systems. This poses a major challenge to effective development and implementation of adaptation measures. To base adaptation policies on the best scientific and technical knowledge, it is important to understand both the potential climate impacts, as well as the capacity of social and natural systems to adapt. Both are characterized by large uncertainties at different geographical scales that range from individual and local to regional and global. This paper discusses the adaptation activities that have been or are being developed in the Rhine basin at all relevant scales, taking into account the match of supply and demand of scientific information and the use of uncertainties by policy makers. Results of this research show that policy choices relating to water safety are as much influenced by political priorities as by evolving scientific insights. In general communication of uncertainties in river basin adaptation only covers a small part of the spectrum of prevailing uncertainties, e.g. by using only one model and one scenario. Two approaches are taken: the dominant top-down approach links adaptation options to impacts projected by climate and impact models and a bottom-up approach looking at the climate resilience of development plans that incorporate a broad range of issues. Positive experiences with the latter suggest that this method may be applied more widely. Finally, development and implementation of adaptation options derived from integrated analysis at the full river basin level rather than within the boundaries of the riparian countries can offer new opportunities but will also meet with many practical challenges.

1. Introduction

The problem: too much water, or too little

Climate change is one of the major challenges society will face during this century. Temperatures are projected to increase up to 6.4 ºC, which is expected to result in major changes in the atmosphere's energy balance and the hydrological cycle (IPCC, 2007).

[1] Earth System Science and Climate Change Group, Wageningen University. Correspondence to: saskia.vanpelt@wur.nl

Especially extreme events that result from these changes will impact European society, for example through heat waves, droughts and floods (Beniston *et al.*, 2007). A recent example of the effect of climate extremes was in the summer of 2003 when a heat wave afflicted Europe. During this heat wave mean summer (June, July, August) temperatures exceeded the 1961-1990 mean by 3 ºC (Schär *et al.*, 2004). While this heat wave is mostly remembered because of the large number of casualties and other health impacts, also water resources were seriously affected. For example, the water level in the Rhine in the Netherlands reached critically low levels for power plants (Jacob *et al.*, 2009). A year earlier, in 2002, the opposite was happening when a large region, stretching from Germany and Austria to Romania and Russia experienced severe floods. Although these events cannot directly or conclusively be attributed to climate change (Jacob *et al.*, 2009), the IPCC's Fourth Assessment Report (IPCC, 2007) concluded that in the future anthropogenic climate change 'likely' to 'very likely' leads to increases in intensity and frequency of temperature and precipitation extremes. These phenomena are not constrained by watersheds or national boundaries, they can afflict large areas and many countries simultaneously and during these events conflicts between competing resource requirements can be most intense. As a consequence, the urgency of a better understanding of risks of extreme hydrological events is increasing, both from a scientific and political perspective (Lehner *et al.*, 2006). In this paper, we focus on the challenges of climate change adaptation for transnational river basin management using the Rhine river basin as a case study area.

Rhine river basin

The river Rhine (see Figure 1) originates in the Swiss Alps as a mountain river, fed by glacier water, snowmelt and rainfall. From Switzerland it flows through Germany, France and the Netherlands into the North Sea. The total catchment area of about 185 000 km2 and the length of 1320 km, makes the Rhine the longest river in Western Europe. In the course of time, along the Upper Rhine the discharge section has been reduced from a width of about 12 km to some 200-250 m. The course of the Rhine have been shortened by 82 km, the mere construction of dams has reduced the surface of the flood plains by 130 km. Today the Rhine disposes of less than 15 % of the original flood plain (ICPR, 2009b) The Rhine basin includes densely populated and highly industrialized areas with approximately 50 million inhabitants. The river is of great economic and environmental importance for the riparian countries. Its water is used for many sectors, such as hydropower generation, agriculture and industry and domestic water use. About 20 million people depend on Rhine water as a source of drinking water (Aerts *et al.*, 2004) and it is the busiest waterway for inland navigation in Europe (Middelkoop *et al.*, 2001). In the flood prone areas, an estimated total of about 1,500 billion Euro is at risk (Klein *et al.*, 2004). Continued implementation and improvement of flood and drought prevention measures is an economic and social must.

Fig. 1: Rhine basin (source www.kennislink.nl)

Climate change adaptation in international river basins under uncertainty

The development of adaptation strategies has started just recently in river basins such as the Rhine, after the emergence of climate change and associated impacts as a reason for concern. This paper reviews the current situation and identifies key questions that should be addressed to facilitate the development of adaptation strategies. Formulating adaptation strategies poses a great challenge for both the scientific community and policymakers, particularly because of the incomplete understanding of natural and societal systems and the many associated uncertainties. Dealing with uncertainties is not new to water managers, because they have been dealing with uncertainties for decades. Floods and droughts are extreme events and it is hard to predict when they are going to happen and what the consequences will be. Water managers have tried to estimate the chances of especially flooding on the basis of historical data and use these data to set the standards for safety levels. Adaptation strategies for river basins are necessarily not only based on historical data, but also on scenario analyses using climate impacts models. These impact models, for example hydrological models, use the temperature or precipitation simulations of global or regional climate models as input. In climate simulations used for the development of adaptation strategies, uncertainties at various levels of the assessment accumulate. The uncertainties are associated with future greenhouse emissions, the response of the climate system and with the spatial and temporal distributions of impacts (Dessai *et al.*, 2007b). Climate change is also associated with conditions of deep uncertainty. It refers to conditions that policymakers do not know, or do not agree on. The conditions of deep uncertainty are related to the appropriate model to describe interactions among a system's variable, the probability distributions to represent uncertainty about key parameters in the models, or how to value the desirability of alternative outcomes (Lempert *et al.*, 2004). Risk management needs to deal with (deep) uncertainties in such a way that robust 'low-regret' or 'win-win' strategies can be formulated. When a strategy is robust, it performs relatively well, compared to alternatives, across a wide range of plausible futures (Lempert *et al.*, 2006). Thereby also criteria like e.g. costs and social acceptance can be taken into account. Formulating robust strategies will only be possible with effective knowledge sharing between the scientific climate community and policymakers at the many relevant governance levels. Risk management does not only pose a challenge for local water managers, it is an issue relevant also at higher levels of governance: regional, national and in case of the Rhine basin also international. The Rhine flows through several countries and many governmental authorities with different territorial boundaries are involved. Climate adaptation strategies are therefore of international importance and one may expect that really effective risk management would benefit from cooperation between the riparian countries. But are the opportunities that could be provided by such cooperation fully explored already?

Objectives of this review

In a transnational river basin, effective risk management requires a good match between information needs of policymakers and knowledge availability from the scientific community, robust management of uncertainties and transboundary cooperation. The objective of this paper is to take stock of current policy and science developments in the Rhine river basin and to address the following three questions:

- How does a (mis) match between information needs and knowledge availability across different geographical and administrative scales stimulate or constrain effective adaptation policy development?
- How are uncertainties dealt with?
- What is the effect of (lack of) transboundary cooperation on adaptation management?

Addressing these questions, priority research gaps to improve robust adaptation policy development in transnational river basins can be identified. This paper is based on a yet rather limited knowledge base. By structuring the problem of transnational climate change adaptation in a multilevel context we can give preliminary answers to these questions that may guide future research and policy development. The following sections will elaborate on the above questions, illustrated for the Rhine basin case study. Section two summarizes the framework and approach used for structuring this paper. Section three summarizes the scientific climate change knowledge base, focusing on spatial and temporal scales of climate models and introducing the uncertainties that are involved with climate change modelling. Section four examines the challenges that arise from transboundary cooperation in the Rhine basin. The final section presents preliminary responses to the above questions and identifies research gaps.

2. Approach

A framework for analysis

Figure 2 is used as an organizing structure for our paper. It shows interactions of the governance processes at different levels and the natural science processes at different spatial scales. The left hand side of the figure represents the multi-level governance processes which result in the formation of adaptation strategies and measures. The right hand side of the figure represents the natural processes, where the impacts of climate change are simulated, usually with computer models. Adaptation strategies are partly based on the results of these models. Socio-economic scenarios, such as those developed by the IPCC, are used to create emission scenarios, which serve as input for global climate models (GCMs). GCM results are then downscaled, e.g. using regional climate models (RCMs). RCMs are then used to simulate the impacts of climate change on social- and biophysical systems, for example river basins. These models capture different geographical and temporal scales.

Types of uncertainties

Three types of uncertainties can be distinguished that determine the uncertainty range of future climate projections: (a) incomplete knowledge (epistemic uncertainty), (b) unknowable factors (stochastic uncertainty, e.g. intrinsic variability in the climate system) and (c) human reflexivity. (Dessai *et al.*, 2003). Policy makers at different levels are confronted with the output of climate models and simulations of impacts. At higher administrative levels this knowledge is mostly used to support the formulation of rather broad adaptation strategies, while at local levels it provides input into the design of more concrete adaptation measures. This process requires adequate 'vertical interaction' in the governance system and 'horizontal action' with the scientific community. Epistemic and stochastic uncertainty are part of the scientific knowledge output. The third type of uncertainty, human reflexivity, is introduced by the social system. Humans can reflect critically on information regarding their behaviour. Society is likely to act upon scientists' projections that climate will change (Dessai *et al.*, 2003). The behaviour of society influences the climate and impact projections because the social-economic scenarios change as a function of the policy responses. In our review we first focus on the right hand side of the figure, then the left hand side. The danger of examining both sides separately is that interactions within the whole system are missed and the complete picture is lost. For the sake of simplicity of this review paper we decided to deal with the two sides subsequently and in the final section to focus on the whole integrated system.

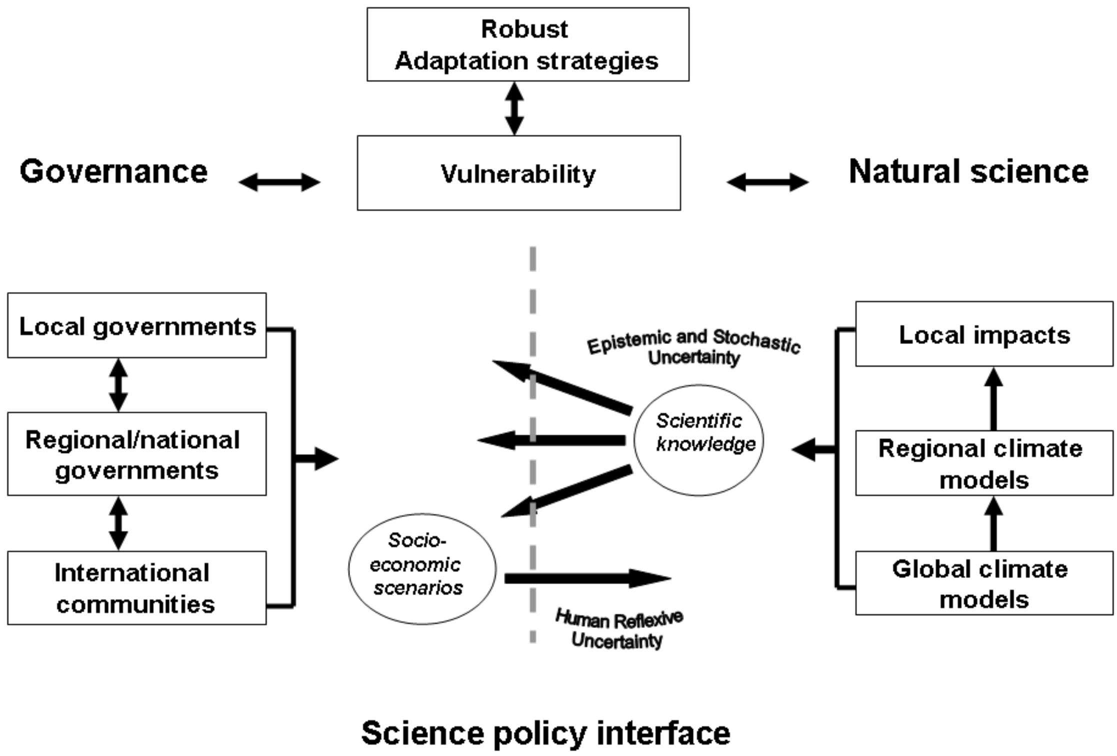

Fig. 2: Interactions of governance-- and biophysical system at different spatial and temporal scales.

3. Information needs and knowledge availability of climate change

Climate change projections for the Rhine basin

The changes in the weather system above Europe, which serve as input for hydrological models, have been analyzed in different studies. An overview of Beniston (2007) presented changes in extreme events that are most likely to affect Europe in the coming decades. The results showed that the intensity of extreme temperatures increases more rapidly than the intensity of more moderate temperatures due to increases in temperature variability. The projections showed that heavy winter precipitation is projected to increase in central and northern Europe and decrease in the south. In a high resolution simulation (10 km) over the Rhine basin, the regional pattern of temperature change displays a stronger warming in the south and south-east of the domain covering Germany, the Alps and Switzerland for the time period 2071-2100 compared to 1961-1990. This is associated with a decrease in precipitation in summer. An increase in winter precipitation in south and south-west regions was simulated. Less precipitation will fall in the occurrence of snow. (Jacob *et al.*, 2009) The 2006 scenario's of the Royal Dutch Meteorological Institute (KNMI (van den Hurk *et al.*, 2006)) project a summer decrease of the wet day frequency up to 10-20 % and an increase of wet day precipitation in the winter of 4-9 % for the Netherlands. The results above are confirmed by a recent study of the International Commission for Protection of the Rhine (ICPR) which assessed the state of knowledge on climate change. Because of the high uncertainty in projected precipitation, the uncertainty in the impact indicators that are linked to precipitation and water supply is high (Jol *et al.*, 2009).

Runoff projections for the Rhine basin

The potential impact of climate change on the hydrological regimes of the river Rhine has been assessed quantitatively in several studies. To estimate the impact of climate change on river discharge, different scenarios of future meteorological conditions are used as input of a hydrological model. As a scale mismatch exists between the coarse resolution of a GCM and the regional catchment scale, the GCM results have to be downscaled. This is usually done with statistical or dynamical downscaling techniques. Statistical downscaling techniques use an observational relationship between large-scale phenomena and local quantities. This observational relationship is applied to GCM output to obtain regional climate signals (Fowler *et al.*, 2007a; Jacob *et al.*, 2009). Dynamical downscaling techniques use high resolution RCMs. Additional detail is added to the large scale phenomena that are inherited from the host GCM. They add information on local conditions at specific locations and on processes that are small scale, but which are not necessarily tied to a specific location. Model skill depends strongly on biases inherited from the driving GCM and the presence and strength of regional scale forcing (Lenderink *et al.*, 2007; Fowler *et al.*, 2007a). For the Rhine basin different SRES scenarios, driving GCMs and hydrological models are used. The most used hydrological model is RhineFLow (van Deursen *et al.*, 1993). Studies published on this subject show different results ranging from an average increase in discharge of 14 % in 2050 (Krysanova *et al.*, 2008) to 14 % (Graham *et al.*, 2007) or even up to 30 % (Lenderink *et al.*, 2007a) at the end of this century. Drought projections show similar variabilities ranging from an average decrease in discharge of 10 % (Aerts *et al.*, 2004) to 40 % (Graham *et al.*, 2007; Leipprand *et al.*, 2007; Lenderink *et al.*, 2007a) The simulated results in these publications do have a large uncertainty range and for each study only a limited amount of driving models has been used, but the results appear to agree at least in sign and order of magnitude.

Table 1 :List of published research on hydrological simulation of the influence of climate change on discharge of the river Rhine

Study	**Year**	**GCM**	**IPCC Scenario**	**Hydrol. Model**	**Spatial resolution RCM**	**Temporal resolution**
(Kwadijk *et al.*)	(1995)	CLIMAPS	BaU	RhineFlow	0.5 º x 1.0 º	2100
(Middelkoop *et al.*)	(2001)	UKHI/ XCCC	IS92a	RhineFlow	0.5º x 0.5º	2050
(Shabalova *et*	(2003)	HadRM2	IS92a	RhineFlow	50 km	2080-2099

al.).						
(Jasper *et al.*)	(2004)	HadCM3	A2-B2	Wasim	-	2081-2100
(Klein *et al.*)	(2004)	HadCM3	A2-B2	RhineFlow	-	2070-2099
						2010-2039
(Hurk van den *et al.*)	(2005)	HadAM3	A2	-	50 km	2070-2100
(Droogers *et al.*).	(2005)	HadCM3	A2-B2	RhineFlow	0.5º x 0.5º	2070-2099
(Menzel *et al.*).	(2006)	HadCM3	IS92a	HBV-D	-	2061-2095
(Lenderink *et al.*)	(2007a)	HadRM3H	A2	RhineFlow	50 km	2070-2099
(Graham *et al.*)	(2007)	HadAM3H	A2	HD/Wasim	50 km	2071-2100

<u>Uncertainties</u>

The overview above and table 1 show that studies, simulating discharge for the river Rhine only use one or two IPCC scenario, initially mainly the older IS92a, later the IPCC SRES A2 scenario. The IS92a scenario is a ‘middle’ scenario, while A2 is one of the higher emission scenarios, suggesting and intentional move from ‘best guess’ to ‘worst case’ scenario selection. Because the approach of these studies is different their results can only be compared with caution.

The choice of the driving GCM generally provides the largest source of uncertainty in downscaled scenarios (Dessai, 2005a; Fowler *et al.*, 2007a; Leander *et al.*, 2008; Prudhomme *et al.*, 2009). This makes the results perhaps a bit debatable as most studies on the impacts of climate change on the river Rhine only make use of one driving GCM. Uncertainties from downscaling techniques and emission scenarios are generally smaller than GCM uncertainty (Prudhomme *et al.*, 2009). Outputs from RCMs cannot be used in impact studies without first applying a bias correction (Fowler *et al.*, 2007a). The use of bias correction can add another level of uncertainty as the used method influences the resulting discharge (van Pelt *et al.*, 2009). Three sources of uncertainty arise from the use of hydrological models: random or systematic errors in the output data, uncertainty due to sub-optimal parameter values and errors due to incomplete or biased model structure (Butts *et al.*, 2004). When simulations are done for the next decades, there is less certainty about the cause of change, because on this time-scale, forecasts are dominated by higher frequency climate variations and external forcing by natural and anthropogenic factors. The human climate signal will be even harder to discern at river basin scale (Wilby *et al.*, 2009a). It is important to know the extent to which the climate events are the product of natural variability, or are the result of potentially irreversible, forced anthropogenic climate change (Hurrell *et al.*, 2009). To date, there is little knowledge about how to separate the natural and anthropogenic climate change signals for short-term forecasting.

The (mis) match between the information needs and knowledge availability

Political systems are caught in four to five year democratic cycles, while future climatic impacts are calculated for time scales that are much longer. In table 1 it is shown that most studies focus on at least 2050. Policymakers are more interested in changes for the next couple of years. Here a temporal mismatch can be identified between the long-term supply of knowledge and the short-term demand of policymakers. Table 1 shows that the spatial resolution of RCMs of the studies is at a maximum of 50 km. The spatial uncertainty of grid cells can be decisive for hydrological analysis of the river basin, making it difficult to make judgments on regional levels (ICPR, 2009a) and indicating that this low resolution does not always match the territorial boundaries of policymakers. Local policymakers may need much more specific information. Temporal and spatial scaling complicate effective knowledge sharing between climate science and policy. Next to scaling issues the communication and representation of uncertainties is under a lot of debate. The UK is the first country to present climate change projections (incl. temperature, precipitation, sea level rise) for policy applications in a probabilistic framework. Some scientists are against this way of presenting uncertainties as they state there are important limitations to our ability to predict future climate conditions for adaptation decision-making (Hall, 2007): uncertainties can only be quantified to a certain extent. Climate prediction should not be the central tool to guide adaptation to climate change (Dessai *et al.*, 2009). Others find it is essential that GCM predictions are accompanied by quantitative estimates of the associated uncertainty (Murphy *et al.*, 2004; Giorgi, 2005). This discussion demonstrates that there is still much to be researched. The debate about how to present and how to manage uncertainties can be confusing and may make it more difficult for policymakers to formulate adaptation strategies on the basis of available scientific knowledge.

Top-down versus bottom-up approach

In order to deal with uncertainties in climate change adaptation two approaches can be identified. The first approach is the top-down approach also referred to as the ‘predict-than-act’ approach. It focuses on downscaled global climate change scenarios and it is strong in dealing with statistical uncertainty (Dessai *et al.*, 2007b).One or more climate scenarios are used as starting point for an impact assessment. The goal is then to derive an optimum adaptation strategy, based on the results of the impact assessment, seeking to find a solution that performs best contingent to a particular view(Lempert *et al.*, 2007). It is widely used and accepted. The IPCC and the Dutch KNMI, for example, take this approach. The second approach is called the bottom-up approach, also referred to as the ‘asses-risk-of-policy’ framework. It does not take projections as a starting point, but the resilience of the system. This approach takes into account a broader set of issues from the start, and is stronger in coping with ignorance and surprises. It seeks adaptation strategies that can make the system less vulnerable to uncertain climate change impacts and unpredictable variations in the climate system (Dessai *et al.*, 2007b). An example of a bottom-up approach is evaluating the robustness of strategies. An adaptation strategy is robust when it works good across a wide range of future scenarios (Lempert *et al.*, 2007). In the Netherlands the bottom-up approach has been applied for the area of water management using the concept of "adaptation tipping points". These "tipping points" are reached if the current management strategy can no longer meet its objectives (Kwadijk *et al.*, 2009). Only beyond the tipping points an adaptation strategy is needed. The focus of this approach is on the resilience of the water system. The results of this study also have been input to the authoritative study on future adaptation options by the 2nd Delta Committee (see chapter 4). A number of case studies on sea level rise in the Netherlands which have explored this approach suggest that it may better match the way policy makers address questions than the top-down approach. The results have shown, for example, that for dikes along the tidal river area no major technical and financial adaptation tipping points will be reached any time soon, but that potential tipping points might arise on the social- and political level. Social acceptability, for example, of living behind giant dikes may decline. (Kwadijk *et al.*, 2009). These experiences suggest that a bottom-up approach might be useful or at least complementary to the more commonly used top-down approach, as the application was useful to reduce the complexity of developing adaptation strategies to climate change.

Design discharge

Important policy variables in river basin management are politically agreed safety levels and design discharges derived from scientific analyses. Safety levels refer to the frequency of flood evens that is considered to be acceptable. The amount of water per second that can be associated with these safety levels and which statistically has a certain probability to occur ('design discharge') is used to design adaptation or flood protection measures, e.g. to determine the necessary height of a river dike. Both safety level and design discharge are different between countries and vary over time as scientific insights and political priorities evolve.

Table 2: Safety levels and design discharge for German and Dutch part of the Rhine basin

Part of river basin	Safety level (recurrence interval in years)	Design discharge ($m^3 s^{-1}$)
Oberrhein (Dld)	110-1000	5,500-7,300
Niederrhein (Dld)	200-500	12,900-14,800
Rhinedelta(NL)	1250 -10 000	16,000

Table 2 shows different safety levels and corresponding design discharges for Germany and the Netherlands. The safety levels in the Netherlands are up to tenfold higher than in Germany. The Dutch norm are legally binding at the national level, while the German norm can differ between Länder, depending on historic water levels and local initiatives (Steenhuisen *et al.*, 2006).

Table 3 shows the history of design discharges over the previous and the beginning of this century. The first design discharge as we define it today was set in 1956 after the major floods of 1953 in the Netherlands. After twenty years it became clear that a design discharge of 18,000 m^3 s^{-1} , with a safety level of 1/3000 would be too costly and the measures would have a huge impact on cultural, historical and nature values. The Commission Becht, assigned by the national government, calculated that the safety level could be adjusted to 1/1250 and the design discharge could be decreased to 16,500 m^3 s^{-1}. Another twenty years later the design discharge was decreased further to 15,000 m^3 s^{-1} , because of a lot of public resistance against raising and broadening the dikes. This decrease in design discharge with the same safety level was possible because of a different statistical calculation method. The high waters of 1993 and 1995 placed safety back on the political agenda and the design discharge was raised again to 16,000 m^3 s^{-1} in 2001 .

Table 3: Evolution of design discharges for the Dutch part of the Rhine basin (Kwadijk *et al.*, 2008b)

Year	Design discharge (m^3 s^{-1})	Safety level (recurrence interval in years)	Event
1926	Level of 1926 + 1m	-	Flooding 1926
1956	18,000	3000	Flooding 1953
1976	16,500	1250	Commission Becht
1992	15,000	1250	Public resistance – Commission Boertien
2001	16,000	1250	Flooding and evacuation 1995

On the basis of a study of Middelkoop (2000) the Committee Water Management 21st century (WB21) has calculated an increase in design discharge of 5 % per grade temperature rise. If a 'middle' scenario of the Royal Dutch Meteorological Institute (KNMI) is taken, this translates into a design discharge of 18,000 m^3 s^{-1} for the Rhine. Spatial reservations are already made for the possibility of this discharge, although other measures taken at this moment are still based on a design discharge of 16,000 m^3 s^{-1}. When a more extreme scenario is taken, the maximum design discharge could be up to 22.000 m^3 s^{-1} for 2100 (Kabat *et al.*, 2009). The design discharge has been reason for a lot of discussion. The example of table 3 illustrates the high impact of extreme events on the formulation and implementation of adaptation strategies. The determination of design discharges from statistical analyses of the measured peak discharges faces various problems. The estimation of the 1250 year discharge event from statistical information in a discharge record of about 100 years involves a strong extrapolation, which is quite uncertain. Recent developments like the development of GRADE (Generator of Rainfall And Discharge Extremes) (de Wit *et al.*, 2007) have improved these extrapolations, but it does not eliminate all uncertainty. Without additional flood-protection measures in Germany an amount of 18,000 m^3 s^{-1} would never reach the Netherlands, as the Niederrhein would flood in Germany when the discharge is between 11,000 m^3 s^{-1} and 16,000 m^3 s^{-1}. Transboundary floods would occur at 14,000 m^3 s^{-1}. Hence, according to the report of the Dutch Delta Committee it is very unlikely that in the medium term discharges higher than 18,000 m^3 s^{-1} will reach the Netherlands. The cooperation and communication between the Netherlands and Germany definitely could have been better. The amount of 16,000 m^3 s^{-1} was already included in water safety legislation in the Netherlands in 2001, before research was done on flooding in Germany in 2004.

4. Transboundary cooperation on adaptation management in the Rhine basin

The European level: European Union policies

As to the management of water in the Rhine basin policies at all levels are relevant: EU, transnational, national and local. Up to recently, climate change impacts have not been a major concern in EU water policy (Leipprand *et al.*, 2007). At the European level, legislation that is relevant for climate adaptation regarding the water sector are the Water Framework Directive (WFD) and the Flood Directive. The WFD requires a river basin management plan to be established for each river basin district. Although originally not explicitly included in the legislation, this management framework allows for the inclusion of climate change adaptation issues and must be updated every six years. In 2015 the first management cycle of the WFD and the river basin management plans ends. At that time the programmes can be updated and the latest insights as to climate change impacts taken into account. The Flood Directive requires Member States to coordinate their flood risk management practices in shared river basins and to avoid taking measures that would increase the flood risk in neighbouring countries. The Directive has been published in 2007 and it requires Member States to carry out a first assessment by 2011 to identify those river basins and associated coastal areas that are at risk of flooding. The flood risk management plans should be finished by 2015. As they only contain a limited number of explicit references to climate change impacts, these existing policy instruments can be used as a starting point but have to be developed further. While to date little has been done to mainstream adaptation into the relevant EU policies, (Leipprand *et al.*, 2007), recently the European Commission released a White Paper in which a framework is set out to reduce EU's vulnerability to the impact of climate change in general

(EU, 2009a). It provides suggestions for a stepwise development of European adaptation policy, including the mainstreaming of adaptation into sector policies such as those related to water management. The intention is that phase 1 (2009-2012) will lay the ground work for preparing a comprehensive EU adaptation strategy to be implemented during phase 2, commencing in 2013.

The river basin level: International Commission for Protection of the Rhine

In the case of the Rhine, a river-basin-wide institution has been established, notably International Commission for Protection of the Rhine (ICPR), a platform for the riparian countries to discuss the sustainable development of the Rhine. The ICPR was initiated in the 1950s following concerns about pollution of the river and the implication for drinking water supply. The IPCR has no formal authority to carry out measures, the decisions taken are not legally binding and implementation is the responsibility of member states (Van Ast, 2000; ICPR, 2009b). The Flood Action Plan, which has been established as part of the Rhine 2020 programme on sustainable development of the Rhine by the ICPR in 1998, aims to reduce risks of flooding by for example creating retention areas. Such measures would reduce vulnerability to climate change as well, although in 1998 there was no explicit mentioning of climate change adaptation yet. On October 18th 2007 the Conference of Rhine Ministers decided to jointly develop adaptation strategies for water management in the Rhine Watershed, in order to cope with the challenges of climate change. This intention has not been put into action yet.

The national level: German and Dutch adaptation plans

Adaptation strategies at the national level in Germany are mainly related to strategic action. The implementation of federal laws is usually delegated to the federal states (Länder) which have the primary right to develop and implement legislation in the field of water protection. (Kastens *et al.*, 2008) The German National Adaptation Strategy (NAS) has been adopted by the Cabinet in 2008. The NAS aspires to integrate the work that is already in progress in various ministries (Swart *et al.*, 2009). It creates a framework for adaptation to climate change, but it will require further specification. The Federal Government is therefore aiming to present an Adaptation Action Plan drawn up jointly with the Federal States by the end of March 2011. The NAS confirms the responsibility of the Länder for water safety, with the federal government playing a role in providing knowledge and tools. Regarding international cooperation the German NAS only states that the Federal Government will coordinate the German position. In the Netherlands the government has formulated a National Adaptation Strategy in 2007 called ‘Make Space for Climate’. The government is currently working on a National Adaptation Agenda, this will be finished by the end of 2009. The strategy documents are starting points for formulating more substantive climate adaptation policy. The document relates primarily to spatial measures, although raising awareness and identifying gaps in knowledge are also part of the strategy (VROM, 2007; Swart *et al.*, 2009). Attention for international cooperation is limited to a few sentences that indicate the importance of cooperation with other countries. How this should be managed is not elaborated. The Netherlands forms a delta where major European rivers flow into the North Sea, which makes the country vulnerable to flood risk. Therefore, complementary to the NAS, the Dutch government requested an independent Committee of State (the Delta Committee) to advice on flood protection and flood risk management in the Netherlands for the next century. The Delta Committee formulated twelve recommendations to secure the country against flooding on the short and medium term. The recommendations focus on this century, but the Committee's report also includes a long-term vision to 2200 (DeltaCommittee, 2008). An important outcome of this research is the advice to increase safety levels with a factor 10. Although in the EU White Paper transboundary or international cooperation is an important topic, in the national adaptation strategies of both the Netherlands and Germany, this seems to have little priority as yet.

Institutional and cultural challenges

Adaptation actions take place within hierarchical structures; administrations at different levels interact with each other. Actions are therefore determined (facilitated or constrained) by institutional processes such as regulatory structures, property rights and social norms associated with rules in use (Adger *et al.*, 2005). Trans-boundary cooperation is restrained by several differences between the Netherlands and Germany. The two countries have different administrative structures, more specifically there are several differences regarding their water policy and risk perception:

- The Dutch government has adopted stricter legal obligations concerning flood prevention and damage compensation than Germany. In Germany this legislation differs between Länder (Raadgever, 2005);
- Safety levels in the Netherlands are much higher than in Germany;
- The interpretation of future uncertainties is different (Becker *et al.*, 2007);
- In the Netherlands floods are calamities with large financial and social consequences, in Germany people are more used to floods and in most areas the consequences are less severe (Steenhuisen *et al.*, 2006);
- Dutch inhabitants expect higher authorities to take action regarding flood safety, in Germany floods are perceived as regional or local events against which measures have to be taken by officials as well as individuals (Becker *et al.*, 2007);
- The competence for water management in the Netherlands is primarily allocated to the national level, while in Germany the competence is allocated to the sixteen Länder, making the Länder of central importance for transboundary issues.

The diverse perceptions on flood risk and the corresponding safety levels can be explained by differences in potential flood impacts. In the Netherlands more than 8,5 million people live in flood risk areas, that is more than 50% of the total population. In Germany, over 2 million people live in flood risk areas, which is less than 2,5 % of the total population. The financial damage in case of a flood is estimated at 130 billion euro for the Netherlands, compared to 34 billion in Germany (ICPR, 2001). Although the Länder coordinate policy and legislation concerning water management in the Länder Water Working Group (LAWA), the fact that Germany is divided in sixteen authorities makes harmonization of water management in the whole Rhine basin more difficult (Steenhuisen *et al.*, 2006). The Rhine basin does have a history of successful international cooperation, due to the pollution of the Rhine (Dieperink, 2000). International formal interactions can be a competence struggle, but due to long lasting cooperation, trust between the riparian countries has developed (Raadgever, 2005). Although collaboration and information exchange on climate change has been rather ad hoc until now, experiences in the past suggest that also in the area of climate change adaptation opportunities for more structural cross-boundary collaboration in policy and science exist and can be enhanced.

5. Discussion, conclusions and recommendations

In this paper we have identified factors that facilitate or constrain effective risk management with respect to climate adaptation in transnational river basins. The Rhine river basin was taken as case study area, as it is a large international river basin with a history of droughts and floods. Three questions were addressed in particular: ‘ How does a (mis) match between information needs and knowledge availability across different geographical and administrative scales stimulate or constrain effective adaptation policy development?’, ‘How are uncertainties dealt with? ‘ and ‘What is the effect of (lack of) transboundary cooperation on adaptation management?’ A number of findings emerge:

<u>Political priorities and evolving scientific insights both determine water safety choices</u>

A view on history shows that river basin management with regard to safety levels has been applying design discharges provided by scientific and technical advisors. As for this matter, the demand of knowledge by policymakers appears to be matched by the supply by scientists. However, whether statistical calculations have the biggest impact on the design discharge can be debated as over the last century the design discharge in the Netherlands changed a number of times, not only as a result of new scientific insights or statistical methods, but also as result of extreme events, financial reasons or public opposition. Extreme events, for example, increase the level of public attention and sense of urgency and design discharges are increased to address public concerns. After some time remembrance of extreme events seem to fade away in the minds of people and the design discharges are lowered. The political and societal discussion that follow extreme events offer a particular window of opportunity for scientists and scientific information to play a role in policy making. Uncertainties related to runoff extremes provide sufficient room for political choices related to the design discharge. While after an extreme event re-active adaptation takes place, climate adaptation strategies, targeting future extreme events, ought to be pro-active. This proves to be very challenging as it is more difficult to create a sense of urgency for events that have not happened yet. Climate adaptation decisions need to be made before conclusive scientific evidence is available, while the potential error of wrong costs can be huge (van der Sluijs *et al.*, 2005).

Scientific support to water management strategies inadequately address uncertainties

Even if communication between scientists and policymakers in the area of water safety appears to have been quite satisfactory, particularly in The Netherlands, some questions can be asked. First of all, the question of selection of long-term climate scenarios is interesting. While initially a “best guess” middle scenario was used, and even incorporated in legislation, later a more “worst case” scenario was applied (A2). It is not completely clear if this was a decision by the relevant policymakers or by the scientific experts. At the same time, model calculations generally only used the output of one climate model, ignoring differences between model outcomes. It might be that for the coming decades the differences in terms of runoff projections between scenarios and climate models are relatively small and multiple model runs would be too costly, but this is not systematically discussed in the various reports underpinning Dutch water policy. In general research on the human dimensions of climate change suggest that available information on climate change is often not perceived to be useful by policymakers, or is misused and contributes to undesired outcomes (Sarewitz *et al.*, 2007). In national and regional Dutch and German adaptation strategies uncertainties are mentioned in rather general terms, but it is not explicitly explained how governments are dealing with these uncertainties. It raises the impression that policy makers do not have enough interest in or understanding of uncertainties. They can use uncertainties strategically, as illustrated by the evolving choices on design discharges. At the same time, we feel that the scientific output to date in the area of water management often does not provide the policy makers with clear information about the uncertainties and how to manage them. Two mismatches between the supply of knowledge and the demand of policy makers relate to spatial and time scaling. Most climate change information is available at long-term temporal scales and large spatial scales. As all management plans or adaptation strategies, from the Water Framework Directive to national plans have their goals set for at the latest 2015, it seems that more short-term projections are needed. Furthermore the coarse resolution of RCMs can not always be fitted to the needs of local policy makers.

Early experiences with bottom-up analysis of options (looking at the climate resilience of development plans rather than linking adaptation options to projected impacts) suggest that this method may be applied more widely.

Top-down scenario approaches are most commonly used in developing climate adaptation strategies and measures. This approach is strong in coping with statistical uncertainties and can profit from the large amount of available impact assessments. However, projections of future climate change also have uncertainties that cannot be quantified. Too much focus on climate change scenarios alone ,may lead to ineffective risk management. In the Netherlands, for example, the top-down approach may not lead to optimal decision making in the water sector if only one scenario and one model is chosen as a best-estimate (Kwadijk *et al.*, 2009). The bottom-up approach offers possibilities to deal with uncertainties that cannot be quantified, by focusing on the resilience of the system. Research on this approach has currently started with the concept of adaptation tipping points. First results of this method show that it can offer policy makers a new tool for evaluating adaptation strategies that also addresses their non-climate priorities and a different view on the urgency of adaptation to climate change. Therefore it would be interesting to do more research on bottom-up approaches and apply these approaches more widely.

Development and implementation of adaptation options derived from integrated analysis at the full river basin level rather than within the boundaries of the riparian countries can offer new opportunities, but will also meet with many practical challenges

The history of water management in the Rhine basin has shown that international cooperation could be successful. Agreements on water pollution of the Rhine have led to a successful improvement of water quality. This can be an example for other trans boundary cooperation, e.g. to address climate change adaptation in the most cost effective manner. International cooperation in river basins with respect to climate change adaptation can be very important, as measures in one country could have negative effects in another or country-by-country measures could be less effective or more expensive than measures optimized over the full river basin. In the case of the Rhine the latter can be illustrated by the current understanding that the design discharge of 16,000 $m^3 s^{-1}$ was included in Dutch legislation before research was done on the impacts of floods on high water in Germany. Results of this research showed for example that an extreme discharge of 18,700 $m^3 s^{-1}$ at Lobith would be reduced to 15,500 $m^3 s^{-1}$ at Lobith because of flooding in Germany (Lammersen, 2004). Of course, this may change as the climate changes and further protective measures are taken throughout the river basin. This example shows the potential importance of enhanced cooperation, especially since the projection of climate change impacts suggests that more adaptation measures will be necessary in the future. If the difficulties caused by different institutional arrangements and cultural differences would be explicitly recognized and systematically addressed, more effective transnational collaboration would be possible.

However, to reach this goal, a political will from the riparian countries is essential. Until now this will and the means to put this will into action is not clearly expressed in governmental documents on climate adaptation.

When assessing risk management in river basins with regard to climate change it is important to remember that management actions are not solely determined by scientific knowledge. As the history of design discharge in the Netherlands showed, a number of other factors can influence risk management. Furthermore climate change uncertainties are not the only barrier for decision making and adaptation decisions are not only made because of climate change. For example, the Dutch program Room for the River was initially started because of an intensive discussion between the government and nature organizations about the trade-off between safety and environment. Finally, it should be emphasized that society should often adapt to a number of pressures at the same time, not just to climate change. This is also one of the complicating factors in research that focuses on risk management of climate change and climate adaptation strategies.

For future research a few recommendations can be made:

- More coordinated or joint transnational research on climate change adaptation measures in the whole Rhine basin;
- Research on institutional barriers for pro-active adaptation;
- Research on the propagation of climate change uncertainties in climate and impacts models and implications of this uncertainty propagation for risk management;
- Social scientific research on the specific demands for climate change knowledge by policy makers;
- Social scientific research about how different governance levels interact with each other and how this affects the formulation and implementation of adaptation strategies;
- More research on the application of bottom-up approaches in support of reduction of climate change vulnerabilities;
- Research on the constraints and opportunities of transboundary cooperation with respect to climate change adaptation in international river basins.

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