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Adaptation

ACER: developing Adaptive Capacity to Extreme events in the Rhine basin

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ACER: developing Adaptive Capacity to Extreme events in the Rhine basin

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Summary

Summary in Dutch

Waterbeheerders in het stroomgebied van de Rijn worden steeds vaker geconfronteerd met de gevolgen van klimaatverandering en klimaatvariabiliteit op het afvoerregime. De Rijn heeft een lange geschiedenis van overstromingen met ernstige schade en slachtoffers tot gevolg. Het is de vraag of de maatregelen die momenteel stroomopwaarts in Duitsland worden uitgevoerd positieve of negatieve effecten op de piekavoeren benedenstrooms hebben. Zogenaamde adaptatie maatregelen worden gezien als een belangrijk onderdeel van de maatschappelijke reactie op de wereldwijde klimaatverandering. Klimaat adaptatie impliceert het ontwikkelen van beleid en maatregelen die helpen om te anticiperen op veranderingen in klimaat gerelateerde risico's.

Het algemene doel van het ACER project is om de gevolgen van klimaatverandering en adaptatie strategieën te onderzoeken voor het Rijnstroomgebied, zowel grensoverschrijdend in Duitsland en Frankrijk als voor het regionale waterbeheer in Nederland. ACER gebruikt een scenario analyse om effecten en oplossing te analyseren en vergelijken, onder de veronderstelling van verschillende klimaatverandering en sociaal-economische scenario's voor 2050. Aan de basis van van deze scenario aanpak staat een internationale groep van belanghebbenden en waterbeheerders uit verschillende bestuurslagen in het Rijnstroomgebied.

De resultaten kunnen worden ingedeeld in twee thema's:
1) het modelleren van processen – een trade-off.
In plaats van het creëren van een overkoepelend nieuw Rijn model voor dit project, realiseerden we ons dat er trade-off bestaat tussen model complexiteit en de mogelijkheid om lange tijdreeksen en / of meerdere ensembles van klimaatverandering scenario's door te rekenen. Afhankelijk van de modelprestaties, de focus en omvang van het deelproject, hebben we een unieke model combinatie geoptimaliseerd. We hebben twee complexe modellen gekoppeld om landoppervlak - atmosfeer terugkoppelingsmechanismen te simuleren en te onderzoeken. Om het gecombineerde effect van klimaatverandering en maatregelen voor overstromingsbeheer simuleren, werd echter een ander model ontwikkeld. Dit model kan worden geforceerd met de uitvoer van een neerslag-generator (10.000 jaar meteorologische dagwaarden), en beschrijft alleen de meest relevante processen bij de beoordeling van de effecten van klimaatverandering en maatregelen op extreem hoge afvoeren, in een zogenaamde 'proces-gebaseerde' benadering.

2) Effecten van klimaatverandering en adaptatie.
De resultaten laten zien dat de overstromingskans kan toenemen met een factor 2.5 to 4.7 in 2050, als gevolg van klimaatverandering. Dit resulteert in een veel hoger overstromingrisico (kans maal gevolg) dan in de huidige situatie. De maatregelen in het Actieplan Hoogwater van de Internationale Rijncommissie ter Bescherming van de Rijn (IKSR) die momenteel worden uitgevoerd en nog gepland zijn voor de komende jaren, alsmede een aantal aanvullende maatregelen, zijn waarschijnlijk niet in staat om de toegenomen overstromingskansen voldoende te verlagen. Op de regionale schaal van Waterschap Rivierenland blijken de effecten van klimaatverandering op de hydrologie in de polder (nattere winters en drogere zomers) intenser dan verwacht. Dit wordt veroorzaakt doordat de effecten van klimaatverandering op zowel lokale neerslag en temperatuur, als afvoeren op de Rijn en de Maas, elkaar wederzijds versterken.

Summary

Water managers in the Rhine basin are increasingly confronted with information on the impact of climate change and climate variability on the discharge regime of their river system. The river Rhine has a long history of flooding events that caused casualties and severe damage. The question remains whether measures that are currently implemented upstream in Germany have either positive or negative effects on peak water levels downstream. Adaptation can significantly reduce impacts of climate change and is seen as an important part of societal response to global climate change. Planned adaptation implies decisions and measures within society that help to anticipate to climate related risks.

The overall aim of ACER is to investigate the impact of climate change and to explore adaptation strategies for the Rhine basin under climate change, for both basin wide as well as regional water managers. The ACER project follows a so-called scenario analysis whereby solution trajectories are analyzed and compared, under the assumption of various long-term climate change and socio-economic scenarios. At the core of the ACER scenario approach are a group of stakeholders representing water managers at different levels in the Rhine basin.

The results can be grouped in two themes:
1) Modeling processes – a trade-off.
Instead of creating an overall new 'Rhine model' for this project, we realized there is a trade-off between model complexity and the ability to run long time series and/or large ensembles of climate change scenarios. Considering model performance, focus and scale of the problem, a unique model set-up had to be optimized for each project objective. We coupled two complex models to simulate and investigate land surface – atmosphere feedback mechanisms. However, to simulate the combined effect of climate change and flood management measures, another model was developed that can be forced with output from a rainfall generator (10.000 year series of meteorological daily data). This model set-up aims to capture only the most relevant processes when assessing the effects on low-probability flood events, in a so-called 'process-based' approach.

2) Effects of climate change and adaptation strategies.
We project that climate change may increase flood probabilities with a factor 2.5 to 4.7 in 2050, which may strongly influence the expected annual losses due to flooding. The currently implemented and proposed measures in the Action Plan on Floods by the International Commission for the Protection of the Rhine (IKSR), as well as several additional measures we evaluated may be inadequate to cope with the increased flood probabilities. At the regional scale of a Dutch Water Board, the effects of climate change on polder hydrology is more intense than expected, caused by the dependence on both local climate conditions and water levels of the Rhine and Meuse rivers, which are mutually reinforcing.

1. Context

Water managers in the Rhine basin are increasingly confronted with information on the impact of climate change and climate variability on the discharge regime of their river system. Increased winter precipitation in combination with earlier snowmelt will probably cause a shift in peak discharge from spring to winter [Belz, 2007; Middelkoop et al., 2001; Pfister et al., 2004; Te Linde et al., 2010a]. This will probably lead to an increase in the frequency and magnitude of extreme floods. The awareness seems to rise that socio-economic developments and related land-use change affects the vulnerability of society to changes in water resources [Aerts and Sprong, 2008].

The river Rhine has a long history of flooding events that caused casualties and severe damage [Glaser and Stangl, 2003]. To cope with current conditions, the river is to a large extent canalized and embanked. In Germany retention basins exist that allow for controlled flooding during extreme events [ICPR, 2001]. The question remains whether measures that are currently implemented upstream in Germany have either positive or negative effects on peak water levels downstream. However, no adequate modeling capacity exists to calculate the effectiveness of basin wide adaptation measures under future climate change.

There are several reasons why basin-wide adaptation to climate change impacts has received little attention so far: (1) Climate impacts are surrounded by uncertainties, (2) 'Basin-wide' implies cross-boundary water management and adaptation measures, (3) Lacking modeling capacity, (4) Local versus basin-wide water management. These four issues are shortly explained below.

Climate impacts are surrounded by uncertainties

These uncertainties are not yet well understood and policy makers are struggling to cope with them in decision making processes. Various climate scenarios exist and, in addition, there are several ways to transform these climate signals into rainfall and temperature series that feed hydrological models. The simulation of future low probability flood-peak events should take these differences into account, in order to better represent inherent uncertainties.

'Basin-wide' implies cross-boundary water management and adaptation measures

To date, most flood management measures in the Rhine basin have been optimized for regional aims. Cross-boundary management and institutional organization is complex due to administrative and legal differences between countries. Although riparian countries see the advantage of cooperation, they are reluctant in shifting political influence to the ICPR [Hooijer et al., 2004]. Nevertheless, the extreme flood peaks in the Lower Rhine of 1993 and 1995 initiated the development of the Action Plan on Floods (APF) [ICPR, 2005]. The Netherlands initiated the Room for the River project [Ministry of Transport, Public Works and Water Management, 2006]. Implemented and planned measures include dike relocation, the allocation of retention basins and land-use change to store water in head watersheds. The APF is scheduled to be completely implemented by 2020. However, an evaluation of the APF in 2005 revealed that the targets for water level and risk reduction set out in the plan will not be met given current climate conditions [ICPR, 2005]. Moreover, the plan does not address the impact of climate change on peak discharges and questions exist as to whether the plan is effective in the long term, especially when focusing on managing extreme flood events. Therefore, the effectiveness of additional measures, such as land-use change restoring abandoned meanders, bypasses and dike relocation, needs to be assessed.

Lacking model capacity

The complex system of meteorological changes due to climate change, rainfall-runoff process and flood control structures that influence discharge behavior in the Rhine basin, requires a modeling approach with various models. This requires the development and/or improvement of both a hydrological and a hydrodynamic model. These models are to a large extent available, but they need to be coupled.
A model describing the land-surface feed back mechanisms in more detail, however, is lacking. Especially when meteorological conditions are changing due to climate change, understanding and describing soil-atmosphere processes is vital for runoff simulation.

Also, no model exists that enables basin-wide estimation of flood risks. Such a model should be able to estimate potential damages in flood prone areas. Estimating flood risks, and how they will develop in the future, helps to define appropriate safety standards and related dike heights. Or, if dike heightening is physically not possible, of socially not accepted, how potential damages can be lowered in order to reach acceptable risks.

Local versus basin wide water management

Regional water managers (Water Boards) have been confronted with extremes in Rhine discharges causing severe problems for Water Boards. Besides the direct threat of flooding as a result of dike burst (which is not be considered in this research), Water Boards have encountered severe problems in draining water excess into the Rhine during high flow conditions. On the contrary, during extreme low flow conditions water intake was limited resulting in severe losses for agriculture and nature reserves due to drought. It is expected that the projected increase in extreme low and high flows as a result of climate change will intensify the situation in the future. Therefore, new adaptation strategies for the whole Rhine basin need to be fine-tuned with measures at the local level.

One of the major problems is related to the fact that areas in the vicinity of the Rhine will not be hit only by extreme weather conditions, but also by extreme Rhine discharges. During extreme precipitation events three factors are a potential threat to the area: access rainfall, access seepage from the Rhine, reduced drainage capacity to the Rhine. Similarly, during periods of extreme droughts, areas in the vicinity of the Rhine are more vulnerable: less rainfall, access seepage losses to the Rhine, reduced intake options from the Rhine. The combined effect of these three processes is unclear and requires advanced approaches based on data, modeling and data assimilation techniques.

2. Goals

2.1 Adaptation

Adaptation can significantly reduce impacts of climate change and is seen as an important part of societal response to global climate change. Adaptation also has the potential to realize new economic opportunities. Planned adaptation implies decisions and measures within society that help to anticipate to climate related risks. The acceptable risks are determined to which risk a society or economy wish to accept or to pay for precautionary measures. As a result, major different adaptation strategies can be found between countries.

Within this context, spatial planning is increasingly seen as key to manage water related risk such as floods and droughts. Hence, since climate change will affect water resources by an increase in extreme events, new adaptations are needed that combine the effective use of land and space with innovative water management measures.

2.2 Project aim

The overall aim of ACER is to investigate the impact of climate change and to explore adaptation strategies for the Rhine basin under climate change, for both basin wide as well as regional water managers.

The four objectives are:

1. To develop a detailed basin wide coupled atmospheric-hydrological model with an improved module on initial soil moisture conditions for simulating an accurate timing of extreme events.
2. To develop new basin-wide adaptation strategies to mitigate floods and to develop basin-wide climate change and socio-economic scenarios for testing the robustness of these strategies.
3. To calculate the effectiveness of (new) adaptation measures under climate change by using an integrated model for the whole Rhine. The integrated model incorporates hydrological and hydro-dynamic modeling.
4. To describe the role and problems of regional water boards in dealing with extreme events for regional water managers within new cross boundary adaptation strategies.

2.3 Case studies

Our study area is the complete Rhine basin. In addition, we used two regional case studies in the Netherlands to meet our objectives. The first is Water Board Rivierenland. Even though flood or drought management measures are often designed at a national scale, the implementation is often performed by local authorities, such as a Water Board in the Netherlands. The success or failure at this scale, determines the success or failure of a basin-wide strategy. Discharges and water levels in the Dutch Rhine branches directly influences dike safety and water availability of the regional water system of Water Rivierenland, which makes this a suitable case study. Also, Water Board Rivierenland was eager to cooperate to the ACER project.

The second is the Veluwe. Understanding and simulating land surface – atmosphere processes, requires knowledge of these processes at a regional scale. The Veluwe is a forested area in the Netherlands, where many of the required data for such an exercise is available. The regional weather conditions, vegetation and altitude differences are similar to many other forested areas in the Rhine basin, except for the Alpine area.

3. Study areas

3.1 Rhine basin

With a length of 1320 km and a river basin area of 185,000 km², the Rhine is one of the larger rivers of Northwest Europe. The river basin covers parts of Switzerland, Austria, Liechtenstein, France, Luxembourg, Germany, and the Netherlands. The main tributaries of the Rhine are the Neckar, Main, Mosel, Lahn, and Sieg (Figure 3.1a). The river basin can be subdivided in five sections using geographical and geological features [Preusser, 2008]. The first section is the Alpine mountains where the river originates. Second is the Upper Rhine from Basel (where the flood plain is used for agriculture) up to Mainz. Several cities exist along the Rhine branch in this section. Third is the Middle Rhine between Mainz en Bonn, which is hilly. In this section, the Rhine flows through a narrow gorge. Fourth is the Lower Rhine, which is densely urbanized. From here, the flood prone area widens until it becomes a river delta in the Netherlands (fifth section) [Hooijer et al., 2004]. About 50% of the basin is used for agriculture, and 15% for urban or suburban uses. The remainder is forest and otherwise fallow lands [Wessel, 1995, Eberle et al., 2005] (Figure 3.1c).

The Rhine is extensively used for inland shipping [Jonkeren et al., 2007; CCNR, 2009] and connects one of the world's largest seaports, Rotterdam, to the inland European markets. The river also provides water for cooling energy plants, and for industrial, domestic, and agricultural purposes [Grabs, 1997]. The Rhine basin is one of the most heavily industrialized areas in the world. It has 58 million inhabitants, of which 10.7 million live in flood prone areas that are protected by dikes [ICPR, 2001].

3.2 Water Board Rivierenland

The area for which Water Board Rivierenland is responsible covers 147,000 hectares and includes the area between the Meuse and the Lower Rhine in the Netherlands. One of the duties of Water Board Rivierenland is to ensure that there is sufficient surface water in the region that it manages. In practice, this means preventing flooding during wet periods and preventing surface water shortages in periods of drought. This case study area is also used within closely linked BSIK projects CS7 ('Tailoring climate Scenarios') and project A9 ('Financial Arrangements for disaster losses under climate change').

3.3 Veluwe

The Veluwe is a densely forested and elevated area of approximately 625 km² with a maximum altitude of just over 100 meter in an otherwise flat surrounding and is part of the Rhine river basin. The area is covered with glacial deposits, but in the early 20th century it was decided that the area would be afforested to reduce wind erosion that was threatening the surrounding agricultural area. In this area the feedbacks were studied between the land surface and the atmosphere to assess the possible effects on precipitation and evaporation of land use change in the Rhine river basin and the feedbacks involved.

Interestingly, the Veluwe exhibits an average yearly precipitation sum, which is 75-100 mm higher than the rest of the country, a difference of around 20 % per year. The distribution of rainfall throughout the year is reasonably uniform with an average monthly precipitation sum at the

Veluwe of almost 70 mm. To investigate the reason behind the precipitation maximum of the Veluwe the relative contribution of topography and of land cover to precipitation was under study in this project.

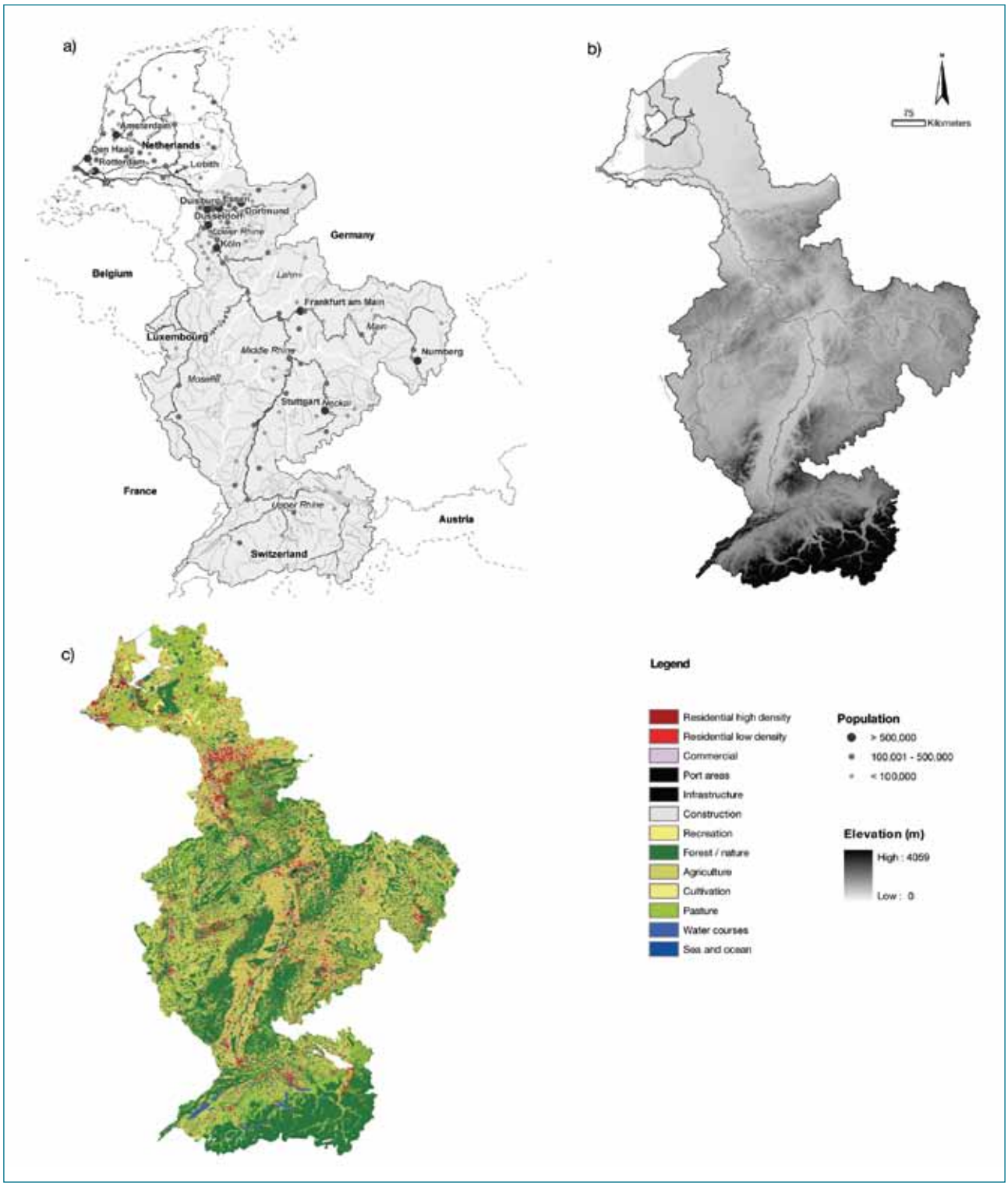


Figure 3.1.
Maps of the Rhine basin: a) sub-basins and major cities, b) elevation, and c) land use.

4. Approach

The ACER project follows a so-called scenario analysis whereby solution trajectories are analyzed and compared, under the assumption of various long-term scenarios. The scenario method is derived from research in the area of scenario and policy analysis [Findeisen and Quade, 1985; Aerts, 2002], and is explained in detail by Aerts and Droogers [2004]. The method is illustrated in Figure 4.1 and is comprised of steps 1 to 4 (Figure 4.1, left). The research activities are related to each of these steps (Figure 4.1, right).

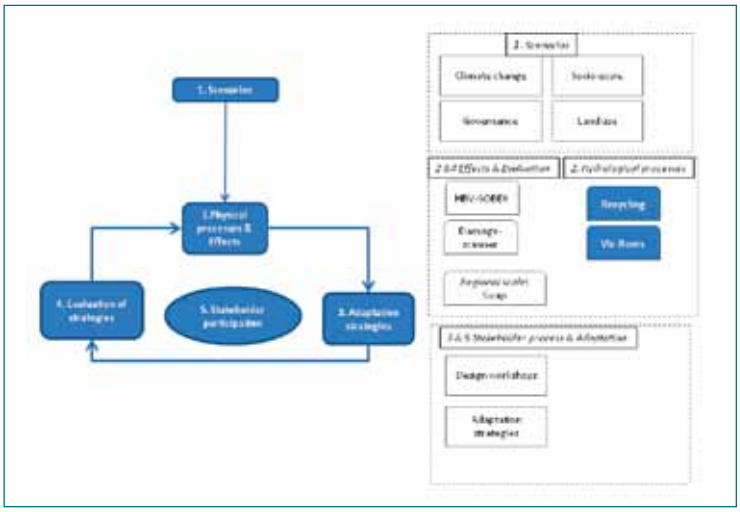


Figure 4.1.
ACER project scenario approach (left) and the related research activities (right).

At the core of the ACER scenario approach are a group of stakeholders (Step 0) representing water managers at different levels in the Rhine basin. The stakeholders were involved within each of the steps 1 to 4 and hence provided feedback on scenario development, modeling results and supported the development of flood adaptation strategies. We now briefly describe each step:

1. **Scenarios:** A scenario is a combination of internally consistent assumptions with regards to future socio-economic and climatologically developments. In this project, scenarios are seen as external variables and cannot be influenced by the users. One can think of sea level rise, changes in EU water policy influence, etc. These are often developments that have an international dimension. Feedback mechanisms have not been included. The developments are coupled to the horizon year 2050.
2. **Processes and effects:** based on the scenarios, several effects will occur in the water system of the river Rhine. Effects are calculated using different models. The ACER project has divided the modeling work into two parts (1) Effect models that are developed to calculate the effect of the scenarios with and without adaptation strategies. For this we use measurable indicators such as "potential damage due to a flood", "the probability of a flood" and "change in water levels". (2) Land-use atmosphere models were developed to scientifically deepen our knowledge on several hydrological processes.
3. **Adaptation strategies:** An adaptation strategy is a set of measures that share a logical cohesion.
4. **Evaluation:** In order to discern if a strategy is effective, the same indicators as the base line scenario are employed. In the case of a full evaluation, the costs and benefits of the various strategies should also be detailed. However, a social cost-benefit analyses or a multi-criteria analysis (MCA) has not been employed in this project.

In the following Sections, we will describe the research activities that were conducted during the project.

4.1 ACER stakeholder process

We have organized several workshops with stakeholders and researchers to exchange and transfer information on atmospheric-hydrological 'Rhine-models', and to create basin-wide socio-economic scenarios and potential adaption strategies [Raadgever et al., 2007; Raadgever et al., 2008]. The workshop participants consisted of delegates from all project partners and stakeholders that varied from decision makers at the national government level, to municipalities and NGO's. In this way, we obtained unique and specific scenarios for the Rhine basin.

The aim of the workshops was also that the stakeholders could learn from each other and from the additionally introduced (expert) knowledge. The learning process might result in convergence of individual perspectives and into a joint vision on future flood management.

In addition, to improve the adaptive capacity to cope with extreme flood events in the Rhine basin, a participatory process was applied. 17 semi-structured interviews with flood managers and political decision makers were used to gain the broad perspective on issues concerning longer term, cross border flood management and on possible strategic options and their effectiveness [Becker and Raadgever 2006].

In the first workshop, we discussed climate/spatial planning/institutional trends until 2050, the related uncertainties and risks, the planned flood protection measures 2005 – 2020 and possible additional activities and the different hydrological research models (HBV/VIC, Sobek). The second workshop provided additional information on climate change and land use trends and on relevant institutional and socio-economic developments. Four scenarios 2050 were introduced, discussed and adjusted to serve as the input for the third workshop. In the third workshop, potential protection measures were discussed and indicators prioritized for evaluating specific measures. Finally, the participants developed preferred protection strategies related to each of the four prepared scenarios and tried to quantify and locate the measures in the basin, where possible.





Figure 4.2.
Some pictures of (results of) the stakeholder workshops.

4.2 Scenarios

4.2.1 Socio-economic scenarios

Socio-economic scenarios are plausible and consistent pictures of how the future might unfold. They are a useful tool for exploring potential flood strategies under different sets of conditions and a powerful support to consider and get better prepared for an uncertain and unpredictable future.

There is a large variety of scenario approaches and numerous socio-economic scenarios have been produced at global, European and more local levels [Börjeson et al., 2006; Van't Klooster and Van Asselt 2006; Klijn, 2006; Parson et al., 2006; Ringland, 1998; Van der Heijden, 1996]. Common to most of them are five key drivers towards change, which are demography, economy, style of governance, technology and social and political values. The drivers can be combined into two, most decisive dimensions of uncertainty: 'values' and 'governance' [Berkhout et al., 2002]. The 'values' dimension (horizontal axis in Figure 4.3) represents political and social priorities and the distribution of public and private responsibilities: on the one end rights of the individual, self-interest, reactive, liberal and rational behavior, and on the other end communitarian orientation, with concern for pro-active, sustainable management of common goods, social solidarity and cohesion.

The 'governance' dimension (vertical axis in Figure 4.3) describes political and economic power relations and spatial and structural orientation of decision-making: on the one hand globalization with international alliances and interdependencies, on the other hand regionalization with national and regional autonomies and boundaries.

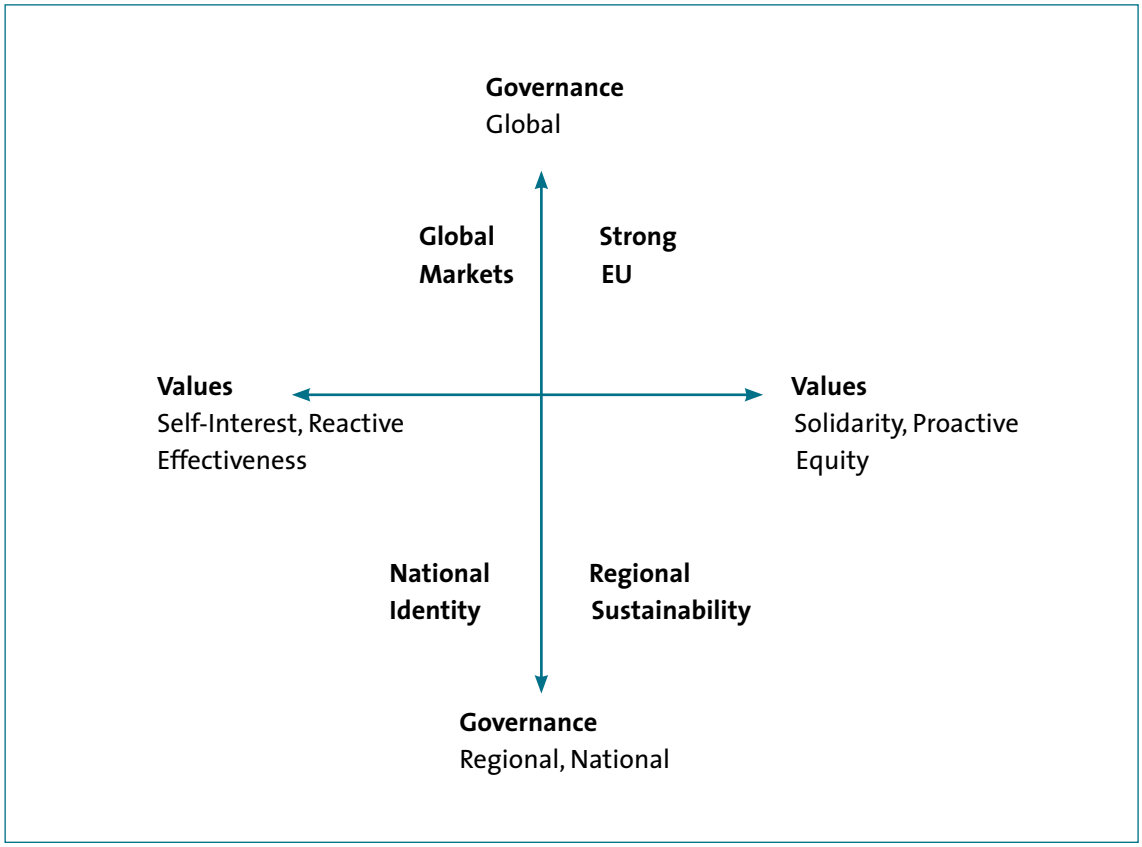


Figure 4.3.
Four socio-economic Scenarios 2050 [Raadgever et al., 2007].

Because of geographic and substantial similarities with the case study, the research team used the Dutch WLO scenarios [Janssen et al., 2006] and the English Foresight scenarios [Evans et al., 2004] most intensively to develop relevant scenarios for the Rhine basin study. These two scenario sets cover the autonomous developments that are relevant for flood management. In addition, the Foresight scenarios, and in less detail also the WLO scenarios, link each set of autonomous developments to a set of flood management measures. The scenario names and key characteristics used in the case study are presented in Table 4.1.

1) Global Markets

In the market scenario, economic growth is key to all sectoral policies. In water and flood management, technical solutions dominate and (costly-) ecological measures such as room for water are not considered. Societal characteristics are: self-responsibility, only basic flood protection for all. This means that especially rich citizens can afford additional protection costs and may even cause cities near the river to grow by developing adjusted building. The law is flexible, and there are no restrictions as to build in the flood plain.

2) Strong EU

In this scenario, the political power has shifted towards Brussels. This does not only mean more European rules and laws, but also the strict control system that comes with them, for example considering land use. The EU Flood Directive will be strictly managed and a basin-wide risk-based approach will be adopted.

Table 4.1.
Four socio-economic Scenarios 2050 [Raadgever et al., 2007].

	Global Market	Strong EU	National Identity	Regional Sustainability
Socio-Economic Trends				
Population NL (million)	20	19	17	16
(current=16 million)				
Population DE (million)	80	73	70	67
(current=83 million)				
GDP growth/year (%)	3,0	2,0	1,8	1,0
GDP/head (2001=100)	230	190	160	130
Public investment (%GDP)	36	47	38	51
Land use (% area)				
Agro	min (15-25)	min (12-15)	min (15-25)	min (10-15)
Nature	min 5 to plus 10	plus (8-10)	min 5 to plus 2	plus 10
Urban	plus (5-10)	plus 5	plus (2-7)	+/- 0
Potential damage (current index=1)	20	5	15	2
Safety standard (vs. current)	++	+	+/-	-

3) National Identity
The national identity scenario comes with low economic growth due to the deglobalization of the economic sector. Flood management has a low priority and measures are planned at a national scale, which results in high vulnerability. Flood damage can be insured, though. The International Commission for the Protection of the Rhine basin is minimized and only plays a minor role in water quality issues, but not in flood risk management.

4) Regional Sustainability
In this scenario the regional community is flexible, and informed about the benefits and risks of living near the river. A regional financial fund enables flood adaptation and mitigation measures. Flood management measures are planned at a local scale, and not communicated in detail either upstream or downstream.

The socio-economic scenarios were applied as input data for the Land Use Scanner to derive future land-use and basin-wide flood risk projections (Chapter 5.3).

4.2.2 Climate change scenarios

Climate change will increase winter precipitation and in combination with earlier snowmelt, it will very likely cause a shift in peak discharge in the Rhine basin from spring to winter. This will probably lead to an increase in the frequency and magnitude of extreme floods. We will setup a modeling chain to verify this assumption, and quantify projected changes in discharge regime of the Rhine.

In the Netherlands, the KNMI'06 scenarios are generally used to assess the impact of climate change. However, these scenarios do not apply for the whole Rhine basin, since they are developed for the Netherlands only. Therefore, we applied an additional scenario that is optimized for basin-wide impact assessment in the Rhine. This scenario is called 'RACMO', which is a Regional Climate Model

(RCM), forced by ECHAHM5 GCM output. Furthermore, we used different methods to transform the meteorological 'climate signal' into precipitation and temperature forcing data for the hydrological models (Figure 4.4): the so-called delta change approach and (bias-corrected) direct RCM output [Te Linde et al., 2010a].

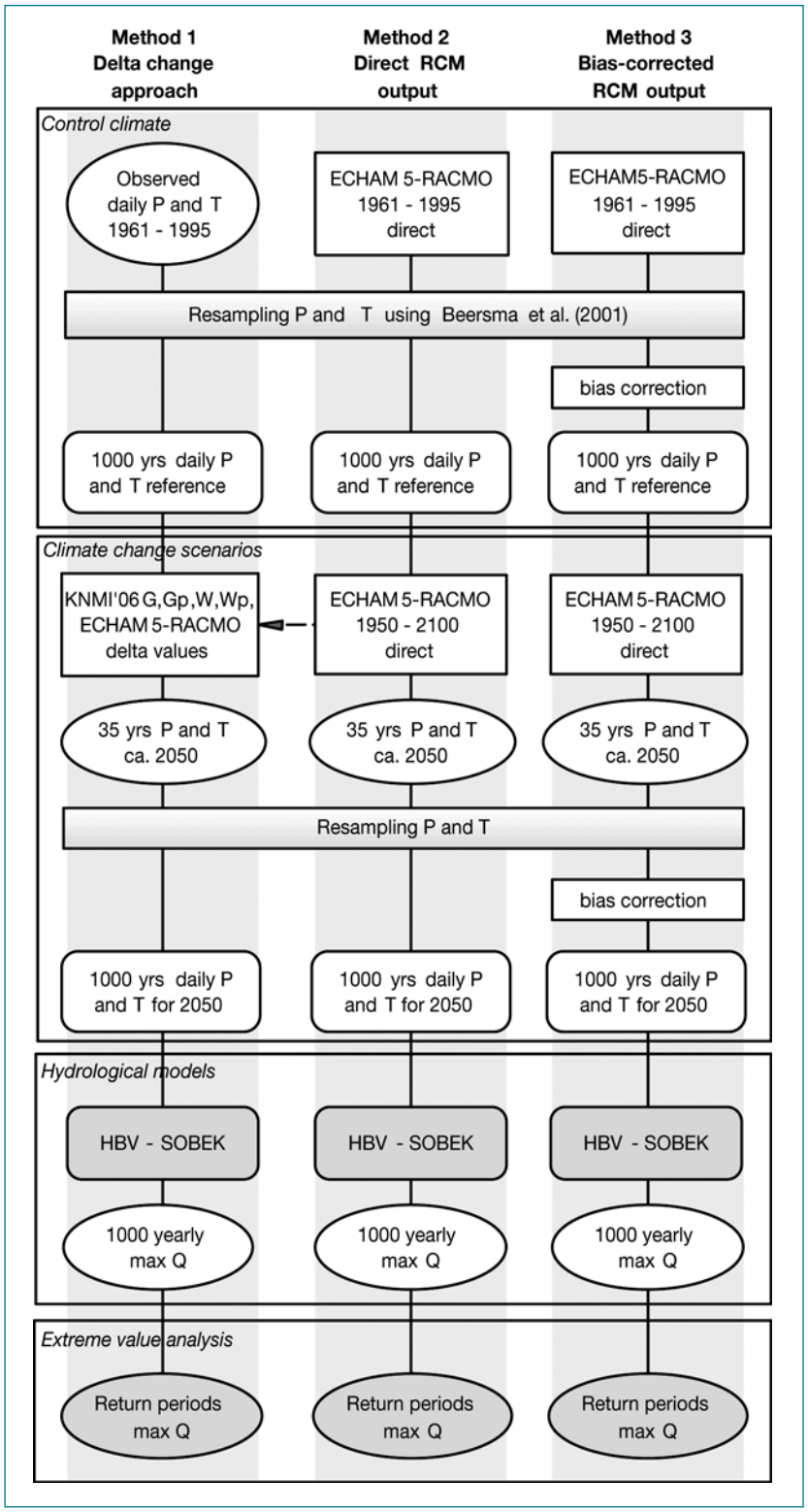


Figure 4.4.
Flow chart describing all modeling steps [Te Linde et al., 2010a].

Another problem with available meteorological data describing climate change is the length of these series, typically ~ 35 years. Safety levels along the Rhine are relatively high, up to 1/1250 per year at Lobith. Statistical extrapolation of 35 years of data to estimate discharge at such low probabilities of occurrence obviously leads to large uncertainties [Klemes, 2000a, b].

To overcome this limitation and gain insight in low-probability events, the KNMI developed an improved resampling method to generate 10,000 years of weather data, the so-called weather generator [Beersma et al., 2001]. We developed an approach that enables the use of RCM output and a weather generator for creating long, resampled time series of climate change discharge scenarios.

4.3 Governance structures

To cope effectively with the future flood risk does not only present a scientific and engineering challenge, but it also requires an effective governance structure. Institutional changes during the last few decades and differences in the governance of water resources between the riparian countries in the Rhine basin were investigated by literature surveys and questionnaires. Based on this data, we analyzed the feasibility of adaptive flood management in the German Rhine basin from a governance perspective. Furthermore, we investigated the perception of natural hazards, particularly of floods at municipality level in Germany, since risk perception of policy makers is crucial for decision making on flood management measures.

4.4 Land use – atmosphere feedback mechanisms

Due to the growing wish and necessity to simulate the possible effects of climate change on the discharge regime of large rivers such as the Rhine in Europe, there is a need for well performing hydrological models that can be applied in climate change scenario studies. It is argued that Land Surface Models (LSMs) carry the potential to accurately estimate hydrological partitioning, because they solve the coupled water and energy balance

The ability to position the volume of the storm core in the right spot of the basin largely determines the skill of the modeling system to simulate runoff [see e.g. Syed et al., 2003]. Hence as it may be expected that if high resolution precipitation data will be used to drive an hydrological model, this will result in improved runoff simulations [see e.g. Chang et al., 2004, Roberts et al., 2009]. Especially for extreme flooding events, improved positioning and timing of storms will be beneficial. Typical conditions for which improvement in the position of storms are to be expected are for orographic precipitation events over terrain with steep topography. Besides these topographic induced improvements, also other land surface characteristics such as albedo, surface roughness and soil moisture status may cause feedbacks effecting precipitation. These feedbacks are not only of importance for periods with an abundance of water, i.e. during winter and spring, but also for periods with a shortage of water, i.e. during summer.

To investigate the feedbacks of the land use to the atmosphere and possible consequences for the runoff, four approaches were used:

- a dynamic precipitation recycling model was used to study the larger scale feedbacks, and
- a stand alone hydrological model including an energy balance was used to study the effects of land use change on the runoff (VIC)
- a meso-scale atmospheric model was used to study the feedbacks between land use change and atmosphere at high resolution (RAMS), and

- a coupled version of the stand alone hydrological model and the meso-scale atmospheric model was used to study the combined effects on the discharge at three different scales, i.e. 18 x 18 km², 6 x 6 km² and 2 x 2 km².

4.5 Effect models

4.5.1Rainfall-runoff processes

Due to calibration problems of VIC (Chapter 5.2.2), and the wish to simulate long time series (10,000 years) gain insight in low-probability events, a more simple hydrological model (HBV) was introduced. Te Linde et al. [2008] compared the hydrological models HBV and VIC for the Rhine basin by testing their performance in simulating discharge. Overall, the semi-distributed conceptual HBV model performed much better than the distributed land surface model VIC (Nash-Sutcliffe *(E)*=0.62, r^2=0.65 vs. *E*=0.31, r^2=0.54 at Lobith). The authors argued that even for a well-documented river basin such as the Rhine, more complex modeling does not automatically lead to better results. Moreover, they concluded that meteorological forcing data has a considerable influence on model performance, irrespectively to the type of model structure and the need for ground-based meteorological measurements is emphasized.

For the effect modeling, a method is explored to evaluate both the impact of climate change, as well as the effectiveness of flood management measures for the river Rhine. The method includes resampling of meteorological data and a hydrological model (HBV) to simulate long discharge series (10,000 years). A hydrodynamic model (SOBEK) will then be used to schematize and evaluate measures that are proposed in the Action Plan on Floods [ICPR, 2005], and several additional measures. This model also allows simulating the effect upstream flooding in Germany. The method can be described as a process-based approach to estimate peak discharges of low-probability flood events (Figure 4.3).

HBV

The HBV-96 model [Bergström, 1976] model is a semi-distributed conceptual model. The model that is used in this study simulates discharge on a daily basis for 134 sub-basins of the Rhine. The model simulates snow accumulation, snowmelt, actual evapotranspiration, soil moisture storage, groundwater depth and runoff. The required forcing data are precipitation, temperature, and potential evaporation. The model consists of different routines in which snowmelt is computed by a day-degree relation, and groundwater recharge and actual evaporation are functions of actual water storage in a soil box. Discharge formation is represented by a linear reservoir for base flow and a non-linear approach for fast runoff components. The HBV model was developed for the Rhine in several steps since 1997 by the Dutch Institute for Inland Water Management and Waste Water Treatment (RIZA) and the German Federal Institute of Hydrology (BfG). A complete description of the HBV calculation scheme and the model structure for the Rhine basin is found in Eberle et al. [2005].

SOBEK

The routing scheme in HBV is not capable of simulating flood wave propagation, backwater effects, and damping in low gradient river stretches where floodplain inundation plays an important role. Therefore, a 1D-hydrodynamic model (SOBEK) was used to simulate flood routing in the main Rhine branch at an hourly time step [Delft Hydraulics, 2005]. This model allows the implementation of structural measures, such as dike heightening, dike relocation, weirs, and detention areas. Cross sections at every 500m, dike locations, dike heights, and detention areas as they currently exist in the Rhine are schematized in the model.

Extreme value analysis

The current practice in river management in the Netherlands to estimate the Q1250 design discharge is to fit the Gumbel, the log-normal and the Pearson-III distributions on the annual maximum observed discharges at the Lobith gauging station. The Gumbel fit is mostly used in visualizations of extreme value analysis at Lobith. We chose to extend the Gumbel or type I extreme value distribution by adding a shape parameter so it evolves into the Generalized Extreme Value distribution (GEV).

We plotted the GEV distribution on Gumbel paper, creating a concave curve instead of a straight line when the shape parameter is not 0 (Figure 5.8). The maximum likelihood approach was used to estimate the distribution parameters. The exceedance probability denotes the probability that a certain discharge value will be exceeded in one year. In this report, we mainly use the term return period, which denotes the mean interval between two events of the same intensity and is the inverse of the exceedance probability.

4.5.2 Basin-wide flood risk

In order to conduct an assessment for trends in flood risk (in terms of flood probabilities and flood losses) for the Rhine basin we took the following steps: (1) Develop a land use model for the Rhine basin. (2) Use these future land use maps to estimate potential flood losses in flood-prone areas using a damage model. Together with the projected increases in flood probabilities that result from climate change, we can then derive current and future flood risk for the Rhine basin.

Land Use scanner

The Land Use Scanner simulates future land use and is based on demand-supply interaction of land, whereby different sectors compete for allocation of land within land suitability and policy constraints. The model has previously been applied in a number of policy-related research projects in European countries [Koomen et al., 2005; Dekkers and Koomen, 2007]. It was recently applied in studies on the long-term development of flood risk in the Netherlands and the evaluation of the effectiveness of various adaptation strategies [Aerts et al., 2008b; Bouwer et al., 2010]. The land use model for the Rhine basin operates on a spatial resolution of 250 250m grid cells and provides information on 13 different land use classes, including six different urban functions, infrastructure, nature, agricultural land uses and water.

Damage scanner

Given the spatial and temporal scale of the present study, which looks at the development of flood risk on a basin-wide level in the future, we used a simple damage model for land use categories, the Damage Scanner [Klijn et al., 2007]. This model is based on two input parameters: water depth and land use. Potential losses are calculated by the model using so-called damage functions that define for a land use category the damage that can be expected when a respective inundation level occurs. The model applies damage functions for the 13 land use classes distinguished by the Land Use Scanner and reflects predominantly direct tangible damage caused by physical contact between economic assets and flood water.

4.5.3 Regional water system

SWAP (Soil, Water, Atmosphere and Plant) simulates transport of water, solutes and heat in unsaturated/saturated soils. The model is designed to simulate flow and transport processes at field scale level, during growing seasons and for long term time series. It offers a wide range of possibilities to address both research and practical questions in the field of agriculture, water management and environmental protection [Immerzeel and Droogers, 2008; Droogers et al., 2008].

4.6 Adaptation strategies

4.6.1 Action plan on Floods

A Ministers conference in February 1995, attended by representatives of all countries sharing the Rhine basin, resulted in the Action Plan on Floods (APF), which is under the mandate of the International Commission for the Protection of the Rhine [ICPR, 1998]. This plan has four goals: (1) to reduce flood risk by 10% in 2005 and by 25% in 2020, as compared with 1995; (2) to reduce extreme flood stages by 30 cm in 2005 and by 70 cm in 2020, as compared with 1995; (3) to raise awareness of flood risks; and (4) to improve flood forecasting. Measures to reduce flood stages were targeted mainly at upstream retention methods in the tributaries and the creation of extra retention volume by inundation polders along the main Rhine branch.

4.6.2 Additional measures

In addition to implementing measures from the APF, we developed six flood management measures: additional retention polders, land-use change to forest, a bypass around Cologne, increased friction by reforestation of the floodplains, restored meanders of the Upper Rhine, and increased dike height [Te Linde et al., 2010b].

Potential adaptation measures were grouped and ranked differently for each of the four socio-economic scenarios, during the ACER stakeholder workshops. For example, the 'Market' scenario reflects high flood risk, because of industrial growth and urban development and flood prone areas. In this scenario, it is likely that flood risk will be reduced by 'hard' measures, such as dike heightening and widening. In the National Identify scenario, on the other hand, it is more likely that retention basins are used, or land-use planning at a local scale.

4.6.3 Regional water management

The overall approach is based on developing and applying integrated simulation modeling frameworks for some selected demonstration areas within the area of regional water managers (Water Boards). The main focus was on Water Board Rivierenland, but additional methodological development was undertaken at other Water Boards as well.

For one particular Water Board the benefits and costs of additional irrigation to overcome the expected drought under climate change were explored [Droogers and Den Besten, 2006].

5 Effects and evaluation

5.1 Climate change

In Te Linde et al., [2010a] we aimed to enhance the simulation of future low probability flood-peak events in the Rhine basin using different climate change scenarios and downscaling methods. We used the output of a regional climate model (RCM) and a weather generator to create long, resampled time series (1000 years) of climate change scenarios as input for hydrological (daily) and hydrodynamic (hourly) modeling. We applied this approach to three parallel modeling chains, where the transformation method from different resampled RCM outputs to the hydrological model varied (delta change approach, direct output, and bias-corrected output).

On the basis of numerous 1000-year model simulations the results indicate a basin-wide increase in peak discharge in 2050 of 8 % to 17 % for probabilities between 1/10 and 1/1250 years (Figure 5.8 a and b). A discharge at a return period of 1250 years at Lobith in the control climate situation would occur once in 510 to once in 265 years. This is equivalent to an increased probability with a factor 2.5 to 4.7. When analyzing maximum water levels instead of peak discharges, the mean increase in peak water level due to climate change in 2050 is 50 cm, but varies between several centimeters and 140 cm [Te Linde, 2010b]. Furthermore, the results show that increasing the length of the climate data series using a weather generator reduced the statistical uncertainty when estimating low probability flood-peak events from 13 % to 3 %.

We further conclude that bias-corrected direct RCM output is to be preferred over the delta change approach, because it provides insight in geographical differences in discharge projections under climate change. Also, bias-corrected RCM output can simulate changes in the variance of temperature and rainfall and in the number of precipitation days, as changes in temporal structure are expected under climate change. These added values are of major importance when identifying future problem areas due to climate change, and when planning potential adaptation measures.

5.2 Land use – atmosphere feedback mechanisms

5.2.1 Precipitation recycling in NW Europe

The main objective was to assess the effect and understand the underlying mechanisms, which involve the land-surface and the overlying atmosphere with respect to processes of extreme events (both wet and dry conditions) and future climate. One of these mechanisms is the feedback process from local evaporation to local precipitation, called “precipitation recycling”. Precipitation in regions with a large “recycling” is potentially susceptible to land cover and/or land use changes. As a first approach, we applied the dynamical precipitation recycling model of Dominguez et al. [2006] to determine which areas in Europe are susceptible to land–atmosphere interactions by calculating a dynamic recycling ratio, which investigates this feedback at all relevant meteorological time scales.

During extreme dry or wet periods, the hydroclimatology of a large region can be abruptly changed. However, most precipitation recycling studies that have been performed to define the role of land surface-atmosphere interactions focus on monthly or longer time scales. Long time scales however, mask key relationships between precipitation recycling and other variables involving the feedback process that occur at shorter time scales. The advantage of the dynamical precipitation recycling model is that it can be used on a daily time scale. We performed temporal and spatial analysis of the process of precipitation recycling in a dry and wet year on a daily time scale.

A good representation of soil moisture is required to improve simulations of the interactions between the surface and atmosphere, and thus ultimately, to improve predictions of local circulations and (convective) precipitation. Accurate estimates of surface soil moisture are often difficult to obtain, especially at larger spatial scales. Satellite remote sensing can be an ideal tool for obtaining data at globally scales. We explored the applicability of remotely sensed near-surface soil moisture over Europe to initialize a regional climate model.

To calculate summer variability of the precipitation recycling over Europe based on 40-yr European Centre for Medium-Range Weather Forecasts (ECMWF) Re-Analysis (ERA-40) data, a dynamic precipitation recycling model has been applied [Bisselink and Dolman, 2008]. Time series for three subregions in Europe (central Europe, the Balkans, and Spain) are obtained to analyze the variability in recycling and to compare the potential in the subregions for interactions between land surface

and atmospheric processes. In addition, the recycled precipitation and recycling ratios are linked to several components of the water vapor balance equation (precipitation, evaporation, precipitation minus evaporation (P - E), and moisture transport). It is found that precipitation recycling is large in dry summers for central Europe, while the opposite is true for the Balkans. Large precipitation recycling is determined in relation with weak moisture transport and high evaporation rates in central Europe. This occurs for dry summers. For the Balkans, precipitation recycling is large in wet summers when moisture transport is weak, and P - E and evaporation are large. Here, the recycling process intensifies the hydrological cycle due to a positive feedback via convective precipitation and therefore the amount of recycled precipitation is larger. For Spain, recycling is also larger when moisture transport is weak, but other correlations are not found. For regions such as central Europe in dry summers and the Balkans in wet summers, which are susceptible to land–atmosphere interactions, future climate and/or land use can have an impact on the regional climate conditions due to changes in evaporation.

To calculate the warm season variability of the precipitation recycling over central Europe at a daily time scale for 2003 (dry) and 2006 (wet) the dynamical precipitation recycling model is applied [Bisselink and Dolman, 2009]. For the central part of Europe advection is the most important contributor to precipitation. In dry spells in both years 2003 and 2006, when moisture of advective origin diminishes, local evaporation becomes an important contributor to precipitation (negative feedback). In two dry periods (June 2003 and July 2006) where there is enough moisture storage in the soil to continue evaporation, precipitation recycling is enhanced. In case studies we follow the path of an air column for days with high precipitation recycling to discuss the role of moisture recycling in land-atmosphere interactions. For 2 days with enough moisture availability (28 May 2003 and 5 July 2006) moisture particles stay long in the study area due to weak winds. By following the paths we show that the air is transported over land for a very long distance before it precipitates. It thus takes a considerable amount of time to traverse the region and capture moisture of evaporative origin. However, we hypothesize that the precipitation falling on those days still originates (partly) from oceanic sources, but that the triggering of precipitation may itself be a result of enhanced instability induced by soils, which still have sufficient moisture storage. In dry periods with enough moisture available precipitation recycling acts as a mechanism to keep the precipitation at a stable level. In August 2003 evaporation is affecting the precipitation recycling due to the lack of water availability caused by the dryness of the preceding spring and summer season. According to a Granger Causality test the evaporation in 2003 exerts the strongest causal impact on the precipitation recycling ratio. For the case study of 10 August 2003, the atmosphere is too dry to generate precipitation with exception of the mountainous regions due to orographical lifting.

In order to assess the model accuracy in predicting soil moisture and other components of the hydrological cycle, regional climate simulations over Europe were initialized with soil moisture derived from the Advanced Microwave Scanning Radiometer (AMSR-E) [Bisselink et al., 2010]. The AMSR-E soil moisture initially showed systematic differences with model predicted soil moisture. For proper initialization the AMSR-E product had to be rescaled and after that vertically profiled. To retrieve a root-zone soil moisture profile we tested the application of an exponential filter. The smoothing through the layers of the ERA-Interim soil moisture profile was applied to the rescaled AMSR-E surface soil moisture. The filter performed very well for that part of the data set where the top layer is positively correlated with the deeper layers. After the preparation of the soil moisture fields, several sensitivity simulations were performed. The model's soil moisture was replaced with the vertically profiled AMSR-E soil moisture at different initial times for a dry summer (2003) and a wet summer (2005). In general, the surplus of soil moisture in the AMSR-E data resulted in a better performance in predicting temperature when compared with observations. This finding was more

pronounced in the dry summer of 2003 when the model results appeared very sensitive to land-atmosphere feedbacks.

5.2.2 Combined effects of resolution and on-line feedbacks using RAMS – VIC coupled

To investigate the added value of improved resolution and land surface – atmosphere interactions in the Rhine river basin two models have been applied. One model is a hydrologically based land surface model (VIC, Variable Infiltration Capacity model) and the other model is the mesoscale atmospheric model, RAMS (Regional Atmospheric Modeling System). A first assessment of the models and feedbacks involved was performed by running the models separately from each other. Both models were executed with a control simulation, but also with various land use scenarios to assess the influence of land use on the hydrological cycle.

The next phase in the project was to couple both models with each other for better simulating an accurate timing of extreme events. As the coupled model is very expensive in computing time two cases were selected: a flood and a drought case. For the flood case the period of January and February in 1995 were chosen and for the drought case the summer of 2003 was selected. The coupled model will allow assessment of the hydrological effects from adaptations related to land use change. Land use measures influence both the available amount of water within the basin and the hydrological transfers between the different (conceptualized) hydrological compartments.

The coupling of RAMS and VIC was not as straightforward as thought at the beginning. Many issues had to be solved to come to a good control simulation. The discharges at several observing stations along the Rhine River were taken as validation points. The most difficult part seemed to be to find the right calibration parameters for the VIC model. The automatic calibration procedure was therefore replaced by a more hands-on optimization by changing parameter values by hand. This method resulted in more realistic discharge values at the chosen stations. Figure 5.1 shows the various sorts of parameterizations used. The pink line in this graph is the simulated discharge when the parameter values are optimized using the automatic calibration procedure. In general the VIC model has difficulty in simulating the maximum peak discharge. However, some parameter combination come close to the values observed at Lobith.

The main focus in the simulations performed with RAMS/VIC was on two sub-catchments: the Lahn basin and the Neckar basin. The Lahn basin was selected as it is the basin with highest percentage of rural area and, as such, potentially the strongest affected by changes in agricultural land use. However, as the Lahn basin is relatively flat and stretched, the peak discharge of the Lahn will not have great consequences for the overall discharge of the Rhine at Lobith. We also selected the Neckar basin, which is one of the larger sub-basins of the Rhine and has a more pronounced topography. The peak and low flow contribution of the Neckar determines in a large part the behavior of the overall discharge of the Rhine.

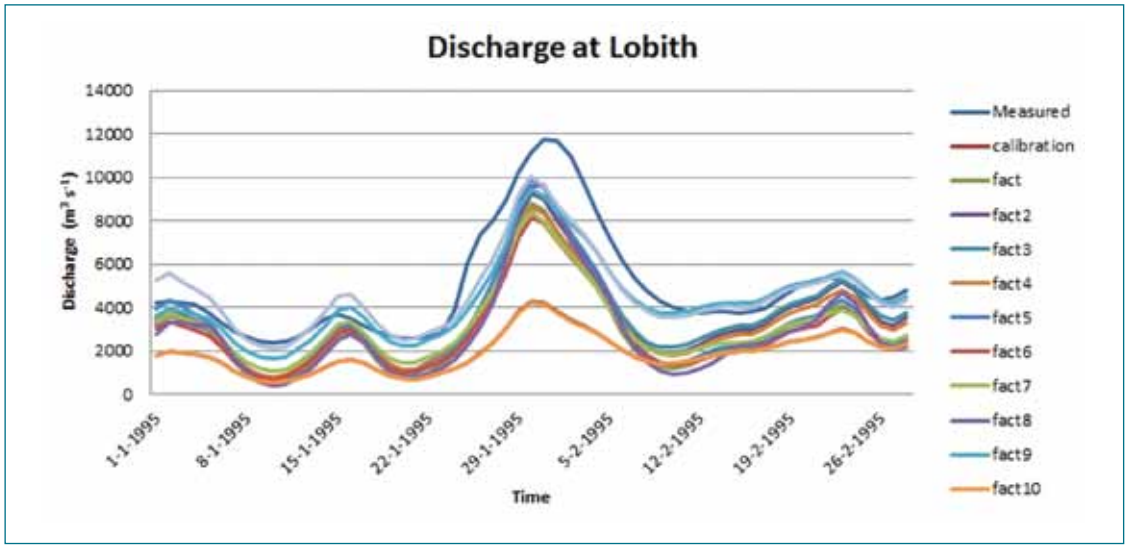


Figure 5.1.
Observed and simulated discharge (m3 s-1) at Lobith for the period from 1 January 1995 till 1 March 1995. The dark blue line represents the observed discharge while the other line graphs show the simulated discharge for a certain combination of parameter values.

Part of the coupling of RAMS and VIC was to investigate the effect of different model resolutions on simulated precipitation and subsequent runoff and streamflow. Figure 5.2 shows the total model precipitation on three WAMMS grids (18, 6 and 2 km spatial resolution, 1 hour temporal resolution) for the Lahn catchment, as well as the REGNIE regional precipitation analysis (an interpolation of precipitation measured at stations, daily temporal resolution [Dietzer, 2005]. As can be seen, the variation between the precipitation simulated by model at the three different resolutions is much smaller than the variation with the measured precipitation. Therefore, we conclude that the improvement in precipitation simulation by a finer grid is only marginal compared with the difference between simulated and measured precipitation.

The effect of different model resolutions on streamflow is shown in figure 3.5. The coupled model was run on different resolutions with both RAMS and VIC and the different resulting streamflows are compared. For a typical grid 1 (18 x18 km) grid cell in the Lahn catchment, the streamflow is plotted, together with the streamflow of the nine grid 2 cells and eighty-one grid 3 cells within the grid 1 grid cell. During times with peaks in the streamflow, the coarsest grid has a higher simulated streamflow than the mean of the streamflows on the finer grids. However, the two finer resolutions (6 and 2 km) do not differ significantly. Therefore, the streamflow seems to be adequately modeled at a 6 km resolution and the effect of an increased resolution is minimal.

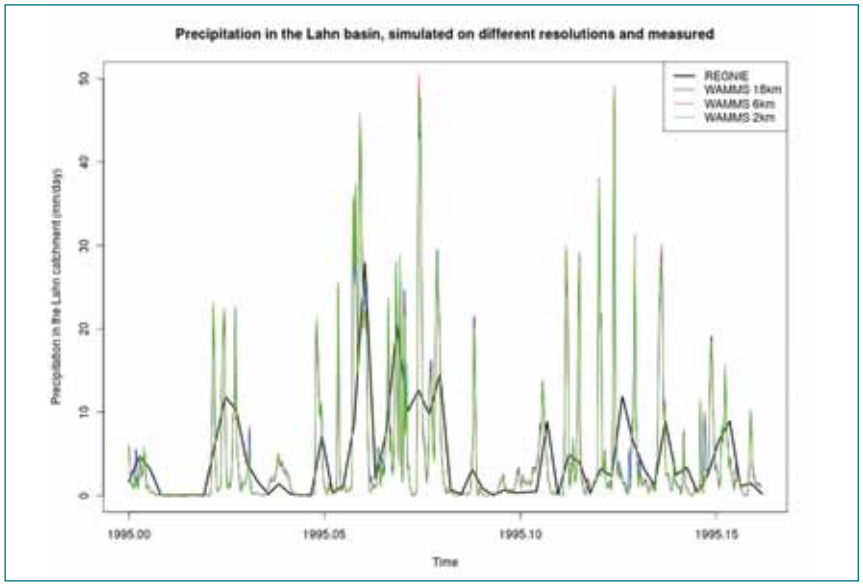


Figure 5.2.
Precipitation for Lahn basin (mm/day). Observations from REGNIE (black), simulated precipitation (18 km – blue, 6 km – red, 2 km – green).

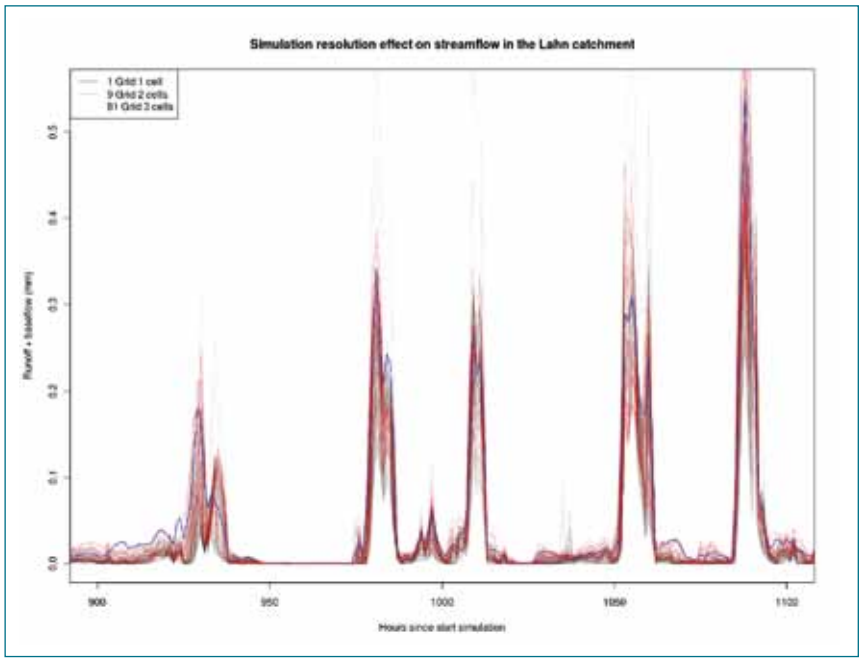


Figure 5.3.
Simulated runoff en baseflow for various grid configurations. Blue: grid 1 (18 km resolution), pink: grid 2 (6 km), light pink: grid 3 (2 km).

5.3 Land-use change

5.3.1 Land use change effecting discharge using VIC standalone

With the simulations performed with the VIC model (version 4.0.5) the effect was investigated of projected land use change scenarios on river discharge. For atmospheric forcing, a downscaled re-analysis dataset is used, which is described in detail in Hurkmans et al. [2008]. It consists of re-analysis data from ECMWF (ERA15 1, extended with operational ECMWF analysis data. Downscaling

to approximately 10 x 10 km² of the data was done dynamically by the regional climate model REMO [Jacob, 2001]. The model is modified to allow for bare soil evaporation and canopy evapotranspiration simultaneously in sparsely vegetated areas, as this is more appropriate to simulate seasonal effects. The land use change scenarios for 2030 are based on the Eururalis study [Verburg, 2006]. All projected land use change scenarios lead to an increase in streamflow. The magnitude of the increase, however, varies among sub-basins of different scales from about 2% in the upstream part of the Rhine (about 60,000 km2) to about 30% in the Lahn basin (about 7,000 km2), see Figure 5.4.

Streamflow at the basin outlet proved rather insensitive to land use changes, because over the entire basin affected areas are relatively small. Moreover, projected land use changes (urbanization and conversion of cropland into (semi-)natural land or forest) have opposite effects. At smaller scales, however, the effects can be considerable. For management purposes, i.e., mitigating extreme floods and low flows, land use changes can have local effects and can affect streamflow from small tributaries significantly. As far as influencing the magnitude and timing of peaks arriving at Lobith are concerned, however, effects are small. In different areas, different types of land use changes would be necessary. For example, only the relatively small Lahn basin proved relatively sensitive to afforestation, because in the current situation the dominant land use type is cropland. Therefore, afforestation has a relatively large influence. For each area, specific land use changes, depending on the current dominant cover could be designed. In further research, therefore, alternative scenarios should be taken into account for each sub-basin separately, or for even smaller sub-basins. An effective combination of different land use changes in different parts of the basin could be able to significantly alter the magnitude of low flows and/or the timing of flood peaks at the basin outlet.

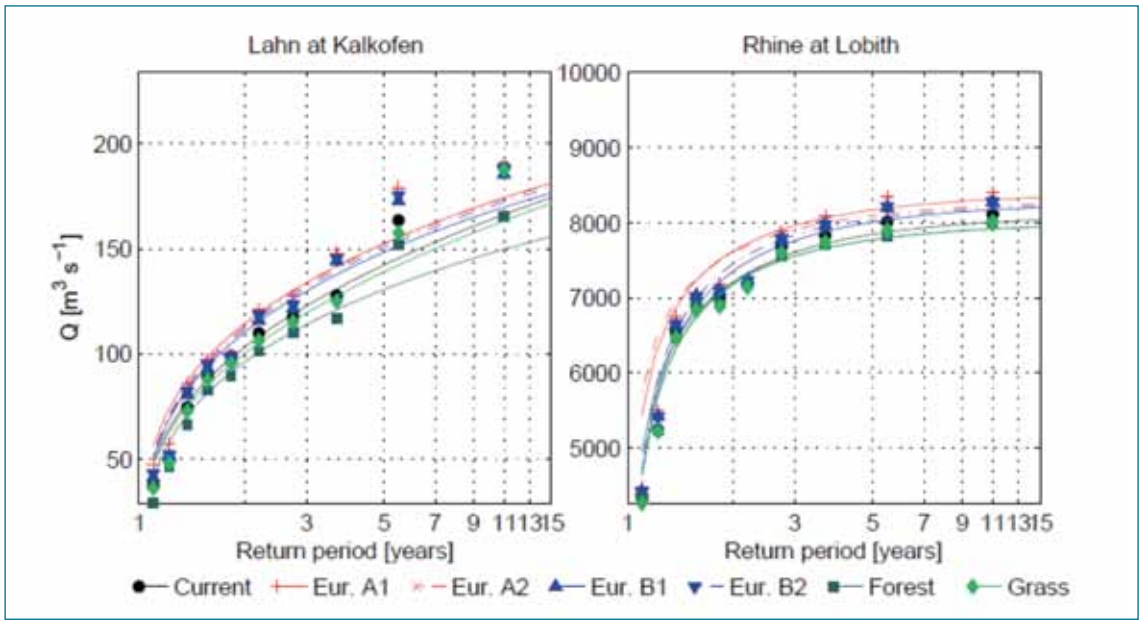


Figure 5.4.
Annual maximum streamflow versus their recurrence time for the Lahn sub-basin and the entire Rhine basin. A Generalized Extreme Value (GEV) distribution is fitted through the data points. Six scenarios are plotted (4 Eururalis scenarios, and crop replaced by resp. forest and grass, as well as the current situation) [Hurkmans et al.,2009].

5.3.2 Land use change effecting atmospheric feedbacks using RAMS

The influence of changes of the land surface (topography and land use) was investigated from an atmospheric point of view with RAMS version 4.3. To assess the possible effects on precipitation and evaporation of land use change in the Rhine river basin and the feedbacks involved, an area

in the central part of The Netherlands (Veluwe) was studied. The scenarios used in this study are highly idealized but are designed in such a way that the possible reasons behind the precipitation maximum could be unraveled.

RAMS was validated using actual vegetation and topography in a control simulation for a winter and a summer case. These periods cover varying large-scale atmospheric dynamics that are representative synoptic conditions of summer and winter months, with convective conditions prevailing under warm conditions. Winter precipitation is mostly part of a low-pressure system with accompanying frontal precipitation under westerly conditions.

Besides the aforementioned control simulation, the following scenarios were analyzed (Figure 5.5):

- NoForest (NF): The dominant forest type (coniferous forest, dark green) has been replaced by grassland (light green) in a rectangular box around the Veluwe (upper panel in figure 2). This change leads to a change in aerodynamic roughness (z0) from 0.9 meter to 0.02 meter and a change in albedo from 0.10 to 0.20 [-].
- NoTopo (NT): The topography of the Veluwe has been brought back to sea level in a rectangular box around the Veluwe (lower panel in figure 2) reducing the maximum difference in topography from 100 meters to 1 meter.
- No Topo/No Forest (NTF): Combination of the scenarios NoForest and NoTopo.

While improving the control simulation it appeared that the original parameterization of the planetary boundary layer (PBL) in RAMS was far from perfect for the summer case. Rainfall was overestimated using the Mellor-Yamada PBL. The hypothesis was that the rainfall would be better simulated while using the MRF PBL-scheme. This appeared to be a good choice as the rainfall was more in line with the observations.

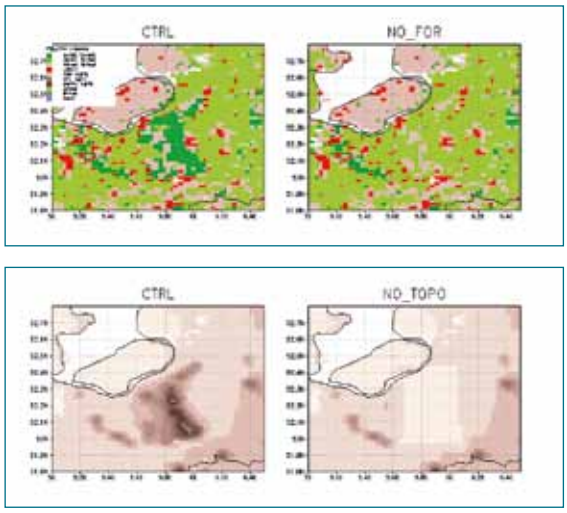


Figure 5.5.
Graphical representation of the various scenarios used in the simulations. Top left: actual land use (CTRL); Bottom left: actual topography; top right: land use in the NF-and NTF-scenario; bottom right: topography in the NT- and NTF-scenario [Ter Maat et al., 2008].

Figure 5.6 shows the difference in accumulated precipitation between the scenarios and the control simulation. In the NF-simulations the signal in change of precipitation is more diffuse than in the NT-simulations. Due to the change in roughness length above the 'deforested' area, a change in flow is observed. This change is apparent in the winter simulation where a band of heavy precipitation seems to be displaced to a more southerly position. The difference in precipitation between the scenario simulations and the control simulation is between 5% (summer) and 15 % (winter).

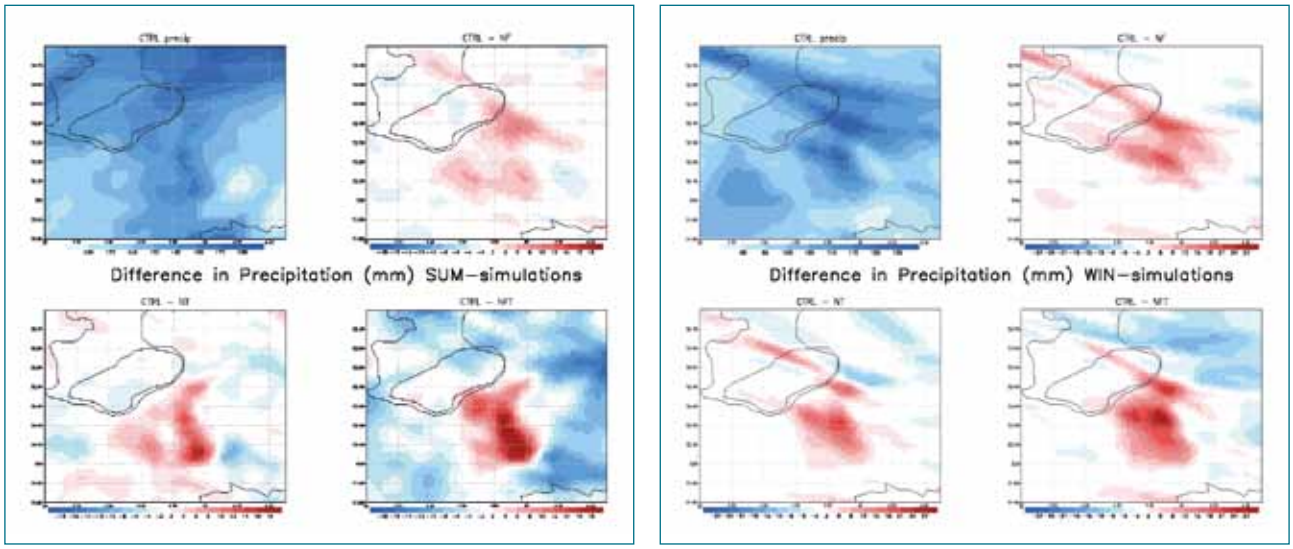


Figure 5.6.
Difference between simulated precipitation between CTRL and NF (mm) for a summer (left) and a winter (right) situation [Ter Maat et al., 2008].

5.4 Flood risk

In Europe, water management is moving from flood defense to a risk management approach, which takes both the probability and the potential consequences of flooding into account. It is expected that climate change and socio-economic development will lead to an increase in flood risk in the Rhine basin. To optimize spatial planning and flood management measures, studies are needed that quantify future flood risks and estimate their uncertainties.

We estimated the current and future fluvial flood risk in 2030 for the entire Rhine basin in a scenario study. The change in value at risk is based on two land use projections derived from a land use model representing two different socio-economic scenarios. Potential losses were calculated by a damage model, and changes in flood probabilities were derived from two climate scenarios and hydrological modeling. We aggregated the results into seven sections along the Rhine (Figure 5.7).

It was projected that flood risk in the Rhine basin will not be stationary and might considerably increase over a period of several decades. Expected annual losses in the entire Rhine basin may increase by between 54 % and 230 %, due to socio-economic and climate change. The increase in flood risk can mainly be attributed to increasing probabilities of flood peaks due to climate change (43-163 %, which is ~6/8 of the total risk increase), whereas socio-economic change accounts for 7-25 % increase, which is ~1/8 of the total risk increase.

The results displayed large variations in current risk and flood-risk projections between regions along the Rhine. The highest current potential damage can be found in the Netherlands (110 billion

Euro), compared with the second (80 billion Euro) and third (62 billion Euro) highest values in two areas in Germany [Te Linde et al., 2011]. Results further show that the area with the highest fluvial flood risk is located in the Lower Rhine in North Rhine-Westphalia in Germany, and not in the Netherlands, as is often perceived. This is mainly due to the higher flood protection standards in the Netherlands as compared to Germany.

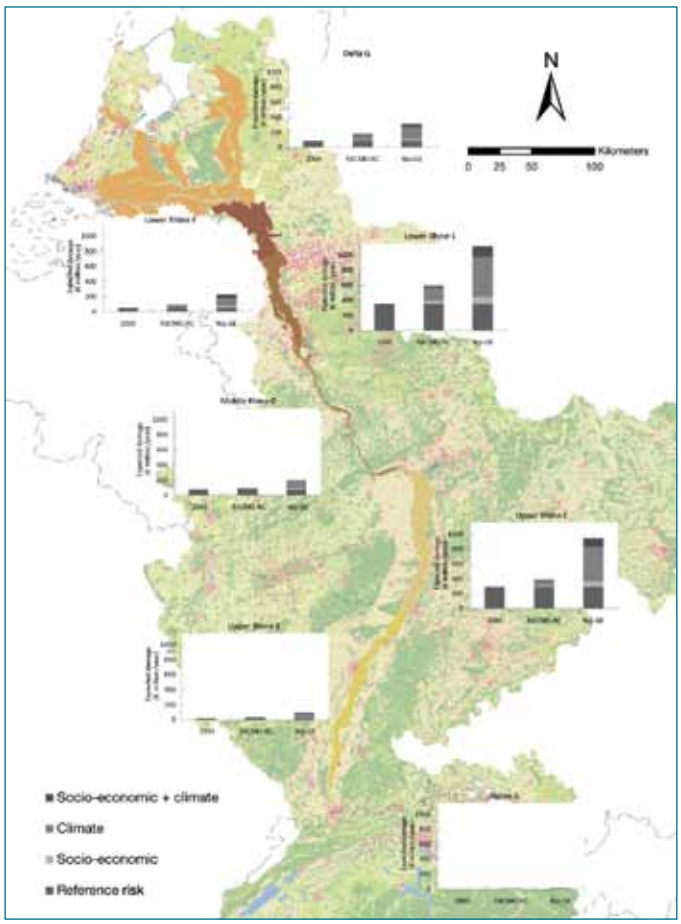


Figure 5.7.
Annual expected damage (flood risk) for the reference situation and projections for 2030, aggregated into seven regions along the Rhine [Te Linde et al., 2011].

5.5 Basin wide adaptation strategies and upstream flooding

The APF2020 measures, as well as additional retention polders, reduce peak water levels by 5 cm to 13 cm over medium return periods (between 50 and 100 years) for the control climate. At T=200 and more, they have no effect at all [Te Linde at al., 2010b]. The minor effectiveness of the APF2020 can be explained firstly by the way the retention polders are operated. We have shown that retention polders as outlined in the APF2020 become operational between T=20 and 200, and require well-defined control rules and excellent flood forecasting in order to operate optimally, which is also explained by Lammersen [2004]. At higher flood peaks with longer return periods, such as in our simulations, they are not effective.

Increased friction by reforestation of the flood plains showed to be beneficial at a local scale by lowering the water level several decimeters. However, higher friction values resulted in a storing effect that caused increased water levels in the upstream direction. The bypass around the city of

Cologne reduced water levels at a local scale. Restoration of abandoned measures in the Upper Rhine was also very effective in reducing water levels locally, but resulted in increased water levels in the Lower Rhine [Te Linde at al., 2010b].

We observed in Section 5.1 that the mean increase in peak water level due to climate change in 2050 is 50 cm, and varies between several centimeters and 140 cm. As a result, currently implemented and proposed measures in the Action Plan on Floods, as well as most additional measures, seem inadequate to cope with the increased flood probabilities and water levels that are expected in the future climate change scenario. According to the results, the only measure that can prevent the Rhine from flooding is drastic dike heightening of between 1.30 and 3.30 m, depending on location, on the assumption that these dikes cannot fail [Te Linde et al., 2011].

It is further found that in the current situation, large upstream floodings occur in Germany at discharge above ~12.000 m^3/s at Lobith. These volume losses have a profound decreasing effect on the simulated peak water levels and discharges along the main Rhine branch and downstream in the Netherlands (Figure 5.8). The decrease varied between 2-13 % in control climate conditions and 10-19 % in the W-plus climate change scenario. Hence, upstream floods in Germany are favourable for reducing flood risk in the downstream areas of the Netherlands. However, it is possible that future flood policies in Germany will aim at raising their dikes, especially in a scenario with increased flood probabilities due to climate change. This may increase peak discharges and water levels downstream (in the Netherlands).

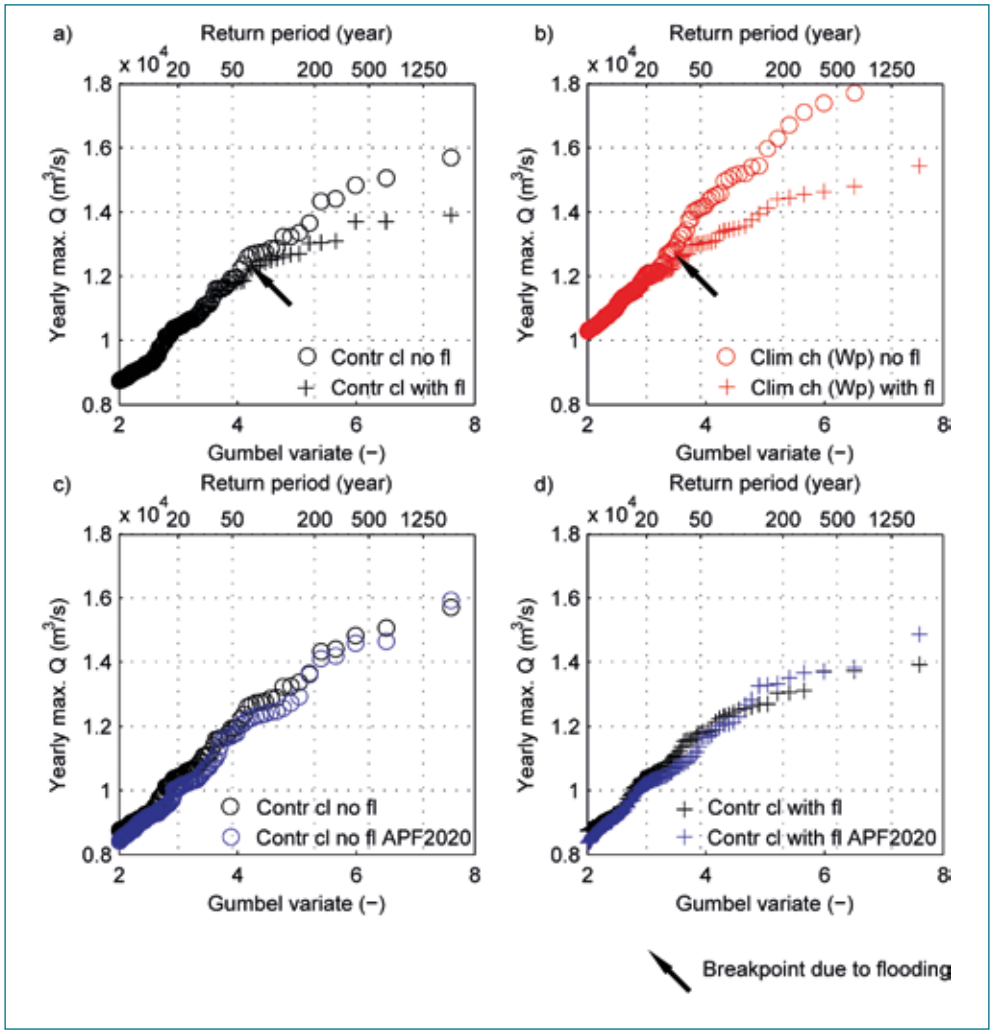


Figure 5.8.
Extreme value plots for the yearly discharge maxima at Lobith for different climate conditions and measures. Contr cl is control climate, fl is flooding, clim ch (Wp) is the Wp climate change scenario for 2050 [Te Linde et al., 2010b].

5.6 Regional adaptation

A summary of the outputs for developing and applying integrated simulation modeling frameworks and regional adaptation (at Water Board level) is presented here, focusing on the four major components:

1. Development of an analysis framework.
2. Impact and adaptation assessment.
3. Detailed demonstration and case studies.
4. Regional adaptation.

5.6.1 Analysis Framework

An initial inventory of existing framework approaches to assess the impact of climate change on regional water management was undertaken. It was clear that no existing approaches were available that could be used directly. The majority of the frameworks available were focusing on the surface water component only. Although very relevant, in many areas capacity of the surface water to overcome expected increases in extremes due to climate change was not the limiting factor.

Another set of existing frameworks focused mainly on the deep groundwater, ignoring by enlarge the interactions between river flows, extreme rainfall events and soil water. It was therefore decided to develop an integrated framework including all components necessary to undertake impact assessment and to explore adaptation scenarios.

The development of the framework took substantial amount of time, as many processes were not well understood. Especially the interaction between water levels in the Rhine and Meuse and seepage and drainage processes were poorly understood. Based on a combination of observations and mathematical approaches a better modeling framework was developed for the area under consideration.

5.6.2 Impact and Adaptation Assessment

The developed framework, referred to as FutureViewR, enables spatial quantification of the complex interaction between climate change, land use, and soils in and under influence of water levels in big rivers (Rhine and Meuse) [Immerzeel et al., 2009]. The Soil-Water-Atmosphere-Plant (SWAP) model is used in a grid based mode. A river module was developed to take into account seepage and percolation in the polder as an effect of the interaction with the main rivers. A simple surface water model was linked to the grid based SWAP models. The functionality of the FutureViewR modeling suite is demonstrated by modeling a climate change scenario for 2050. The analysis showed that it is likely that the dryer summers in combination with lower water levels in the Rhine and Meuse will yield a decrease in agricultural production. The wetter winters do not necessarily result in an increase in discharge, since the initial soil moisture storage at the winter onset is lower due to the dryer summers. It is concluded that the effects of climate change on polder hydrology is more intense than expected, caused by the dependence on local climate conditions and water levels on the Rhine and Meuse rivers, which are mutually reinforcing.

5.6.3 Demonstration cases and specific methodological development

A set of relevant demonstration cases and specific studies were undertaken. The most relevant will be summarized here.

Time Series Approaches

For the assessment of the impact of climate change on local and regional scale different methods exist that make use of physical based hydrological models. The 'time series method' uses time series of precipitation and evaporation as input for these models, while the 'simplified stochastic method', uses specific combinations of meteorological and hydrological characteristics (e.g. amount of precipitation, precipitation pattern, groundwater level, and surface water level). These combinations are constructed a priori based on statistical analysis of recurrence periods. Both approaches are compared for the Quarles van Ufford polder in the Netherlands, using the climate change scenarios of the Dutch Meteorological Service KNMI and the agro-hydrological model Soil-Water-Atmosphere-Plant (SWAP).

The time series analysis revealed that the impact of climate change on the discharge from the Quarles van Ufford polder is considerable. For the most extreme KNMI scenario the once in 10-yr peak discharge increases with more than 50%. The simplified stochastic method did not show significant differences in discharge between the scenarios or the recurrence periods. This is due to the large storage capacity in the soil profile and the short spin-up period before the extreme rainfall event. The conclusion of the comparison between the two methods is that the simplified stochastic method is less realistic, because in reality the conditions at the time an extreme rainfall event occurs are determined by the complex interaction of rainfall during a long preceding period, storage in the groundwater and soil profile, and discharge. This interaction can not be captured by a small selection of meteorological and hydrological characteristics. Based on the results it was

recommend to agricultural water managers to use the time series approach in impact studies of climate change, because it is more realistic and offers more possibilities for detailed analysis.

Model accuracy in impact analysis

Numerical simulation models are frequently applied to assess the impact of climate change on hydrology and agriculture. A common hypothesis is that unavoidable model errors are reflected in the reference situation as well as in the climate change situation so that by comparing reference to scenario model errors will level out. For a polder in The Netherlands an innovative procedure has been introduced, referred to as the Model-Scenario-Ratio (MSR), to express model inaccuracy on climate change impact assessment studies based on simulation models comparing a reference situation to a climate change situation. The SWAP (Soil Water Atmosphere Plant) model was used for the case study and the reference situation was compared to two climate change scenarios. MSR values close to 1, indicating that impact assessment is mainly a function of the scenario itself rather than of the quality of the model, were found for most indicators evaluated. A climate change scenario with enhanced drought conditions and indicators based on threshold values showed lower MSR values, indicating that model accuracy is an important component of the climate change impact assessment. It was concluded that the MSR approach can be applied easily and will lead to more robust impact assessment analyses.

Benefit Cost ration of irrigation under climate change

For one particular Water Board the benefits and costs of additional irrigation to overcome the expected drought under climate change were explored. Based on the analysis framework as described earlier the current situation and the changes under climate change were explored. The focus of the analysis was on the impact on agricultural production and in which way regional water managers could influence this. The results showed that under climate change yield would decrease and the economic costs are on average about € 180 per hectare. The average cost to supply additional water would be around € 80 per hectare. The conclusion was drawn that if sufficient water would be available it is from an economic point of view recommended to enhance the water supply capacity.

5.6.4 Regional adaptation

In the context of ACER, in combination with ARK (AdaptatieRuimte en Klimaat), an inventory of existing and promising adaptation projects has been undertaken (details at http://www.futurewater.nl/ark/). A total of 134 adaptation measures/projects has been identified, distributed over the following sectors:

- Agriculture: 7
- Nature: 26
- Leisure: 8
- Spatial planning: 28
- Transportation: 5
- Water: 45
- Miscellaneous: 15

Of these 134 projects, 45 adaptation measures are related to water and 28 to spatial planning. Based on an inventory of these projects and the most promising measures a knowledge deficit analysis has been assessed (Table 5.1). Details of these adaptions can be found at http://www.futurewater.nl/ark/.

Recently, one of the ACER consortium partners was selected in a highly competitive call in the context of the Small Business Innovation Research (SBIR) to undertake a pilot project focusing on

regional adaptation for water managers. The pilot project, referred to as Climate Adaptive Drainage (CAD), will develop and test an innovative method of automatically adjusted drainage levels to conserve water for droughts and at the same time retain water in the soil to overcome peak flows in downstream areas. The unique concept of this project is that farmers and water managers work closely together on a local concept that has regional impacts (think regionally, act local). The challenges of this concept are technical as well as on the managerial aspects of CAD. Details can be found at http://www.futurewater.nl/kad/.

Table 5.1.
Regional adaptation measure (in Dutch).+, o, - refers to level of knowledge and projects related to these adaptations.

+	Meer ruimte voor water
-	Ruimtelijke ordening gestuurd door risico's
-	Risicomanagement als basisstrategie
-	Nieuwe institutionele allianties
+	Geïntegreerd natuur- en waterbeleid
o	Geïntegreerd kustbeheer
o	Voorkómen hitte-eilanden, zorgen voor koelcapaciteit in steden
o	Constructie klimaatbestendige nieuwe gebouwen
-	Ontwikkelen klimaatbestendige vervoersinfrastructuur en transportopties
-	Evacuatieplannen
+	Creëren Ecologische Hoofdstructuur
-	Klimaatbestendige infrastructuur en gebouwen
-	Ontwerpen energie-efficiënte huizen
o	Ontwikkelen slimme indicatoren extreem weer
+	Verhogen biodiversiteit bossen
+	Creëren zoetwateropslagplaatsen voor overbruggen droogteperioden
+	Verhogen waterspiegel ter voorkoming indringen zout water
+	Bebossen met verscheidene soorten
o	Onderwijsprogramma's
o	Verbreden kustverdedigingstrook
+	Versterken rivier- en zeedijken
+	Vergroten bewustzijn burgers
+	Reviseren rioleringsstelsels
+	Herontwerpen grote infrastructuur; synergie reduceren overstromingsrisico's
+	Ecosysteembeheer in de visserijsector

5.7 Institutional factors and governance

5.7.1 Adaptability - challenges and opportunities

During the last few decades, flood management in Germany and the Netherlands has gone through several phases that were mainly triggered by extreme events and the invention of new discourses. Each phase and its main characteristics will be described in terms of institutional cooperation and resulting flood protection activities. The main developments are summarized in Table 5.2.

Table 5.2.
Phases in flood management in Germany and the Netherlands.

Netherlands	**1950-1970**	**1985**	**1995**	**2005**		
Events	Central Technocratic Top down New standards LCN values	Central Engineering Integrate functions Natural processes Nature development	Democra-tization	Internationalization Spatial planning		
Policy focus	Safety	Safety + ecology	Integral safety		Safety + space	Safety + climate
Design discharge (m^3/s at Lobith)	18.000	16.500	15.000		16.000	
Germany	**1950-1970**	**1985**				
Events	Federal state Decentral Flood management Technocratic	Re-naturalization	Integrate functions Ecology + economy		Flood prevention Technical + spatial + individual	
Policy focus	Economy	Natural safety	Integral safety		Preventive safety	
Design discharge (m^3/s at Rees)	14.200				14.700	

Current flood management is complex, being characterized by a multi-actor, multi-perspective and multi-level structure [Meijering, 2004]. The predicted climate change will aggravate the management task even further due to the expected increase of the flood frequency and severity will enlarge flood losses in future [Klijn et al., 2004; Deltacommissie, 2008; IKSR, 2009]. To address this challenge, researchers and practitioners have suggested to increase the capability to change, and new, more efficient and flexible management concepts have been proposed such as adaptive governance [e.g. Dietz et al., 2003; Folke et al., 2005; Armitage et al., 2007; Plummer 2009].

Adaptive flood governance asks for institutions with an adequate balance of robustness to control divergent interests and with the flexibility to adapt to change [Dryzek, 1987] and a number of prescriptions have been suggested to enhance adaptability such as a polycentric organization, collaboration and interplay, ecological fit and the recognition of scale impacts, participation, learning and a shared vision [Berkes, 2002, 2003; Young 2002, 2006; Gleick, 2003; Lebel et al., 2005; Olsson et al., 2006; Pahl-Wostl, 2007, 2009].

We proposed six prescriptions as theoretical lenses to analyze the feasibility of adaptive flood governance in the German Rhine basin Table 5.3. Our selection was motivated by their prominence in the literature and their specific qualification considering the political and administrative context in the German part of the Rhine. Their application suggests a mix of success and failures to navigate towards adaptation and to increase adaptability, although it has to remain a value judgment, whether the current institutional arrangements and procedures are sufficient to effectively respond to the future challenges.

Table 5.3.
Assessment of adaptive flood governance.

Poly-centric	+	Innovative competition and political
Multi-level	-	Scattered responsibilities, reactive action, delayed correction
Ecological Fit	+/- -	Flood Action Plan improved fit, but no consolidated basin wide concept No institutional review, weak leadership, sovereignty thinking
Interplay		
Horizontal	+/- -	Activation by LAWA/IKSR; delayed implementation Linkage deficits between domains, sectors and water functions
Vertical	+ -	Improved process management, partnerships Hierarchical structure, rules
Participation	+ -	Increasing involvement, mediation & dialogue Deficits in context analysis
Learning, experimenting	+ +/- - -	New flood risk prevention strategy Extended knowledge, numerous (local) studies No basin wide dissemination, limited political impact Climate change controversial
Shared vision	-	No long term concept across political domains, no scenario planning

The analysis of the current institutional arrangement revealed institutions appear more engaged with correcting the past than anticipating the future. The rather non-harmonized listing of functions, goals and measures of the 'Rhine 2020 Program' (www.iksr.org) reduces the chance of an integral concept. The delays and sceptical expectations in the current program indicate tensions between strategies and suggest that adaptability to the uncertain flood risk is less a technical but rather an institutional and organizational problem.

Useful steps might be a basin wide master plan for adaptive governance with common standards and a shared interpretation of available knowledge, a harmonized perception of future risks and a general agreement of urgency and priorities. Also more adaptive institutions are advocated with the courage to review rigid rules, hierarchical management procedures and traditional power distributions. Political will for a basin wide collaboration and to work accordingly to common objectives and indicators, is crucial for success.

5.7.2 Municipal survey in Germany: multi-level governance and risk perception

Following the federal structure in Germany, the strategic responsibility of flood management and the decision about major protecting projects is located at the level of the Federal States (Länder). The riparian municipalities[1] in the German Rhine basin are in charge of the local flood management, which includes risk assessment, contingency planning and dealing with disasters and they manage

1 In the State of North Rhine –Westphalia together with the Dike associations and River associations.

the local spatial planning and land use including the building rules and restrictions in flood prone areas. This makes the public officials responsible for municipal flood management important actors in the flood protection regime because they combine the understanding of the local situation, the relevant expertise, a political interest on safety and – at least partially – the decision power for protective action [Becker, 2009; Jüpner, et al., 2008; Böhm et al. 2004].

To cope effectively with the future flood risk does not only present a scientific and engineering challenge but it also implies a social and a political enterprise. The literature suggests that the way these challenges are picked up is importantly influenced by the perception of risk. The setting of priorities, the allocation of resources and the protective action depend on how the policy makers, the experts and the public perceive the risk of future floods [Lindell and Hwang, 2008; Burns, 2007; Sjöberg et al., 2004; Slovic and Weber, 2002; Paton, 2001; Sjöberg, 1999; Slovic, 1999, 1987].

It is of interest to investigate how municipal officials responsible for the local flood management perceive climate related flood risks, the level of preparedness and the need for additional measures to reduce the municipal vulnerability. Their judgement is of particular importance as they may be considered as the local experts and decision makers in the case of flood events.

Most of the panel members have shown a sound knowledge of increasing flood frequency, intensity and the connected consequences and the level of the perceived risk is relatively high. However their professional positions as experts and their institutional demands as public officials and decision makers may constrain the often presumed direct link between perception and protective behavior.

Our results show that the perceptive risk and coping appraisal correlates with the protective behavior. The results also emphasize certain features, for example that 'worry' and 'risk perception' are different elements of risk appraisal with different mediating effects on protective responses. Furthermore, outcome variables are an important link between risk perception and preparedness and 'trust' turned out to be a powerful predictor of protective behavior. The outcomes thus produce additional explanations of the decision making process including the means and opportunity to relate better to the local socio-geographic context.

The survey furthermore resulted in the following recommendations:

- Aim for a closer top-down and bottom-up integration at both the strategic and the operational levels to enhance the transparency of the decision process.
- A more enthusiastic interplay between the Federal States is desired, as well as a rigid coupling of the water functions and spatial development. In combination with the dissemination of scientific knowledge on future scenarios across administrative levels this will deliver a broader perspective of the risks and the options to mitigate.
- Organize an audit or benchmarking exercise to assess local vulnerability to flooding. Measures to build social capacity, such as public awareness, participation, financial compensation and flood insurance are perceived of high performance, while official numbers and a clear policy often lack at the municipality level.

6 Conclusions

This research project covered many topics at different scales. This final Chapter describes some overall conclusions that can be drawn from the ACER project. For details on further work we refer to the separate publications. Many results have been published in peer-reviewed journals and in publically available reports. These are available for download from www.climateresearchnetherlands.nl. Several spin-offs of A07 ACER can be found in new research projects, amongst others in the Dutch Knowledge for Climate Research Program. In addition, this final report will be communicated to all our stakeholders that contributed to one or more of our workshops.

6.1 Modeling processes – a trade-off

One of the land surface – atmosphere mechanisms relevant in climate change research is the feedback process from local evaporation to local precipitation, called "precipitation recycling". When simulating this at a European scale, it is found that precipitation recycling is large in dry summers for central Europe. In the Balkan, the recycling process intensifies the hydrological cycle due to a positive feedback, which increases precipitation with increasing temperatures. For these areas, future climate and/or land use can have an impact on the regional climate conditions due to changes in evaporation.

For the Rhine basin, land surface – atmosphere feedback mechanisms were simulated by the RAMS model (Regional Atmospheric Modeling System). This model enables simulating adaptations related to land use changes and provides accurate information on the timing of extreme events. The latter through enhanced simulation of soil moisture conditions and a more appropriate description of the land surface – atmosphere exchanges and possible feedbacks. When RAMS is coupled to the more hydrologically based land-surface model VIC, this combination of models solves both the water balance and the energy balance for many relevant soil, land and atmosphere mechanisms. In theory this would allow for better simulating the impact of climate change and land-use change on dry periods, and on the volume and timing of extreme events.

RAMS/VIC was used to investigate the effect of different model resolutions on simulated precipitation and subsequent runoff and streamflow. It was concluded that the difference between measured and simulated precipitation was relatively large, and improvement in precipitation simulation by a finer grid is only marginal. For discharge simulation in the Lahn catchment, the optimal resolution was 6 km, but model performance remained poor.

However, the coupling of RAMS and VIC was not as straightforward as thought at the beginning, and however useful for fundamental research on hydrological and atmospheric processes, the models performed poorly when simulating discharges. Also, these models require very long calculation times. As a result, a simpler hydrological model (HBV) was chosen to simulate the impacts of climate change on the discharge regime of the Rhine. However, from literature it is known that the conceptual, semi-distributed HBV model is not well suited for simulating the impact of land-use change on hydrology. Therefore, VIC and RAMS were used in separate studies to analyze the effect of land-use change.

HBV was linked to the hydro-dynamic model SOBEK that enables simulating routing processes and the impact of flood management measures such as dike heightening and retention basins. By forcing the model with output from the rainfall generator (10.000 year series of meteorological

daily data), this model setup aims to capture only the most relevant processes when assessing the effect of climate change and flood management measures on low-probability flood events, in a so-called 'process-based' approach.

At the regional scale, a comparison was made between a 'simplified stochastic method' and a 'time series method' for the assessment of climate change impact, in order to obtain if more simplification is possible. The first method uses specific combinations of meteorological and hydrological characteristics, while the latter uses time series of precipitation and evaporation as input for hydrological models. It was concluded that the simplified stochastic method is less realistic, because in reality the conditions at the time an extreme rainfall event occurs are determined by the complex interaction of rainfall during al long preceding period, storage in groundwater and soil, and discharge.

When we started the ACER project, we aimed at building an overall new 'Rhine model', using novel techniques and models, which we could use for all four project objectives. In this way, the results would be perfectly intercomparable. However, we quickly realized there is a trade-off between model complexity and the ability to run long time series and/or large ensembles of climate change scenarios. Considering model performance, focus and scale of the problem, a unique model set-up had to be optimized for each project objective.

During the final part of the ACER project, partly due to the interaction with stakeholders, the research increasingly focused on flood risks. Only considering safety levels, maximum water levels and flood-peak probabilities in flood management is not enough according to several, mainly German, stakeholders. One should also take the potential consequences of a flooding event into account, moving the analysis towards a flood risk approach. However, in climate impact analysis, especially at a basin-wide scale, a flood risk approach is new. Considerable effort was put into building a basin wide land-use and damage model for the Rhine. The development and application of this model continues in new projects.

6.2 Effect of climate change and adaptation strategies

It was found that the annual expected loss (flood risk) in the Rhine basin may increase by between 54 % and 230 % in 2030, of which the major part (~three-quarters) can be accounted for by climate change. The remainder results from socio-economic developments in flood prone areas. The results displayed large variations in current risk and flood-risk projections between regions along the Rhine.

We project that climate change may increase flood probabilities probability along the Rhine with a factor 2.5 to 4.7 in 2050, which may strongly influence the expected annual losses. Therefore, it is important to test whether the implementation of flood defense measures, such as retention basins and dike heightening, might prevent the increase of flood probabilities due to climate change, and thus the flood risk.

The currently implemented and proposed measures in the Action Plan on Floods by the IKSR, as well as most additional measures we evaluated reduce peak water levels by 5 cm to 13 cm over medium return periods (between 50 and 100 years) for the control climate. As a result, these measures may be inadequate to cope with the increased flood probabilities and peak water levels (up to 140 cm) that are expected in future climate scenarios. The only measure that can prevent the Rhine from flooding in 2050 is drastic dike heightening of between 1.30 and 3.30 m, depending on location, with the assumption that these dikes cannot fail.

With current dike heights, large upstream floodings occur in Germany at discharge above ~12.000 m3/s at Lobith. These volume losses have a profound decreasing effect on the simulated peak water levels and discharges along the main Rhine branch and downstream in the Netherlands. Hence, upstream floods in Germany are favorable for reducing flood risk in the downstream areas of the Netherlands. However, it is possible that future flood policies in Germany will aim at raising their dikes, especially in a scenario with increased flood probabilities due to climate change. This may increase peak discharges and water levels downstream (in the Netherlands).

At the regional scale in the Dutch Water Board Rivierenland the analysis showed that it is likely that the dryer summers in combination with lower water levels in the Rhine and Meuse will yield a decrease in agricultural production. The effects of climate change on polder hydrology is more intense than expected, caused by the dependence on both local climate conditions and water levels of the Rhine and Meuse rivers, which are mutually reinforcing.

It requires good governance to cope with these challenges both at a basin-wide and regional scale. However, the current institutional arrangement appears more engaged with correcting the past than anticipating the future. The delays and sceptical expectations in the current 'Rhine 2020 Program' by the IKSR indicate tensions between strategies and suggest that adaptability to the uncertain flood risk is less a technical but rather an institutional and organizational problem.

Useful steps might be a basin wide master plan for adaptive governance with common standards and a shared interpretation of available knowledge, a harmonized perception of future risks and a general agreement of urgency and priorities. Also more adaptive institutions are advocated with the courage to review rigid rules, hierarchical management procedures and traditional power distributions.

The future challenges of climate change will increase the urgency for effective coordination and collaboration. More importantly, however, is the political will for a basin wide collaboration and to work accordingly to common objectives and indicators.

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Climate changes Spatial Planning

Climate change is one of the major environmental issues of this century. The Netherlands are expected to face climate change impacts on all land- and water related sectors. Therefore water management and spatial planning have to take climate change into account. The research programme 'Climate changes Spatial Planning', that ran from 2004 to 2011, aimed to create applied knowledge to support society to take the right decisions and measures to reduce the adverse impacts of climate change. It focused on enhancing joint learning between scientists and practitioners in the fields of spatial planning, nature, agriculture, and water- and flood risk management. Under the programme five themes were developed: climate scenarios; mitigation; adaptation; integration and communication. Of all scientific research projects synthesis reports were produced. This report is part of the Adaptation series.

Adaptation

Dutch climate research uses a 'climate proofing' approach for adaptation. Climate proofing does not mean reducing climate based risks to zero; that would be an unrealistic goal for any country. The idea is to use a combination of infrastructural, institutional, social and financial adaptation strategies to reduce risk and optimalise opportunities for large scale innovations. Climate changes Spatial Planning realised projects in a multidisciplinary network that jointly assessed impacts and developed adaptation strategies and measures. The following themes were central to the programme: water safety, extreme precipitation, nature and biodiversity, agriculture, urban areas, transport (inland and road transport) and the North Sea ecosystem. In special projects, the so called hotspots, location-specific measures were developed that focused on combining 'blue', 'green' and 'red' functions.

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