Analysis of climate change, high-flows and low-flows scenarios on the Meuse basin

WP1 report - Action 3

This project has received European Regional Development Funding through INTERREG IV B.
INTERREG IVB

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Work package	1
Action	3

AMICE Adaptation of the Meuse to the Impacts of Climate Evolutions
is an INTERREG IVB North West Europe Project (number 074C).
Climate change impacts the Meuse basin creating more floods and more droughts. The river managers and water experts from 4 countries of the basin join forces in this EU-funded transnational project to elaborate an innovative and sustainable adaptation strategy. The project runs from 2009 through 2012. To learn more about the project visit: www.amice-project.eu

The NWE INTERREG IV B Program

The Program funds innovative transnational actions that lead to a better management of natural resources and risks, to the improvement of means of communication and to the reinforcement of communities in North-West Europe.
To learn more about the program visit: www.nweurope.eu

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INTRODUCTION

Objectives of the AMICE Project

Climate change experts are increasingly pointing-out the possible consequences of global warming (IPCC). It is clear that reduction of the emissions is not enough and that we also have to adapt to expected changes, as opposed to waiting until impacts are irreversible. Consequences of climate change on river basins can be potentially catastrophic. Floods are the main hazard, whereas droughts and low-flows are a newer threat, conditioned both by climate change and an increased water demand. Adaptation is necessary if we are to maintain our living standards and remain competitive.

Recently, climate change and its impact on water management have been put high on the agenda in the EU: Green Paper on climate change, Communication on Water Scarcity and Droughts, Floods Directive (2007/60/EC), Meeting of the Water Directors, etc. The goals are clear, and now is the time to start acting at the basin level.

Despite many uncertainties on the future climatic context, especially on extreme events, climate models are increasingly reliable and the spatial downscaling of climate model outputs has already produced several regional scenarios. According to the precautionary principle, uncertainty about the damage likely to be incurred should not serve as an argument to delay action.

Water managers from 4 countries of the Meuse basin (France, Belgium, Germany and the Netherlands) have decided to unite forces and knowledge in order to propose an adaptation strategy at the international basin scale.

Each member state has already started developing national adaptation strategies, although they are not easily shared or compared: the climate scenarios are different, the damage costs are evaluated with different methods, the measures enforced by neighbouring countries are not taken into account, etc.

By working together jointly in sharing data and methodologies, it is intended to develop a transnational strategic response to the impacts of climate change to the benefit of all the regions covered by the Meuse basin. Transnational cooperation will also facilitate the development of a "basin culture", both between water managers and the population, and increase solidarity.

We created the 'AMICE' Project: Adaptation of the Meuse to the Impacts of Climate Evolutions. The Project receives financial support from the European 'INTERREG IV B' Program as well as from the Meuse basin's Member States and Regions. It will last 4 years (2009-2012) and is coordinated by EPAMA.

The 17 AMICE Partners are:
<u>In France:</u>

- EPAMA (Etablissement Public d'Aménagement de la Meuse et ses Affluents), responsible for flood prevention and protection on the French Meuse
- CEGUM (Centre d'Etudes Géographiques de l'Université de Metz), Center for geographical studies, the University of Metz
- CETMEF (Centre d'Etudes Techniques Maritimes et Fluviales), technical center for inland and maritime waterways

In Belgium (Wallonia):

- Région Wallonne – GTI (Groupe Transversal Inondations), the cross-disciplinary working-group on floods in the Walloon Region
- Gembloux Agro-Bio Tech, the department of Hydrology and Hydraulic Eng., University of Liege.
- ULg – HACH, the department of Hydrology, Applied Hydrodynamics and Hydraulic Constructions of the University of Liège
- APS (Agence Prévention et Sécurité), the regional agency for overall prevention and security
- Community of Hotton

In Belgium (Flanders):

- nv De Scheepvaart, manager of the channels for water transport and drink water production
- Waterbouwkundig Laboratorium, the research center for hydraulic sciences in Antwerp
- Vzw RIOU, association for communication and renaturation

In Germany:

- WVER (Wasserverband Eifel-Rur), manager of the Rur tributary
- RWTH Aachen Universität - Lehrstuhlund Institut für Wasserbauund Wasserwirtschaft: the institute of hydraulic engineering and water resources management
- RWTH Aachen Universität - Lehr-und Forschungsgebiet Ingenieurhydrologie: the academic and research department engineering hydrology

In the Netherlands:

- Rijkswaterstaat, Ministry of Transport, Public Works and Water Management is involved through two of its departments: Waterdienst and Limburg
- Waterschap Aa en Maas and
- Waterschap Brabantse Delta, water authorities in the Province of Noord-Brabant, water managers of the sub-basins among the 5 of the Meuse basin in the Netherlands.

The aims of AMICE are to:
1) Develop a basin-wide climate adaptation strategy, coordinated transnationally, and focused on water discharges and the functions influenced by them. The strategy development will take into account climate scenarios, on-going projects, existing measures and the EU Floods Directive (2007/60/EC), with a particular focus on floods and low-flows.
2) Realize a set of measures against low-flows and floods, profitable for the international basin of the Meuse and that can be used by other river basins in Europe.
3) Reinforce and widen the partnership between stakeholders of the Meuse basin, and increase the exchange of knowledge and experience on prevention, preparedness and protection against flood and drought risks.
4) Engage the local population and stakeholders by improving their understanding of climate change, sustainable development, basin functioning, risk consciousness of water hazards and the sense of belonging to a common river basin, across administrative and language borders.

Studies have already been undertaken relating to future climate change, synthesized in ‘The impacts of climate change on the discharges of the river Meuse’, 2005, International Meuse Commission.

Conclusions were:
-increased frequency of floods in winter, extreme events in particular,
-increase in low-flows, more likely the result from higher water demand than higher air temperatures,
-need to agree on common scenarios, jointly examine the effect of an improved coordination of water management policies.
The transnational cooperation will result in basin-wide scenarios on climate change and discharges, used as input for the adaptation strategy.

The Project is divided into 5 Work Packages (WP) (Figure 1). The present report is part of WP1.

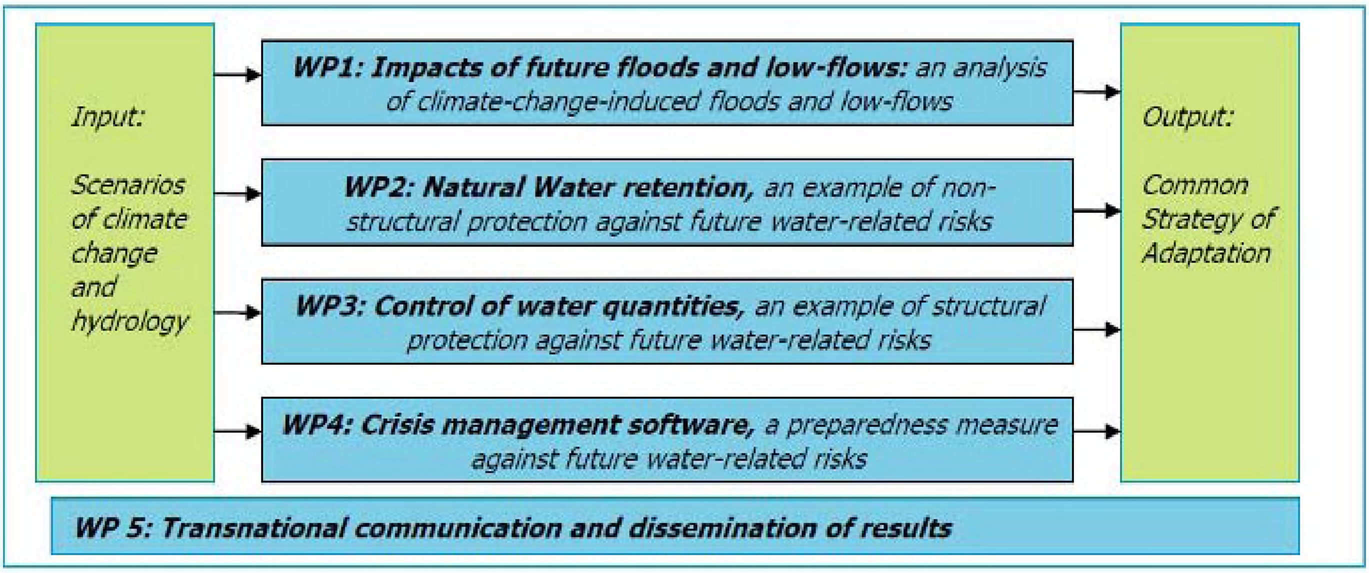


Figure 1 : AMICE project organization chart

Objectives of action 1 and action 3

AMICE's Work Package 1 is dedicated to the impacts of future floods and low-flows on the Meuse basin. Partners will perform a technical and scientific analysis of climate-change-induced floods and low-flows through prospective modeling, efficiency evaluation of water management measures, damage calculation, and proposition of solutions.

Scenarios of the future climate are already exchanged by i.e. Meteorological offices and Research institutes in FP6 and FP7 projects, but many others need to be shared, especially regarding the borderless question of climate evolutions. There is no point in developing complex techniques if the outputs cannot be shared with the neighbour specialists. The AMICE project provides the opportunity to use common scenarios, tools and methods to evaluate measures and elaborate strategies that can finally be comparable between countries.

The present report details methods and results from Actions 1 and 3 which have been carried-out in 2009 and supervised by the University of Metz.

The WP1's objectives will be carried-out in 9 Actions scheduled according to Table 1:

1 : Bibliography
2 : Mapping
3 : Hydrological modeling
4 : Meetings
5 : Reports
6 : Hydraulic modeling
7 : Impact assessment
8 : Climate check
9 : Adaptation strategy

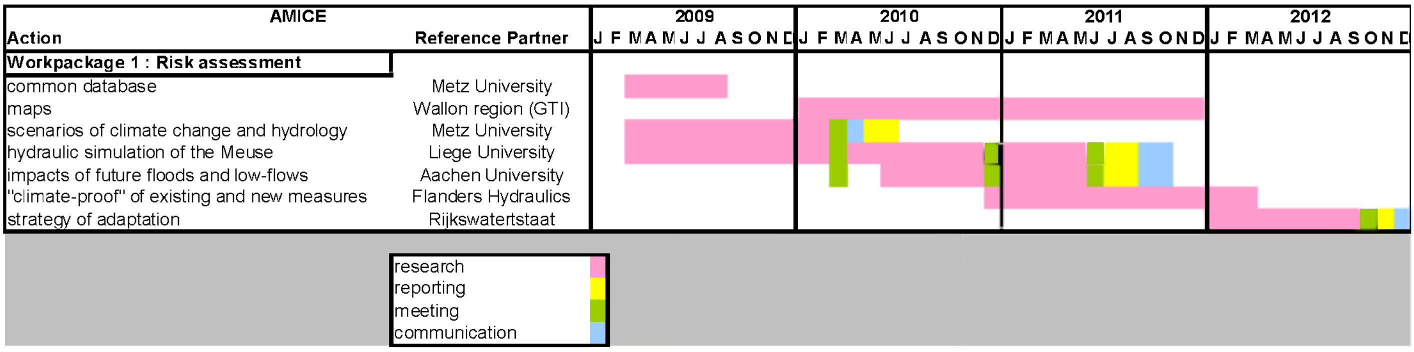


Table 1. AMICE Workpackage 1 organization chart

Action 1 description:

The objective is to share our knowledge on the present and future characteristics and hydrological behaviour of the Meuse river basin.

Knowledge on this topic is still scattered and hardly available within the 3 official languages spoken on the Meuse basin. Information has been gathered by the Partners, translated into English, French, Dutch or German when required and organized by topics into an online database.

Action 3 description:

This Action is dedicated to the study of downscaled climate simulations for 2020-2050 and 2070-2100 and their consequences in terms of floods and low-flows on the Meuse river basin. The following questions will be answered:
- which discharges can be expected on the river Meuse and main tributaries?
- how the return period, duration, extent of floods and low-flows will change from now to 2020-2050 and 2070-2100?

Partners have analyzed climate simulations from meteorological institutes (IPSL, Cerfacs, KMI, KNMI, ...), national and EU research programs (Prudence, Ensembles, ADAPT, etc): bibliographies, interviews of users, experts invited to meetings. They have checked if they can be applied to the Meuse basin, assess their uncertainty and the required corrections.

New production or acquisition of climate data was not carried-out because:
- The project is more oriented on climate change consequences rather than on its causes,
- The length of the project is insufficient for running new meteorological simulations,
- There are existing scientific publications and data that can be used to document the issue.

Position of the advanced report in the elaboration of an adaptation strategy for the Meuse river basin

The Partners involved in the above-mentioned actions achieved the basis research that will be used throughout the AMICE project. The climate and hydrological scenarios will not only be used for WP1 but also for some investments in WP2 and WP3, as well as for the definition of the transnational exercise in WP4.

The present report details the hypotheses that were made and the knowledge used to define the climate scenarios for the Meuse basin.

It is thus extremely important to emphasize that the AMICE adaptation strategy will respond to two climate scenarios (a wet and a dry ones) – the most reliable we could find but not the only possible ones – with their assumptions and uncertainties. These climate scenarios represent what could, most likely, happen on the Meuse basin.

1 Presentation of the study area

1.1 The Meuse river basin

The Meuse river basin is one of the most densely populated areas of Western Europe and a major geographic link between Belgium, France, Germany, Luxembourg and the Netherlands. The river itself is navigable and provides drinking water for more than 5 million inhabitants.

The main characteristics of the Meuse Basin are (De Wit et al., 2007):

Length : 900 km Drainage area : 35.000 km² Number of inhabitants : 9 million

Its discharge fluctuates considerably with seasons: it reached 3000 m^3/s in winter 1993 in Liege and can be as low as 10-40 m^3/s in the summer season. Classed as a rain-fed river, it has no glacier and little groundwater storage capacity to buffer precipitations. Most of the water comes from the Walloon tributaries in the Ardennes.

A direct link exists between climate evolutions/change and changes in high and low-flows, putting at risk the assets of the basin, including major infrastructures, industries, priceless historical and ecological heritage.

The 5 European countries are working together in the International Meuse Commission (IMC), created in 2002 to coordinate the application of the Water Framework Directive (2000/60/CE). The Commission will now coordinate the application of the EU Flood Directive (2007/60/CE).

1.2 Sub-basins selected for the hydrological impact assessment of climate change

Figure 2 presents a map of gauging stations selected by the Amice partners for the hydrological simulations. Nine stations were chosen within the Meuse basin (Table 2):

- Four stations on the French part of Meuse
- One at the Walloon/Netherlands border.
- Four stations on Walloon and German right-side tributaries located on the Lesse, the Vesdre, the Niers and the Rur rivers.

For practical reasons (short delay, existing models calibration, etc) it was not possible to take into account others stations. For each selected station, hydrological simulations were realized in order to estimate the evolution of high-flows and low-flows discharges during the 21st century (2021-2050 and 2071-2100).

Figure 2. Drainage network of the Meuse river and gauging stations selected for the AMICE project

	Station	Drainage area (km2)	Source of discharge data	River kilometers for tributaries confluence with the Meuse (km)*	Main lithological formation	Main land-use	Highest gauging discharge value in high flows	Lowest gauging discharge value in low flows	Anthropogenic influence on natural flows
Meuse	Saint-Mihiel	2540	http://www.hydro.eaufrance.fr/	-	Mesozoic	Forest & Agriculture	596 m^3/s	-	-
Meuse	Stenay	3904	http://www.hydro.eaufrance.fr/	298	Mesozoic	Forest & Agriculture	600 m^3/s	-	-
Meuse	Montcy-Notre-Dame	7724	http://www.hydro.eaufrance.fr/	-	Mesozoic	Forest & Agriculture	960 m^3/s	-	Agriculture
Meuse	Chooz	10120	http://www.hydro.eaufrance.fr/	477	Mesozoic	Forest & Agriculture	1610 m^3/s	-	Nuclear plant
Lesse	Gendron	1284	SETHY	505	-	Forest	390.8 m^3/s	0.6 m^3/s	-
Vesdre	Chaudfontaine	683	SETHY	597	-	Forest	274.5 m^3/s	0.2 m^3/s	dams
Meuse	Sint Pieter	20.200	KNMI	631	Mesozoic	Forest	3039 m^3/s	< 20 m^3/s	Important water diversions to upstream channels, water use by agriculture, industry and households
Rur	Stah	2135	LANUV NRW	694	Unconsolidated rock (north) consolidated rock (south)	Arable land	129 m^3/s (27.5.1983)	8.1 m^3/s (15.07.1996)	Reservoirs Lowering of groundwater table Admissions of water
Niers	Goch	1203	LANUV NRW	771	Unconsolidated rock	Arable land	42,4 m^3/s (7.12.1960)	1,2 m^3/s (24.08.1976)	Lowering of groundwater table Admissions of water

*Table 2. Main characteristics of gauging stations selected for the Amice project. *De Wit et al. (2007)*

1.2.1 The French part of the Meuse basin

The French basin is located upstream of the transnational basin (Figure 3). It is oriented from the south to the north and can be divided into two parts:

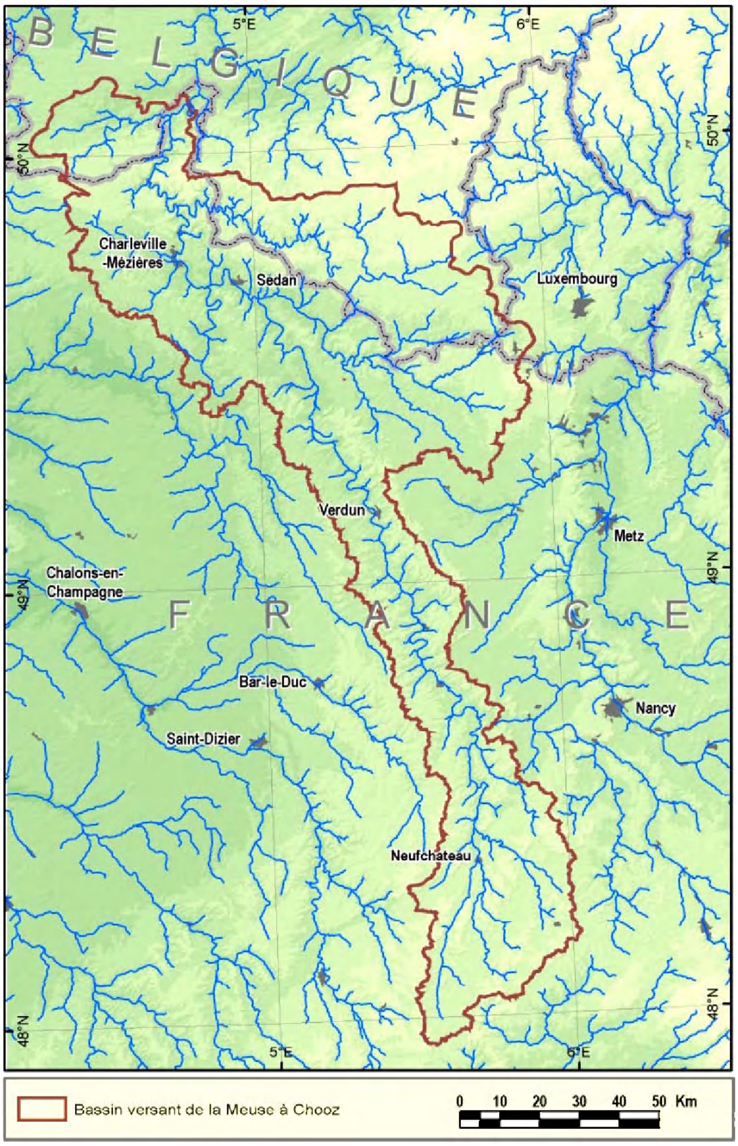


Figure 3. French sub-basin of the Meuse

- The first part extends from the source, on the plateau de Langres (384m above sea level) to Verdun. This area is very elongated because the basin is limited by the Côtes de Moselle in the east and the Côtes de Meuse in the west. Agriculture is dominant in this region.

- The second part includes the French Ardennes and presents higher altitudes (400-500 meters). The orographic effect we can observe in this area results in more precipitations than in the south (>1000mm/y). There are few medium-sized cities like Verdun (20.000 inhabitants), Sedan (20.000), and Charleville-Mézières (100.000). This area is predominantly forested.

The climate of the French sub-basin is semi-oceanic: rainfalls are fairly regular throughout the year (approximately 80mm/month). The hydrological regime is unimodal (only one low flows period each year in summer, and one high flows period in winter). The French part covers approximately one third of the whole Meuse basin in terms of surface, length, and mean annual flows.

Flows of the French part of Meuse are mainly conditioned by the amounts of precipitation and potential evapotranspiration (PET).

Mapping portal
The Géoportail (*Ministère de l'écologie, de l'énergie, du développement durable et de la mer, IGN, BRGM*) gives access to a lot of dynamical maps, regularly updated : http://www.geoportail.fr/

	Transnational basin	French sub-basin
Surface	33.000 km²	10.120 km²
Length	950 km	355 km
Average discharge	350 $m^3.s^{-1}$	148 $m^3.s^{-1}$

1.2.2 Walloons sub-basins

The Meuse reaches Belgium at the Heer's level. It runs through the Ardennes via the Fagnes in the Province of Namur where it successively receives the Lesse and the Sambre in the city of Namur. It runs through the Province of Liège where it receives the Houyoux close to Tihange and the Ourthe at Liège. The Meuse leaves the Walloon Region at Visé. After a turn in the Netherlands via Maastricht, it acts as a border between Belgium and the Netherlands in the Province of Limburg. It runs through Maasmechelen and Maaseik before leaving Belgium.

In the Walloon Region, the Meuse sub-basins are (Figure 4): Meuse-aval, Sambre, Meuse amont, Lesse, Vesdre, Ourthe, Amblève and Semois-Chiers. One third of the Meuse river basin area is located in the Walloon Region, let approximately 12000 km² *(Ashagrie et al., 2006).*

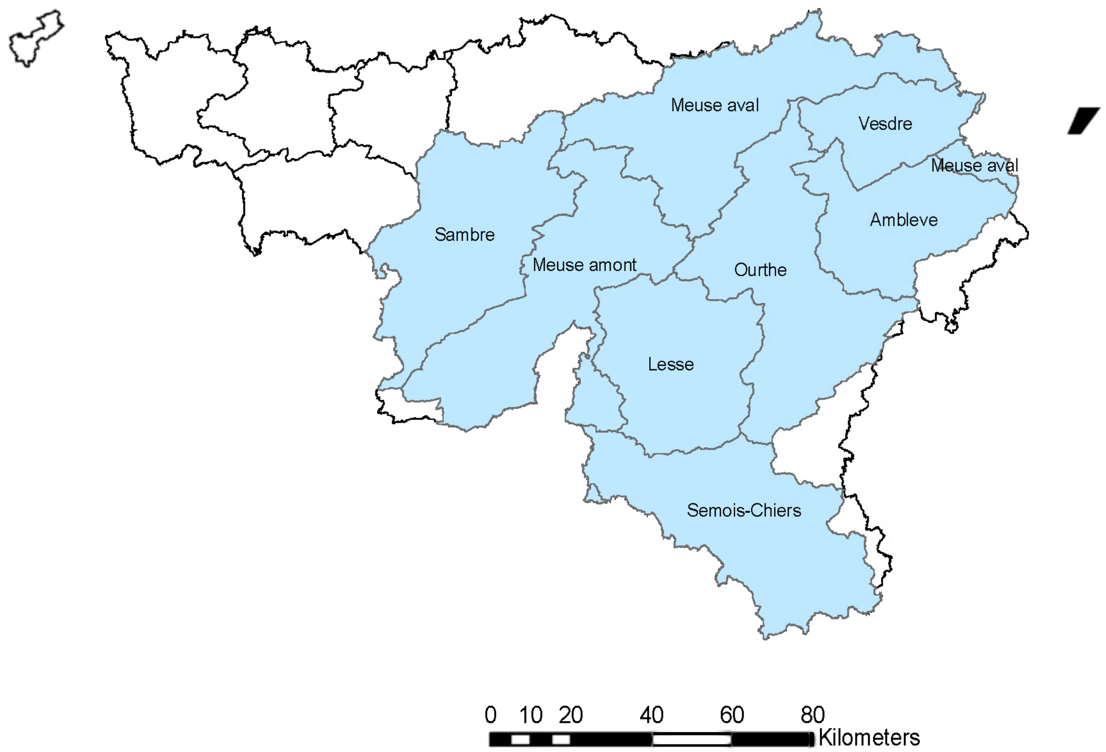


Figure 4. Walloons sub-basins of the Meuse

<u>Climate of the Meuse basin in Walloon Region</u>

Belgium has a maritime, wet temperate climate due to its latitude and its proximity to the sea. Air temperatures are moderate with a yearly mean of 10°C. Prevailing winds blow from South-West and West sectors. Cloud coverage is important and rain is common and regular, weak snowfall can be observed in the Ardennes.

Between the south and the north of the country, difference in air temperature are weak in summer but more pronounced in winter due to an hilly relief in the south.

Concerning rainfall, the Semois valley and the Hautes-Fagnes receive about 1.400 mm per year whereas the centre and north of the country receive less than 800 mm per year. Usually, all Ardennes receive more rainfall. There, it rains for about 200 days a year, against 160 to 180 days in the centre *(Ministère de la Région wallonne, Direction Générale des Ressources naturelles et de l'Environnement, Observatoire des Eaux de Surface, Direction des Eaux de Surface Direction des Eaux souterraines, 2005).*

<u>Soils</u>

The main soils associations for the Walloon basin of the Meuse are stony loam soils, loamy soils, slightly stony loam soils, loamy sand soils (Figures 5 and 6).

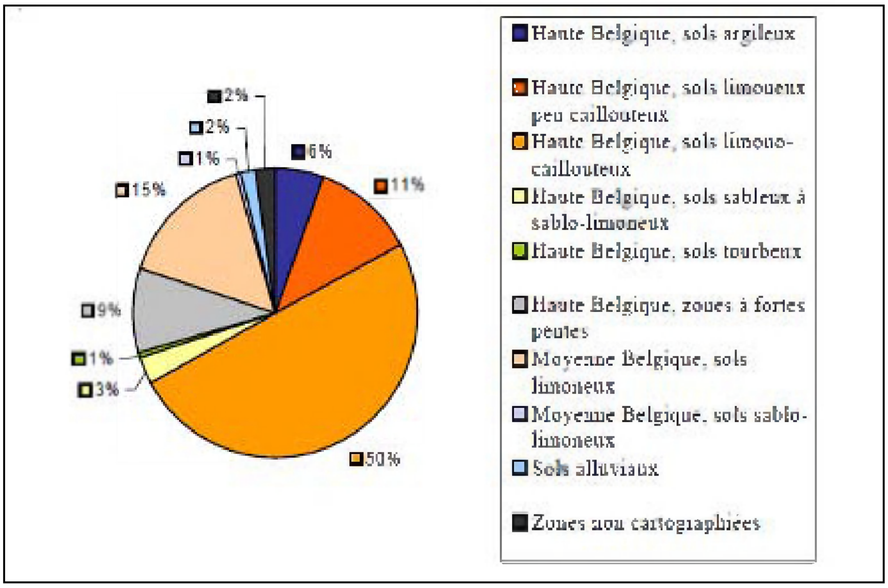


Figure 5. Distribution of the main soils associations for the Meuse river basin in Wallonia. *Source: Ministère de la Région Wallonne, Direction Générale des Ressources naturelles et de l'Environnement, 2002.*

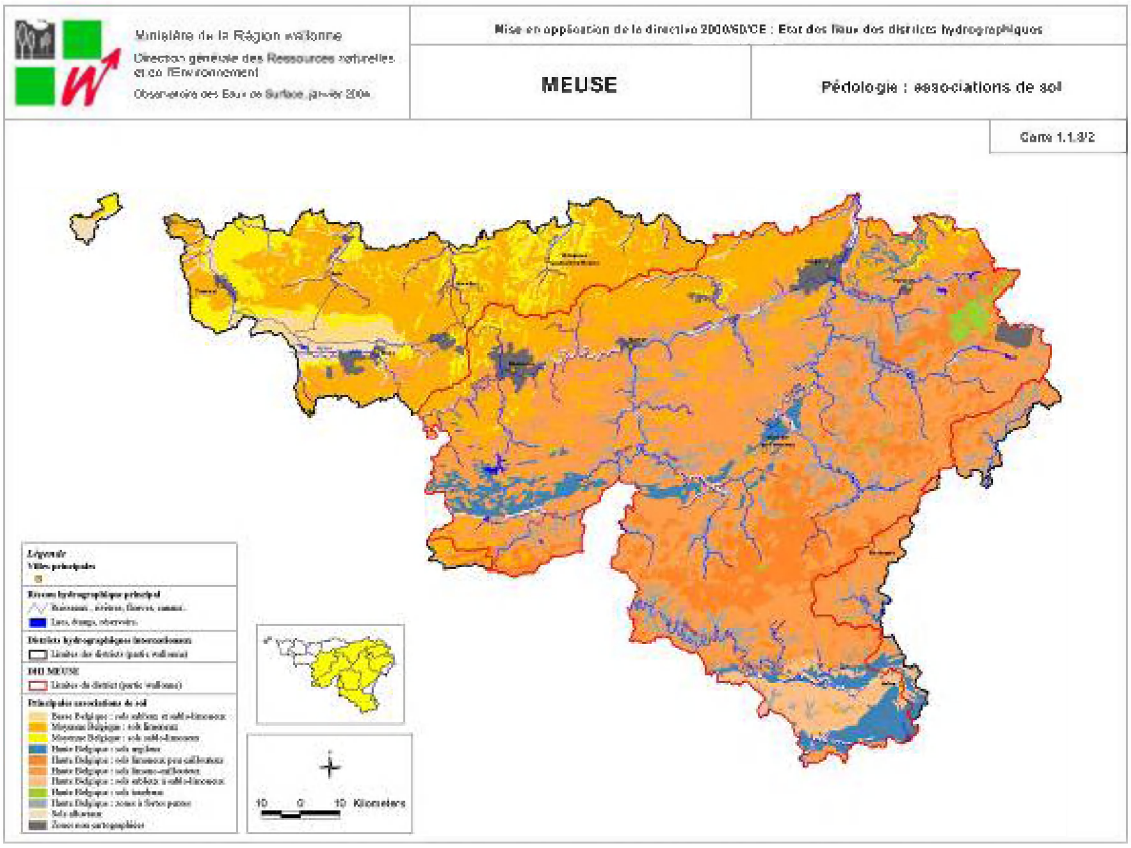


Figure 6. Pedology in Walloon Region. *Source: Ministère de la Région wallonne, Direction générale des Ressources naturelles et de l'Environnement, 2002.*

Land-uses

Land-uses of the Meuse river basin in the Walloon Region are constituted by 25% of grassland, 24% culture, 18% deciduous forest, 18% coniferous forest. Urban area covers 7% of the territory. (Figure 7)

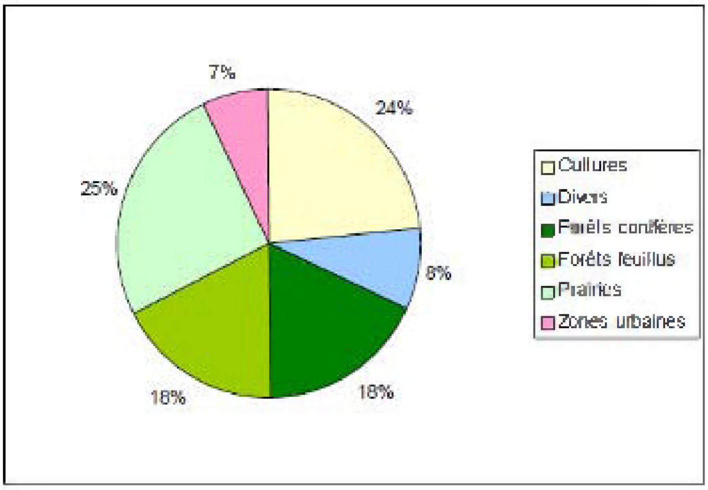


Figure 7. Land uses for the Meuse river basin in Walloon Region. *Source: Ministère de la Région Wallonne, Direction générale des Ressources naturelles et de l'Environnement, 2002.*

Mapping portal

- The Walloon Region gives access to a lot of dynamical maps, regularly updated : http://cartographie.wallonie.be
- Geological maps are viewable at the address : http://environnement.wallonie.be/cartesig/cartegeologique/

1.2.3 Flemish sub-basins

Compared to the total area of the Meuse basins, the Flemish part is relatively small and hydrologic models covering the whole international Meuse basin already exist in the Netherlands. The Dutch delegation of the International Meuse Commission brought researchers at FHR and Deltares together and a study to calculate the 3 Belgian climate change scenarios for hydrologic impact with the models from Deltares was ordered by FHR.

1.2.4 German sub-basins

The following tables 3 and 4, give an overview of the size of the basin area and the mean discharge at lower reaches of the German tributaries to the Meuse. It can be stated, that Rur and Niers have for both aspects a higher order of magnitude than all other German tributaries together.

For the mentioned reasons we share the opinion that Rur and Niers are the decisive German tributaries to the Meuse and we think that it is thus justified to take only Rur and Niers into consideration for the present study.

Table 3. Basin areas and percentage of Meuse basin for main German tributaries to the Meuse (values taken from (*MUNLV, 2005-1*))

	Basin area [km²]	percentage of Meuse basin [%]
Meuse	**34.548**	
Rur	**2.338**	**6,77**
Niers	**1.382**	**4,00**
Schwalm	**273**	**0,79**
other northern Meuse inflows	**158**	**0,46**
other southern Meuse inflows	**129**	**0,37**

Table 4. Mean discharges at lower reaches for Rur, Niers, Schwalm (values taken from (*MUNLV, 2005-1*))

	mean discharge at lower reaches [m³/s]
Meuse	
Rur	**22,71**
Niers	**7,79**
Schwalm	**1,66**

1.2.4.1 Rur basin area

The Rur basin area covers parts of Germany, Belgium and the Netherlands. With 89%, the majority of the area is located in Germany. The headwaters are located in Belgium, the estuary in the Netherlands with the outlet into the Meuse at Roermond (NL). In Figure 8 an overview is given.

The Rur has a run length of 163 kilometers of which 10 kilometers are located in Belgium, 132 in Germany and 21 in the Netherlands. The main tributaries are Urft for the upper reaches, Inde for the middle reaches and Wurm for the lower reaches. The size of the basin area is 2.338 km². The average total annual precipitation is 855 mm (*MUNLV, 2005-1*).

The basin area is divided into two totally different landscape-regions. The southern part of the basin area with mostly consolidated rock belongs to the Rhenish Massif. Its northern border is in line with the cities of Aachen, Eschweiler and Düren. The area northern of this line with mostly unconsolidated rock is part of the Lower Rhine lowlands. This area is intensively used for the recovery of drinking- and industrial water.

For the German parts of the basin area the main land use categories are arable land (approx. 30%), grassland (approx. 20%) and forests (approx. 30%). But they are not homogeneously distributed over the basin. Settlement areas take about 10% of the German part of the basin area. Most of them are lying right beside the major rivers and cover partly wide parts of the former floodplains. Another important land-use is the open pit mining. Although the percentage is low it has great impacts due to the necessary rearrangement of the area and the extensive lowering of groundwater. Within the Netherlands the area is mostly used for agriculture. In the Belgian part of the basin area there is, with 57%, a great percentage of forests. The agricultural area is, with 25%, lower than in the Netherlands (*MUNLV, 2005-1*).

The discharge behaviour is heavily influenced by the nine reservoirs in the Eifel and the approximately 50 flood control basins. Further influences are the river development with standard sections and water management structures and extractions and discharges.

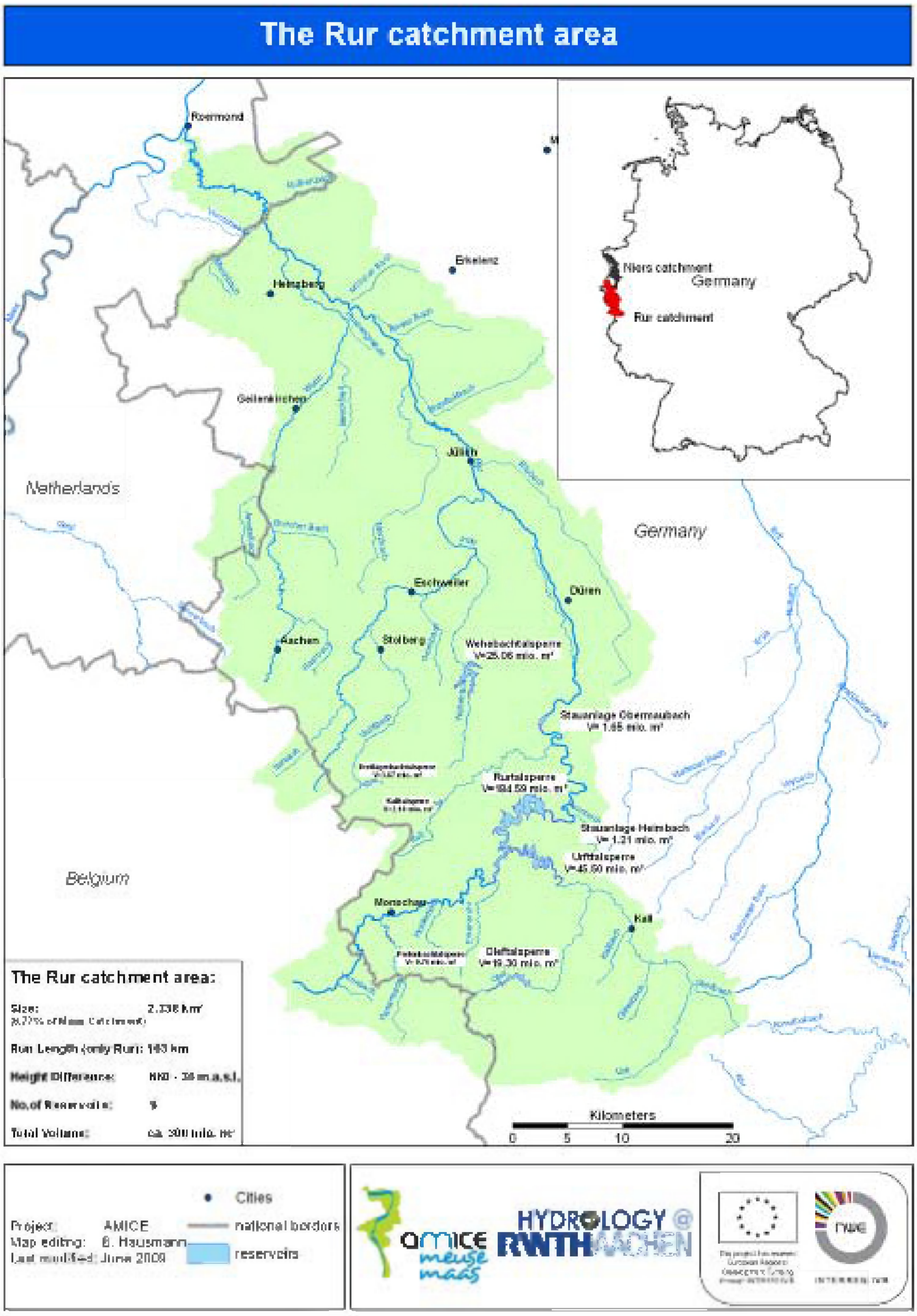


Figure 8. Overview over the Rur basin area

The nine reservoirs have a total storage volume of about 300 million m³. They serve among other purposes for drinking water supply, flood control, low-flows enrichment, power generation or recovery. For the optimization of the water resources management the reservoirs in the upper Rur reaches including Urft and Olef are operated in a linked system.

Within the middle and lower reaches of the Rur there are many admissions of municipal or industrial clarification plants. The settled areas cause increased surface runoff and the rivers are stressed by combined wastewater or rainwater admissions.

The Rhenish brown coal mining area covers parts of the Rur basin area. To mine the brown coal in open pits it is necessary to lower the groundwater table by draining the mines. The effects of this lowering go beyond the Rur basin area. About 50% of this draining water is used for water supply, the other part is within the Rur basin area mainly discharged into the Inde. By these interventions the water balance of the area with unconsolidated rock has been heavily influenced since the 1950s. This influence will remain in the next decades. The end of the open pit mining in the Rur basin area is aimed for about 2030 (*MUNLV, 2005-1*). For the mining area "Inden" it is planned to create a lake by filling the remaining pit with water. For this several strategies concerning the details of the filling are discussed.

1.2.4.2 Niers basin area

The Niers basin area covers parts of Germany and the Netherlands. The estuary is in the Netherlands with the outlet into the Meuse at Gennep (NL). In Figure 9 an overview is given.

The Niers has a run length of 118 kilometers of which 8 kilometers are located in the Netherlands. The total size of the basin area is 1.382 km². The average total annual precipitation is 708 mm (*MUNLV, 2005-2*).

The Niers can be divided into three parts. The upper Niers with its main tributary Gladbach reaches until gauge Trabrennbahn. This area is mainly influenced by the brown coal mining and the associated lowering of the water table. As adjustments there are several admissions of draining water into the rivers or into wetlands. The discharge behaviour is impressed by the surface runoff from the city of Mönchengladbach.

The middle Niers with the main tributaries Nette, Cloer and Gelderner Fleuth reaches until gauge Geldern. This part is influenced by the sewage treatment plant Mönchengladbach-Neuwerk.

The lower Niers is impressed by the agricultural area of the environment. Main tributaries are Issumer Fleuth and Kervenheimer Mühlenfleuth.

The basin area of the Niers is impressed by unconsolidated rock and is part of the Lower Rhine lowlands. Particularly in the north-west of Mönchengladbach (near Krefeld) are many facilities for the recovery of drinking water. Besides the water bodies are partly area-wide used for industrial purposes.

In the German part of the Niers basin area the land use is dominated by agricultural and silvicultural purposes. About 50% of the area is used as arable land. Grassland and silvicultural areas make 15% each of the basin area. In the Dutch part of the basin area the distribution of land use is comparable to the one in Germany (*MUNLV, 2005-2*).

The discharging of the admissions of municipal or industrial sewage treatment plants is an important task for the rivers in the basin area of the Niers. There are many admissions from combined wastewater or rainwater.

Due to the very flat topography in the basin area flood control measures are necessary. The retention is done, besides the natural one within the floodplains, via regulated flood retention basins. Dikes along the rivers ensure the flood protection for small and middle size flood events (*MUNLV, 2005-2*).

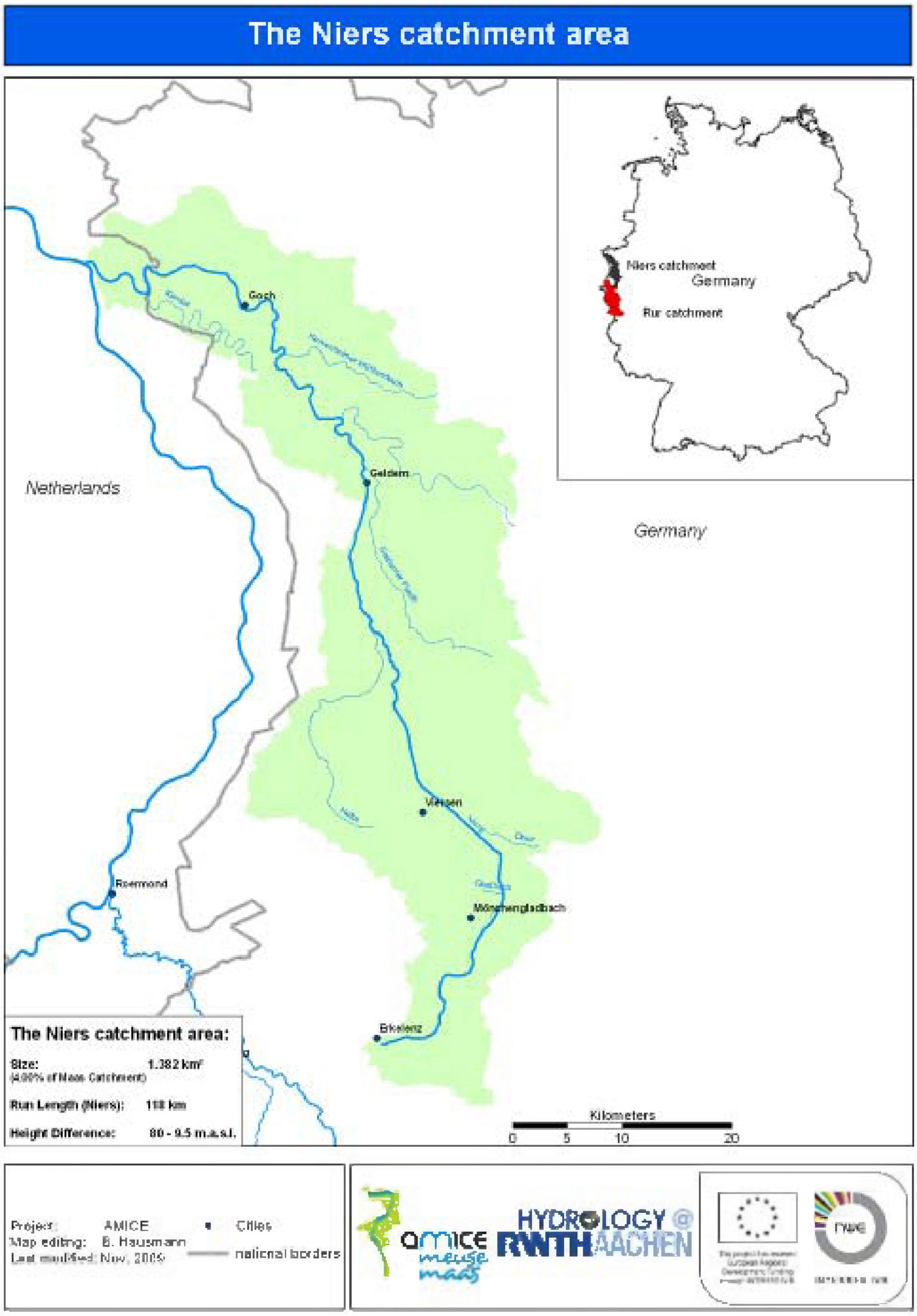


Figure 9. Overview over the Niers basin area

1.2.5 Dutch part of the Meuse basin

The Dutch part of the Meuse basin counts with 3,5 million inhabitants and has a surface area of 7.700 km2. The Dutch Meuse is the last stretch of the Meuse River where after around 250 horizontal kilometres and 45 vertical meters from the Dutch-Belgium border it drains into the North Sea. Several large cities are situated next to or close to the Meuse river, such as Roermond, Venlo, Nijmegen and 's-Hertogenbosch.

Most of the land surface in the Dutch Meuse basin is used for agriculture: about 550.000 ha or 70% (*Internationale Maascommissie, 2005*). About 15% of the surface has a nature function. Recreation, urban areas and industry also occupy about 15% of the land surface of the Meuse basin. However, urbanization, transport, industry and agriculture increasingly take more space in the basin. The southern part of the basin is relatively open (lower rates of urbanization etc.).The percentage of open water is limited (*Arcadis, 2007*).

The Meuse basin represents about 22% of the national production value and is of great importance for the Dutch industry. Sand and gravel is excavated from some parts of the basin. Intensive animal husbandry and mixed farms (both agriculture as well as cattlebreeding) are strongly represented. Especially in the province of Noord Brabant intensive animal husbandry has increased. Near the mouth of the Meuse, salinification has a negative impact on agriculture (*Arcadis*, 2007).

The Meuse enters the Netherlands at Eijsden, south of Maastricht (Figure 10).Historically, the discharge is measured at Borgharen, a small town just north of Maastricht. Currently, discharge is measured at St. Pieter as morphology downstream is being changed by the Maaswerken project. From Eijsden to Borgharen, the Meuse is called “Upper” Meuse (Bovenmaas). At Borgharen, the Meuse water is divided over the “Border” Meuse (Grensmaas), which forms the natural border with Belgium for about 40 km, and the Julianakanaal next to it. Note that the Julianakanaal is not shown in Figure 10. The Julianakanaal has been constructed for navigation, and most of the navigation towards Belgium occurs through this canal. Near Roermond, the Julianakanaal and the Meuse join again, to be divided over the Zuid Willemsvaart (which cuts off part of the original Meuse, see Figure 11) and the Meuse, which are both navigable.

At Mook (near Nijmegen), the Meuse bends towards the west, and a canal through Nijmegen connects the rivers Waal and Meuse. The river continues to flow as one stream to Heusden, near ‘s Hertogenbosch. In older days, the Meuse split into two streams here. Today, the connection with the Merwede is closed and the Meuse as a whole flows via the Bergsche Maas and the Amer through the natural park Biesbosch towards the Northsea.

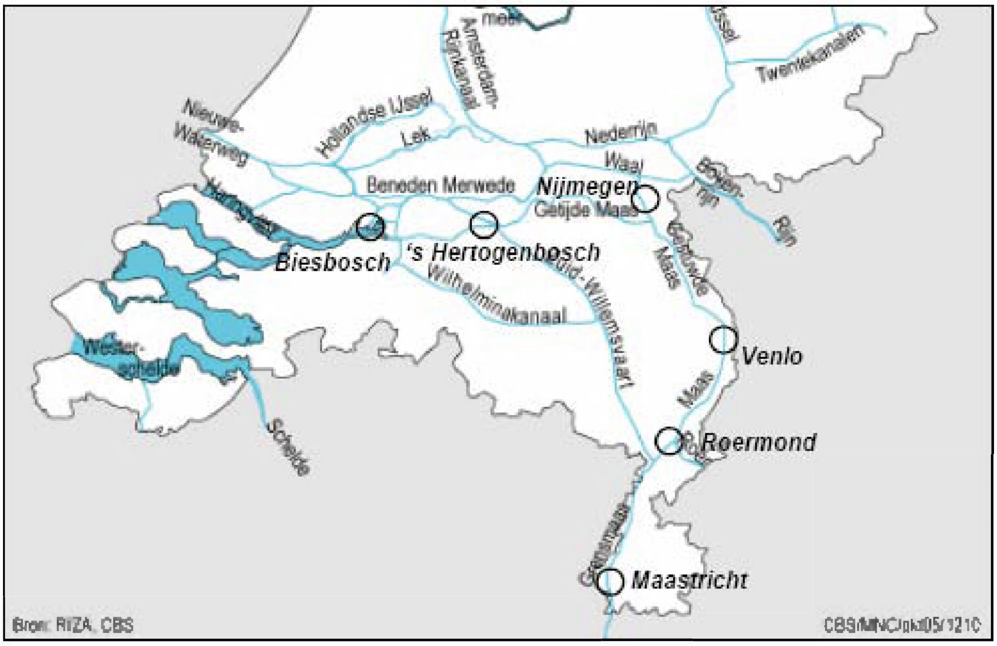


Figure 10. The Meuse in the Netherlands

Several (small) tributary streams join the Meuse in the Netherlands. The main ones are the Jeker, Voer, Geul, Roer, Niers, Dieze, Dommel and Aa. Important canals that are fed by the Meuse are Zuid-Willemsvaart, Wilhelminakanaal and Julianakanaal.

Table 5. The most important subcatchments of the Meuse in the Netherlands and their surface areas. Note that some subcatchments areas are partly situated in Belgium (B) or Germany (G) and therefore the sum of the catchments is larger than the Meuse basin area in the Netherlands. *Source table: Ministerie V&W, 2005*

Stream	**Area (km^2)**
Geul	388 (B)
Jeker	138 (B)
Voer, Margratenplateau, other streams	121
Geleenbeek	400
Vlootbeek	123
Roer	2436 (D)
Neerbeek	386
Peel	504
Niers	1320 (D)
Dommel, Aa, Dieze and Drongelens kanaal	2283 (B)

Weirs have been constructed along most of the Meuse to facilitate shipping; the only non-navigable part of this river is the southernmost part, the Grensmaas. Here, the Meuse meanders over shallow gravel banks; there are no weirs and the river flows swiftly at times of high discharge. Shipping goes along the Julianakanaal, which runs parallel to the Grensmaas. At Roermond, large lakes have been formed following gravel dredging. During the course of the years, the Meuse has cut increasingly deeper into the surrounding country between Cuijk and the Belgian border, resulting in a step-like terraced landscape in which the top terraces are the oldest river beds. This is a unique landscape by Dutch standards due to the vast differences in height. Old villages are situated at the transition point between low terraces and central terraces. No dykes are required here, since the banks are naturally high. Following the river downstream from Cuijk, the Meuse valley becomes a plain where both Meuse and Rhine have left sediment deposits. At this point, the river flows through high natural levees and low-laying sedimentary basins; this part of the river has been embanked. The major bed has levelled up rapidly since the dykes were constructed, so that the floodplains are currently situated at a much higher level than the surrounding area. The water pursues its course to the sea through the Bergsche Maas and the Nieuwe Waterweg; it also flows through the Haringvliet at times of high discharge *(Liefveld, W.M & Postma, R., 2007: Two rivers: Rhine and Meuse).*

The Rhine-Meuse estuary

Rhine and Meuse meet at the Rhine-Meuse estuary. Here, water levels are mainly determined by sea tides and to a considerably lesser extent by river discharge. Tidal influence runs through the entire course of the Nieuwe Waterweg. This influence is already noticeable in the river's downstream sections at Hagestein (Lek), Zaltbommel (Waal) and Lith (Meuse). At high tide, salt water enters the Nieuwe Waterweg, and travels as far as Dordrecht when the river discharge is low. If high sea tides coincide with low water discharges, this salt water can even reach the Haringvliet and the Hollandsch Diep (*Liefveld, W.M & Postma, R., 2007: Two rivers: Rhine and Meuse*).

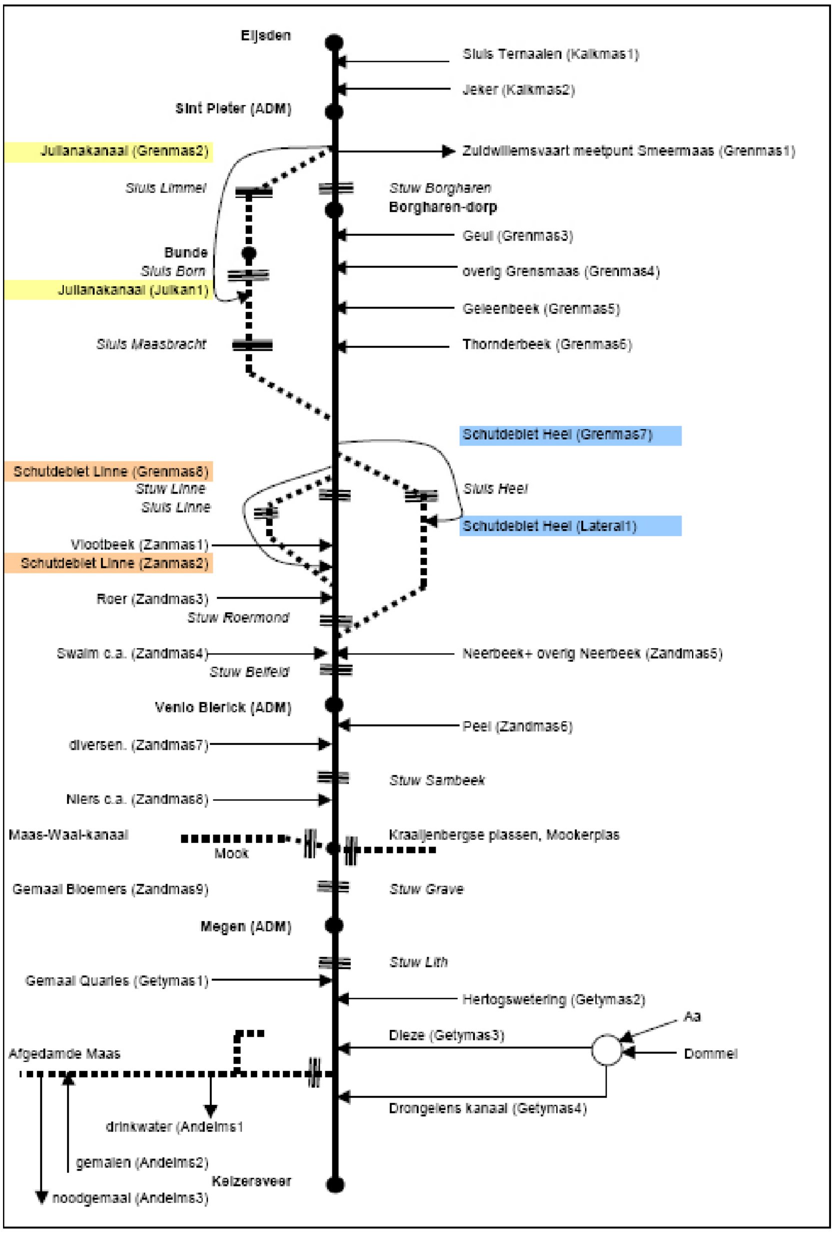


Figure 11. Schematic overview of the Dutch Meuse and its tributaries (*Ministerie V&W, 2005*)

At the Rhine-Meuse estuary, the Haringvliet sluices constitute the regulating cock for the distribution of discharge among the various tributaries. During times of average discharge, most of the river water flows to the sea through the Nieuwe Waterweg. A small part flows into the sea via the Haringvliet, where the river water reaches the North Sea at low tide through the 17 discharge sluices in the Haringvliet dam. When discharge is high, the sluices open still wider, and more river water ultimately flows out through the Haringvliet than through the Nieuwe Waterweg. With a Rhine discharge of approximately 9000 m^3/s, the sluices are completely open at low tide, while at high tide, they are always closed to prevent salt water from flowing into the Haringvliet. This transition area from river to sea consists of a tangle of watercourses. At low tide, the small banks, with their characteristic reed lands, are dry. The Biesbosch used to be a unique freshwater tidal area, but these tides have largely disappeared since the damming of Haringvliet and Hollandsch Diep. Despite this, it is still an attractive area with its mud flats, salt marshes, creeks, osier thickets, embankments, agricultural polders and riparian woodlands. The waters of the Rhine-Meuse estuary flow through low-lying country that is sometimes way below sea level (*Liefveld, W.M & Postma, R., 2007: Two rivers: Rhine and Meuse*).

2 Analysis and synthesis of the literature on future climate and hydrological scenarios on the Meuse river basin

2.1 Presentation of the AMICE TORD

The first action of the AMICE project has consisted in the implementation of a tool for sharing bibliographic references in order to pool knowledge. This tool is called AMICE TORD (Transnational Online Reference Database) and each partner (in particular those involved in the Work Package 1) can view and add references dealing with the Meuse, climate change and other topics of interest to AMICE.

2.1.1 Structure of the TORD and statistics

2.1.1.1 Structure of the TORD

The application that was chosen is *Wikindx*®. One of its advantages is the possibility to create as many user accounts as needed. Visitors can see the references, however a user account is necessary to modify the database and to add or delete publications (Figure 12).

In addition to entering basic bibliographic information (title, authors, years...), it is also possible to attach files (picture, pdf, doc...) and URL. Queries can be based on keywords, author and publisher by using two search forms available (quick & power search).

A system of categories based on issues of the AMICE project has also been developed to refine search (Figure 13).

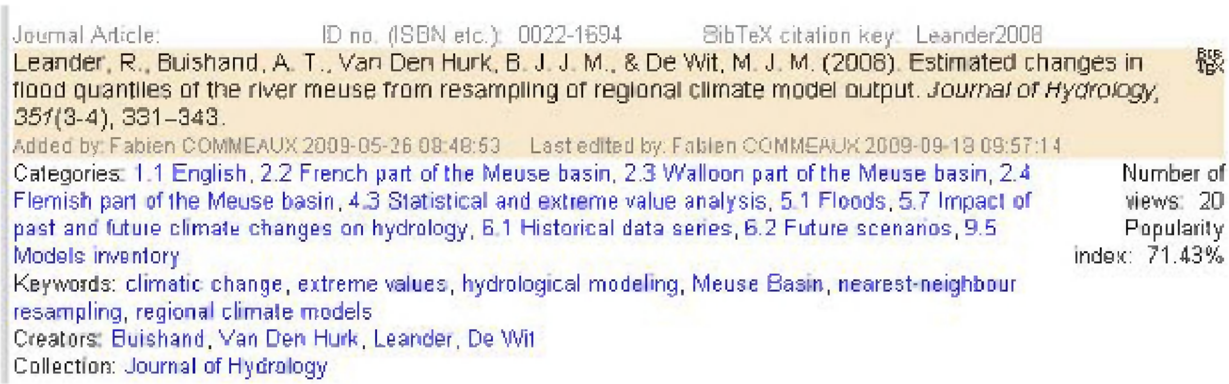

Journal Article: ID no. (ISBN etc.): 0022-1694 BibTeX citation key: Leander2008
Leander, R., Buishand, A. T., Van Den Hurk, B. J. J. M., & De Wit, M. J. M. (2008). Estimated changes in flood quantiles of the river meuse from resampling of regional climate model output. *Journal of Hydrology, 351*(3-4), 331–343.
Added by: Fabien COMMEAUX 2009-05-26 08:48:53 Last edited by: Fabien COMMEAUX 2009-09-18 09:57:14
Categories: 1.1 English, 2.2 French part of the Meuse basin, 2.3 Walloon part of the Meuse basin, 2.4 Flemish part of the Meuse basin, 4.3 Statistical and extreme value analysis, 5.1 Floods, 5.7 Impact of past and future climate changes on hydrology, 6.1 Historical data series, 6.2 Future scenarios, 9.5 Models inventory
Number of views: 20
Popularity index: 71.43%
Keywords: climatic change, extreme values, hydrological modeling, Meuse Basin, nearest-neighbour resampling, regional climate models
Creators: Buishand, Van Den Hurk, Leander, De Wit
Collection: Journal of Hydrology

Figure 12. Interface of the AMICE TORD (screenshot of a reference)

Nine categories were created, comprising 45 sub-categories. The two firsts categories pertain to language (one of the three official languages or English) and geographic area (national sub-basin of the Meuse, Meuse transnational basin, outside of the basin...). The seven other categories are optional and give information on topics (physiography, climatology, hydrology, trend analysis, drinking water, water hazard mitigation, water management system). When entering a new reference, the user can select as many categories as topics.

Thanks to this system it is possible to refine the researches of bibliographic references and to have an overview of the most (and least) represented subjects in the AMICE TORD.

Main categories and sub-categories

1. Language
1.1 English
1.2 French
1.3 Dutch
1.4 German

2. Basin
2.1 Meuse river
2.2 French basin
2.3 Walloon part
2.4 Flemish part
2.5 Dutch part
2.6 German part
2.7 Luxemburgish part
2.8 Adjacent basin
2.9 Outside of the basin

Optional categories and sub-categories

3. Physiography
3.1 Geology
3.2 Pedology
3.3 Topography
3.4 Hydrogeology
3.5 Geomorphology
3.6 Land Uses
3.7 Biodiversity
3.8 Water quality

4. Climatology
4.1 General features
4.2 Climate mechanisms
4.3 Statistical and extreme value analysis
4.4 Climatological mapping
4.5 Downscaling techniques

5. Hydrology
5.1 Floods
5.2 Low flows
5.3 Hydrological regime and hydrography
5.4 Hydraulic characteristics of the river bed
5.5 Hydrometry
5.6 Origin of water, natural and artificial water pathways
5.7 Impact of past and future climate changes on hydrology

6. Trend analysis
6.1 Historical data series
6.2 Future scenarios

7.1 Drinking water
7.2 Fluvial navigation
7.3 Agriculture
7.4. Hydropower, nuclear plant
7.5. Industries

8. Water hazard mitigation
8.1 Flood control
8.2 Low water supply
8.3 Impacted economic activities

9. Water management system
9.1 Flood forecasting
9.2 Low flows forecasting
9.3 Design flood
9.4 Water management services
9.5 Models inventory

Figure 13. List of categories and sub-categories created for the AMICE TORD

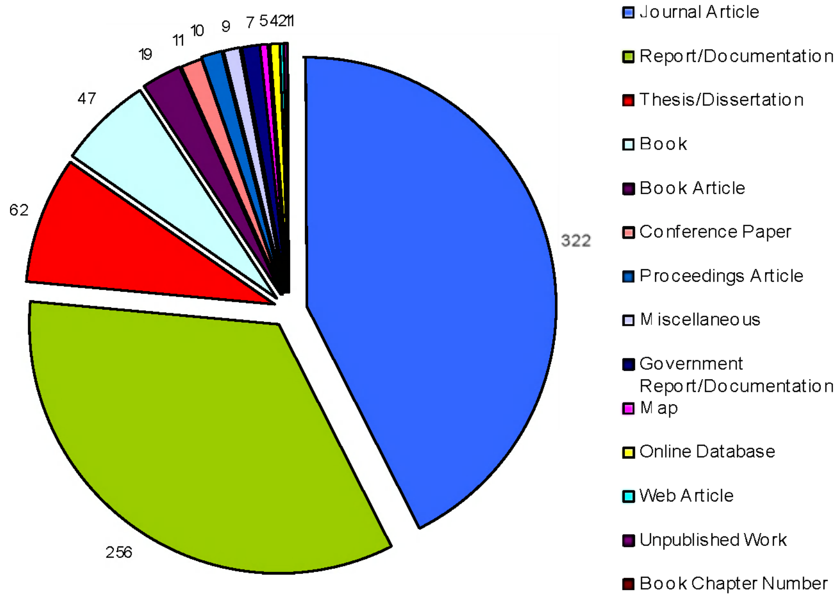
Another feature of *Wikindx*® is to allow each user to comment on the references by adding new fields as quotes, paraphrases, musings, and comments. Annotated references then enjoy a better visibility. Finally, this software is compatible with the *Bibtex* (.bib) file format, making it possible to import and export several references at once with Zotero for example (extension for Mozilla Firefox).

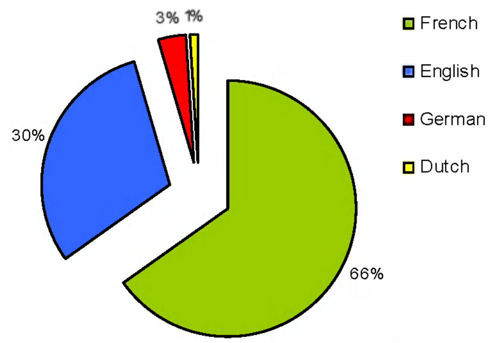
Since December 2009, hosting and administration of TORD are insured by the EPAMA and accessible on the official website of the AMICE project (www.amice-project.eu/biblio).

2.1.1.2 Statistics

Early 2010, 8 months after its start, the AMICE TORD had about 800 references and more than 1.000 authors (Figure 14).

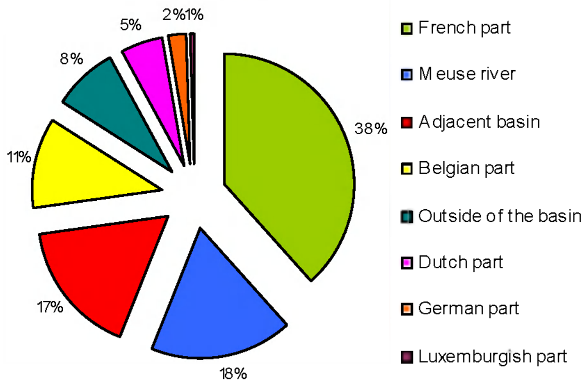
Figure 14. Overview of the TORD references





- Most references (≈80%) are journal articles or reports/documentations. 9% are books or book articles. Finally, PhD thesis and dissertations represent 8% of the total content of the database.

- About two thirds of the publications are written in French. The rest is predominantly written in English. Only 40 references are in German or in Dutch.

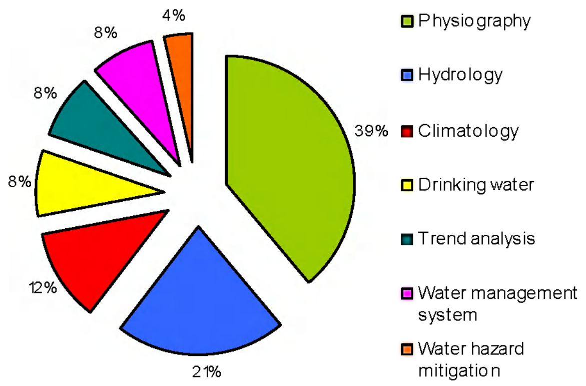


The origin and language of publications depend largely on the contributions of Partners. The low proportion of German and Dutch publications only reflects the lack of time to carry this task.

- About 60% of the references study one or several national sub-basin, often the French (66%) or Belgian (20%) parts of the Meuse. The Dutch part is less documented (only 5%). 18% of the TORD deals with the whole Meuse basin and 17% concern an adjacent basin interesting for the AMICE project because of its proximity (often the Rhine). 8% are considering a further away area (e.g. climate change on another basin in the world) or general topics that can sometimes be transposed to the Meuse (e.g. method of downscaling)

The filling and using of the database is an ongoing process. The share between the different topics and languages may evolve with the development of the AMICE actions until 2012.

- More than one third of the topics cern physiography. Among these publications, 20% deals with geology and 12% with climatology (often climate change).



2.1.2 Identification of gaps and missing knowledge / promotion of new studies

The most important study on climate change impacts on the Meuse basin was carried out by De Wit et al., 2007. The conclusions are on the possible increase of extreme events, both high and low flows. But the exact impacts need to be detailed.

In France, no study exists specifically on the Meuse basin. Research institutes have started analyzing the possible effects of climate change, but they are working at the national scale. The diversity of climates in France, with a huge contrast between the Mediterranean region and the North-East area, calls for more detailed studies. However, the methods developed can be used again in AMICE. The Ministry of Environment has selected the Meuse basin has one of the pilot basins for climate impact studies. The AMICE project will provide methods for the other river basins in France.

To our knowledge no studies concerning the impacts of climate change on the water balance and stream flows have been undertaken specifically for the Rur and Niers basin areas. Such studies have only been carried out for the adjacent sub basins of the Meuse (e.g. (*de Wit et al., 2007*), (*van Pelt et al., 2009*)) or the Rhine (e.g. (*Pfister et al., 2004*), (*Middelkoop et al., 2001*)). Thus in the framework of AMICE impact studies specifically for the Rur and Niers basin areas will be undertaken for the first time. For the impacts of climate change on the water balance of the Rhine basin area (*Gerlinger, 2009*) states that there are large regional differences in the simulation results. Therefore our studies will provide new findings.

2.2 Future climate scenarios

2.2.1 Fundamentals on climate scenarios

The greenhouse gases emission scenarios commonly used in studies of climate change have been developed by the IPCC (Intergovernmental Panel on Climate Change) since 1996 and they have been described in the SRES (Special Report on Emission Scenarios). Four groups of scenarios exist depending on factors determining the emissions of greenhouse gases, their quantity and the evolution of their concentration in atmosphere. A total of forty scenarios consider different possibilities of demographic, economic, and technological evolutions and their impacts on emissions.

For each group of scenarios, one scenario of reference has been selected by the IPCC (A1B, A2, B1 and B2) (Figure 15). Thereafter, two other scenarios related to new forms of technological progress have been added (A1FI and A1T). These 6 scenarios are the most used for GCM simulations and for impact studies of climate change (Figure 16).

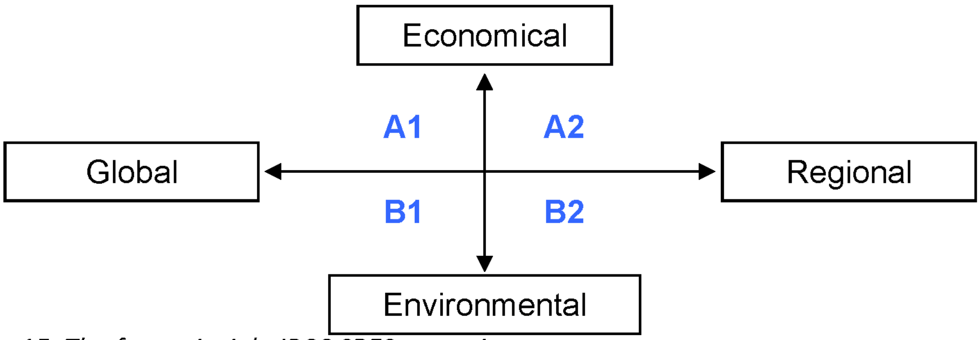


Figure 15. The four principle IPCC SRES scenarios

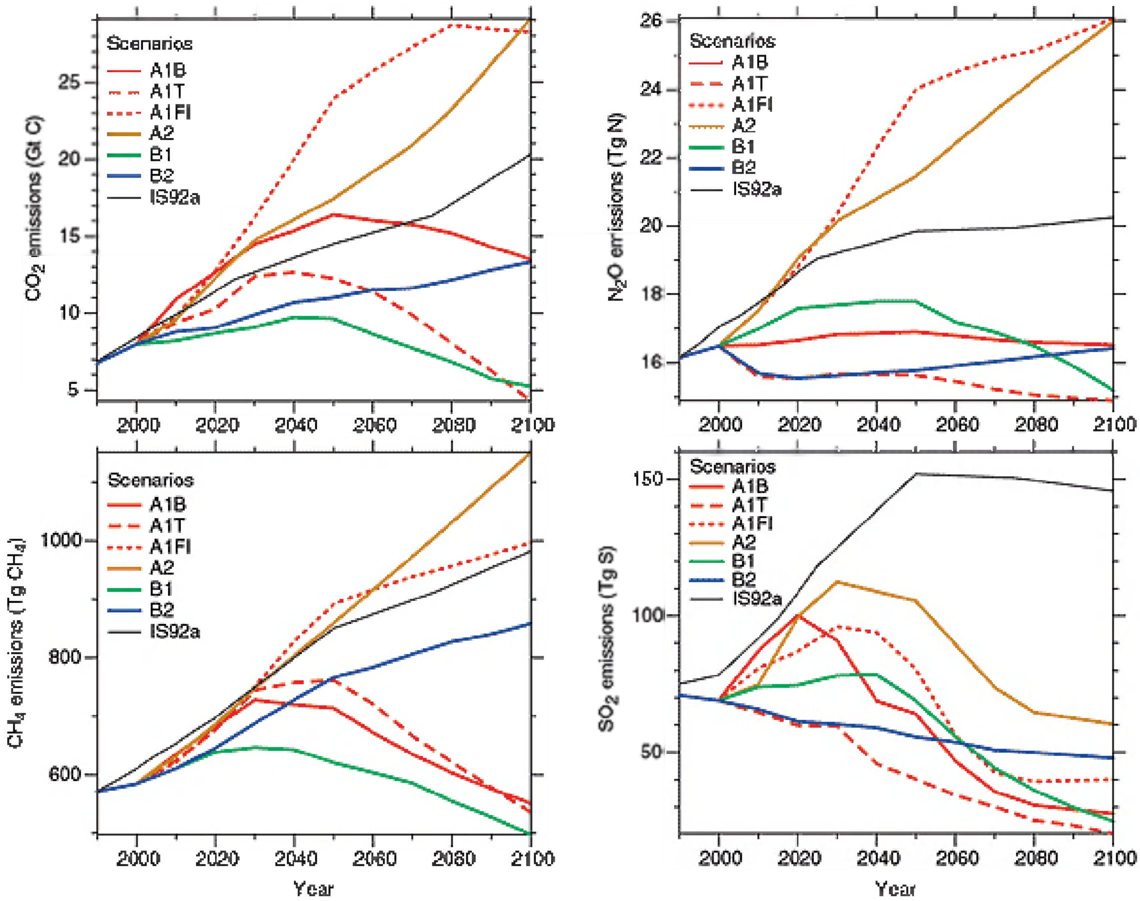


Figure 16. Evolution of some GHG during the 21st century (IPCC, 2001).

For example, emission scenarios A2 and B1 are described in the SRES report as follow:

A2 : "The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines."

B1 : "The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives."

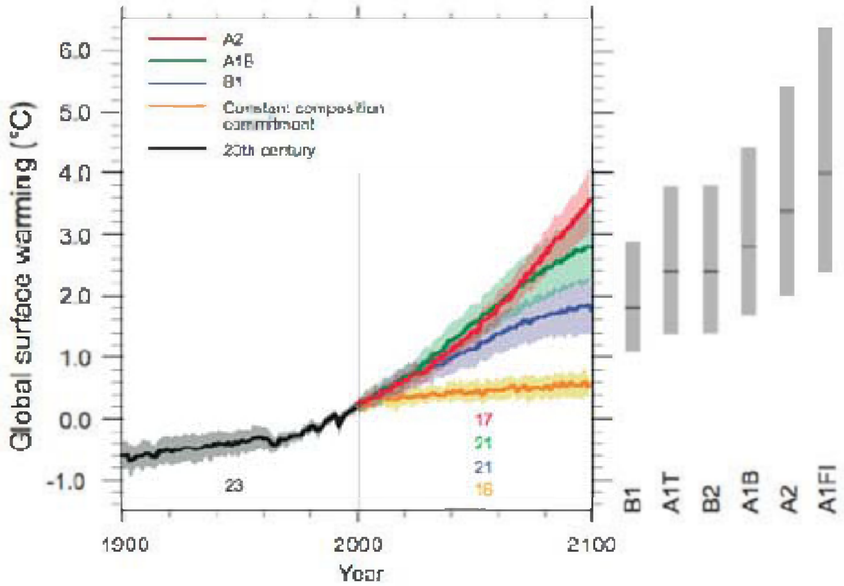


Figure 17. Evolution of the global surface warming during the 21st century (IPCC, 2001).

B1 and A2 scenarios are respectively the most optimistic scenario and the most pessimistic scenario in terms of global warming (Figure 17). Consequently impact studies produced by AMICE come to a fairly complete range of variation in air temperature and precipitation.

For climate simulations, the most used models are the GCM (Global Climate Model). They model the atmospheric circulation throughout the earth, climatic influences of the ocean and ocean/atmosphere interactions. Because of their low resolution (only few hundreds kilometers and daily step) it is not possible to use them for impact studies at the scale of a basin or sub-basin. Hydrological impact studies require data at a finer scale and at hourly step (especially for high flows), depending however on the size of the basin.

A data processing for the change of spatial (and eventually temporal) scale is also necessary (Figure 18). There are several approaches:

- Statistical downscaling:

These approaches are based on the assumption that there is a direct or indirect link between the local meteorological variables and atmospheric circulation variables. The model assigns a climatological observed structure to each atmospheric simulated daily state. This method requires a long and homogeneous climatological dataset.

- Dynamical downscaling :

There are three types of approaches:

- The increase in the resolution of the atmospheric model outputs (important computation time).

- Using a high resolution climatic model (RCM) only on the study area and forcing the limits with low resolution climatic model (GCM).

- Using a climatic model with variable resolution: high resolution on the study area and gradual decrease as the distance (e.g. ARPEGE Climate)

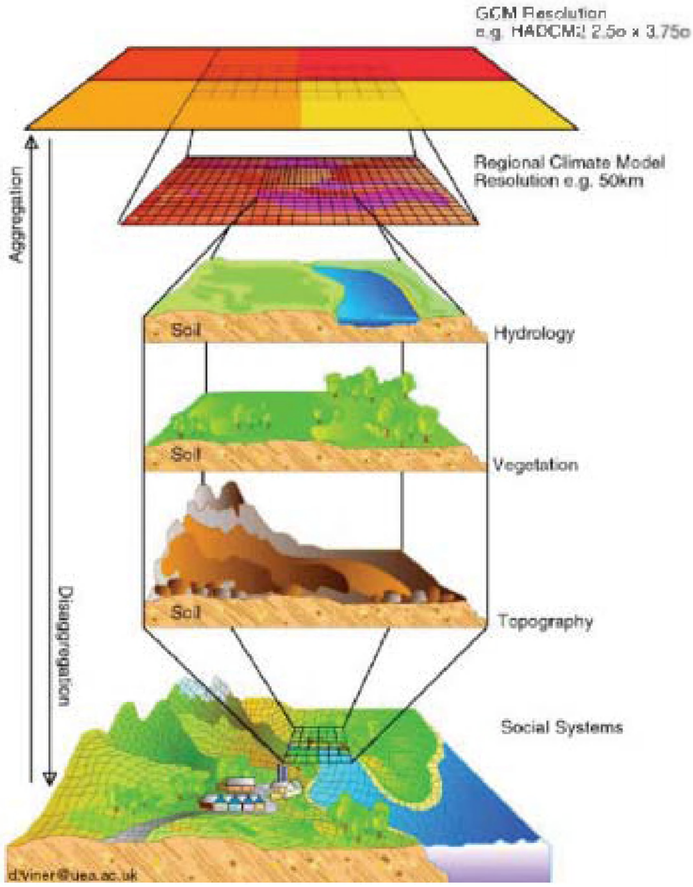


Figure 18. From global to local scale (D. Viner on http://www.cru.uea.ac.uk/link)

2.2.2 Overview of existing climate scenario databases

The WP1 began with a questionnaire sent to all partners involved in action 3. Thus a list of all databases known and used by partners has been established to make an inventory (Table 6). The objective was to see if one of them could be used as such.

Existing climate scenarios databases													VS AMICE PROJECT
SRES scenarios	**Climate experiment or model**	**Data provider and contact person**	**Downscaling method**	**Time step of simulation**	**Climate variables**	**Source of data**	**Data access and availability**	**Spatial resolution of the grid**	**control run**	**Time period for the scenarios**	**Data format**	**Geographical area**	**Suitability of climate simulations for Actions 6,7, 8, 23, 24**
A1B/A2/B1	ARPEGE-climat v4.6	Météo-France (L. Labbé)	Bias correction (Q-Q plot)	Daily	Tm, RH, precipitation, wind, PET	Météo France	convention with DIREN Lorraine	25x25 km	1971 2000	2001-2100		French part of the Meuse basin	Not suitable for calculating the impact of climate change on High flows variables (e.g. Qhx100)
A1B/A2	ENSEMBLES	ENSEMBLES EU project	No bias correction	Sub-daily	Air temperature, precipitation, etc.	ENSEMBLES GCM/RCM	http://ensemblesrt3.dmi.dk/extended_table.html	25x25 km 50x50 km	1950 2000	2001-2100	Netcdf	Europe	ditto
A2-B2 A1B/ A2/B1/B2	HadCM2 CGCM1 CCI-HYDR	UK Canada KU Leuven (P. Willems)	By RMI (E Roulin) By RMI (E Roulin) Perturbation approach	Daily Daily Daily Hourly	P and ETo perturbations factors per season (winter – summer) P, ETo, Air temperature, wind speed	A2/B2 PRUDENCE; A1B/B1 IPCC AR4	Restricted access Restricted access http://www.kuleuven.be/hydr/CCI-HYDR.htm, available	1 perturbation factor by tributary (2 tested)	1961 1990	2010-2039 2040-2069 2070-2099 2071-2100	ASCII ASCII	? Flemish part of the Meuse basin	ditto limited suitability for AMICE (absence of hydrologic models for Meuse in Flanders, tackled by research of Deltares with Belgian perturbation tools on their models)
A2-B2	PRUDENCE GCM/RCM matrix	PRUDENCE EU project	No bias correction	Sub-daily	Air temperature, precipitation, etc.	PRUDENCE EU project	http://prudence.dmi.dk/, available	50x50 km	1961 1990	2070-2099	Netcdf	Europe	ditto (only one future time slice available)
A1B/A2/B1	ARPEGE-climat v4.6/15 IPCC GCMs	CERFACS (C. PAGE)	Weather regime	Daily, Hourly	Air temperature, precipitation, PET, etc.	CERFACS	Public access	8x8 km	1961 1990	2001-2100	ASCII	French part of the Meuse basin	Suitable for all Actions Do not cover the whole basin

Table 6. Existing climate scenarios databases (v.11/2009)

2.2.3 Climate projections for the Meuse basin

In addition to the existing databases list, a synthesis of literature about the climate change on the Meuse basin was performed. The purpose of this step is to know if the subject has already been sufficiently documented to allow the execution of AMICE works based on the findings of existing studies. These studies are presented in Figure 19 for the future change in precipitation and in Figure 20 for the future change in air temperature.

Several GCMs and RCMs are used in the studies. They all give quite clear trends for the Mediterranean region (very strong increase of temperature and decrease of precipitations) and the Scandinavian region (strong increase of temperature and increase of precipitation). But the Meuse basin lies between these two regions and, depending on the models used, the Meuse basin gets dryer or has increased precipitation.

The Amice partners decided to split climate model outputs into two future climates to study the two possible evolutions of the basin's climate: a wet one and a dry one. This pragmatic approach was adopted due to: (1) a limited time to use what was available, (2) the uncertainty of some climate models saying it will be drier and others indicate a wetter future. However most models indicate a drier summer. And most models in the Rhine catchment say that winters will be wetter.

We can mention here that, in the framework of the EU PRUDENCE project, Blenkinsop and Fowler (2007) tested several regional climate models, in particular on the Meuse basin. The regional climate models yielded a wide range of abnormalities: from 0% change to 60% change on a same month. It is thus not surprising that the AMICE Partners are confronted with very distinct outputs from their national climate simulations. The same authors mention also that several models demonstrate the spatial variability of climate change. It is noted that the drought effect will be more pronounced in the southernmost and northernmost parts of the Meuse basin.

In the Netherlands, until 2006, the climate scenarios of Waterbeheer 21e eeuw or WB21 (Water Management 21st century, 2000) were used as a reference for future water management. Based on more recent insights from worldwide climatological research, these scenarios were replaced by the KNMI 2006 scenarios, presented by the Royal Netherlands Meteorological Institute (KNMI). These (four) scenarios now serve as the national standard in adaptation policies in the Netherlands (Hurk et al., 2006; Ministerie van Verkeer en Waterstaat (2009) Nationaal Waterplan).

The scenarios proposed by the AMICE Partners are plausible scenarios: they are not much different from the trends used in other climate impacts studies. However, it does not mean that the wet or dry climate scenario will indeed happen. The water managers and decision makers should be very aware that our results only represent two possible future climate trends, without any absolute certainty on which climate will occur.

Figure 19 : Future Trends of Precipitation on the Meuse river Basin: A Synthesis from the Literature

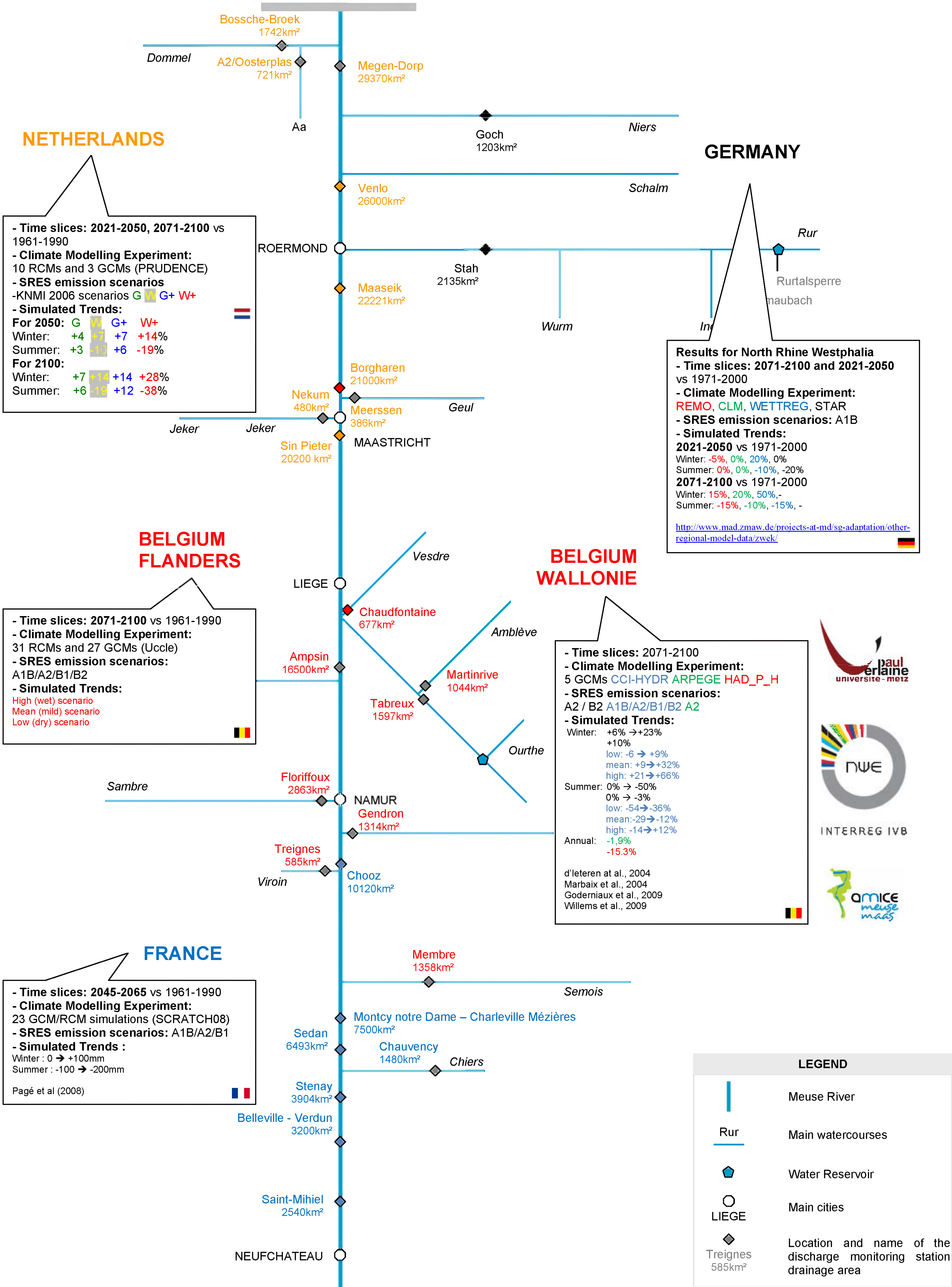
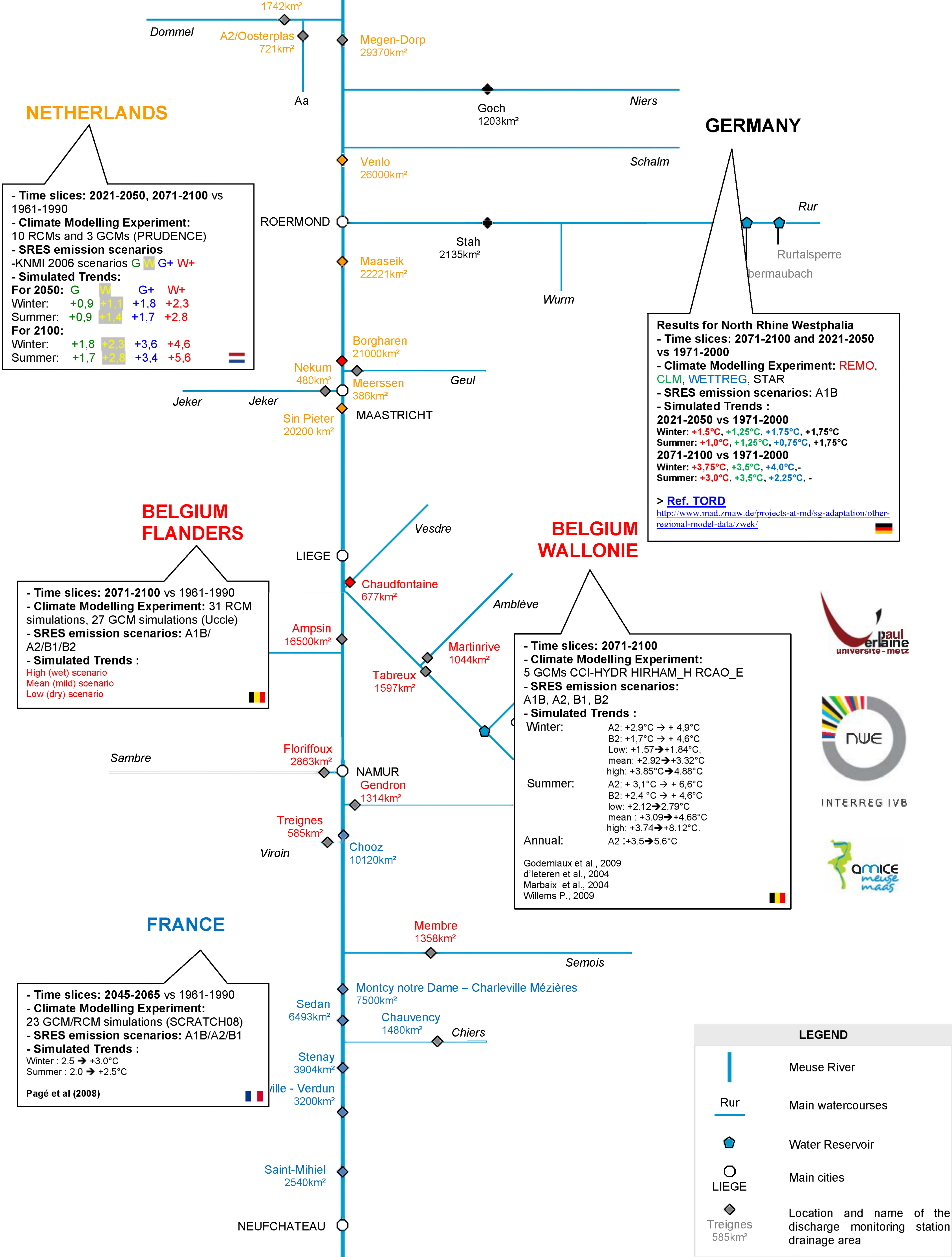


Figure 20 : Future Trends of Air temperature on the Meuse river Basin: A Synthesis from the Literature



2.3 Future hydrological scenarios

In the same way as made for climate change, a synthesis of the literature was conducted about impacts of climate change on the hydrology of the Meuse. The existing studies are indexed in Figure 21 for high flows and in Figure 22 for the low flows.

This bibliographic step shows that there is no climate database ready to use for the AMICE Project. Indeed in most of the cases the climate databases do not cover the whole basin. When it does, a bias correction is always necessary which was not achievable within the time-frame of the project.

Concerning the climate change studies, the literature contains interesting works but the results are generally too heterogeneous and sporadic to be used at the scale of the whole Meuse basin. Hydrological studies are difficult to use and generally do not use the same impact variables which makes them difficult to compare.

Time slices used in former studies are also different. The most widely used is 2071-2100. The climate trends are indeed clearer towards the end of the century. The 30 years span is most common in hydrology: most discharge monitoring stations have been installed in the 1960s or 1970s and thus our reference period is now 30 years long. In AMICE, we decided to study also the 2021-2050 period: we intend to propose an adaptation strategy and knowledge of the medium-term situation will help us define priorities and urgent adaptation measures. Information on the medium-term is more useful for local policy-makers than the long-term.

The main finding that emerges is that the easiest solution for the AMICE Project was to create new climate and hydrological scenarios. To this end, the optimal solution is to apply the delta change approach to existing national climate scenarios.

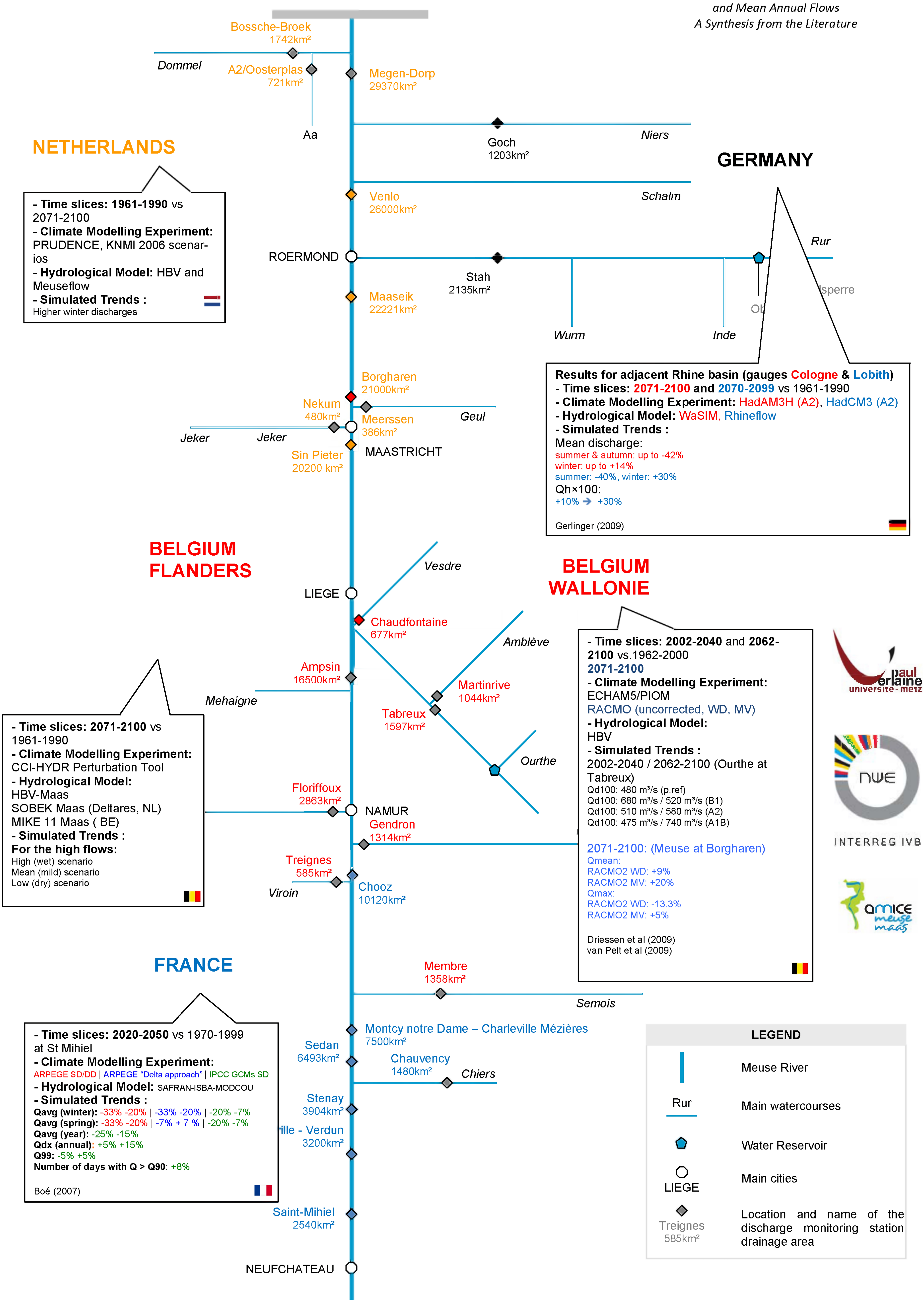
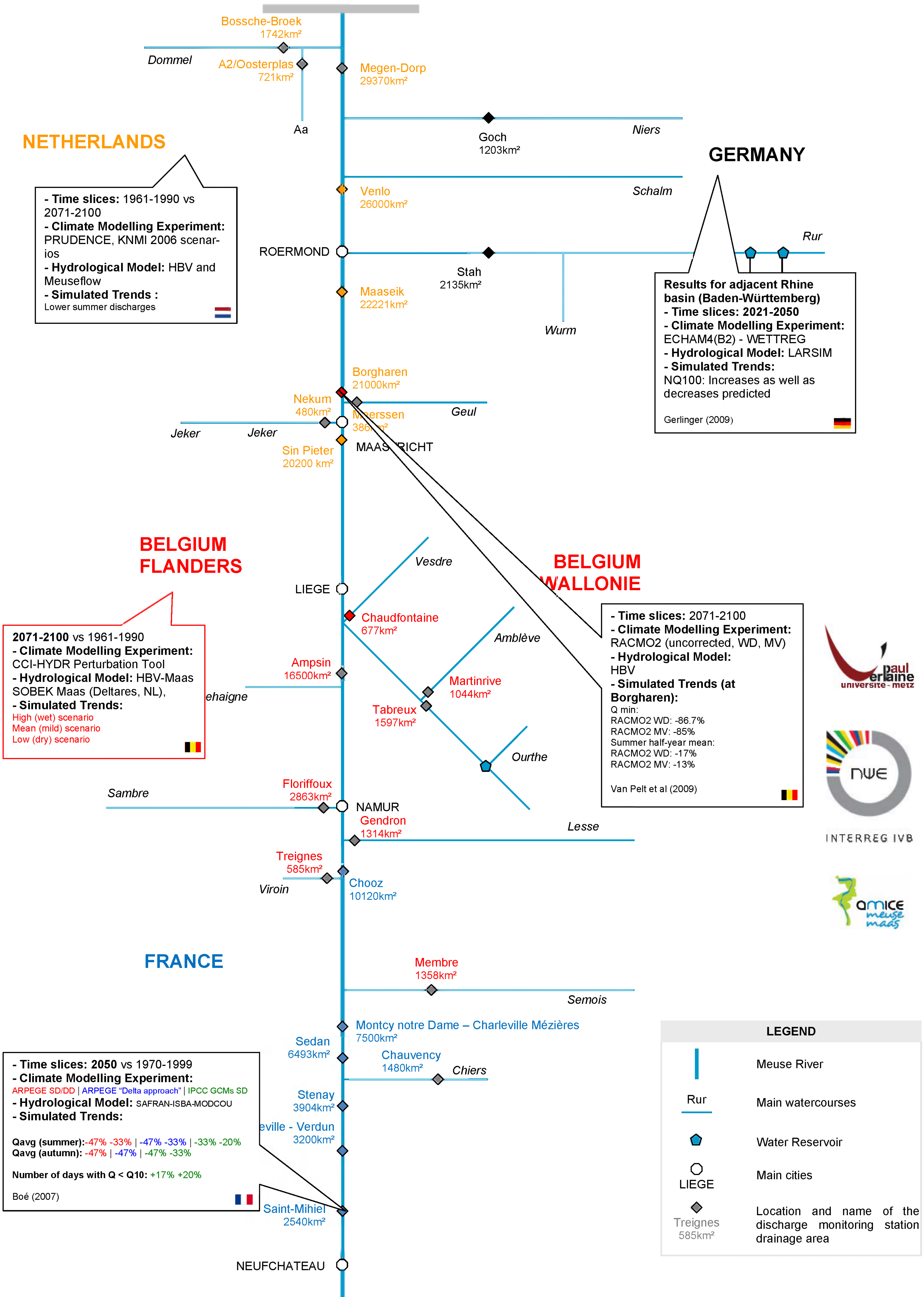


Figure 21. Future Trends of the Meuse High Flows and Mean Annual Flows
A Synthesis from the Literature

Figure 22. Future Trends of the Meuse Low Flows
A Synthesis from the Literature



3 Production of future climate scenarios

3.1 Material and methods

3.1.1 The delta change approach

The delta change approach is the method selected by the AMICE partners for producing hydrological scenarios. Seasonal trends (% for ΔP and °C for ΔT) have been provided by meteorological national agencies for the 2021-2050 and 2071-2100 periods based on GCM simulations forced with emission scenarios (Figure 23). The seasonal trends have then been used to force a present climatology (i.e. E-OBS gridded climatology) on the 1961-1990 or 1971-2000 periods.

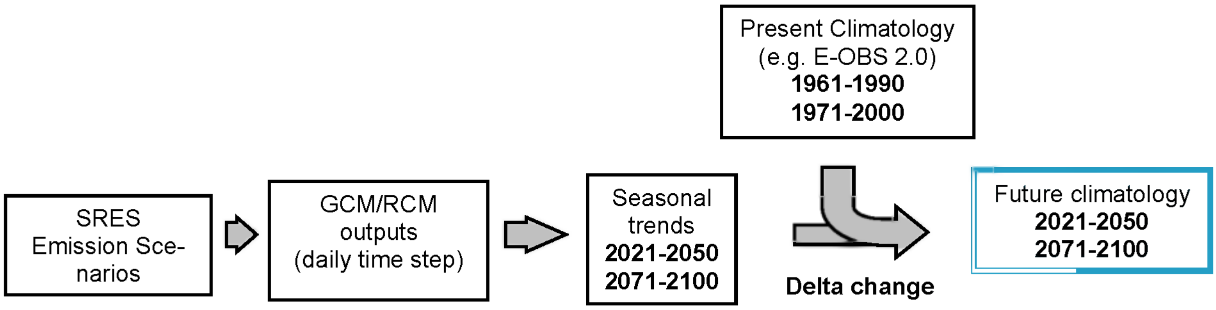


Figure 23. Flowchart of the delta change approach applied for climate scenarios generation.

This downscaling method has been implemented to create one wet and one dry scenario for each period and for each national sub-basin.

3.1.2 Presentation of the baseline climatology

3.1.2.1 Partners' hourly database

The SAFRAN database was used by EPAMA. It is a mesoscale (8km resolution on extended Lambert-II projection) atmospheric analysis system for surface variables. It is managed by Météo-France. SAFRAN produces an analysis at the hourly time step using ground data observations. One of SAFRAN's main features is that it is based on climatically homogeneous zones (600 over France) and is able to take vertical variations into account. SAFRAN takes into account all of the observed data in and around the area under study. The analyses are computed every 6 hours, and the data are interpolated to an hourly time step.

EPAMA accessed the data through a Convention signed between Météo-France, owner of the data, and the DREAL Lorraine (Direction Régionale de l'Environnement, de l'Aménagement et du Logement), funder of the AMICE project. The points for which climate data are available on the Meuse basin are represented on Figure XX (French basin area of the Meuse basin, hydrological simulation).

For the Walloon part (Figure 24) of the Meuse basin, four measured stations provide hourly rainfall from 1967 to 2000 (Table 7):
- Rochefort (longitude : 5°13'26,086'', latitude : 50°13'23,356'')
- Bierset (longitude : 5°26'54,071'', latitude : 50°30'40,172'')
- Nadrin (longitude : 5°40'53,067'', latitude : 49°59'35,928'')
- St-Hubert (longitude : 5°24'04,089'', latitude : 49°52'31,675'')

Data are provided by the SETHY (Service Public de Wallonie, Direction générale opérationnelle Mobilité et voies hydrauliques, Direction de la Gestion hydrologique intégrée, Service d'Etudes Hydrologiques).

Station's name	River	Measure's name	Owner	Longitude	Latitude	First hourly d.	Last hourly d.
Rochefort	Lesse	PVG IRM	IRM	5°13'26.086''	50°13'23.356''	03/01/0967	30/04/2005
Bierset	Meuse	PVG IRM	FAe	5°26'54.071''	50°30'44.172''	02/01/0967	30/04/2005
Nadrin	Ourthe	PVG IRM	IRM	5°40'53.067''	49°59'35.928''	02/01/1967	30/04/2005
Saint_Hubert Aéro	Ourthe Occidentale	PVG IRM	RVA	5°24'04.089''	49°52'31.675''	03/01/1967	30/04/2005

Table 7. Measuring stations in Walloon Region.

For these stations, only daily air temperature data are available. For the stations of Rochefort, Nadrin and St-Hubert data are available from 1967 to 2000, for the station of Bierset, they are available from 1979 to 2000.

Some rainfall data are missing:
- At Rochefort, 812 days of data are missing on 34 years,
- At Nadrin, 638 days of data are missing on 22 years,
- At Bierset, 276 days of data are missing on 34 years,
- At St-Hubert, 32 days of data are missing on 34 years.

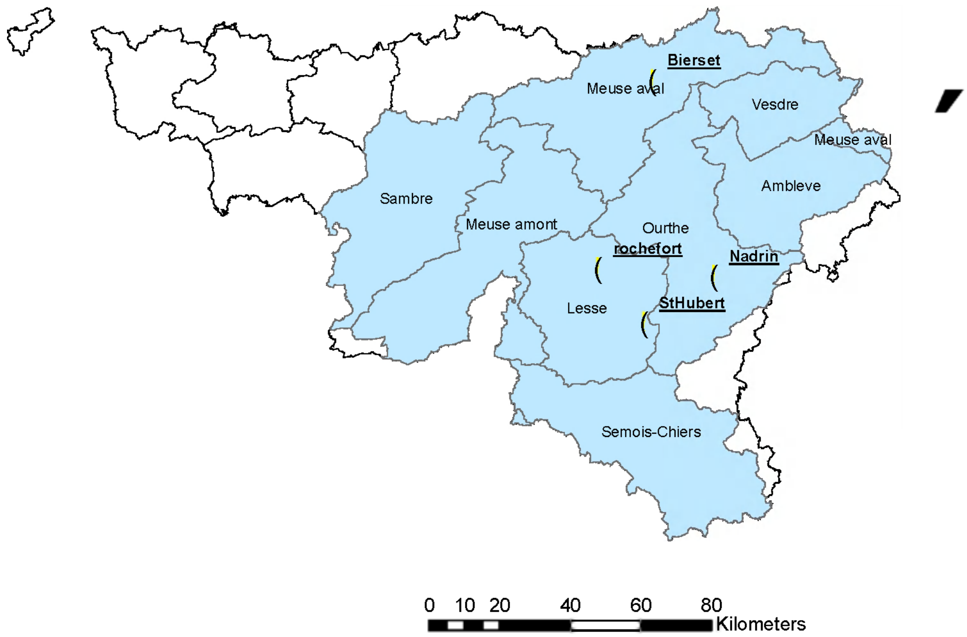


Figure 24. Location of measured stations in Walloon Region.

For the Flemish part, Input data are the 30 year time series for precipitation, air temperature and PET_0 on a daily base. For the control period (1969-1998) the series from KNMI (Dutch Royal Meteorological Institute) for all sub basins of the Meuse based on data from KMI and Météo France. More information about this can be found in Leander et al. (2005).

The North Rhine-Westphalia State Agency for Nature, Environment and Consumer Protection (LANUV) has kindly given us the permission to use precipitation data from the ExUS project. The air temperature data from the DWD of the KLAVE project were also kindly provided by the LANUV. Both data have been recorded by pointwise measurements.

In Figure 25 an overview of the locations of the provided precipitation records is given. The green dots show all stations where data was available. Since not all records were long enough for the necessary simulations of a thirty year period, only the stations with an additional red point could be used for our purposes. Only these stations had records covering the period from at least 1970-2000. As one can see, most stations are assigned to an area of several hundred square kilometers. The maximum appears for station Borschemich (about 620 km²). For none of the stations the assigned area is smaller than 25 square kilometers. At least for statistical precipitation values this is the upper limit up to which the precipitation values may be used without reducing the values depending on the assigned area and the duration of a specific event (Verworn, 2008).The thirty year period from 1961-1990 would have caused an even much coarser resolution of the data and thus even larger areas to be assigned to the stations.

Since no models for the area upstream of the reservoir Obermaubach were available only recordings from the stations Raffelsbrand, Kornelimünster, Borschemich, Dülken, Heiligendorf, Kronen and Hoppenstedt were used.

The data result from continuous recordings. Before they were used as input for the rainfall-runoff models they have been aggregated to an hourly resolution.

In Table 8 an overview over the mean annual sum of precipitation is given. It can be seen that the 1980s have been wetter than the antecedent and the subsequent decade. Concerning the Rur basin area an increase in annual sum of precipitation from north to south can be seen. As more detailed studies (Bogena et al., 2005) have shown this is known to be at least qualitatively correct. Concerning the Niers basin area the mean annual sum of precipitation for station Heiligendorf seems to be extraordinary high. Both to the north and to the south the mean annual sum of precipitation decreases following the available records.

Table 8. Overview of mean annual sum of precipitation for 1971-2000 and for according decades

	1971-1980 [mm]	1981-1990 [mm]	1991-2000 [mm]	1971-2000 [mm]
Hoppenstedt	611	717	713	680
Kronen	760	906	845	837
Heiligendorf	838	1.085	984	969
Dülken	633	734	739	702
Borschemich	625	789	727	714
Kornelimünster	763	915	851	843
Raffelsbrand	827	1.112	1.077	1.005

In Figure 26 an overview over the air temperature stations that have been used for the hourly high-flows simulations is given. The temporal resolution of the data is – different to the precipitation data - one day. The recordings have been done in the morning at 7:30 am. Again the spatial resolution of the data is very coarse. In comparison to precipitation data we regard this to be less crucial.

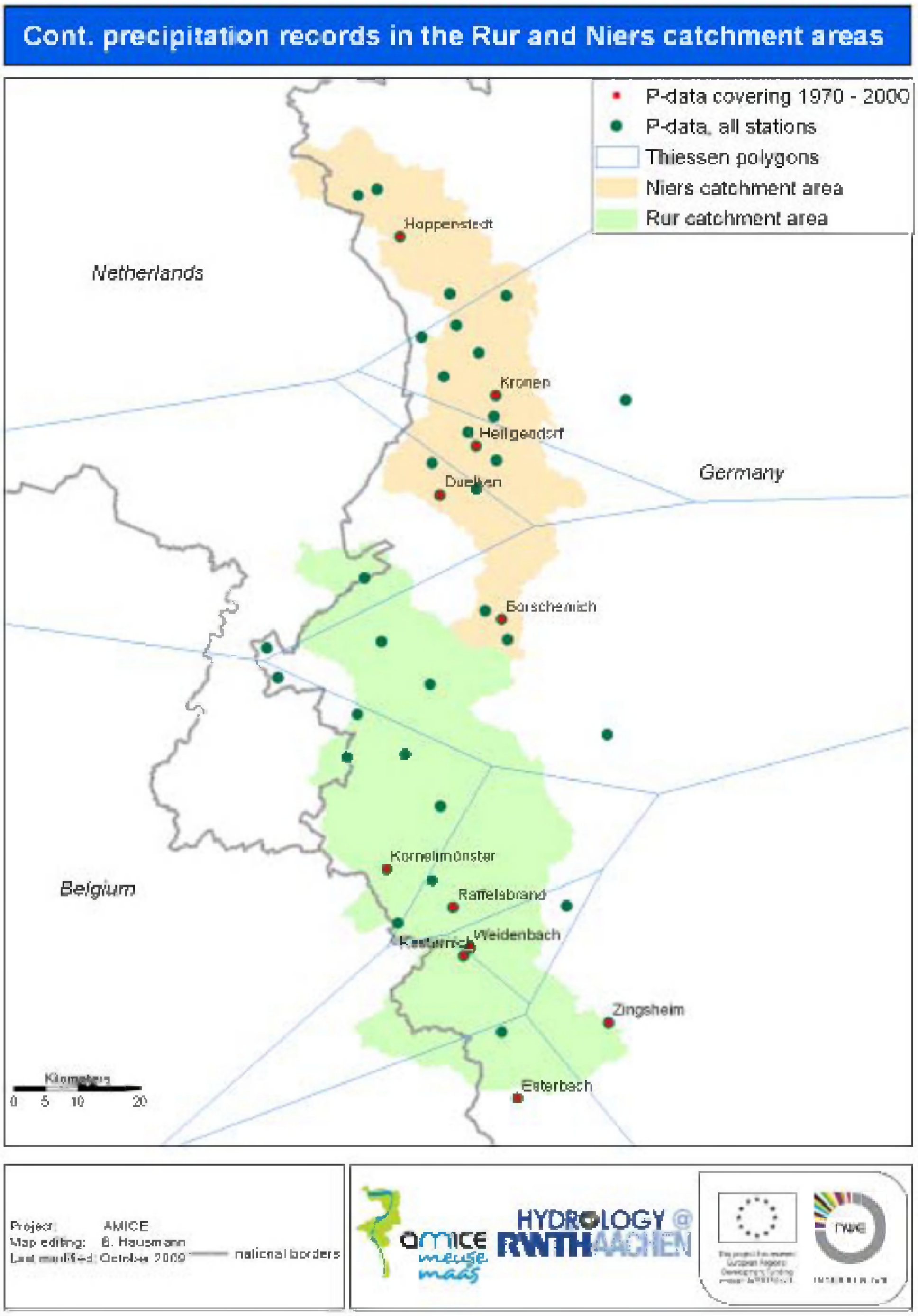


Figure 25. Overview over the spatial distribution of the precipitation records

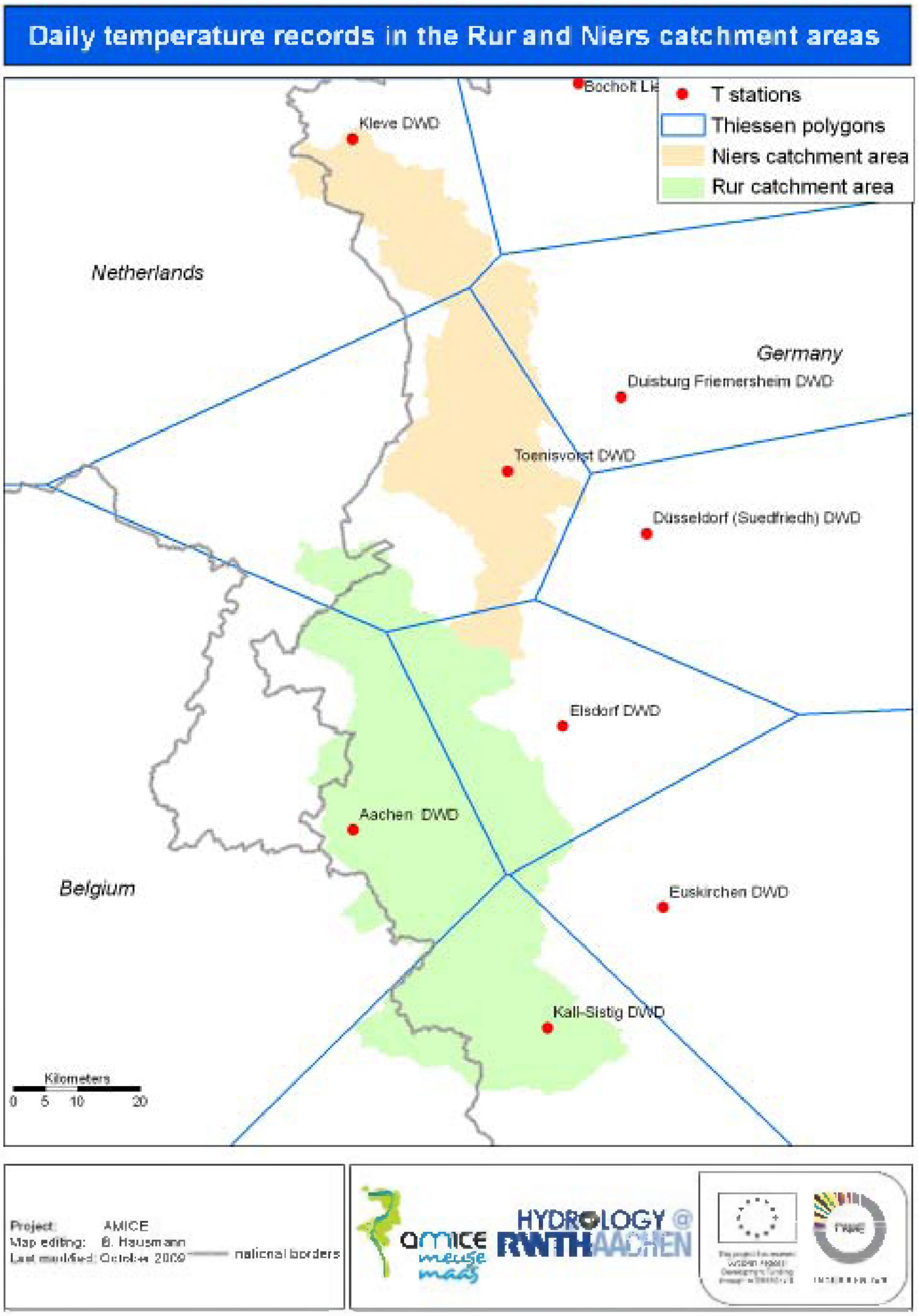


Figure 26. Overview over the air temperature stations

As shown in figure 27 the mean monthly air temperatures are very similar for the stations. The only exception is Kall-Sistig. One reason for this is its elevation of 505 m above sea level. The next highest station is Aachen with 202 meters above sea level. The other stations have elevations between 31 and 85 meters.

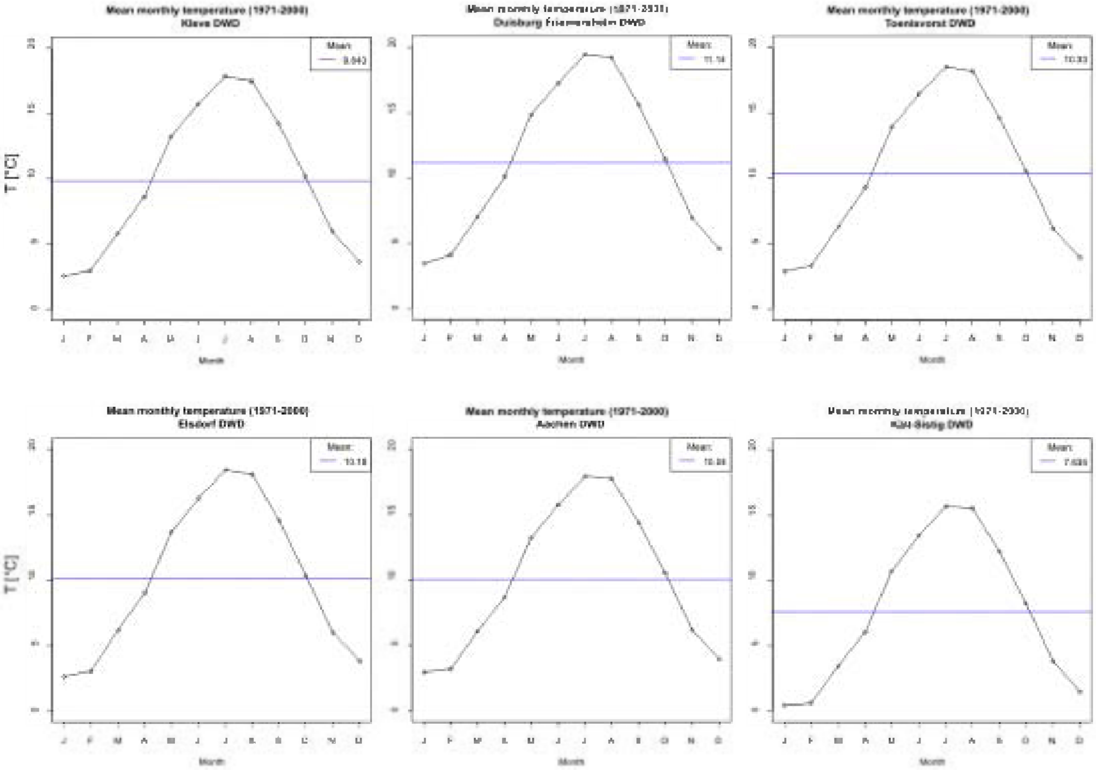


Figure 27. Measured mean monthly air temperatures for 1971-2000

3.1.2.2 Daily E-OBS gridded database

The daily climatological database used for hydrological simulations is the E-OBS 2.0 climatology provided by the European Climate Assessment & Dataset project. This database contains daily precipitations and air temperatures (2 meters) from 1950 to 2008 for Europe (Haylock et al. 2008). Data from meteorological stations are collected and distributed on two regular grids 0.5° and 0.25°.

For the HBV-model used to calculate the discharges for Sint Pieter in the Netherlands, the E-OBS dataset gives (still) unsatisfactory results. This might be due to the fact that in the E-OBS dataset, fewer weather stations are included than in the dataset the HBV-Meuse model was calibrated with.

KNMI provided Deltares with a dataset with mean values for the 15-HBV sub-basins. It consists of daily precipitation, temperature reference evaporation data for the period 1969 to 1998, and is based on a large amount of meteorological data from France and Belgium.

3.1.3 Evapotranspiration Calculation

For modeling purposes we also need daily potential evapotranspiration values (PET). This third variable is calculated from mean daily air temperature and latitude on each point of the grid by the method of Oudin (2004).

3.1.4 Selection of climate modeling experiment and scenarios

The Table 9 presents the characteristics of the national scenarios used by each partner to create its own wet and dry scenarios (France, Walloon, Germany, and Netherlands/Flanders).

It makes a big difference that it rains 20% stronger or 20% longer. The climate scenarios available presently cannot precise this point. However, most climate-related projects are modifying the intensity of rainfalls but not their duration. The AMICE project will follow this line. This decision was mainly agreed because our interest is on the maximum or minimum discharges, and less on the volume of the flood. The maximum discharge is related to the water height and determines the area which is flooded. The volume is related to the duration of the flood itself and is important to calculate how long the area will be flooded. In AMICE we assume that the flooded area can be modified but that the flood durations will remain the same as present days.

Table 9. Main characteristics of national climate scenarios

	SRES scenarios	Climate experiment or model	Data provider and contact person	Downscaling method	Source of data	Type of simulation	Time period for the control run
French part of the basin	A2/A1B	ARPEGE-climat v4.6	Météo-France (L. Labbé)	Bias correction (Q-Q plot)	Météo France	Transient simulation	1961-1990
Walloon part of the basin	A1B/ A2/B1/B2	CCI-HYDR Perturbation Tool	KULeuven (P. Willems)	statistical	Royal Institute Belgium		1961-1990
German part of the basin	A1B	WETTREG (wet scenario) CLM (dry scenario)	DWD (T. Deutschländer)		WETTREG: Meteo Research pp Umweltbundesamt CLM: MPI-M-M/MaD pp BMBF	Transient simulation	1971-2000
Dutch and Flemish parts of the basin	A2/B1	PRUDENCE	KNMI	dynamical & statistical	KNMI	Transient	1961-1990

3.2 Results of the climate projections for the Meuse basin

Figures 28 and 29 present seasonal trends obtained with the delta change approach for each national sub-basin. The results are presented in percentage for the change in rainfall and in Celsius degree for the change in air temperature. Results of both scenarios (wet & dry) and both time slices (2021-2050 & 2071-2100) are presented (Table 11).

We can observe clear heterogeneities between the climate scenarios coming up from the four areas. In order to maintain downstream consistency of discharges, especially at boundaries, a transnational scenario was established. To this end national trends were weighted according to the drainage area of each sub-basin (Table 10).

	Drainage area (km^2)	**Weighting coefficient**
France	10.120	0,31
Walloon	10.880	0,33
Flanders & Netherlands	8.662	0,26
Germany	3.338	0,10
Transnational Meuse	**33.000**	**1,0**

Table 10. Weighted coefficients used to create the transnational seasonal trends

Figure 28. Seasonal trends in precipitation (%) and air temperature (°C) for the national Meuse sub-basins and for the two time slices (2021-2050 & 2071-2100) – Wet scenario

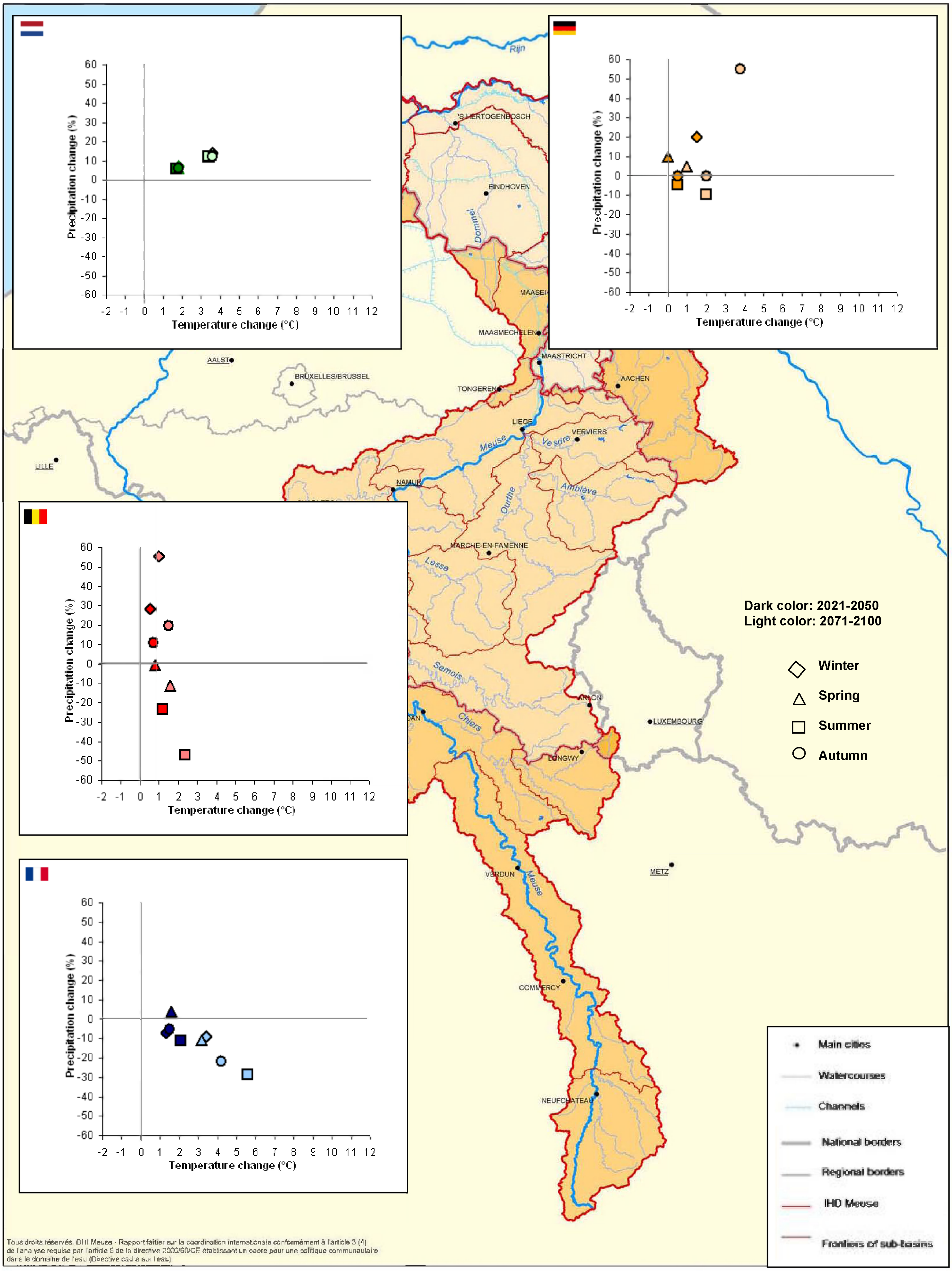
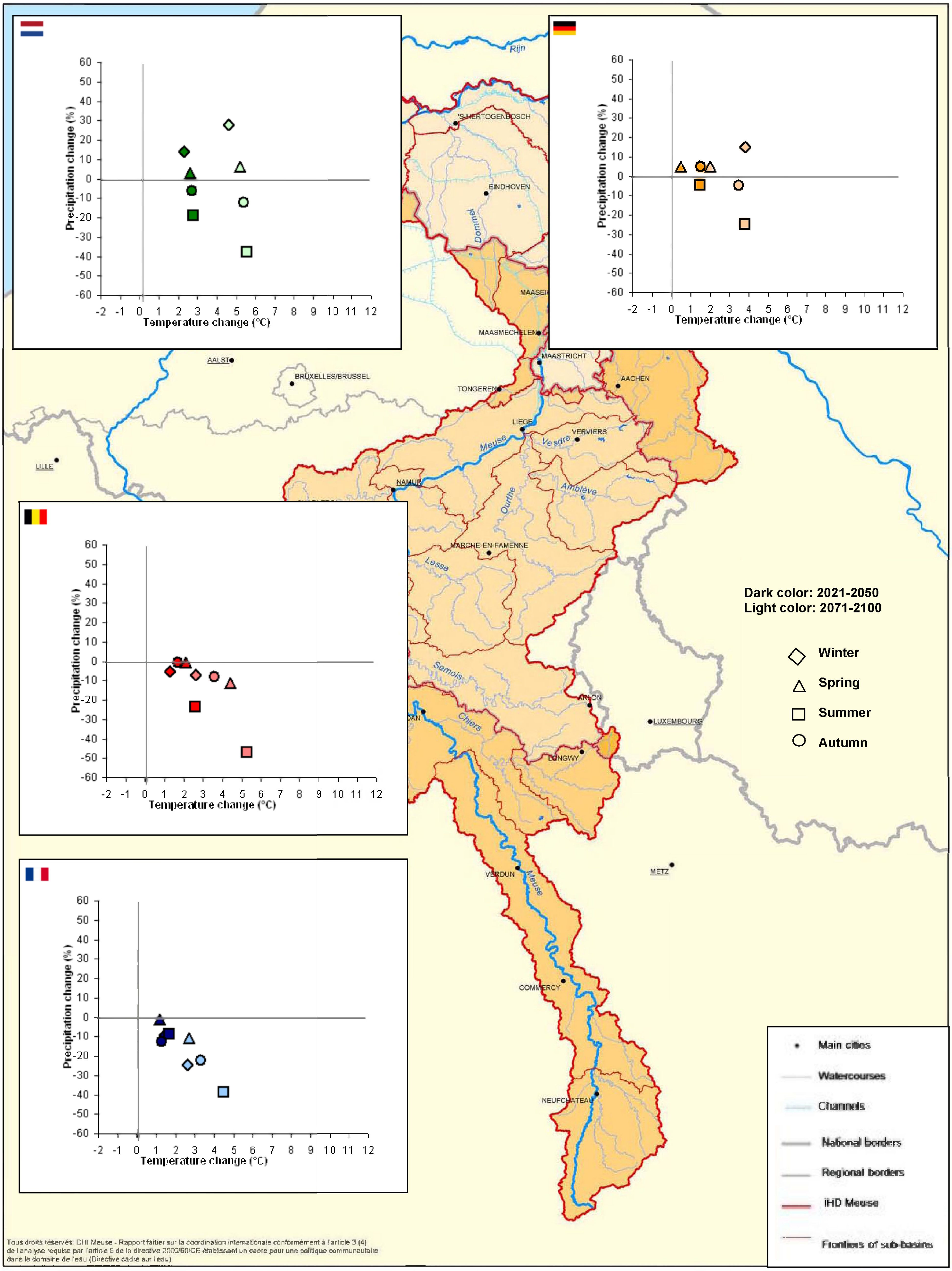


Figure 29. Seasonal trends in precipitation (%) and air temperature (°C) for the national Meuse sub-basins and for the two time slices (2021-2050 & 2071-2100) – Dry scenario



Period	Scenario	Region	Annual	Winter	Spring	Summer	Autumn
2020-2050	WET SCENARIO		**Annual**	Winter	Spring	Summer	Autumn
		France	**1,6**	1,3	1,6	2,1	1,5
	Temperature change (°C)	Walloon	**0,8**	0,5	0,8	1,2	0,7
		Flanders & Netherlands	**1,8**	1,8	1,8	1,7	1,8
		Germany	**0,6**	1,5	0,0	0,5	0,5
		Meuse	**1,3**	**1,2**	**1,2**	**1,5**	**1,2**
	DRY SCENARIO		**Annual**	Winter	Spring	Summer	Autumn
		France	**1,4**	1,4	1,2	1,7	1,3
	Temperature change (°C)	Walloon	**1,9**	1,3	2,1	2,6	1,7
		Flanders & Netherlands	**2,6**	2,3	2,6	2,8	2,7
		Germany	**1,3**	1,5	0,5	1,5	1,5
		Meuse	**1,9**	**1,6**	**1,8**	**2,3**	**1,8**
2020-2050	WET SCENARIO		**Annual**	Winter	Spring	Summer	Autumn
		France	**-4,9**	-7,3	4,0	-11,3	-5,1
	Precipitation change (%)	Walloon	**3,6**	28,2	-0,8	-23,6	10,7
		Flanders & Netherlands	**6,1**	7,0	6,0	5,5	6,0
		Germany	**6,3**	20,0	10,0	-5,0	0,0
		Meuse	**1,9**	**10,9**	**3,5**	**-10,3**	**3,5**
	DRY SCENARIO		**Annual**	Winter	Spring	Summer	Autumn
		France	**-8,0**	-9,2	-1,0	-9,1	-12,8
	Precipitation change (%)	Walloon	**-7,6**	-5,1	-0,8	-23,6	-0,7
		Flanders & Netherlands	**-2,0**	14,0	3,0	-19,0	-6,0
		Germany	**0,0**	-5,0	5,0	-5,0	5,0
		Meuse	**-5,5**	**-1,3**	**0,7**	**-16,1**	**-5,2**
2070-2100	WET SCENARIO		**Annual**	Winter	Spring	Summer	Autumn
		France	**4,1**	3,4	3,2	5,6	4,2
	Temperature change (°C)	Walloon	**1,6**	1,0	1,6	2,4	1,5
		Flanders & Netherlands	**3,5**	3,6	3,4	3,4	3,6
		Germany	**2,2**	3,8	1,0	2,0	2,0
		Meuse	**2,9**	**2,7**	**2,5**	**3,6**	**2,9**
	DRY SCENARIO		**Annual**	Winter	Spring	Summer	Autumn
		France	**3,3**	2,6	2,7	4,5	3,3
	Temperature change (°C)	Walloon	**4,0**	2,6	4,4	5,3	3,6
		Flanders & Netherlands	**5,2**	4,6	5,2	5,6	5,4
		Germany	**3,3**	3,8	2,0	3,8	3,5
		Meuse	**4,0**	**3,2**	**3,8**	**5,0**	**4,0**
2070-2100	WET SCENARIO		**Annual**	Winter	Spring	Summer	Autumn
		France	**-17,6**	-8,9	-10,7	-28,7	-22,0
	Precipitation change (%)	Walloon	**4,2**	55,3	-11,2	-47,2	19,7
		Flanders & Netherlands	**12,5**	14,0	12,0	12,0	12,0
		Germany	**12,5**	55,0	5,0	-10,0	0,0
		Meuse	**0,5**	**24,7**	**-3,3**	**-22,2**	**2,9**
	DRY SCENARIO		**Annual**	Winter	Spring	Summer	Autumn
		France	**-24,0**	-24,6	-10,7	-38,7	-22,2
	Precipitation change (%)	Walloon	**-18,4**	-7,1	-11,2	-47,2	-8,1
		Flanders & Netherlands	**-4,0**	28,0	6,0	-38,0	-12,0
		Germany	**-2,5**	15,0	5,0	-25,0	-5,0
		Meuse	**-14,7**	**-1,0**	**-4,9**	**-39,9**	**-13,1**

Table 11. Seasonal trends in precipitation (%) and air temperature (°C) for the national sub-basins and for the transnational scenario for the two time slices (2021-2050 & 2071-2100) - Dry & wet scenarios

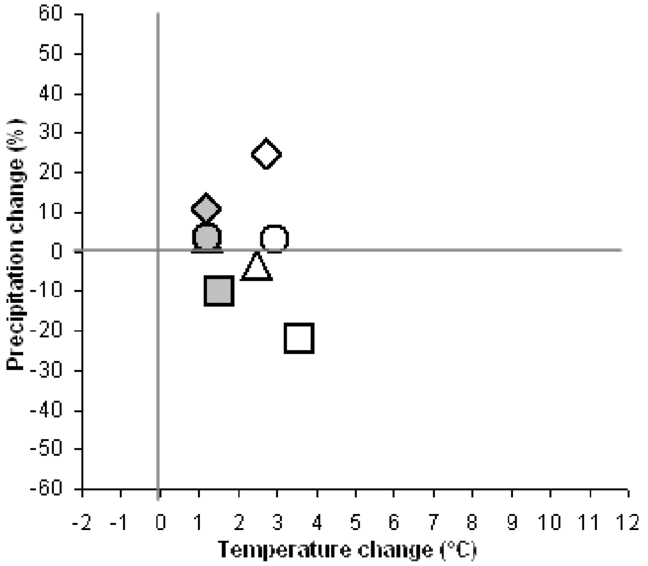


Figure 30. Seasonal trends in precipitation (%) and air temperature (°C) for the transnational scenario and for the two time slices (grey: 2021-2050 - white: 2071-2100)

Wet scenario

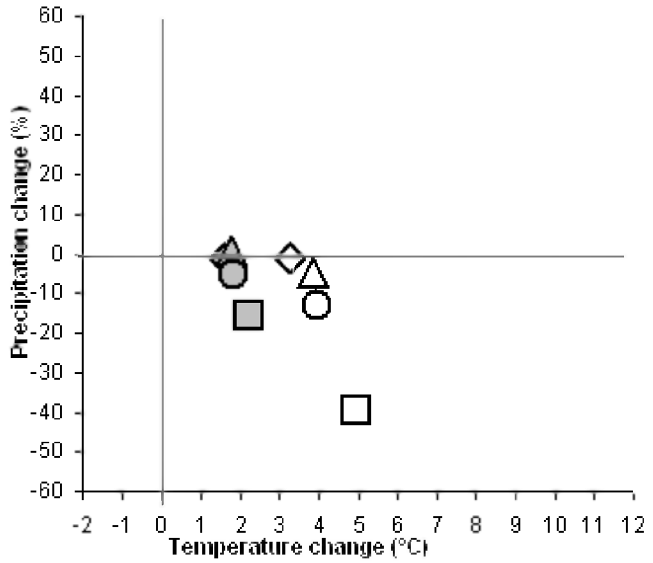


Figure 31. Seasonal trends in precipitation (%) and air temperature (°C) for the transnational scenario and for the two time slices (grey: 2021-2050 - white: 2071-2100)

Dry scenario

In order to validate our methodology, the transnational seasonal trends (Figures 30 and 31) have been compared to the PRUDENCE RCM simulations (*De Wit & al 2007*) for the end of 21st century. The Figure 32 shows that the AMICE Project values are matching closely the PRUDENCE RCM simulations.

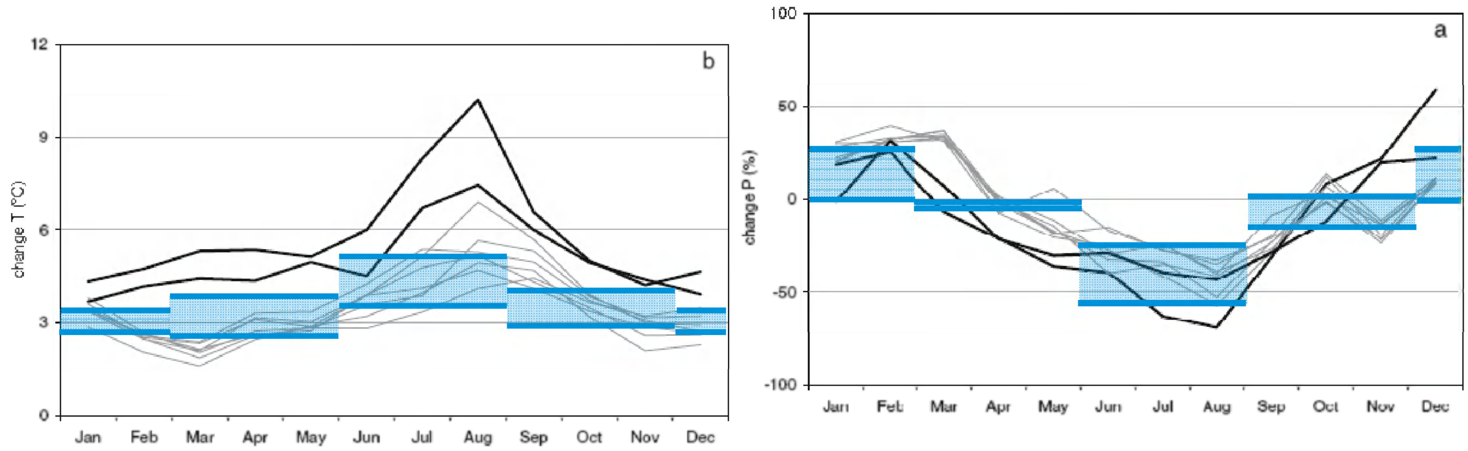


Figure 32. AMICE transnational wet and dry scenarios (blues lines) vs PRUDENCE RCM simulations (black and grey curves) - 2071-2100 (De Wit & al 2007)

4 Production of future hydrological scenarios

4.1 Material and methods

4.1.1 Presentation of the hydrological models

For the hydrological simulations each partner has used its own models except in Germany where NASIM and GR4J were calibrated especially. The Table 12 presents the main characteristics of hydrological models used along the Meuse river for the AMICE Project.

4.1.1.1 AGYR

AGYR is a rainfall-runoff model. It is used by EPAMA. It is made of 150 sub-basins. Each sub-basin uses a GR4 model to transform rainfall data into discharge values. The discharge calculated at each sub-basin's outlet is spread downstream through a simplified 1D model. The model was calibrated on 20 measured floods between 1965 and 1997. Inputs are the measured discharges (instant values) and the measured rainfalls (hourly timestep), as well as values defining the basin scale, the reservoirs, the rivers. The PET is assumed to be zero in flood periods.

4.1.1.2 GR4J

GR4J is a daily conceptual model with 4 parameters, developed by the CEMAGREF (institut de recherche en sciences et technologies pour l'environnement). The version used for AMICE has been revised by Perrin (2000). The operating principle is as follow (Figure 33):

- The first step consists in a neutralization of the precipitation (Pn) by the PET. If this interception consumes the entire precipitated amount, the excess PET results in a decrease of water level (S) in the production store. Otherwise some of the excess of rain (Ps) supplies the production store. The rest (Pn-Ps) flows to the basin outlet. After the production store, the flows are divided into two parts:

- The first one (10%) is routed by a hydrogram (UH2) and go to the outlet.

- The second part (90%) goes to a second reservoir called routing store via a second hydrogram (UH1)

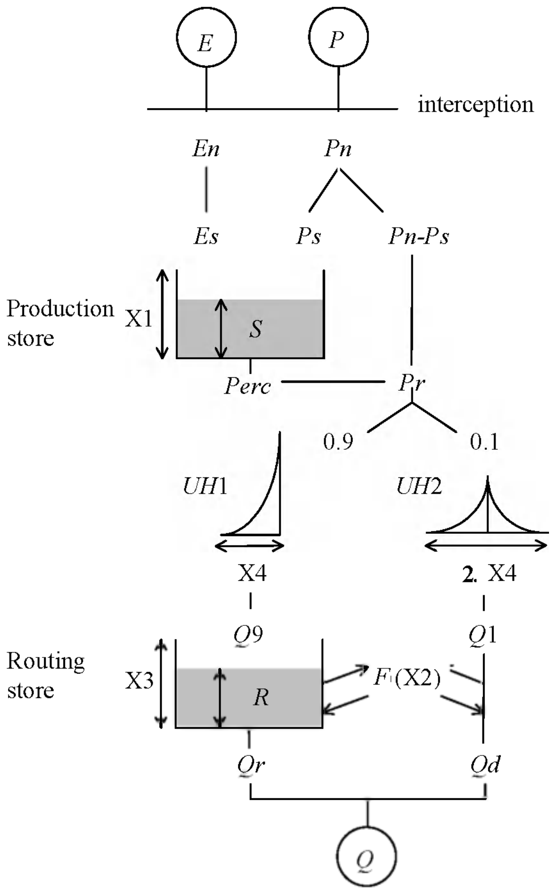


Figure 33. Flowchart of the GR4J hydrological model

Finally, a function is applied to drain the routing store.

The exchange function F reflects others interactions between the flows and the reservoir.

GR4J requires precipitations air temperatures and PET values as input. For the AMICE Project, the model has been calibrated for the whole French basin (low and high flows) and for German tributaries for low flows (Rur and Niers).

Name of the model	**GR4J PRESAGES**	**AGYR**	**TOPMODEL**	**MIKE11 Maas**	**EPIC-Grid**	**HBV**	**NASIM**	**GR4J**
Partner	*U. of Metz (CEGUM)*	*EPAMA*	*FHR*	*FHR*	Gx-ABT	*RWS*	*RWTH*	*RWTH*
Originally developed by	Cemagref (Perrin et al. 2003)	Cemagref (Perrin et al. 2003)		FHR	Williams, (Sohier C. et al., 2009)	SMHI	Hydrotec Ingenieurge-sellschaft für Wasser und Umwelt	Cemagref (Perrin et al. 2003)
Type of RR model	Lumped reservoir-based	Lumped reservoir-based		Conceptual RR model: HBV Maas (Deltares, NL)	Distributed physically-based/conceptual model	Semi-distributed conceptual model	Distributed physically-based/conceptual model	Lumped reservoir-based
Type of running	Continuous simulation	Continuous simulation	Continuous simulation	Continuous simulation	Continuous simulation	Continuous simulation	Continuous simulation	Continuous simulation
Number of optimized parameters	4	4				5 - 6	several	4
Groundwater infiltration and recharge	Percolation function + basin water exchange	Percolation function + basin water exchange			Capacitive method	Percolation function	Percolation function + basin water exchange	Percolation function + basin water exchange
Runoff components	Overland flows Base flows	Overland flows Base flows			SCS method (runoff, hypodermique, base flows)	Fast and slow runoff response	Overland flows Interflows Base flows	Overland flows Base flows
Flows routing	Two unit hydrographs	Two unit hydrographs		Saint-Venant equa-tions		Simplified unit hydro-graph	Kalinin-Miljukov-method	Two unit hydrographs
No. of land use types	-	-	-	-		2 (forest and field)	Several (5-…)	-
Input climate data	P, PET	P, PET	P, PET	P, PET	P, PET	P, PET	P, T, PET	P, PET
Precipitation (hourly) Precipitation (daily)	- 0.5° E-OBS gridded dataset 2.0*	Partner's data set 0.5° E-OBS gridded dataset 2.0	Partner's data set 0.5° E-OBS gridded dataset 2.0	Partner's data set 0.5° E-OBS gridded dataset 2.0	Partner's data set 0.5° E-OBS gridded dataset 2.0	Partner's data set 0.5° E-OBS gridded dataset 2.0	Partner's data set 0.25° E-OBS gridded dataset 2.0	- 0.25° E-OBS gridded dataset 2.0*
PET (hourly) PET (daily)	- Oudin et al. (2005)	- Oudin et al. (2005)	- Oudin et al. (2005)	- Oudin et al. (2005)	Prestley-Taylor	- Daily PET based on mean monthly values + 4% per °C air temperature increase	Oudin et al. (2005) Oudin et al. (2005)	- Oudin et al. (2005)
Temporal resolution of output data	1 day	Minutes to hour	1 hour 1 day	min, hour, day	1 day	1 day	15 min (Rur) 30 min (Niers)	1 day
Reference period for calibration/validation	-	-	-	20/01-15/03 2002 22/12 – 16/01 2003	1961-2000	1969-1984/1985-1998	2001/2003 (Wurm &Rur) Calibration for several high flows events between 1965-1995 (Niers) and 1982-2002 (Inde)	1960-1980/1981-2000 (1985-1992/1993-2000)
Method of optimization	Steepest descent or PEST	-	-	Expert judgment	Expert judgment	Expert judgment (based on sensitivity analysis with GLUE)	Trial and error	Steepest descent or PEST
Objective-function	Nash-Sutcliffe effi-ciency coefficient on (Oudin et al. 2006): - $Q^{1/2}$ for the entire hydrograph - Q for the high flows - log(Q) for the low flows	-	-	-	Nash Statistic extreme	Nash-Sutcliffe effi-ciency coefficient, relative volume error, relative extreme value error	-	Nash-Sutcliffe effi-ciency coefficient on (Oudin et al. 2006): - $Q^{1/2}$ for the entire hydrograph - Q for the high flows - log(Q) for the low flows
Efficiency in high flows	-	good	poor	good	good	good	good	good
Efficiency in low flows	-	Not tested	good	Not available	Quite good	moderate	Not available	good

Table 12. Main characteristics of hydrological models used in the framework of the AMICE Project

4.1.1.3 EPICGrid

The EPICGrid hydrological model (Figure 34) has been developed at the FUSAGx (ULg, Gx-ABT). EPICGrid is a physically based distributed model. It affords to realize daily simulations at basin scale. This model is built upon a “major components” approach and takes into account , inside every surface element (1 km x 1 km), the balanced values of land-use, slope, weather and soil characteristics (root zone and vadose zone), growing culture and agricultural practices like fertilization, ploughing, ... (*Sohier C. et al., 2009*).

Simulations are realized at daily time step (or hourly time step for some applications), they could be based upon water fluxes, particle fluxes and solute towards surface water and groundwater.

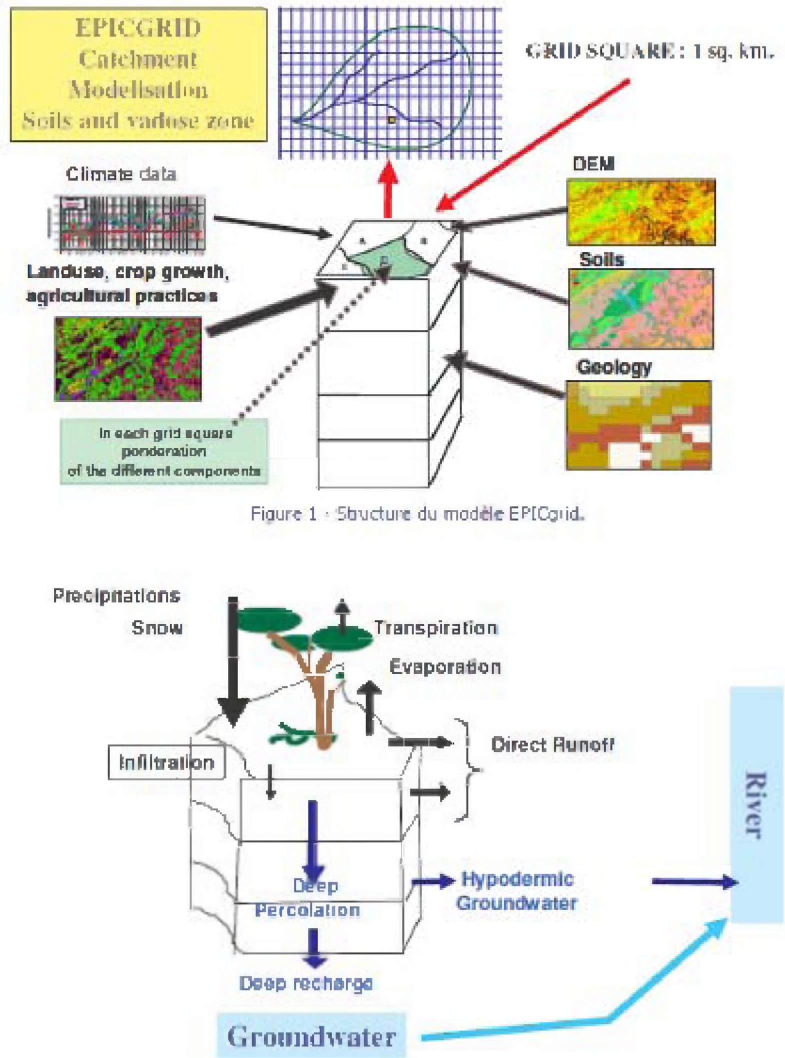


Figure 34. Simulation structure of the EPICGrid model inside an elementary element (*Dautrebande et Sohier, 2006*).

4.1.1.4 RS-PDM

The RS-PDM© software is used to simulate hydrographs for the Meuse sub-basins in the Walloon Region at hourly time step. The RS-PDM © 6.0 is a software from the InforworksTM series, edited by Wallingford software. It implements the Moore theory in order to simulate chronological flows rates.
This conceptual model principle is to attribute a “stock capacity C” in every basin point. The flows rate at the outlet is composed by surface runoff (fast transfer) and a contribution of low hypodermics. Routings are simulated by different transfer functions between successive reservoirs (*Degré et al., 2008*).

4.1.1.5 HBV-96

HBV-96 is a conceptual semi-distributed rainfall-runoff model. Its structure allows deriving discharges based on meteorological data for basins. HBV-Meuse has been calibrated for the period 1969-1984 and validated for the period 1985-1998. The reliability is based on Nash-Sutcliffe efficiencies, standard R2, accumulated difference and visual inspection. It has to be mentioned that Nash and R2 coefficients are more sensitive for deviations in high water periods. Influence of the parameters for low water situations is not researched during calibration as the model is primarily used for high discharge periods and in particular low discharges in the lower part of the basin are heavily influenced by hydraulic infrastructure.

Different calibrations exist for the HBV-Meuse model. Here we applied the 50% parameter set of the Glue analysis by Kramer and Weerts (2008).

4.1.1.6 NASIM

NASIM is a commercial (Hydrotec Ingenieurgesellschaft für Wasser und Umwelt mbH, Aachen) semi-distributed conceptual/physically based rainfall runoff model. It can be used for single event and for continuous simulations. The model provides a breakup of the basin area into a tree structure of tributaries with the fundamental runoff producing units arranged as leaves on the channel tree. The model structure and algorithms defined aim for a compromise between a sufficient degree of sophistication and general applicability under given conditions (*Masoudian, 2009*). The main components of NASIM are

- rainfall formation and distribution,
- runoff components separation: separation into interception, evapotranspiration, infiltration and runoff. The rate at which the different processes occur is closely linked to the soil moisture, which depends on soil specific hydraulic characteristics. The soil properties affecting soil water movement are hydraulic conductivity and characteristics of water retention. A soil layer behaves as a single reservoir. Its content is the soil moisture, inflows are infiltration and capillary suction and outflows are evapotranspiration and percolation. For infiltration and percolation linear and non-linear functions are provided and may be chosen by the user. For the calculation of the interflows several different methods exist and may also be chosen by the user. The actual evapotranspiration is calculated by the approach of Ostrowski, where the determining factors are potential evapotranspiration and soil moisture, assuming a linear relationship. Concerning the overland flows NASIM applies different procedures depending on the surface characteristics. For sealed surfaces surface runoff, evapotranspiration and channel flows are considered. For unsealed surfaces also infiltration, interflows, percolation and base flows are taken into account (*Masoudian, 2009*).
- Runoff concentration: delay and transport in the runoff components. For sealed surfaces translation and retention are calculated following the principal of linear cascades of storages. For unsealed surfaces retention is calculated by a single linear storage. Translation is calculated by a time area function that can either be calculated by a Geographic Information System or be idealized by the user by setting several parameters determining an abstract shape of the watershed (*Masoudian, 2009*).
- Channel flows: deformation of the runoff wave by channel retention using the Kalinin-Miljukov-method. At this the relation between discharge, velocity and flows-depths can be taken from hydraulic models.

NASIM requires time series of precipitation, air temperature and potential evapotranspiration as input. For each subbasin mean elevation, area and percentage of sealed surface have to be provided. The different soils in the basin are described with parameters for field capacity, wilting point, total pore volume, saturated hydraulic conductivity and maximum infiltration capacity. Each land use type is defined with the parameters of root depth, interception storage and sealing. For each basin that receives water from another subbasin, a transport element has to be defined, which can either be a pipe or a stream segment. Depending on the structure and drainage of the basin further elements such as storage basins or channel separation devices may be defined. These require additional information concerning the relation between volume and water level, outflows curves, emergency overflows curves etc (*Masoudian, 2009*).

4.1.2 Calculation methods applied to the Hydrological Impact Variables (HIV)

For achieving the WP1 objectives, the partners decided to work on a common hydrological impact variable set. For low flows, the selected single variable is the MAM7 (mean annual 7-day minimum flows). It was calculated for several return periods: 2-5-10-25-50 years. Concerning the high flows two variables were retained: The Qdx (annual daily maximum discharge) and Qhx (annual hourly maximum discharge). The corresponding return periods are 2-5-10-25-50-100 (+250-1250 for the downstream). Table 13 presents the calculation methods applied to the hydrological impact.

The winter maximum discharge values for different recurrence intervals for the observations and simulations have been calculated using a maximum-likelihood fitting of the Gumbel distribution. Although the goodness of fit cannot be of equal quality for all simulations, according to the Kolmogorov-Smirnov test for a significance level of 5% the Gumbel distribution was never refused.
For the hourly timesteps of both gauges we were faced with the problem that for a significance level of 5% some – not all – of the simulations were identified to hold a trend. We assume that the trend estimation on a significance level of 5% is not representative.

The Mean Annual Minimum 7 days (April to September) discharge values for different recurrence intervals for the simulations and observations were calculated using a maximum-likelihood fitting of the lognormal distribution. According to the Kolmogorov-Smirnov test for a significance level of 5% the lognormal distribution was never refused. The problem of adjusting trends did not occur here.

AGYR is made of 150 sub-basins which make it difficult to update. It was chosen to work on a small number of sub-basins and to try to extrapolate results to the whole French basin (Figure 35).

Rainfall data, modified by the future trends, were applied to a small number of sub-basins (see map) in different places of the French Meuse basin (upstream, middle, downstream). Impact of the modified rainfalls on the discharges was studied for 7 floods: December 1992, January 1993, December 1993, January 1994, December 1994, January 1995, and February 1995.
Each modified flood was compared to present-time flood by comparing the peak discharges.

The study showed that :

- for identical climate variations (same scenario and time-slice) and for the same flood, the modification of the peak discharge is similar wherever the sub-basin is located. We made the assumption that the peak discharge modification could be extrapolated to the whole basin.

- for identical climate variations (same scenario and time-slice), the modification of the peak discharge is different between floods. There are three groups of floods that can be distinguished : major floods with a return period higher than 50 years (Jan. 1993, Dec. 1993, Jan. 1995), medium floods (Dec. 1992, Jan. 1994, Dec. 1994) and small floods with a return period lower than 10 years (Feb. 1995). Each group of flood presents a similar modification of the peak discharge due to climate change scenarios. We concluded that, for similar climate variations and for similar floods, the peak discharge is modified in the same proportions.

Major floods react differently than medium and smaller floods because the underground water and the potential evapotranspiration are negligible in such extreme events. On the contrary, smaller floods are very much influenced by initial conditions.

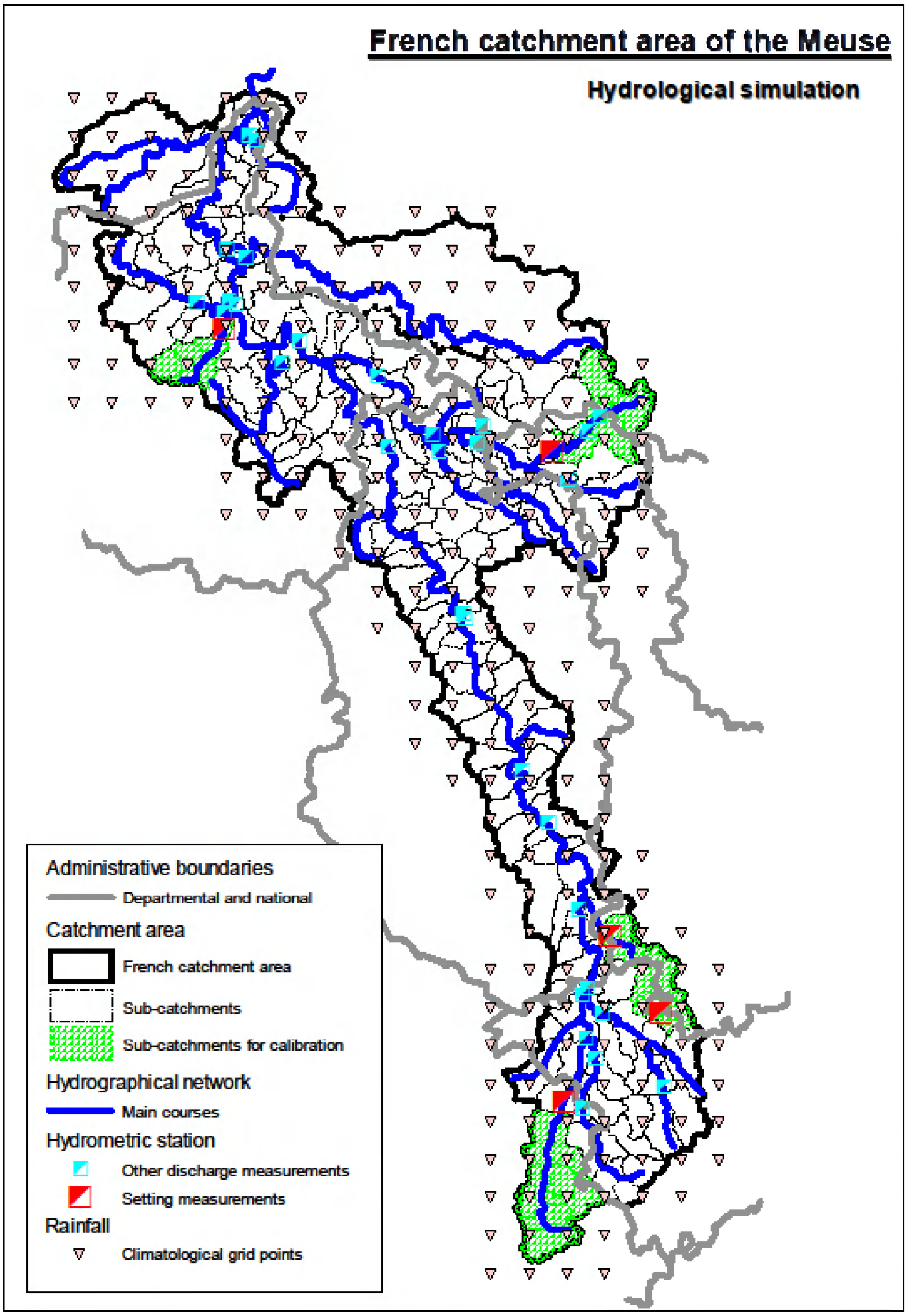


Figure 35. French basin area of the Meuse

		Qhx100		**Qdx100**		**MAM7**	
	Station	**Statistical law**	**Method of parameters estimation**	**Statistical distribution**	**Method of parameters estimation**	**Statistical law**	**Method of parameters estimation**
Meuse	Saint-Mihiel	Gumbel	Maximum-Likelihood	Not calculated			
Meuse	Belleville	/		Not calculated			
Meuse	Stenay	Gumbel		Not calculated			
Meuse	Montcy-notre-Dame	Gumbel		Not calculated			
Meuse	Chooz	Gumbel		Not calculated			
Vesdre	Chaudfontaine	Weibull	Maximum-Likelihood	Weibull/ gamma inverse/gamma	Maximum-Likelihood	Weibull /Gamma	Maximum-Likelihood
Lesse	Gendron	Log-normale/ gamma	Maximum-likelihood	Log-normale	Maximum-likelihood	Weibull	Maximum-Likelihood
Meuse	Sint Pieter	-	-	Gumbel	Maximum-Likelihood		Mean of minimum 7-day sum found for each year
Meuse	Borgharen						
Rur	Stah	Gumbel	Maximum-Likelihood	Gumbel	Maximum-Likelihood	Lognormal	Maximum-Likelihood
Niers	Goch	Gumbel	Maximum-Likelihood	Gumbel	Maximum-Likelihood	Lognormal	Maximum-Likelihood
		Qhx100		**Qdx100**		**MAM7**	
	Station	**Statistical law**	**Method of parameters estimation**	**Statistical distribution**	**Method of parameters estimation**	**Statistical law**	**Method of parameters estimation**
Meuse	Saint-Mihiel	Gumbel	Maximum-Likelihood	Not calculated			

Meuse	Belleville	/		Not calculated			
Meuse	Stenay	Gumbel		Not calculated			
Meuse	Montcy-notre-Dame	Gumbel		Not calculated			
Meuse	Chooz	Gumbel		Not calculated			
Vesdre	Chaudfontaine	Weibull	Maximum-Likelihood	Weibull/ gamma inverse/gamma	Maximum-Likelihood	Weibull /Gamma	Maximum-Likelihood
Lesse	Gendron	Log-normale/ gamma	Maximum-likelihood	Log-normale	Maximum-likelihood	Weibull	Maximum-Likelihood
Meuse	Sint Pieter	-	-	Gumbel	Maximum-Likelihood		Mean of minimum 7-day sum found for each year
Meuse	Borgharen						
Rur	Stah	Gumbel	Maximum-Likelihood	Gumbel	Maximum-Likelihood	Lognormal	Maximum-Likelihood
Niers	Goch	Gumbel	Maximum-Likelihood	Gumbel	Maximum-Likelihood	Lognormal	Maximum-Likelihood
		Qhx100		**Qdx100**		**MAM7**	
	Station	**Statistical law**	**Method of parameters estimation**	**Statistical distri-bution**	**Method of parameters esti-mation**	**Statistical law**	**Method of parameters esti-mation**
Meuse	Saint-Mihiel	Gumbel	Maximum-Likelihood	Not calculated		Lognormal	Maximum-Likelihood
Meuse	Stenay	Gumbel	Maximum-Likelihood	Not calculated		Lognormal	Maximum-Likelihood
Meuse	Montcy-notre-Dame	Gumbel	Maximum-Likelihood	Not calculated		Lognormal	Maximum-Likelihood

Meuse	Chooz	Gumbel	Maximum-Likelihood	Not calculated		Lognormal	Maximum-Likelihood
Vesdre	Chaudfontaine	Weibull	Maximum-Likelihood	Weibull/ gamma inverse/gamma	Maximum-Likelihood	Weibull /Gamma	Maximum-Likelihood
Lesse	Gendron	Log-normal/ gamma	Maximum-likelihood	Log-normal	Maximum-likelihood	Weibull	Maximum-Likelihood
Meuse	Sint Pieter	Gumbel	Maximum-Likelihood	Gumbel	Maximum-Likelihood	Lognormal	Maximum-Likelihood
Rur	Stah	Gumbel	Maximum-Likelihood	Gumbel	Maximum-Likelihood	Lognormal	Maximum-Likelihood
Niers	Goch	Gumbel	Maximum-Likelihood	Gumbel	Maximum-Likelihood	Lognormal	Maximum-Likelihood

Table 13. Presentation and calculation methods applied to the hydrological impact variables

For the Walloons part, the hydrological simulations have been conducted for the Lesse at Gendron and for the Vesdre at Chaudfontaine.

The following data have been used for the Lesse at Gendron :

- Hourly flows rate between 1968-2000
- Hourly rainfall between 1968-2000
- Daily flows rate between 1980-2000
- Daily rainfall between 1980-2000

The following data have been used for the Vesdre at Chaudfontaine:

- Hourly flows rate between 1968-2000
- Hourly rainfall at Battice between 1987-2008
- Hourly rainfall at Balmoral between 1987-2008
- Hourly rainfall at Jalhay between 1987-2008
- Hourly rainfall at Ternell between 1987-2008
- Daily rainfall at Ternell between 1959-2007

Rainfall data have been perturbed with common perturbation factors for the Meuse River Basin for time slices 2020-2050 and 2070-2100.

<u>Estimation of maximum high-flows discharge values</u>

The method of yearly maximums is the classical method used to evaluate exceptional high-flows discharge values. It consists in adjusting a statistical law to the set of yearly maximum flows rate observed or simulated. The work was done on the basis of hydrological years, from October 1st to September 30th of the following year.

The HYFRAN software, developed by the University of Québec, allows testing no less than 15 classical statistical laws, among them Gumbel law, Gamma, Weibull, exponential, Pareto, lognormal, Pearson III and GEV. The HYFRAN software allows classifying the laws tested based upon the posterior probability, this one takes into account the statistical quality of the adjustment and parsimony principle, giving priority to the 2 parameters laws.

The 5 best classed are retained and the χ^2 test is applied in order to control the adequacy of laws to the sample of observed values. Afterwards, a choice of the best law is performed visually by graphical analysis of the 5 best adjustments (Dautrebande and Sohier, 2006).

<u>Estimation of low-flows discharge values</u>

The method of the “mean annual 7-days minimum flows” (MAM7) has been used here. The HYFRAN software has also been used in order to adjust a statistical law to the observed and simulated MAM7 set by hydrological year.

The methodology is the same as the one used for maximum high flows discharge values.

For the Flemish part, the climate scenarios are constructed with a transformation routine from Belgian Science Policy Project “Climate Change Impact on Hydrology” (CCI-Hydr, www.kuleuven.be/hydr/cci/CCI-HYDR) by the Hydraulics Laboratory from the KULeuven University and the Belgium Royal Meteorological Institute (KMI) for the period 2071-2100. The Belgian climate change scenarios are time series on a daily base for precipitation, air temperature and potential evaporation (ETo). For all three scenarios and a control period simulation is done with HBV-Maas by Deltares. The simulated discharges at Borgharen (boundary between

Belgium and the Netherlands) are analysed. The three highest discharges are selected in each scenario and from 10 days before till 10 after the peak and simulated in SOBEK-Maas. HBV results are analysed based on average yearly and seasonal discharges and the 90% percentiles of the discharges of all simulation runs. An analysis is done to compare the highest discharge in the HBV-Maas and SOBEK-Maas models.

For the Netherlands values have been calculated using HBV for Sint Pieter, close to the border with Belgium. In a later phase of the AMICE project with hydraulic simulations more downstream locations will be added.

Extreme high discharges are calculated for 2, 5, 10, 25, 50, 100, 250, 500 and 1250 year return periods. For return periods with T < 25 years the Pareto distribution with a threshold of 1300 m3/s has been applied. For return periods longer than 25 years the censored Gumbel distribution has been applied to the year maxima. In the Netherlands for the Meuse at Sint Pieter flows below 1000 m3/s are censored. Values have been adjusted linearly to values resulting from extensive statistical analysis, which are based on a much longer discharge record (ca. 100 years).

For low discharges no standard method exists. As measured discharges at Sint Pieter are strongly influenced by hydraulic infrastructure upstream, care should be taken with these values as only hydrological modelling is applied in this part of the study. However, the relative change is expected to give a good indication of the expected trend according to the climate scenario.

4.2 Results of hydrological simulations

This paragraph presents the hydrological simulations performed on the four national sub-basins for the 9 gauging stations. In order to compare the trends we calculated the climate change factor (derived from winter maximum hourly discharge series) for :

- The two time slices : 2021-2050 & 2071-2100
- The transnational scenario and the national scenarios
- The wet & dry scenarios

The climate change factor is defined as : Qsimulated(scenario)/ Qsimulated (present climate) which is the same as writing : Qscenario/Qcontrol

A value above 1 means an increase of the present discharge value whereas a value below 1 means a decrease of the present discharge value. Results are presented in tables 14 to 17.

For the transnational scenario the change in discharge is logically homogeneous across the basin (increase in discharge for the wet scenario and decrease in discharge for the dry scenario). These trends are more pronounced for the end of the century.

Concerning the national scenarios the results are more divergent especially on the French part of Meuse where the discharges decrease whatever the scenario is (wet or dry).

Climate change factors based on the Mean Annual Minimum 7-days (April-Sept.) discharge values (MAM7) were also calculated and are presented in table 18.

T[y]	Meuse St-Mihiel	Meuse Stenay	Meuse Montcy	Meuse Chooz	Meuse Sint Pieter	Lesse Gendron	Vesdre Chaudfontaine	Rur Stah	Niers Goch
2	1.12 0.96	1.12 0.96	1.12 0.96	1.12 0.96	1.12 0.92	1.17 0.97	1.02 0.86	1,07 0,84	1,08 0,88
5	1.12 0.96	1.12 0.96	1.12 0.96	1.12 0.96	1.15 0.91	1.17 0.98	1.05 0.88	1,05 0,86	1,10 0,88
10	1.12 0.93	1.12 0.93	1.12 0.93	1.12 0.93	1.16 0.93	1.18 0.98	1.06 0.89	1,04 0,87	1,10 0,89
25	1.12 0.93	1.12 0.93	1.12 0.93	1.12 0.93	1.13 0.95	1.18 0.98	1.07 0.89	1,03 0,87	1,11 0,89
50	1.12 0.96	1.12 0.96	1.12 0.96	1.12 0.96	1.14 0.95	1.19 0.98	1.08 0.90	1,02 0,88	1,11 0,89
100	1.12 0.96	1.12 0.96	1.12 0.96	1.12 0.96	1.14 0.95	1.19 0.98	1.08 0.90	1,02 0,88	1,11 0,89

Table 14. Climate change factors (derived from winter maximum hourly discharge series) as a function of the recurrence interval T[y] for different sub-basins of the Meuse River
Period **2021-2050** vs 1961-1990 - wet scenario & dry scenario - **Transnational climate scenarios**

T[y]	Meuse St-Mihiel	Meuse Stenay	Meuse Montcy	Meuse Chooz	Meuse Sint Pieter	Lesse Gendron	Vesdre Chaudfontaine	Rur Stah	Niers Goch
2	0.89 0.86	0.89 0.86	0.89 0.86	0.89 0.86	1.09 1.07	1,48 0,86	1,42 0,85	1.14 0.90	1.21 0.93
5	0.89 0.86	0.89 0.86	0.89 0.86	0.89 0.86	1.11 1.11	1,52 0,82	1,49 0,87	1.15 0.92	1.23 0.93
10	0.89 0.82	0.89 0.82	0.89 0.82	0.89 0.82	1.10 1.12	1,56 0,80	1,53 0,88	1.15 0.93	1.24 0.93
25	0.89 0.82	0.89 0.82	0.89 0.82	0.89 0.82	1.08 1.11	1,58 0,79	1,55 0,88	1.16 0.94	1.24 0.93
50	0.90 0.86	0.90 0.86	0.90 0.86	0.90 0.86	1.07 1.11	1,59 0,78	1,57 0,88	1.16 0.94	1.25 0.93
100	0.90 0.86	0.90 0.86	0.90 0.86	0.90 0.86	1.07 1.11	1,60 0,77	1,59 0,89	1.16 0.95	1.25 0.93

Table 15. Climate change factors (derived from winter maximum hourly discharge series) as a function of the recurrence interval T[y] for different sub-basins of the Meuse River
Period **2021-2050** vs 1961-1990 - wet scenario & dry scenario – **National climate scenarios**

T[y]	Meuse **St-Mihiel**	Meuse **Stenay**	Meuse **Montcy**	Meuse **Chooz**	Meuse **Sint Pieter**	Lesse **Gendron**	Vesdre **Chaudfontaine**	Rur **Stah**	Niers **Goch**
2	1.27 0.89	1.27 0.89	1.27 0.89	1.27 0.89	1.21 0.79	1.33 0.83	1.11 0.74	1,11 0,60	1,16 0,70
5	1.27 0.89	1.27 0.89	1.27 0.89	1.27 0.89	1.30 0.88	1.40 0.86	1.18 0.77	1,11 0,60	1,20 0,71
10	1.29 0.81	1.29 0.81	1.29 0.81	1.29 0.81	1.33 0.92	1.45 0.87	1.21 0.78	1,10 0,61	1,21 0,71
25	1.29 0.81	1.29 0.81	1.29 0.81	1.29 0.81	1.31 0.90	1.49 0.88	1.23 0.79	1,10 0,61	1,22 0,71
50	1.27 0.89	1.27 0.89	1.27 0.89	1.27 0.89	1.32 0.91	1.52 0.89	1.25 0.80	1,10 0,61	1,23 0,71
100	1.27 0.89	1.27 0.89	1.27 0.89	1.27 0.89	1.33 0.91	1.55 0.90	1.27 0.81	1,10 0,61	1,24 0,71

Table 16. Climate change factors (derived from winter maximum hourly discharge series) as a function of the recurrence interval T[y] for different sub-basins of the Meuse River
Period **2071-2100** vs 1961-1990 - wet scenario & dry scenario - **Transnational climate scenarios**

T[y]	Meuse **St-Mihiel**	Meuse **Stenay**	Meuse **Montcy**	Meuse **Chooz**	Meuse **Sint Pieter**	Lesse **Gendron**	Vesdre **Chaudfontaine**	Rur **Stah**	Niers **Goch**
2	0.84 0.64	0.84 0.64	0.84 0.64	0.84 0.64	1.17 1.18	1,79 0,79	1,66 0,81	1,51 0,98	1.62 1.00
5	0.84 0.64	0.84 0.64	0.84 0.64	0.84 0.64	1.21 1.26	1,81 0,75	1,76 0,81	1,51 1,00	1.70 1.02
10	0.74 0.56	0.74 0.56	0.74 0.56	0.74 0.56	1.20 1.28	1,82 0,74	1,81 0,81	1,51 1,01	1.73 1.03
25	0.74 0.56	0.74 0.56	0.74 0.56	0.74 0.56	1.16 1.25	1,83 0,72	1,84 0,80	1,51 1,02	1.75 1.04
50	0.83 0.63	0.83 0.63	0.83 0.63	0.83 0.63	1.16 1.26	1,83 0,72	1,87 0,80	1,51 1,02	1.77 1.04
100	0.83 0.63	0.83 0.63	0.83 0.63	0.83 0.63	1.16 1.26	1,84 0,71	1,89 0,80	1,51 1,02	1.78 1.05

Table 17. Climate change factors (derived from winter maximum hourly discharge series) as a function of the recurrence interval T[y] for different sub-basins of the Meuse River
Period **2071-2100** vs 1961-1990 - wet scenario & dry scenario – **National climate scenarios**

One of the main lacks in the AMICE project is the study of extreme rainfalls on small basins. Extreme rainfalls concentrated on small-scale areas can create devastating mudfloods. The impact is very limited on the water level in the main rivers but the damages are very costly locally. Contrary to large floods that happen mostly in winters, extreme rainfalls can occur anytime of the year. Such events happened for example in the eastern neighbourhood of Liege in May 2009.

Climate scenarios predict that these extreme events will occur more frequently. But this phenomenon is hardly known in the Meuse basin. There is no detailed monitoring or analysis of their frequency and causes. It is also very hard to forecast the location and intensity of such event, even harder to model it. It would be much too hazardous to apply climate change on an already uncertain phenomenon. Consequently, the AMICE Partners will limit themselves to mentioning that extreme rainfalls could be more frequent in the future century (Christensen and Christensen, 2003).

5 Selection of hydrological scenarios

In order to synthesize the results presented above, table 18 shows the four final hydrological scenarios selected for the AMICE project for most extreme low/high flows, wet and dry climate scenarios. These final hydrological scenarios aggregate results of transnational (France, Belgium and Netherlands) and national scenarios (Germany) for the two main impact variables: Qhx100 for high flows (centennial flood peak) and MAM7 (Mean Annual Minimum 7-days (April-Sept.) discharge values) for low flows.

		Meuse **St-Mihiel**	Meuse **Stenay**	Meuse **Montcy**	Meuse **Chooz**	Meuse **Sint Pieter**	Lesse **Gendron**	Vesdre **Chaud-fontaine**	Rur **Stah**	Niers **Goch**
MAM7	**2021-2050**	0.79	0.73	0.88	0.88	0.82	1.00	1.17	0.68	0.84
		0.61	0.64	0.75	0.74	0.65	0.83	0.93	0.56	0.63
	2071-2100	0.60	0.50	0.71	0.65	0.60	0.96	1.10	0.71	0.60
		0.43	0.47	0.52	0.52	0.33	0.57	0.67	0.36	0.27
Qhx100	**2021-2050**	1.12	1.12	1.12	1.12	1.14	1.19	1.08	1.02	1.11
		0.96	0.96	0.96	0.96	0.95	0.98	0.90	0.88	0.89
	2071-2100	1.27	1.27	1.27	1.27	1.33	1.55	1.27	1.10	1.24
		0.89	0.89	0.89	0.89	0.91	0.90	0.81	0.61	0.71

Table 18. Values of climate change factors for the most extreme hydrological scenarios selected for the AMICE project for low flows/high flows/wet and dry climate scenarios.

The AMICE Partners met on March 11th, 2010 at the University of Metz to discuss their results and present them to a panel of stakeholders operating within the Meuse river basin.

The table 18 thus displays MAM7 from the summer season (i.e. from April to September) and Qhx100 from the winter season (i.e. from October to March).

These hydrological scenarios will be used by AMICE partners involved in the next actions, particularly the one dedicated to hydraulic modeling. It is indeed important to agree on similar values between countries and to limit the number of simulations. The AMICE Partners selected the most extreme values only: the wet climate scenario value for high-flows and the dry climate scenario value for low-flows.

All other simulations under the transnational climate scenarios lie within this range of hydrological situations.

The **final selected hydrological scenarios** correspond to:

- An increase in **Qhx100 (centennial hourly flood peak)** of **+15% for 2021-2050** and **+30% for 2071-2100**
- A decrease in **MAM7** (Mean Annual Minimum 7-days (April-Sept.) discharge values) of **-10%** for **2021-2050** and **-40% for 2071-2100**

6 Outlook

In the process of checking if there is a reasonable scientific backing for the AMICE climate scenarios, the AMICE partners involved in Action 3 had a post-meeting discussion after the meeting of March 11th, 2010.

Another possible approach that could be tested is to analyse the FP7 Ensemble results for the Meuse to get a more scientific understanding of how changes can happen. This could be done in parallel with the AMICE project. The University of Metz already compared the AMICE scenarios with the results of the Prudence project. The next step would be to compare the AMICE scenarios with more recent ENSEMBLE results. This might be done during the third year, when AMICE partners are able to start the additional work. The idea is not to change the AMICE scenarios, but to compare them with the most recent climate model results.

References

Ashagrie A. G., de Laat P. J. M., de Wit M. J. M., Tu M., and Uhlenbrook S., (2006). Detecting the influence of land use changes on discharges and floods in the Meuse River Basin – the predictive power of a ninety-year rainfall-runoff relation- Hydrology Earth System Sciences, Volume 10, pp. 691-701.

Baguis P., Boukhris O., Ntegeka V., Roulin E., Willems P., Demarée G., 2008, "Climate change impact on hydrological extremes along rivers and urban drain-age systems. I. Literature review", Final Report, K.U.Leuven – Hydrolics Section & Royal Meteorological Institute of Belgium, May 2008, 60 p. http://www.kuleuven.be/hydr/cci/reports/CCI-HYDR_I-LiteratureReview.pdf (11/02/2010).

Baguis P., Ntegeka V., Willems P., Roulin E., 2009. "Extension of CCI-HYDR climate change scenarios for INBO", Instituut voor Natuur- en Bosonderzoek (INBO) & Belgian Science Policy – SSD Research Program, Technical report by K.U.Leuven – Hydraulics Section & Royal Meteorological Institute of Belgium, January 2009, 31 p.

Blenkinsop S. and Fowler H.J., (2007). Changes in European drought characteristics projected by the PRUDENCE regional climate models. International Journal of Climatology, 27, pp. 1595-1610.

Bogena et al., H. 2005. MOSYRUR - Water balance analysis in the Rur basin. [Hrsg.] Forschungszentrum Jülich in der Helmholtz-Gemeinschaft. 2005. Bd. 52.

Booij, M. J. (2003). Determination and integration of appropriate spatial scales for river basin modelling. Hydrological Processes, 17(13), 2581–2598.

Bronstert, A., Bardossy, A., Bismuth, C., Buiteveld, H., Disse, M., & Engel, H., et al. (2007). Multi-scale modelling of land-use change and river training effects on floods in the Rhine basin. River Research and Applications, 23(10), pp. 1102–1125.

Brouyère S., Carabin G., Dassargues A., 2004a. Climate change impacts on groundwater resources: modelled deficits in a chalky aquifer, Geer basin, Belgium. Hydrogeology Journal, Volume 12, Issue 2, pp. 123-134 (2004).

Brouyère S., Dessargues A., 2004b. Spatially distributed, physically-based modelling for simulating the impact of climate change on groundwater reserves. Hydrology: Science & Practice for the 21st Century. Volume I, 2004 British Hydrological Society, pp. 9-14. http://www.hydrology.org.uk/Publications/imperial/1_02.pdf, (29/09/2009).

CEC. 2007. Neue Ergebnisse zu regionalen Klimaänderungen - Das statistische Regionalisierungsmodell WETTREG. 2007.

Christensen O.B., Christensen J.H. 2003. Intensification of extreme European summer precipitation in a warmer climate. Global and Planetary Change, 2004, 44, 107–117.

Corzo G., Solomatine D., Hidayat, de Wit M., Werner M., Uhlenbrook S., Price R., (2009), Combining semi-distributed process-based and data-driven models in flows simulation : a case study of the Meuse river basin, Hydrology and Earth System Sciences, Volume 13, pp.1619-1634.

Dal Cin C., Moens L., Dierickx Ph., Bastin G., Zech Y., (2005). An Integrated Approach for Realtime Floodmap Forecasting on the Belgian Meuse River. Natural Hazards (2005), 36, pp. 237-256.

Dautrebande S., Sohier C., (2006). Evaluation des effets hydrologiques de la modification de la rétention hydrique des zones tourbeuses de la Haute Lesse – Ourthe. Rapport d'étude Août 2006 – janvier 2007. Faculté Universitaire des Sciences Agronomiques de Gembloux (FUSAG), 32p.

De Groof, A., Hecq, W., Coninx, I., Bachus, K., Dewals, B. J., & Pirotton, M., et al. (2006). Adapt – Towards an integrated decision tool for adaptation measures – case study : floods. Intermediary report. Work package I: General study and evaluation of potential impacts of climate change in Belgium - research report, 66p.

De Keizer, O.; Kwadijk, J. (2009). Belgische scenario's voor de Maas, Deltares, in opdracht van Waterbouwkundig Laboratorium Antwerpen, Delft, 1200311-000-ZWS-0004, p. 15.

De Wit et al., M. J. M. 2007. Impact of climate change on low-flows in the river Meuse. Climatic Change. 82, 2007, S. 351-372.

De Wit M.J.M., van den Hurk B., Warmerdam P.M.M., Torfs P.J.J.F., Roulin E., van Deursen W.P.A., (2007). Impact of climate change on low-flows in the River Meuse. Climatic change, 82, pp 351-372.

De Wit, M.; van den Hurk, B.; Warmerdam, P.; Torfs, E.; Roulin, E.; van Deursen, W. (2007). Impact of climate change on low-flows in the River Meuse, Climatic Change, 82, pp. 351-372.

Degré A., Dautrebande S., Sohier C., Debauche O., (2008). Statistique des extrêmes dans les bassins faiblement jaugés : application d'un modèle gloabl pluie-débit à cinq bassins versants en région wallonne (Belgique). Biotechnol. Agron. Soc. Environ., 12 (4); pp. 379-391.

d'Ieteren E., Hecq W., Sutter R.D. et Leroy D. (2004), Effets du changement climatique en Belgique - Impacts potentiels sur les bassins hydrographiques et la côte maritime. Institut Royal pour la Gestion durable des Ressources naturelles et la Promotion des Technologies propres (IRGT-KINT): 28 p.

Driessen T. L. A., Hurkmans R. T. W. L., Terink W., Hazenberg P., Torfs P. J. J. F., and Uijlenhoet R., (2009). The hydrological response of Ourthe basin to climate change as modelled by the HBV model. Hydrology and Earth System Sciences Discussion, 6, pp.7143-7178.

FLOODSITE (2006), Flood risk analysis for the river Scheldt estuary. 21 p. http://www.floodsite.net/html/partner_area/project_docs/T25_06_01_Scheldt_risk_analysis_D25_1_v1_0_P01.pdf (11/02/2010).

Gellens D., Roulin E., (1998). Streamflows response of Belgian basins to IPCC climate change scenarios. Journal of Hydrology, 210, pp 242-258.

Gerlinger, K. 2009. Analyse des Kenntnisstandes zu den bisherigen Veränderungen des Klimas zu den Auswirkungen der Klimaänderung auf den Wasserhaushalt im Rhein-Einzugsgebiet - Literaturauswertung . 2009.

Gerstengarbe et al., F.-W. 2004. Erstellung regionaler Klimaszenarien für Nord-rhein-Westfalen. 2004.

GIEC, (2007). Bilan 2007 des changements climatiques. Contribution des Groupes de travail I, II et III au quatrième Rapport d'évaluation du Groupe d'experts intergouvernemental sur l'évolution du climat. [Equipe de rédaction principale, Pachouri R. K. et Reisinger A. (publié sous la direction de ~)]. GIEC, Genève, Suisse, ..., 103p. http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_fr.pdf (11/02/2010).

Giron E., Sacre D., Hecq W., Coninx I, Bachus K., Dewals B., Detrembleur S., Pirotton M., El Kahloun M., Meire P., De Smet L., De Sutter R., (30/04/2008). ADAPT – Towards an integrated decision tool for adaptation measures – Case study : floods. Final report (Phase I), 130p.

Goderniaux P., Brouyère S., Fowler H. J., Blenkinsop S., Therrien R., Orban P., Dassargues A., (2009). Large scale surface – subsurface hydrological model to assess climate change impacts on groundwater reserves. Journal of Hydrology, 373, pp 122-138.

Haylock M. R., Hofstra NKlein Tank., A. M. G., Klok E. J., Jones P. D., New M., (2008). A European daily high-resolution gridded data set of surface air temperature and precipitation for 1950-2006. Journal of Geophysical Research, 113, D20119, doi:10.1029/2008JD010201.

Jakob et al., D. 2008. Klimaauswirkung und Anpassung in Deutschland - Phase 1: Erstellung regionaler Klimaszenarien für Deutschland. 2008.

Kropp et al., J. 2009. Klimawandel in Nordrhein-Westfalen - Regionale Abschätzung der Anfälligkeit ausgewählter Sektoren. 2009.

Leander R. , Buishand A., ven den Hurk B.J.J.M., de With M.J.M., (2008). Estimated changes in flood quantiles of the river Meuse from resampling of regional climate model output. Journal of hydrology, 351, pp 331-343.

Leander R., and Buishand T. A., (2007). Resampling of regional climate model output for the simulation of extreme river flows. Journal of Hydrology, 332, pp 487-496.

Leander, R.; Buishand, T.; Aalders, P.; De Wit, M. (2005). Estimation of extreme floods of the River Meuse using a stochastic weather generator and a rainfall-runoff model, Hydrological Sciences Journal, 50(6), pp. 1089-1103.

Lenderink G., Buishand T.A., van Deursen W., (2007). Estimates of future discharges of the River Rhine using two scenario methodologies: direct versus delta approach. Hydrology and Earth System Sciences 11, pp 1145-1159.

Marbaix P. et van Ypersele J.-Y., (2004). Impacts des changements climatiques en Belgique. Greenpeace, Bruxelles, 2004, 44p. http://www.astr.ucl.ac.be/users/marbaix/impacts/ (11/02/2010).

Masoudian, M. 2009. The topographical impact on effectiveness of flood protection measures. Kassel : s.n., 2009.

Middelkoop et al., H. 2001. Impact of climate change on hydrological regimes and water resources management in the Rhine basin. Climatic Change. 49, 2001, S. 105-128.

Ministère de la Région wallonne, Direction Générale des Ressources naturelles et de l'Environnement, Observatoire des Eaux de Surface, Direction des Eaux de Surface Direction des Eaux souterraines, (mars 2005). District Hydrographique International de la Meuse. Tome I : Etat des lieux en Région wallonne. Analyse des caractéristiques du District hydrographique. 63 pp.

MUNLV. 2005-1. Ergebnisbericht Rur und südliche sonstige Maaszuflüsse. 2005-1.

MUNLV. 2005-2. Ergebnisbericht Niers, Schwalm und nördliche sonstige Maaszuflüsse. 2005-2.

MUNLV. 2007. Anpassung an den Klimawandel: Eine Strategie für Nordrhein-Westfalen. 2007.

Ntegeka V., Willems P., 2008. « CCI-HYDR Perturbation Tool: a climate change tool for generating perturbed time series for the Belgian climate", Manual, K.U.Leuven – Hydraulics Section & Royal Meteorological Institute of Belgium, December 2008, 7p.

Ntegeka V., Willems P., Baguis P., Roulin E., 2008. "Climate change impact on hydrological extremes along rivers and urban drainage systems. Summary report Phase 1: Literature review and development of climate change scenarios", K.U.Leuven – Hydraulics Section & Royal Meteorological Institute of Belgium, April 2008, 56p. http://www.kuleuven.be/hydr/cci/reports/CCI-HYDR_Phase%201%20report.pdf (11/02/2010).

Perrin et al., C. 2003. Improvement of a parsimonious model for streamflows simulation. Journal of Hydrology. 279, 2003, S. 275-289.

Pfister et al., L. 2004. Climate change, land use change and runoff prediction in the Rhine-Meuse basins. River Research and Applications. 20, 2004, S. 229-241.

Pfister, L., Kwadijk, J. C. J., Musy, A., Bronstert, A., & Hoffmann, L. (2004). Climate change, land use change and runoff prediction in the Rhine-Meuse basins. River Research and Applications, 20(3), pp 229–241.

Smitz J. S., Dautrebande S. et al., 2002. Integrated modelling of the hydrological cycle in relation to global climate change. In: Global Change and sustain-able development, Final reports Summaries, Federal Science Policy Office, 2002, 421p.

Sohier C. et Dautrebande S., 2006. Erosion hydrique et pertes en sols agricoles par modélisation EPICgrid : le bassin versant de l'Escaut en région wallonne. Poster présenté au séminaire de clôture Scaldit – Malines, 24 octobre 2006, http://www.fsagx.ac.be/ha/pdf/Posters_Scaldit_2006.pdf, (29/09/2009).

Sohier C., Degré A., Dautrebande S., (2009). From root zone to modelling regional forecasting of nitrate concentration in recharge flows – The case of the Walloon Region (Belgium). Journal of Hydrology, 369, pp 350-359.

Souchère V., Cerdan O., Dubreuil N., Le Bissonnais Y., King B., (2005). Model-ling the impact of agri-environmental scenarios on runoff in a cultivated basin (Normandy, France). Catena, 61, pp 229-240.

Spekat et al., A. 2006. Fortschreibung der Klimaszenarien für Nordrhein-Westfalen. 2006.

Tu, M., de Laat, P., Hall, M., & de Wit, M. (2005a). Precipitation variability in the Meuse basin in relation to atmospheric circulation. Water Sciences and Technology, 51 (5), pp. 5-14.

Tu, M., Hall, M. J., de Laat, P. J., & de Wit, M. J. (2005b). Extreme floods in the Meuse river over the past century: aggravated by land-use changes- Physics and Chemistry of the Earth , 30, pp. 267-276.

Van Pelt et al., S.C. 2009. Discharge simulations performed with a hydrological model using bias corrected regional climate model input. Hydrology and Earth System Sciences Discussions. 6, 2009, S. 4589-4618.

Van Pelt S. C., Kabat P., ter Maat H. W., van den Hurk B. J. J. M., and Weerts A. H., (2009). Discharge simulations performed with a hydrological model using bias corrected regional climate model input. Hydrology and Earth System Sciences Discussion, 6, pp 4589-4618. www.hydrol-earth-syst-sci-discuss.net/6/4589/2009/(11/02/2010).

Van Vliet M.T.H. et Zwolsman J.J.G., (2008). Impact of summer droughts on the water quality of the Meuse River. Journal of Hydrology, 353, pp 1-17.

Verworn, Hans-Reinhard. 2008. Flächenabhängige Abminderung statistischer Regenwerte. Fachbeitrag aus KW Korrespondenz Wasserwirtschaft 2008 (1) Nr.9 - Hydrologie und Wasserbewirtschaftung. 2008, S. 493-498.

Willems P., Baguis P., Ntegeka V. et al.: Presentation CCI-HYDR interim results at 5th Follow-up Committee Meeting (Leuven, October 2009). http://www.kuleuven.be/hydr/cci/reports/CCI-HYDR%20FCM%20Oct%202009.pdf (11/02/2010).

Zebisch et al., M. 2005. Klimawandel in Deutschland - Vulnerabilität und Anpassungsstrategien klimasensitiver System. 2005.

http://www.irgt-kint.be/Repositories/Documents/medias/docs/IRGT_Notice_scientifique_1.pdf (11/02/2010)

http://dev.ulb.ac.be/ceese/ADAPT/public_section/Doc/Doc/Finalreport0405f.pdf (11/02/2010)

http://dev.ulb.ac.be/ceese/ADAPT/public_section/Doc/WP1_climate%20change%20in%20Belgium.pdf (11/02/2010)

http://environnement.wallonie.be/directive_eau/edl_dhi/me/meuse_dg.pdf (11/02/2010)

http://www.belspo.be/belspo/home/publ/pub_ostc/CG2131/CG_en.pdf (06/01/2010)

List of appendices

Appendix 1: More information about climate projections for the Meuse Basin

Warming of temperature for Belgium could be by the end of 2100:

- In winter, between 1,7°C and 4, 6°C with a SRES scenario B2, and between 2,9°C and 4,9°C with a SRES scenario A2 (Marbaix et van Ypersele, 2004);
- In summer, between 2,4°C and 4,6°C with a SRES scenario B2, and between 3,1°C and 6,6°C with a SRES scenario A2.

The CCI-HYDR Perturbation Tool was developed by the KUL (Katholieke Universiteit Leuven) and the IRM (Institut Royal Météorologique belge) in order to fill in the gaps of the Belgian climate perturbation tool. It has been realised during the project "Climate change impacts on hydrological extremes in Belgium", supported by BELSPO (Belgian Science Policy Office). This tool's main goal is to synthesize relevant climate scenarios for Belgium based upon study on regional climate model from the PRUDENCE project (Ntegeka et al., 2008). In order to achieve that, a perturbation algorithm was developed. It produces perturbation series of variables (temperature, rainfall, ETP, wind) for different climate change scenarios (A1B, A2, B1 and B2) and different time slices (Ntegeka et al., 2008; Baguis et al., 2008). The latest results of the CCI-HYDR project for temperature are presented in Table 1 (Willems et al., 2009; Baguis et al., 2009).

	Low	Mean	High
Winter	+ 1,57°C → + 1,84°C	+ 2,92°C → + 3,32 °C	+ 3,85°C → + 4,88°C
Summer	+ 2,12°C → + 2,79°C	+ 3,09°C → + 4,68°C	+ 3,74°C → 8,12°C

Table 1: Predicted change in temperature for time slice 2070-2100 produces by the CCI-HYDR project (P. Willems, P. Baguis, V. Ntegeka et al.: Presentation CCI-HYDR interim results at 5th Follow-up Committee Meeting (Leuven, October 2009).

In addition to the results of the CCI-HYDR project, we could mention the study led on the Geer Basin in Belgium which forecasts a warming of yearly temperature by 3,5°C (HIRHAM_H) to 5,6°C (RCAO_E) for time slice 2070- 2100 under a SRES scenario A2. Highest temperature rise will occur during spring and summer. The highest rise in temperature calculated occurs in August with +7,5°C (HIRHAM_E) and +9,5° C (RCAO_E). The lowest rise in temperature occurs at the end of winter and beginning of spring with +1,9°C (HIRHAM_E, March) and +5,5°C (RCAO_E, March) (Goderniaux et al., 2009).

Concerning rainfalls, the most likely evolution of rainfall during the 21st century varies considerably between summer and winter. Winter rainfalls could rise moderately between +6% and +23% by 2100 according to Marbaix and van Ypersele (2004), and by +10% according to d'Ieteren et al. (2004). While in the CCI-HYDR project, winter rainfall could decrease by 6% in the driest scenario and rise by 66% in the wettest one. Concerning summer rainfalls, opinions diverge significantly. Marbaix and van

Ypersele (2004) plan a diminution by 0 to 50% while d'Ieteren et al. (2004) plan a diminution between 0 and 3%. The latest results of the CCI-HYDR project (which are slightly different from the results of their perturbation tool) predict a diminution of 54% in the driest scenario and a rise up to 12% in the wettest one (In the coastal area). Results are presented in Table 2 (Willems et al., 2009; Baguis et al., 2009). A possible diminution of rainfall combined with a temperature rise could lead to a sensitive impoverishment of water availability during summer. However, forecasts agree on larger and more intense rainfall for Europe and for Belgium (Tu et al., 2005).

	low	mean	High
Winter	-6% → +9%	+9% → +32%	+21% →+66%
Summer	-54% → -36%	-29% → -12%	-14% → +12%

Table 2 : Predicted change in rainfall for time slice 2070-2100 produces by the CCI-HYDR project (P. Willems, P. Baguis, V. Ntegeka et al.: Presentation CCI-HYDR interim results at 5th Follow-up Committee Meeting (Leuven, October 2009).

In addition to the previous results, a study on the Geer basin in Belgium forecasts, under a SRES scenario A2, a decrease of annual rainfall for time slice 2071-2100 between -1,9% (ARPEGE) and - 15,3% (HAD_P_H). An important diminution could be observed during summer months partially compensated by a rise of winter rainfall (Goderniaux P. et al., 2009).

According to the database set up by the University of Metz (coordinator of Ac1 and Ac3), 776 references are available to date. Approximately 5% of them were introduced by the HACH and are mainly scientific articles. Some reports of projects and conferences related to climate change are also included.

The next paragraphs enable to make a synthesis of the information included in these publications and a synthesis of the current knowledge in the context of climate change regarding the modifications of floods.

In particular, the HACH has been a partner of the research project ADAPT since 2005 (Towards an integrated decision tool for adaptation measures). An innovative methodology was developed in this project in order to integrate the assessment of adaptation measures in the context of climate change. This project also led to a general evaluation of the expected effects of climate change in Belgium.

Secondary impacts, as well as economic as ecological and social ones, were also treated in the ADAPT project. We keep hereafter the main conclusions related to the primary impacts of the climate change, in particular the impacts on the hydrological cycle.

Precipitations

The historical measurements of precipitations in Europe show a rising tendency in the northern part (increase from 10 to 40%), while reductions in the order of 20% are recorded in the south (Mediterranean basin). In the Meuse basin, measurements show a diminution trend regarding the annual or seasonal average values. These variations cannot be regarded as significant compared to the natural variability of precipitations [1].

Projections of climate changes for Belgium show an important seasonal variation. Despite the differences between models and climate scenarios, all of them converge towards a moderate increase in winter precipitations during this century. This evolution is estimated to be between a few percents and about 20% percents according to previous studies. In opposite, precipitations will probably decrease in summer but the quantitative estimates diverge. They lead to estimations located between zero and a reduction of a half of the precipitated volumes.

This seasonal differentiation, challenging for resources management, is well represented in Figure 1 [2]. This last one details the mean evolution of temperatures and precipitations between periods 1961-1990 and 2071-2100. The results are provided for two scenarios of emissions, five global circulation models (GCM) and a series of regional climate models (RCM). It appears that the progression of winter precipitations is included in a range of 3 to 30% until the end of the 21st century. The precipitations in summer follow an evolution that is more dubious, between unchanged volumes and a reduction of a half. These tendencies released for Belgium also apply to the Meuse basin [1].

Major uncertainties in these projections are not only related to the current limits of the models and the subjacent scenarios, but also to the natural variability of the climate parameters. These uncertainties are more pronounced on the variability of precipitations than on temperatures [3].

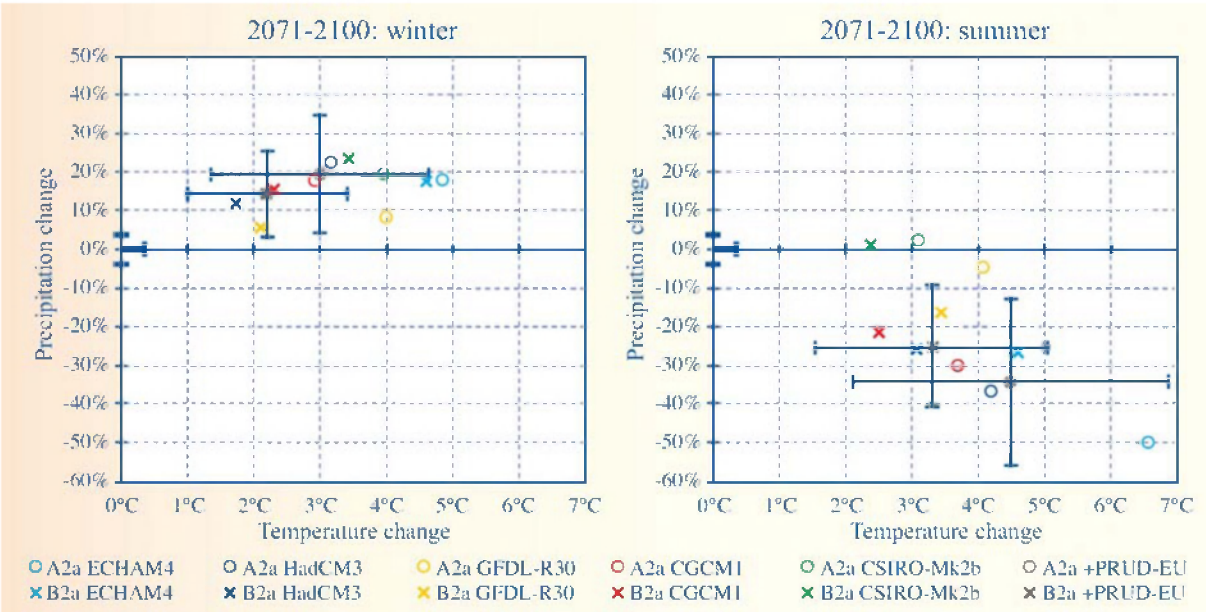


Figure 1: Average evolution of temperatures and precipitations in Belgium between the control period 1961-1990 and the period 2071-2100. The projections are represented for 2 scenarios of emissions (○ : « evolution including few modifications» and × : «evolution oriented to a sustainable development»),5 global circulation models (colour symbols) and some regional climate models [2].

Weather variability and extreme events

In given climate conditions, the intensity and frequency of extreme events such as heatwaves and droughts, intense showers or storms can be characterized by specific statistical distributions. Small changes in climate are likely to induce a strong influence on the frequency and intensity of extreme events that both influence natural and socioeconomic systems. Therefore, beyond average climate trends, projections of extreme events need to be understood properly in line with the objectives of the AMICE project.

In general, it is proven that the climate tends to move towards an increased frequency of extreme weather situations, with some effects on extreme hydrological events, but without precise quantification available. The impact on extreme events is likely to be more pronounced than on the average precipitations. Measures in Central and North of Europe already show an increase in the number of very wet days during the last three decades, often linked with flooding.

Basically in Germany there are four Regional Climate Models (RCM) in use. Those are the Statistical Models WETTREG (CEC Potsdam) and STAR (PIK Potsdam) and the dynamical models REMO (MPI Hamburg) and CCLM (COSMO-CLM).

Gerstengarbe et al. (2004) used the statistical scenario-model (STAR) for the assessment of the future climatic evolution in NRW. Generalized information from GCM-runs is hereby connected with measured data via non- hierarchical cluster analysis. Through Monte-Carlo-simulations the most likely evolution of selected meteorological variables was calculated. The model was validated against measured data. The mean error for all meteorological variables was less than 10%. A transient scenario for 2001-2055 was calculated using a temperature increase that was derived from the ECHAM4-T42-OPYC-run. The results for 2046/2055 are compared to the mean-values for measured data between 1951 and 2000. From the available results conclusions concerning the expected climate changes were drawn. The most important result of the future scenarios in this study is the distinct warming and the further increase of precipitation in wide areas of NRW. There was no distinction between the seasons of the year. Since the simulations only run until 2055 these results are not directly suitable for our purposes.

Spekat et al. (2006) builds up on Gerstengarbe et al. (2004) and focuses on the future climate evolution in the seasons and especially on impact-relevant variables for the vegetation-period. Attention should be paid to the fact that the methodology that underlies the STAR-scenarios had been further improved in the meantime. The conclusions are that the mean temperature for whole NRW increases continuously (Table 3). For the decade of 2046-2055 the increases reaches about 1.7 °K. The spatial evolution of this increase is quite homogeneously distributed over whole NRW. Besides, the seasonal evolution was regarded. The strongest increase in temperature happens in winter (about 2.4 °K to the middle of the century). In summer the increase is weaker and about 1.8 °K in total. For the other two seasons the increase lies at about 1.0 °K . The evolution of precipitation until the middle of the century is twofold. There is a decrease in summer and an increase in the rest of the year. The strongest increase in precipitation is simulated for the winter. The increase in winter-precipitation is not homogeneously distributed over NRW. While there are parts with predicted increases of about 35% , there are also areas with no increase predicted until the middle of the century. The mean decrease in summer-precipitation for whole NRW is at about -20%. The decrease in summer-precipitation is not homogeneously distributed over NRW. While there are parts with predicted decreases of about -35%, there are also areas with decrease of about -10% (Eifel). Again the simulations only run until 2055. So the results are not directly suitable for our purposes. Nevertheless hints for the climate evaluation in NRW until the middle of the century will be very useful for comparisons with other results.

The CCLM modeling area cove rs whole Europe. The simu lations cover the period between 1960 and 2000 in thre e realizations and the pr edicted evolution b etween 2001 and 2100 for the emission-scenarios A1B and B1 with two realizations each. At its boundary CCLM is embedded into the GCM ECHAM5/MPI-OM for all seven realizations. Every realizat ion has equal probability to o ccur. The CCLM results will be mentioned later again.

In (Kropp et al., 2009) the Regional C limate Model CCLM was used for marker-scenario (A1B). For the limitation of the unce rtainty, it was tried, wherever possible, to make use of comparative calc ulations with the RCM STAR. Here CCLM and Star were based on the same results of the same ECHAM5/M PI-OM GCM. An assessment of the bandwidth of future climate evolutions is only possible when using all realizations. For a stable statistic the number of simu lations was too low. Thus, a "mean-climate-change-signal" could not be calculated. In (Kropp et al., 2009) many realizations of STAR have been considered . They could be used to identify three different scenarios: Dry, Mean and Wet.

	T (°C) 1961-1990	T (°C) 2031-2060	ΔT (°C) (1961-1990/ 2031-2060)	P [mm] 1961-1990	P [mm] 2031-2060	ΔN (%) (1961-1990/ 2031-2060)
CCLM	8,5	9,9	+1,4	1089	1120	+ 3%
STAR dry	8,9	11,2	+2,2	911	887	- 3%
STAR middle	8,9	11,3	+2,3	911	1007	+ 10%
STAR wet	8,9	11,3	+2,3	911	1063	+ 17%

Table 3: Overview of mean changes for NRW for (2031-2060)/(1961-190) in temperature and precipitation following (Kropp et al., 2009)

In Table 3 the predicted changes in tem perature and precipit ation following CCLM and STAR are shown. All models show an increase in mean tem perature, but the increase following STAR is much higher, independently of the sc enario (wet, mean, dry). While CCLM shows a slight increase in mean precipitation, STAR results differ very much. The dry scenario even shows a decrease of -3%. The wet scenario shows an increase of 17%. Since the result s only cover the period until the middle of the century the results cannot be used for our purposes.

In Jakob et al. (2008) the model chai n ECHAM5/MPI-OM (GCM) and REMO (RGM) was used. The aims of this project among others are the dynamical building of three regional high-resolution (about 10 km) climat e scenarios for Germany to investigate possible climate changes and the archiving and provision of the output data in the CERA-database.

The temporal resolution of the output is one hour. Addition ally monthly values are computed. All experiments were driven follo wing the method of double nesting. First, REMO was run with a spatial resolution of about 50 km using the results of ECAHM5/MPI-OM as input. Afte rwards, the results of this REMO run wer e used for another REMO run with a spat ial resolution of about 10 km. The inner model area contains Germany, Austria and Switzerland. The complete bas ins of the Rhine and the Elbe are contained. Using this doub le nesting method has the advantage that there are no large scale-jumps.

For the projection of possible climate conditions in the 21 st century, the SRES emission scenarios A1B, B1 and A2 hav e been used. For the GCM ECHAM5/MPI-

OM the horizontal resolution T63 was used for the control run (1950-2000) and for the 3 scenario-runs as well (all 2001-2100).

The rising greenhouse gas concentration leads to an increase of temperature in Germany, which reaches between 2,5 and 3,5 °K in the year 2100. This warming will differ seasonally and regionally. The strongest increase of temperature is predicted in winter in the south and southeast of Germany. In comparison to 1961-1990 in these areas temperatures in winter may increase for more than 4°K.

At the same time – in comparison to the period from 1961 to 1990 – the precipitation in summer will decrease in wide parts of Germany. In contrast to this, whole Germany may become wetter in winter. Especially in the low mountain regions in the south and southwest of Germany an increase in precipitation of more than 30 % can be expected. For all three scenarios there is no clearly visible trend estimated for the annual sum of precipitation.

In (CEC, 2007) the Statistical Regional Model WETTREG was used. WETTREG works with measured data from survey stations and gives results for these stations. Input data from 282 climate stations and of 1695 precipitation stations in whole Germany have been used. The global climate simulations that WETTREG builds on have been calculated with ECHAM5/MPI-OM. The simulations ran from 2010 – 2100 for the scenarios A1B and B1 (and A2 whose results are not mentioned in this study) and were part of the research project "Klimaauswirkungen und -Anpassung in Deutschland – Phase 1: Erstellung regionaler Klimaszenarien für Deutschland."

Concerning the temperature evolution for the time period from 2071- 2100 in comparison to 1961-1990 the range of the results for scenario B1 lies between an increase of 1,5°K in the southwest of Germany and about 3,0° K in parts of Bavaria. The mean increase for whole Germany is 1.8°K. For scenario A1B the range lies between almost 2,0° K and about 3° K in wide parts of Germany. The mean increase for whole Germany is 2,3° K.

The WETTREG simulations of precipitation show clearly visible trends, but with opposed directions for summer and winter. The mean decrease in sum of summer precipitation for 2071-2100 compared to 1961-1990 for scenario A1B is 22%. For scenario B1 the mean value of decrease is 17,7%.

The mean increase in the sum of winter precipitation for 2071-2100 compared to 1961-1990 for scenario A1B is 30,3%. For scenario B1 the mean increase is 19.0%.

In 2007 the German Weather Service (DWD) started within the so called ZWEK project developing a proceeding for the long-term forecast of climate evolution and its impacts on the regional scale. For this purpose the results from CCLM, REMO, WETTREG and STAR driven by the global climate simulations of ECHAM5-T63L31/MPI-OM (emission scenario A1B, run no. 1) of the Max-Planck-Institute for meteorology - the results have been partly mentioned on the previous pages – have been considered. The trend parameter for STAR was also derived from the results of the ECHAM5-model. STAR is different from the other three regional models in not using the direct outputs from global models. It is only necessary to imply a trend that has been identified from the results of the global models. In this case a linear increase of 2 °K for 2004 to 2055 has been impressed.

Within the first phase of this ZWEK project evaluations have been undertaken for the periods of 2021-2050 and 2071-2100 compared to 1971-2000, i.e. for the periods we want to consider within the AMICE project. Afterwards the evaluations were opposed.

The results were compared for the whole year and also broken down to the four seasons of the year.

In Figure 2 an overview over the differences between modelled projections for the periods 2021-2050 and 2071-2100 compared to 1971- 2000 for the mean temperature in the summer season is given. Since the STAR projections only run until 2055 only the first period could be regarded. For both time periods CCLM simulates the strongest increase, while the weakest increase for both periods is simulated by WETTREG.

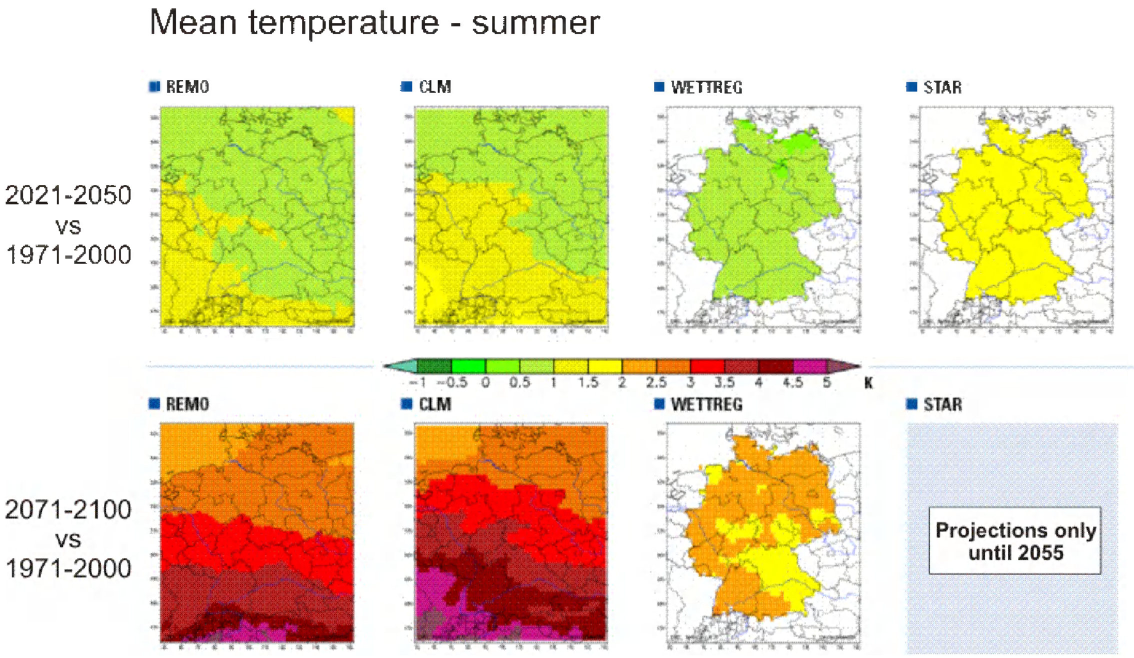


Figure 2 : Differences in temperatures for the summer season between projections of 2071-2100 and 2021-2050 compared to 1971-2000 (on the basis of DWD)

In Figure 3 an overview over the differences between modelled projections for the periods 2021-2050 and 2071-2100 compared to 1971-2000 for the temperature in the winter season is given. For the period from 2071-2100 WETTREG simulates the strongest increase for most parts of Germany.

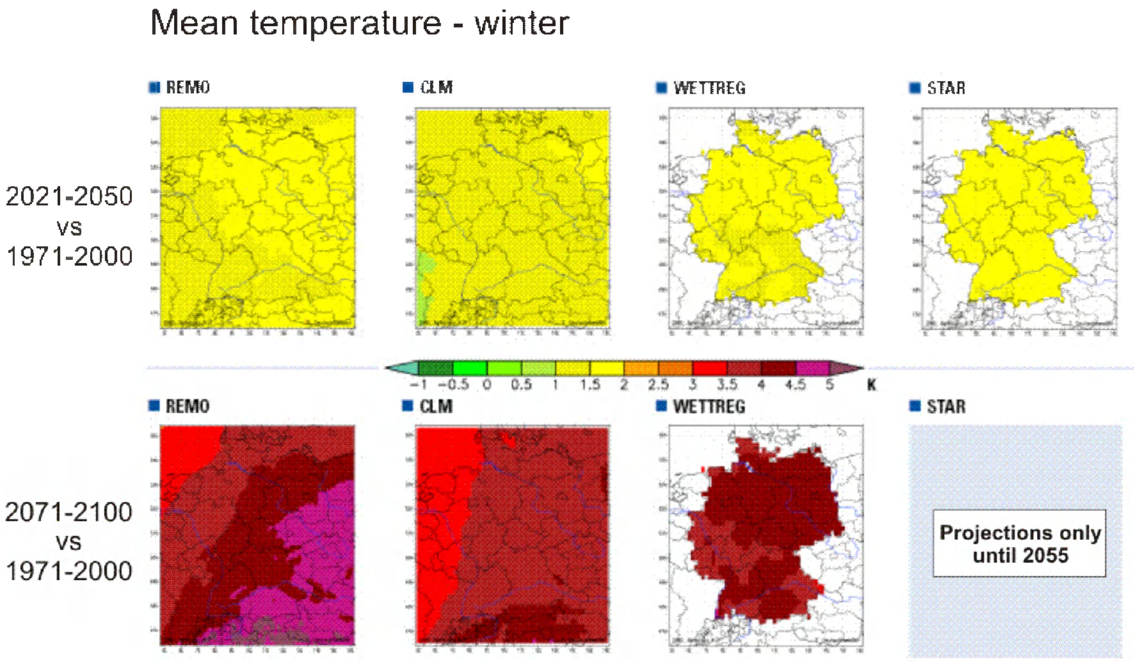


Figure 3: Differences in temperatures for the winter season between projections of 2071-2100 and 2021-2050 compared to 1971-2000 (on the basis of DWD).

Concerning the changes in precipitation for the periods from 2021-2050 and 2071-2100 compared to 1971-2000, Figure 4 and Figure 5 give an overview over the simulation results. For the end of the century all models show a decrease in the amount of precipitation in summer. For the winter season all models show an increase. The spatial distribution is not homogeneous in all cases.

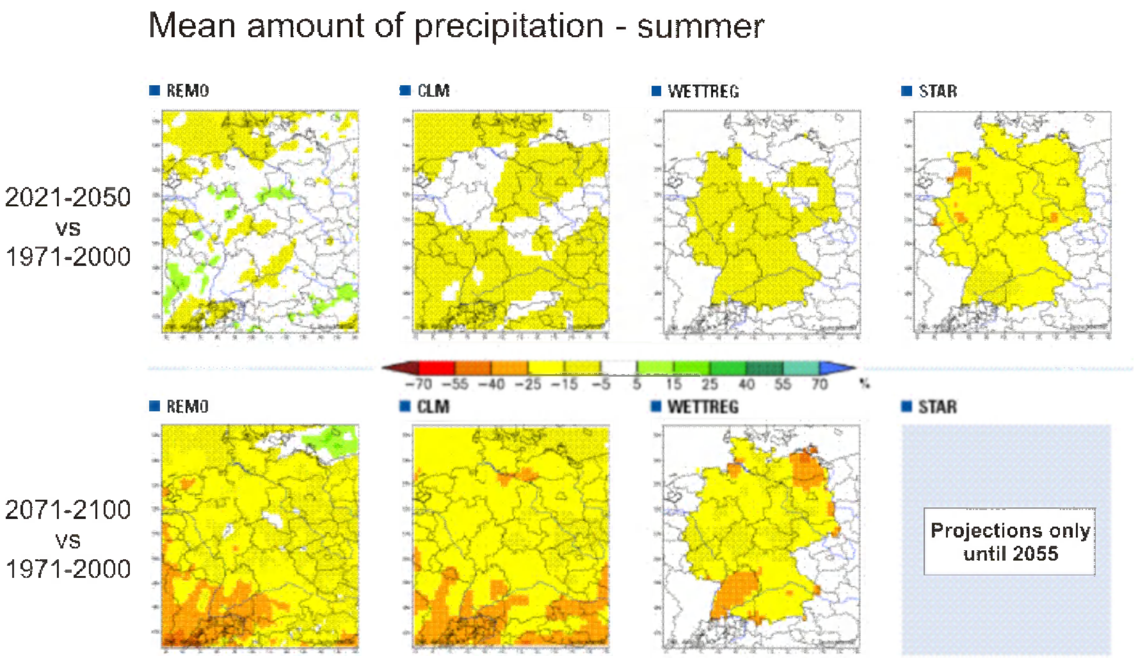


Figure 4: Differences in precipitation amount for the summer season between projections of 2071-2100 and 2021-2050 compared to 1971-2000 (on the basis of DWD).

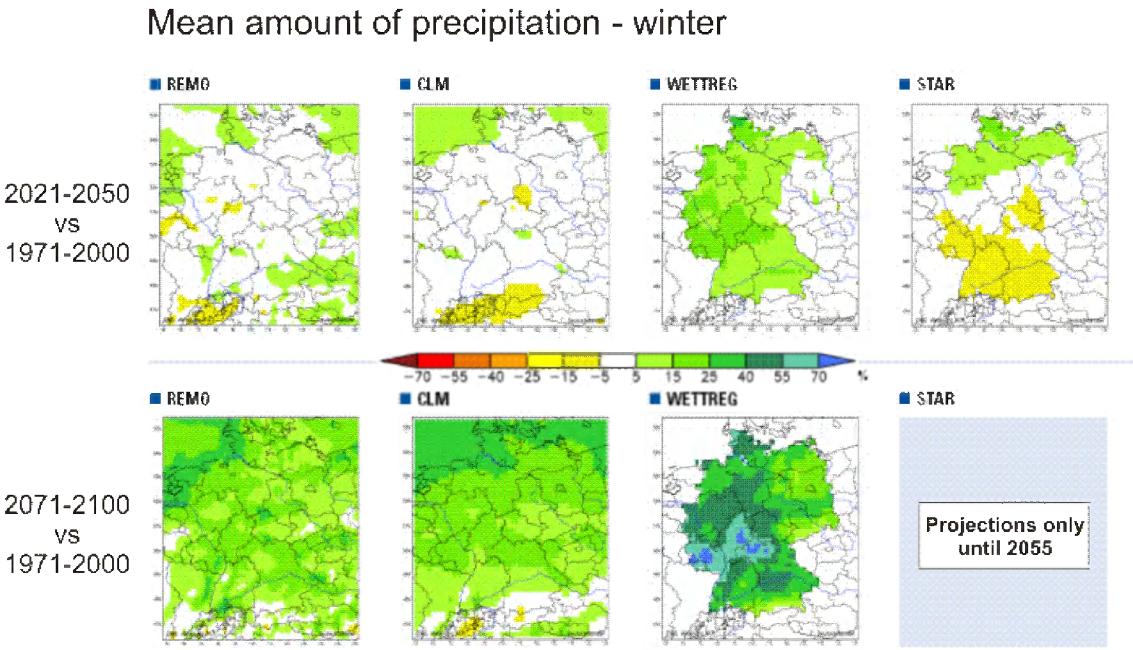


Figure 5: Differences in precipitation amount for the winter season between projections of 2071-2100 and 2021-2050 compared to 1971-2000 (on the basis of DWD).

In the Netherlands, until 2006, the climate scenarios of Waterbeheer 21e eeuw or WB21 (Water Management 21st century, 2000) were used as a reference for future water management. Based on more recent insights from worldwide climatological research, these scenarios were replaced by the KNMI 2006 scenarios, presented by Royal Netherlands Meteorological Institute (KNMI). These (four) scenarios now serve as the national standard in adaptation policies in the Netherlands (Hurk et al., 2006).

KNMI scenarios in short

Based on an ensemble of climate projections from the Prudence project KNMI defined four scenarios. The G scenarios assume a 1°C global temperature rise on earth by 2050 compared to 1990. The W scenarios assume a 2°C global temperature rise on earth by 2050 compared to 1990. The G+ and W+ scenarios assume a change in atmospheric circulation patterns in Western Europe. They assume milder and wetter winters due to more westerly winds, and warmer and drier summers due to more easterly winds. The G and W scenarios assume no change in atmospheric circulation patterns in Western Europe. See Figure 6. The assumed climatological changes per scenario can be found in Table 4.

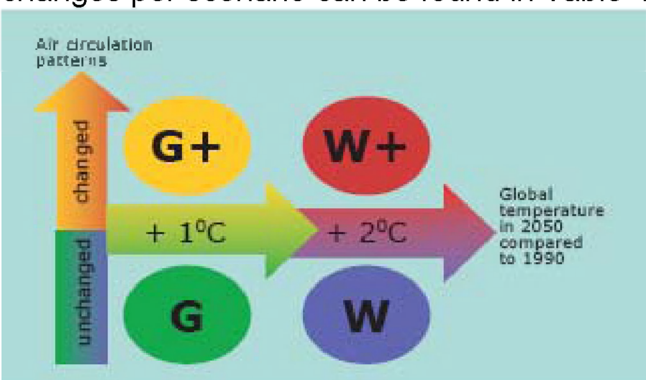


Figure 6. Schematic overview of the four KNMI ’06 climate scenarios (KNMI, 2009)

Table 4. Climate change in the Netherl ands around 2050, compar ed to the baseline year 1990, according to the four KNMI'06 climate scenarios. Winter = Dec, Jan, Feb. Summer = Jun, Jul, Aug (Hurk et al., 2006)

Variable	G	G+	W	W+
Summertime values				
Mean temperature (K)	+0.9	+1.4	+1.7	+2.8
Yearly warmest day (K)	+1.0	+1.9	+2.1	+3.8
Mean precipitation (%)	+2.8	-9.5	+5.5	-19.0
Wet day frequency (%)	-1.6	-9.6	-3.3	-19.3
Precipitation on wet day (%)	+4.6	+0.1	+9.1	+0.3
10yr return level daily precipitation sum (%)	+13	+5	+27	+10
Potential evaporation (%)	+3.4	+7.6	+6.8	+15.2
Wintertime values				
Mean temperature (K)	+0.9	+1.1	+1.8	+2.3
Yearly coldest day (K)	+1.0	+1.5	+2.1	+2.9
Mean precipitation (%)	+3.6	+7.0	+7.3	+14.2
Wet day frequency (%)	+0.1	+0.9	+0.2	+1.9
Precipitation on wet day (%)	+3.6	+6.0	+7.1	+12.1
10yr return level daily precipitation sum (%)	+4	+6	+8	+12
Yearly maximum daily mean wind speed	0	+2	-1	+4

Sea level sensitivity	**low scenario**		**high scenario**	
year (ΔTG since 1990)	*2050 (+1°C)*	*2100 (+2°C)*	*2050 (+2°C)*	*2100 (+4°C)*
Low	15	35	20	40
High	25	60	35	85

Methodology

The KNMI'06 climate scenarios have been produced based on an ensemble of RCM simulations in the context of the European PRUDENCE project (Christensen et al., 2002). In this project dynamical downscaling has been applied using 10 RCMs and 3 GCMs, all run for two 30-year time slices : a control period 1960 – 1990 and a future period 2070 – 2100, assuming two different SRES emission scenarios (A2 and B1).

It was found that most of the temperature range in Western Europe could be related to changes in projected global mean temperature. For this reason global mean temperature change has been used as one of the two steering parameters in the definition of the KNMI'06 climate scenarios. The global mean temperature rise is derived from projections of GCMs which have become available during the preparation for the Fourth Assessment Report (AR4) of IPCC, released in 2007 (See Figure 7).

Figure 8 shows projections of summer and winter precipitation and temperature for the Netherlands for the period 1900-2200. In addition, it was shown that a strong link exists between the strength of the western circulation and (seasonal mean) temperature and precipitation. Therefore, in the KNMI'06 climate scenarios, circulation was used as the second steering parameter.

So, temperature and circulation were used to discriminate four different scenarios for the Netherlands for temperature and precipitation. This was done by choosing two different values of global temperature change and two different assumptions about the circulation response.

The construction of the extreme precipitation and temperature values and the potential evaporation values was carried out using an ensemble of Regional Climate Model (RCM) simulations and statistical downscaling on observed time series. Additional scaling and weighting rules were designed to generate RCM sub-ensembles matching the seasonal mean precipitation range suggested by the GCMs.

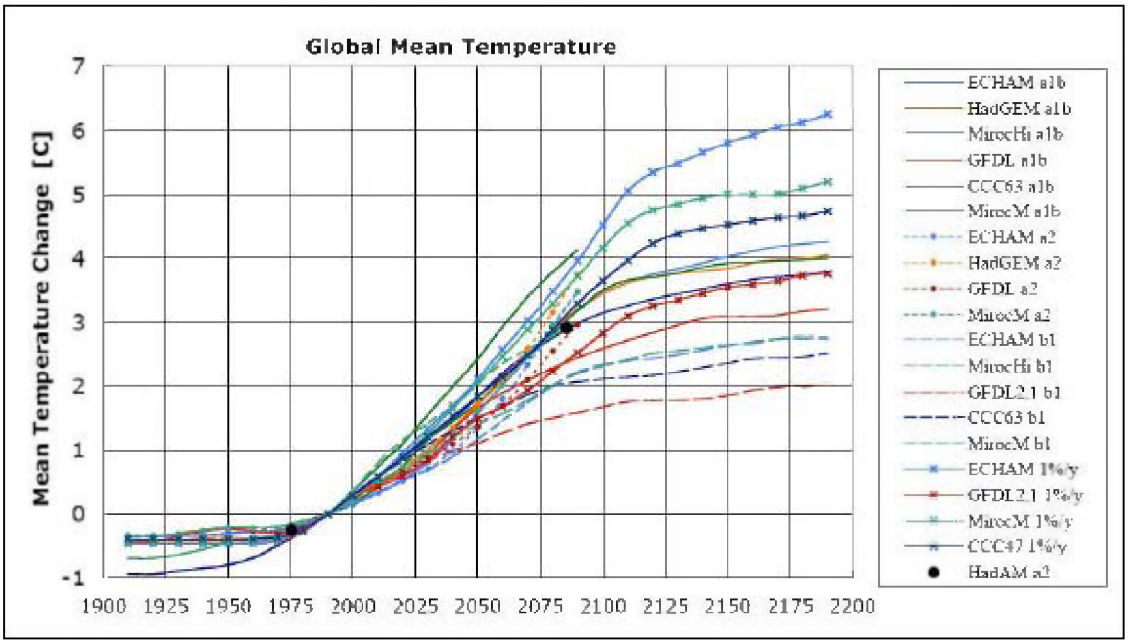


Figure 7. Time series of global mean temperature change for a wide range of GCM simulations, all driven by four different greenhouse gas emission scenarios (SRES B1, A1B, A2 and a scenario with 140 years of 1% CO_2 increase per year)

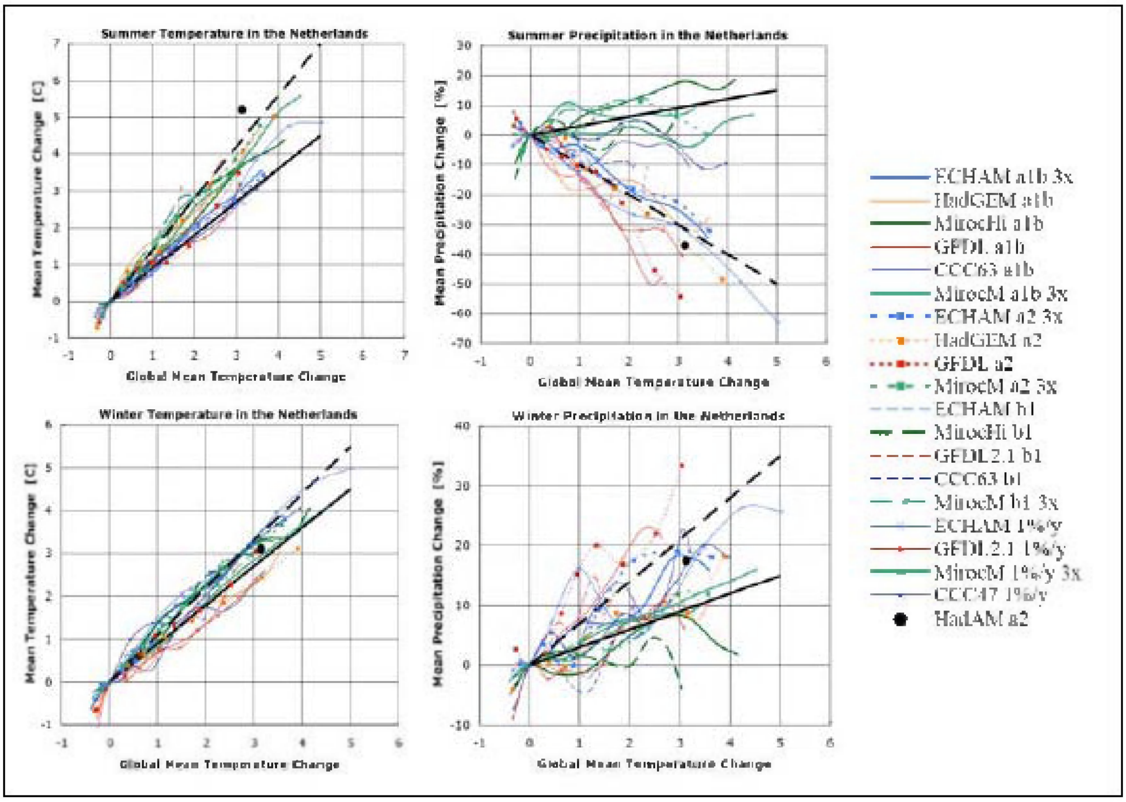


Figure 8. Projected change of seasonal mean temperature (left) and precipitation (right) for summer (top) and winter (bottom) in the Netherlands as function of global mean temperature rise, as simulated for the period 1990-2200. The black straight lines indicate fixed scaling relationships. The black dots represent the value of HadAM3H, used for most PRUDENCE RCM simulations

A more detailed description of these new scenarios and the way they were developed can be found in the English brochure “Climate in the 21st century: four scenarios for the Netherlands” (KNMI, 2006) and in the scientific background document “KNMI Climate Change Scenarios 2006 for the Netherlands” (Hurk et al., 2006).

For the present project, a dry and wet scenario needed to be selected from the 4 KNMI scenarios. A difficulty is that the KNMI scenarios are not defined as dry and wet and each scenario can be a mixture of these. Only for the summer season different scenarios show a different sign in change, reason why the + scenario is chosen as dry scenario although in winter it is wetter. The W scenario is chosen as wet scenario and W+ as dry scenario.

Appendix 2: More information about future hydrological scenarios

Lots of models are used in practice to describe future hydrological scenarios. It is important to take into account the type of model when analyzing conclusions because both the modelling domain and the represented phenomenon can strongly vary from one model to another.

Published study on climate change impacts on floods

Tu et al. noticed that five out of the seven largest floods of the Meuse in the Netherlands recorded in the period 1911-2003 occurred during the last decade. They tested two hypotheses to explain intensity and frequency of floods: quick land-uses changes appeared since 1950 and climate variability. It emerges that flood peaks since 1980 are better explained by climate variability than by land-uses changes.

Considering, Leander et al. (2008), flood quantiles for the Meuse obtained with RACMO-HC and RCAO-HC show the same response for SRES scenario A2. For both model's configurations , they have observed a slight decrease of floods for intermediary return period and a slight increase for higher return period for time slice 2070-2100. While a study of Lenderink et al. (2007) presents an increase of 10% for floods with a 100 years return period, Leander et al. forecast relative increases between 35% and 55% on almost every return period.

Van Pelt et al. (2009) observe an increase in discharge for a 2071-2100 simulation period in contrast to a 1969-1998 reference period. They worked with RCM RACMO2 and a SRES scenario A1B. The HBV model has been used to simulate flows. They observed a flow increase of 9% and 20% respectively with simulations using RACMO2WD and RACMO2MV (only bias calculation method differs). Number of days with a flow higher than 1500m³/s rises slightly with RACMO2WD while it rises sharply with RACMO2MV. In both cases, it seems that using RACMO2 ECHAM5, the Meuse River could have runoff peaks substantially higher at the end of the 21st century.

Giron et al. (2008) study the Ourthe basin as part of the ADAPT project. They have studied influence of climate change on flow modification (runoff speed, water depth) and have generated maps of water depth and flood speed. They have considered flood modification of 5%, 10%, 15% and a most extreme scenario of 30%. Scenarios chosen take into account results of the study on the Meuse at Borgharen forecasting a slight decrease of average yearly flow but an increase of floods rate between 5% and 10% (Booij, 2003). The WOLF 2D model used delivers the following results: for Poulseur-Esneux section, water depth increase between 10 and 75 cm depending on flow scenarios for flow rate having a return period from 25 years and between 15 and 75 cm for flow rate having a return period of 100 years.

Driessen et al. (2009) also have studied the Ourthe basin and impact of climate change on time slices 2002-2040 and 2062-2100 in comparison with reference period 1962-2000. Three SRES scenarios A1B, A2 and B1 have been simulated via GCM ECHAM5/PIOM. Perturbed meteorological data feed the HBV rainfall/runoff model. At the beginning of the century, few differences have been observed between simulations and reference period. The A2 scenario has peak flows weaker for little return period but follows quite regularly the reference period for return period above 2 years. The B1 scenario shows peak flows higher for return time above 5 years. At the end of the century, A1B scenario shows peak flows weaker than the reference period for return time under 3 years, but peak flows are more important for higher return time. This study has revealed that changes in the beginning of the century are weaker than those at the end of the century. Total annual flow will rise during all the century for all scenarios, except for the A1B which forecasts a slight decrease at the end of the century.

If we would make a comparison between studies of Giron and Driessen, we would notice that flow evolutions for the first half of the century simulated by Driessen fits Giron's scenarios. On the other hand, for the second half of the century, Driessen's flow rates are up to 50% higher than those in the A1B SRES scenario in comparison with the reference time slice.

Published studies about impacts on climate change on low-flows

De Wit et al. (2007) have worked on meteorological conditions influencing the most low-flows generation for the Meuse. They have simulated flow rate for time slice 2070-2100. Simulations have showed that climate change induces a decrease in mean flow rate during low-flows periods. Unfortunately, the model has some difficulty to simulate very low flow conditions for the Meuse. Nevertheless, they observed that low-flows are more severe when a succession of dry winter-dry summer occurs. It has also revealed that climate change could increase seasonal variability.

Van Pelt et al. (2009) have observed Meuse with RCM RACMO2 under a SRES A2 scenario and a discharge rate under 60m³/s at Borgharen. The number of days under that value doubles for time slice 2071-2100 in comparison with reference period 1969-1998. The mean for half-year "summer" diminishes between 13% and 17% following bias-correcting method used.

Driessen et al. (2009) have studied the Ourthe and the influence of climate change on low-flows. The threshold value is set at 75th percentile reference time, which suits 14 m³/s flow rate. At the beginning of this century, for every scenario, the mean number of drought events per year, the maximum length of drought in days per year and the maximum deficit in volume per year (m³/s) decrease. B1 scenario shows a decrease of 25% for the maximum length of annual drought. At the end of 21st century, the mean number of drought event decreases but their length strongly increases, mainly for the A1B and B1 scenario. All scenarios even show more intense drought than during the reference period.

Numerous studies have compared changes in river runoff by comparing outputs of hydrological models forced by observed climate records and perturbed climate data. Due to the large variability of climate change scenarios for Northwest Europe, range of possible effects is wide. Generally, studies suggest that climate change induced by man will raise flooding risks and could have substantial impact on low-flows. However, low-flow results are not unequivocal and depend to a large extent upon the climate change scenario used and specific characteristics of the river basin (de Wit et al., 2007).

During dry spells, the Meuse discharge is largely derived from release of groundwater. Basin's aquifers are mostly recharged during winter. An increase of winter rainfalls may reduce occurrence of summer low-flows due to an increase in aquifer recharge if increase in winter precipitation leads really to an increase of recharge aquifers and not to an increase of runoff.

On the other hand, decrease of summer precipitation and temperature increase could potentially lead to an increase in low-flow frequency. It emerges that forecasting future behaviour of the Meuse River in summer requires complementary studies both on climatic aspects and hydrologic aspects.

Published studies about impacts of low-flows on water quality

The water quality of the Meuse has been changing in the last fifty years. From 1960s, a decline of water quality has been observed to reach pollution's peak in 1970. Since that time, water quality has slowly improved due to construction of waste water treatment plants, technological innovations and policy measures. Nevertheless, water quality of the river Meuse has not yet reached natural concentrations in nutrients, salts and metals. Water quality of the Meuse also varies along its course (van Vliet et al., 2008).

Blenkinsop and Fowler (2007) have studied drought characteristics evolution in Europe and in particular the Meuse for time slice 2070-2100. While some regional climate models forecast until 3 more droughts per decades, HadAM3H forecasts only one more drought per decade, principally in Northern regions. Every models, except ARP-C one, have forecasted an increase in droughts length.

Although climate change effects on water quantity are widely recognised, impacts on water quality are less known. Van Vliet et al. (2008) evaluated the impacts of drought on water quality of the river Meuse. Time series of two severe droughts were used: 1976 and 2003. Water quality during these droughts was investigated and compared to water quality during reference period.

Parameters to estimate water quality can be divided into four groups:

- general water quality variables : water temperature, chlorophyll-a, pH, dissolved oxygen and suspended solids,
- nutrients, NH4+, NO2-, NO3- and PO43-,
- major elements : Cl-, Br-, F-, SO42-, K+,
- heavy metals and metalloids: Pb, Cu, Zn, Ni, Hg, Cr, Cd, As, Se, Ba.

To assess the effect of changes in discharge and water temperature on the concentration of chemical substances, empirical relations have been established between concentration and discharge, and between concentration and water temperature.

Results obtained by van Vliet et al. (2008) indicate a general decrease of water quality for the Meuse River during droughts where respectively water temperature, eutrophication, major elements and heavy metals are part of the phenomenon. This decline in water quality is primarily caused by favorable conditions for the development of algae blooms and a reduction of dilution capacity of point source effluents.

Published studies about effects of climate change on groundwater resources

Few studies have been led to assess potential effects of climate change on groundwater resources. But, groundwater resources are very important as they are one of the most protected reserves for water distribution. They constitute also the only contribution in water to stream flow and river during recession period in spring, summer and beginning of autumn.

In temperate area, like Belgium, deep percolation takes place from November to April, when soil and vadose zone have reached field capacity. This deep percolation ends when a water deficit occurs in spring, summer or beginning of autumn.

Climate change is accompanied by a rise in winter precipitation but a decrease in recharge duration is often considered. It is thus very difficult to assess future trend of aquifers recharge which needs a complete modelling of water-soil-plant system in the vadose zone.

Amongst existing studies, Gellens and Roulin (1998) have studied the variation in hydrologic fluxes in some Belgian catchments for different climate change scenarios elaborated at that time by the IPCC. At the same time, the research project MOHISE, based on an integrated soil (FUSAGx), groundwater (ULg) and surface water (ULg) model did the same job.

More recently, Goderniaux et al. (2009) have studied the influence of climate change for an SRES A2 scenario for 3 time slices: 2011-2040, 2041-2070 and 2071-2100 with a model dedicated to groundwater of the Geer catchment. For time slice 2011-2040, no clear change was observed in comparison with reference period. From 2041-2070 and 2071-2100, simulations forecast a significant decrease of practically all level of groundwater and runoffs for the Geer. For time slice 2071-2100, average level of groundwater simulated decreases by 2-8m in relation to the location in the Geer catchment and the climate change scenario studied.

For the HACH the determination of the impact of climate change on flood discharge (part of Ac3) is partially planned in action 7 and 8. This task will be performed during 2010-2011 by focusing on the Vesdre basin and using the “Mohican” model because it is impossible to run this model on the entire Walloon region within the time allocated in the Amice project. The effect of climate change on the discharges will be evaluated in the model, by simulating the effect of management of dams located in the upstream part of river Vesdre.

Modification of rainfall time series will be performed using the the tool developed in the CCI-Hydr project in order to perturbate rainfall, temperature, wind and evapotranspiration time series. This tool uses the results of climate models based on 4 IPCC scenarios. The outputs are time series data that represent the climate evolution at the 2100 horizon. This model was also extended to closest horizons which fit with periods chosen in the Amice project.

Meanwhile, the order of magnitude of flood perturbations and their effects on water levels reached can already be outlined based on recent projects.

The work achieved in the Adapt project, focusing on the downstream part of the Ourthe catchment can quantify the impact expected for an increase of 5, 10, 15 and 30% of the 25 and 100 years return period values. Table 1 summarizes return periods, frequencies and discharges associated to current 25 and 100 years flood as well as the four discharge increases related to the climate change scenarios.

		Current n°1	CC scenario n°2 (+5%)	CC scenario n°3 (+10%)	CC scenario n°4 (+15%)	CC scenario n°5 (+30%)
25 years flood	Discharge	726 m^3/s	762 m^3/s	799 m^3/s	835 m^3/s	944 m^3/s
	Esneux	-	+ 10 cm	+ 25 cm	+ 40 cm	+ 75 cm
	Tilff	-	+ 10 cm	+ 25 cm	+ 40 cm	+ 70 cm
100 years flood	Discharge	876 m^3/s	920 m^3/s	964 m^3/s	1007 m^3/s	1139 m^3/s
	Esneux	-	+ 15 cm	+ 30 cm	+ 45 cm	+ 75 cm
	Tilff	-	+ 20 cm	+ 40 cm	+ 60 cm	+ 85 cm

Table 1 : Discharges modeled on the river Ourthe in the framework of the Adapt project and average impact of climate change scenarios on the water level.

The different figures that illustrate this section show how, in terms of water levels and flood extension, the increases in discharge affect the two main towns that are located close to the considered reaches of river Ourthe, namely Tilff and Esneux. These towns correspond to the areas with the most important vulnerable assets.

The first analyzed parameter is the evolution of flood extensions depending on the different scenarios. Results are then presented on one hand for 25 year return period and (a.) and on another hand for the 100 year return period (b.). These pictures are produced for both towns: Tilff (Figure 1) **Erreur ! Source du renvoi introuvable.** and Esneux (Figure 2) **Erreur ! Source du renvoi introuvable.**. The extensions are superimposed and a color is associated with each discharge: green is linked to current scenario, blue in an increase of 5%, yellow of 10%, orange 15% and red 30%.

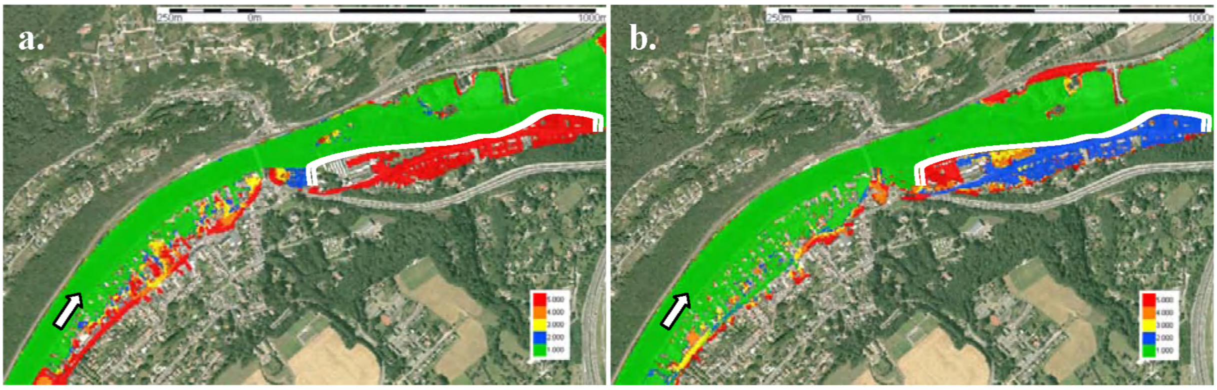


Figure 1: Comparison of flood extension for return periods 25 (a.) and 100 years (b) and the increases of 5, 10, 15 and 30% for the town of Tilff.

A protection wall existing in the downstream of Tilff is highlighted by a white line on **Erreur ! Source du renvoi introuvable.**. This kind of flood protection has been designed on the basis of a 100 year flood. It is therefore overtopped only by the + 30% scenario applied on the 25 year flood and by the + 5% scenario applied on the 100 year flood as well as beyond.

In the upstream part of this protection close to the centre of Tilff, the different increases linked to the discharge of 25 year return period lead to a gradual increase of flooded areas. On the other hand, regarding the discharge of 100 years return period, the maximum flooded area is almost reached with an increase of 5% (including the area protected behind the protection wall). For the higher discharges, only small changes occur due the steeper slopes of the valley.

In comparison with the observations made in Tilff, the case of Esneux (located a few kilometres upstream) reveals no significant changes in the flooding extension

(**Erreur ! Source du renvoi introuvable.**). An exception takes place on the right bank but only for extreme flows Q25 + 30 % (red zone and beyond on F igure 2 (a.) and Q100 + 30% (red zone on the Figure 2 (b.) for which there is an increas e in the flooded area in comparison with the (Q25 and Q100) base scenario.

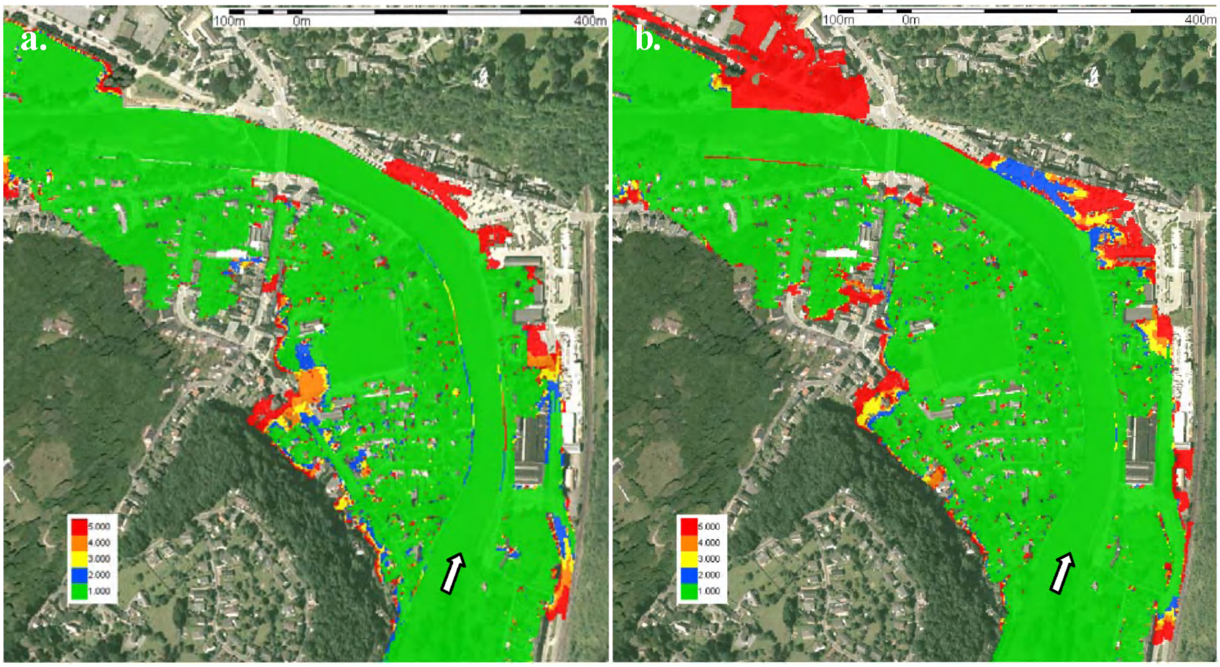


Figure 2 : Comparison of fl ood extension for return peri ods 25 (a.) and 100 years (b) and the increases of 5, 10, 15 and 30% for the town of Esneux.

Another way to express the hydraulic impa ct induced by increasing disc harge is to represent the water depth difference between climate change scenarios and the current situation. The follo wing pictures (Tilff: Figure 3 and Esneux : Figure 4) express the results by a classification of water heights dif ferences into four categories: less than 20 cm (green), between 20 and 50 cm (yellow), between 50 cm and 1 m (orange), more than 1 m (red). In this second analysis, only the discharge of 100 years return period and the corresponding increases are presented. The four maps are respectively:

- water heights Q100 + 5 - water heights Q100.
- water heights Q100 + 10 - water heights Q100.
- water heights Q100 + 15 - water heights Q100.
- water heights Q100 + 30 - water heights Q100.

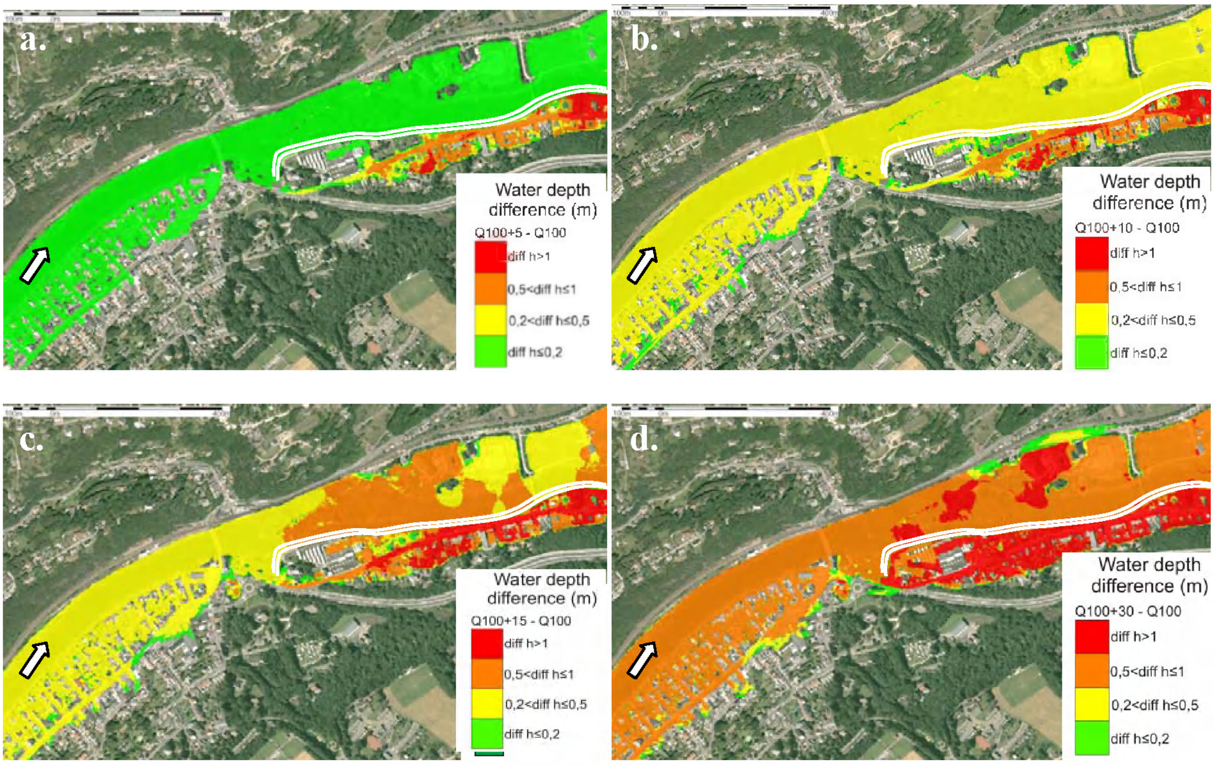


Figure 3: Water depth difference with respect to the current Q100 flood (without any climate change) in the town of Tilff. a. Q100+,5 b. Q100+10, c. Q100+15, d.Q100+30.

In the case of Tilff, Figure 3, the protection wall (white line) is not submerged for the current Q100 but for all increases, the important differences identified behind the wall are linked to the protected area that is filled when the wall is submerged. Accordingly, the computed differences are identical for the increases in the range 5 to 15% because the free surface level behind the wall is quite the same as the one close to the wall.

However by comparing the two towns, we note that the increase of water depth is more pronounced in Tilff than in Esneux for the same discharge. This trend is highlighted when comparing the difference of Q100 + 15% - Q100 (Tilff: Figure 3c. and Esneux: Figure 4c.). Tilff seems to be more sensitive to the discharge modification both in terms of flood extension and increase of water depth.

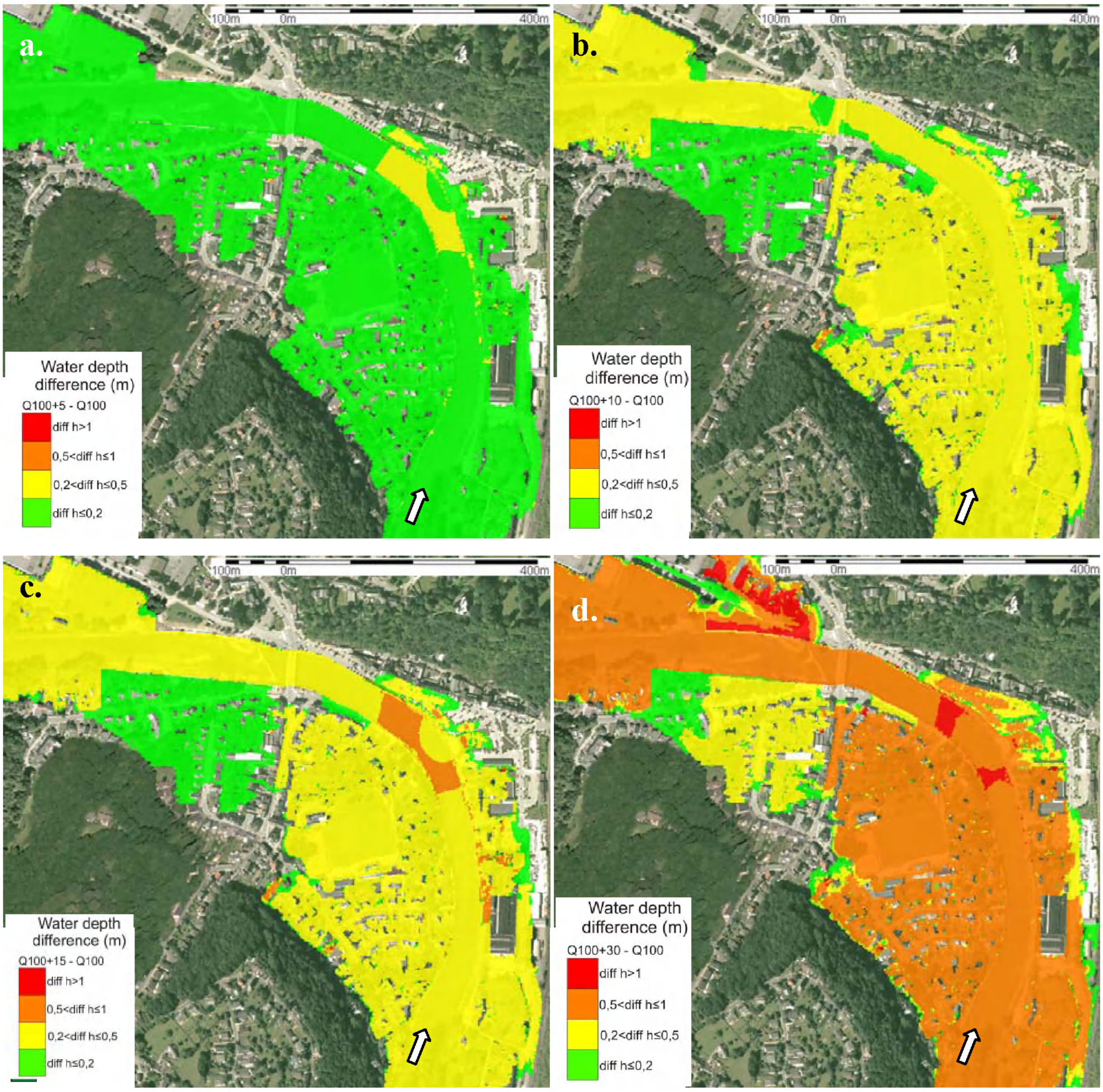


Figure 4: Water depth difference with respect to the current Q100 flood (without any climate change) in the town of Es neux. a. Q100+5, b. Q100+10, c. Q100+15, d.Q100+30

References

[1] de Wit, M. J. M., P. M. M. Warmerdam , P. J. J. F. Torfs, R. Uijlenho et, A. Cheymol, W. P. A. v. Deursen, P. E. V. v. Walsum, M. Ververs, J. C. J. Kwadijk and H. Buiteveld. Effect of climate change on the hydrology of the river Meuse. 134, 2001.

[2] Commission Nationale Climat. Cinq uième communication nationale d e la Belgique à la Convention-Cadr e des Nations Unies sur les Changement s climatiques. 135, 2009.

[3] d'Ieteren, E., W. Hecq, R. D. Su tter and D. Leroy. Effets du changem ent climatique en Belgique - Impacts potentiels sur les bassins hydrographiques et la côte maritime. 28, 2004.

To our knowledge no studies concerning the impacts of climate change on the water balance and streamflow have been undertaken specifically for the Rur and Niers catchment areas. For comparison reasons we will at this point mention the results from (Gerlinger, 2009) where the impacts of climate change on the water balance for the adjacent Rhine catchment area have been investigated by analyzing existing literature. In the following we will present the essential contents of this study.

To investigate the impacts of climate evolution on the water balance the results from Regional Climate Models were used as input for hydrological models. The hydrological models that were used for the simulation of discharges were Rhineflow, HBV (both in combination with SOBEK for the simulation of hydraulic routing), LARSIM and WaSIM-ETH.

The hydrological models using different climate projections of different Regional Climate Models as input show mainly a strong increase in mean flow for the winter-half year and a decrease of mean flow for the summer half year until 2050. But there are large regional differences in the simulation results.

For the gauges in Baden-Württemberg (modelchain: ECHAM4, scenario B2, WETTREG, LARSIM) for 2021-2050 the mean flows in the winter half year increased by about 40% while the mean flow in the summer half year stays unchanged. But again there are large regional differences in the results.

For gauge Cologne (model chain CHRM driven by HadAM3H, scenario A2, WaSIM) for 2071-2100 compared to 1961-1990 a decrease of mean flows in summer and autumn of about 40%, for winter an increase of 30% is simulated. Related to the HQ_{100} values an augmentation of 10% to 30% is predicted.

On the basis of the model chain ECHAM4, scenario B2, WETTREG, LARSIM (2021-2050) statistical analysis have also been carried out for Baden-Württemberg. For the period until 2050 an increase of the HQ_{100} values between 15% and 25% has been established. Concerning low flows for the NQ_{100} values there were both increases and decreases calculated, depending on the particular region.

It has been stated explicitly that the statements concerning extreme values should be handled with care since the climate projections are laid out for the development of average results. These should be considered in their statistical collectivity. But it is contradictory to the request of getting resilient results about the magnitude and frequency of very rare results. Due to the assumptions about the emission scenario and the uncertainties in the model chain Global Model –> Regional Model -> Hydrological Model the predictions about future behavior of mean values are possible with greater reliability than for extreme values.

Appendix 3: More informations about CCI-HYDR perturbation tool

The CCI-HYDR perturbation tool was developed by K.U.Leuven and RMI (Royal Meteorological Institute of Belgium) during the CCI-HYDR Project on « Climate change impact on hydrological extremes in Belgium » for the Belgian Science Policy Office Programme "Science for a sustainable development".

This tool is a perturbation algorithm which was developed to assess hydrological impacts of climate change. Observed series of data are perturbed in view to generate future time series. The observed series are perturbed on the basis of four SRES scenarios (A1B, A2, B1 and B2). The climate model simulations with A2 and B2 regional scenarios were extracted from the PRUDENCES database. The A1B and B1 scenarios were extracted from the IPCC AR4 database.

This tool generates three scenarios: high, mean and low scenarios. These scenarios are based upon the expected hydrological impacts:

- The high scenario represents the most extreme scenario (highest flow impact) which corresponds to the most severe case for flood risk analysis. It projects a future with wet winters and dry summers while the low scenario projects a future with dry winters and dry summers.
- The mean scenario represents the expected average scenario (mean flow impact).
- The low scenario represents the opposite of the high scenario in terms of flow impact, so it corresponds to the most severe low flow situation.

The CCI-HYDR program perturbs or changes the input series of rainfall data (mm), ET0 (mm), temperature (°C) and wind speed (m/s). It uses time series at 10 minutes, hourly and daily time steps. The scenarios were developed mainly for catchment up to 1000 km².

CCI-HYDR perturbation tool perturbs periods of data with a preference for a 30 years –long period. A 30 year period corresponds to an average climate "oscillation" cycle.

The output series represent the perturbed input series for a given time horizon in the future. Target years of 2020, 2030, 2040, 2050, 2060, 2070, 2080, 2090 and 2100 can be selected. Each target year is the centre of a 30 year block if 30 years of data were inputted.

This tool is developed upon data from 1961 to 1990 in view to predict climate change from 2071 to 2100. It is thus more reliable if input data covers the periods from 1961-1990 and if the target years are within the blocks 2070, 2080 and 2090. For the other target years, the interpolation and extrapolation of the changes leads to less certain future perturbations.

Appendix 4: More informations about hydrological model used on the German sub-basins

NASIM models for the Rur basin

For the Rur basin fiv e submodels that cover the area that is illu strated in Figure 1 were provided by the Waterboard Eifel-Rur. These are models for the Inde, the upper and lower Wurm, the middle Rur and the lower Rur. All of them are NASIM models. As Table 1 shows, each model c onsists of several hundred elem ents. At present no model for the area upstream of the reservoir Staubeck en Obermaubach (see Figure 1) was available. Within subsequent ac tion names of AMICE rainfall runoff models will be set up for this area using NASIM. For the Dutch part of the Rur basin no model was available as well. Within AMICE calc ulations were carried out for gauge Stah, which is located just a few kilometers down stream of the inflow of the Wurm into the Meuse.

Rainfall runoff model	Number of elements
Inde	145
Upper Wurm	1174
Lower Wurm	328
Middle Rur	422
Lower Rur	708
Sum	2777

Table 1: Number of elements of the NASIM models for the Rur basin

All models for the Wurm, Rur and Inde wer e handed over calibrated and validated. Concerning this no m odifications were undertaken by the Ac ademic and Research Department Engineering Hydrol ogy. The calibration and validation had been carried out by the Water Board Eifel-Rur or s ubcontractors. The models for the Wurm and Rur were calibrated and validated for a time period of at least tw o years. This was done manually and not following automatic optimization algorithms. For the Inde the calibration and validat ion was c arried out for single high-flow events. The time step for all models is 15 m inutes. All models have in com mon that the calibration did not specifically account for low flow periods. Due to this is seemed to be ques tionable that the existing NASIM model s would be able to carry out low flow simulations with sufficient accuracy.

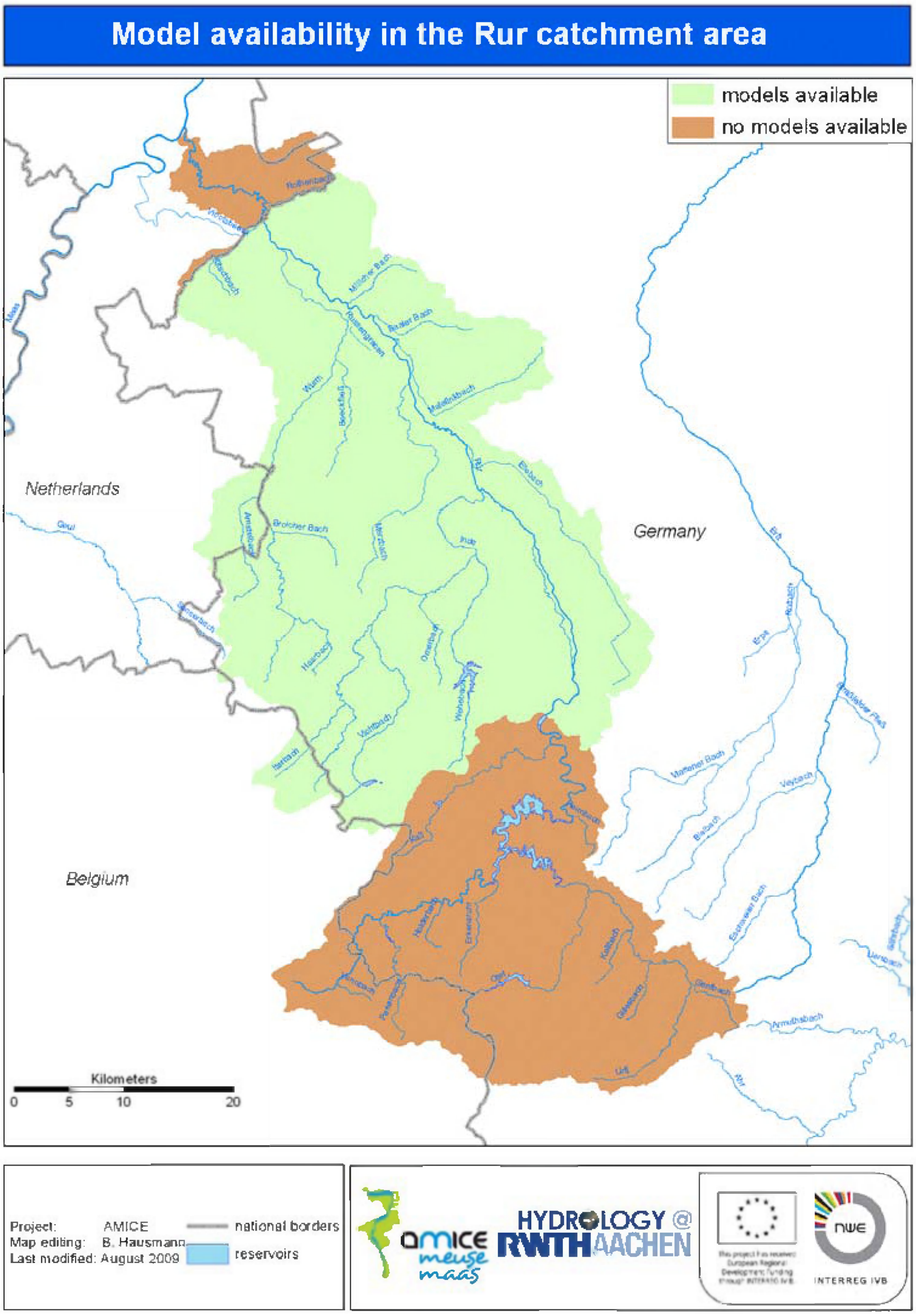


Figure 1: Model availability in the Rur catchment area

Since a variation of the time step would have destroyed the calibrations, for both the high flow simulations with a time step of one hour and the low flow simulations with a time step of one day using the E-OBS gridded dataset the same models with a time step of 15 minutes were used. An aggregation of the results was performed afterwards.

The known circumstances of the present state and the hypothetical conditions of the future states were taken into account as accurately as possible:

- The Wehebachtalsperre started operating in 1983. For the simulations of the present state this was taken into account by using time dependent operating rules. For all simulations the spillway was assumed to start working at a water volume of 25,05 million m^3 inside the reservoir. The thrush discharge was assumed to be between 0,1 m^3/s and 5,0 m^3/s depending on the volume of water inside the reservoir.

- Officially the reservoir Dreilägerbachtalsperre does not have a flood protection volume. For all NASIM simulations we assumed this to be the case although unofficially a flood protection volume exists. The spillway was assumed to start at an impoundment volume of 3,665 million m^3. The thrush discharge was assumed to be at 17 l/s.

- For the mining area "Inden" it is planned to create a lake by filling the remaining pit with water. This is supposed to start right after the end of the open pit mining in 2030 (MUNLV, 2005-1). Several strategies concerning the details of the filling are being discussed. In accordance with the Water Board Eifel Rur we agreed upon using the strategy that is shown in Figure 2. It shows how much water is taken from the Rur depending on the discharge at gauge Jülich. For the scenario simulations for 2021-2050 we implemented this by making use of time dependent operating rules. For the scenarios for 2071-2100 we assumed the filling to be finished.

- The rainfall runoff model for the middle part of the Rur needs the discharge at the outlet of the reservoir Obermaubach as inflow. Of course not only for the present state but also for the future scenarios. But the discharge at the outlet of Obermachbach depends on the water content and especially on the influxes to several other reservoirs which are operated in a linked system. Unfortunately for most of these reservoirs no rainfall runoff models exist at present state. Thus we were faced with the problem of making assumptions about the influxes to several reservoirs for the future scenarios which would allow for an estimation of the discharge at the outlet of Obermaubach. The assumptions we made were that the sum of discharge for every seasons of the year would be the decisive criteria and that the sum of discharge to the reservoirs behaves like the sum of discharge at the outlet of the Inde catchment area which shows similarities to the basins upstream of Obermaubach and which is geographically the closest to the considered reservoirs. For the national wet scenario for 2071-2100 for example we assumed for the winter season an increase of 55% in precipitation and an 3,8 °C increase in temperature. For the Inde catchment area this would lead to an increase of more than 70% in the sum of discharge in winter. This increase was then assumed to be valid for the other reservoirs where no rainfall runoff models were available as well. The measured influx time series of the reservoirs were then modified as described and afterwards used as input for the reservoir management software TALSIM which calculates the discharge at the outlet of the reservoirs – including reservoir Obermaubach. The management rules for the reservoirs will be adapted in later action names of the AMICE project. Since they are too complex to estimate them by implication we assumed the existing management rules to be valid for the future scenarios as well in the absence of better knowledge. For the calculations with TALSIM the Water Board Eifel-Rur commissioned an engineering office.

The results were then taken as input for the future scenarios for the rainfall runoff model for the middle part of the Rur basin. As soon as the lacking rainfall runoff models and the new management rules will be set up the influxes and outflows to and from the reservoirs will be simulated again using the results of these models and the updated management rules.

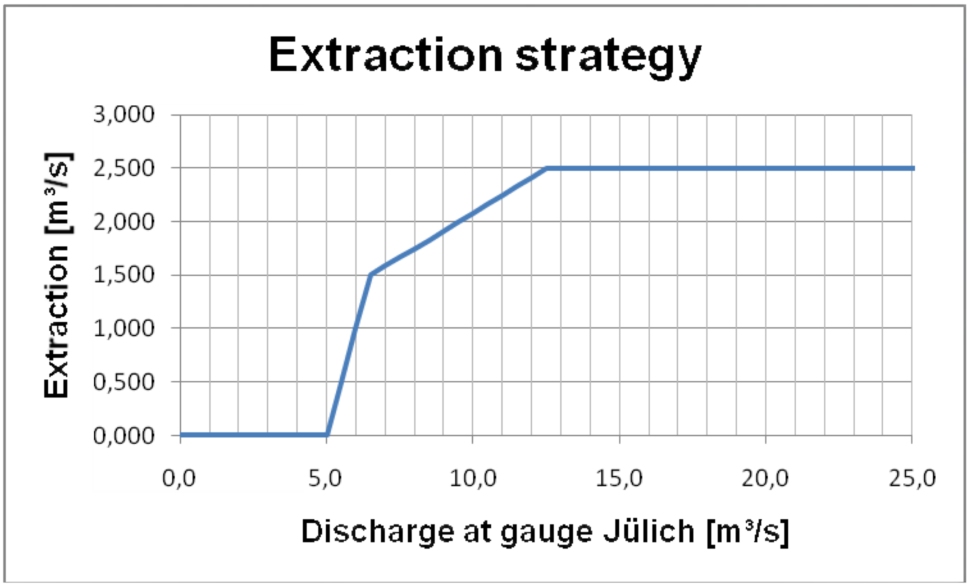


Figure 2: Extraction strategy for the filling of the lake in the mining area “Inden”

GR4J model for the Rur basin

This model was set up in the framwork of AMICE and was only used for the low flow simulations with a time step of one day using the E-OBS gridded dataset. The whole area from gauge Stah to Staubecken Obermaubach was modeled with one element. Needed model inputs are areal mean values for the catchment area of precipitation and potential evapotranspiration. The four parameters to be optimized were found by using the GR_CAL_LM-function of the HYDROGRv50 Scilab toolbox from Julien Lerat. With this function it was possible to automatically calibrate the model by finding the parameters that minimized the least squares error. Here the GR4J model was calibrated for low flows using the Nash-Sutcliffe criterion calculated on the logarithm transformed streamflow, which puts emphasis on the quality of low flow simulation (Perrin et al., 2003).

Here again the outflow from Obermaubach needed to be routed to gauge Stah. This was done via simplified methods for translation and retention (unit hydrograph). The best fitting parameters were identified by iteration them and a subsequent evaluation of the overall results for the routed part of the discharge and the part that results from the catchment area between Obermaubach and gauge Stah simulated with the GR4J-model.

Since the reservoir Wehebachtalsperre could not explicitly be represented in the model we made two different calibrations and validations. One for the state from 1961-1990 to simulate the conditions where the reservoir was build in the meantime. And another one for the future scenarios where the reservoir would be existing the whole time. In the latter case the calibration and validation process was started in 1985. We assumed that the regular operating of the reservoir started then.

Concerning the amount of water that is withdrawn for the creation of the lake in the open pit mine "Inden" the discharge at gauge Jülich is of significance (see Figure 2). We assumed that the sum of the outflow from Obermaubach and half of the discharge simulated for the area between Obermaubach and Stah would be a good approximation. Based on this sum the extraction was calculated.

NASIM models for the Niers basin

The Water Boards of the Niers, the Niersverband, has kindly given us his approval to use an existing rainfall runoff model of the Niers in the framework of AMICE. This model was handed over calibrated and validated. Concerning this no modifications were undertaken by the Academic and Research Department Engineering Hydrology. The model consists of 13 submodels (see Figure 3) with approximately 2500 elements and was set up in an earlier version of NASIM in the end of the 1990's by an engineering office. Since then no update has been performed. Because of this the present state of the Niers catchment area may not be represented with very high accuracy. The downstream boundary is located at gauge Goch (see Figure 3).

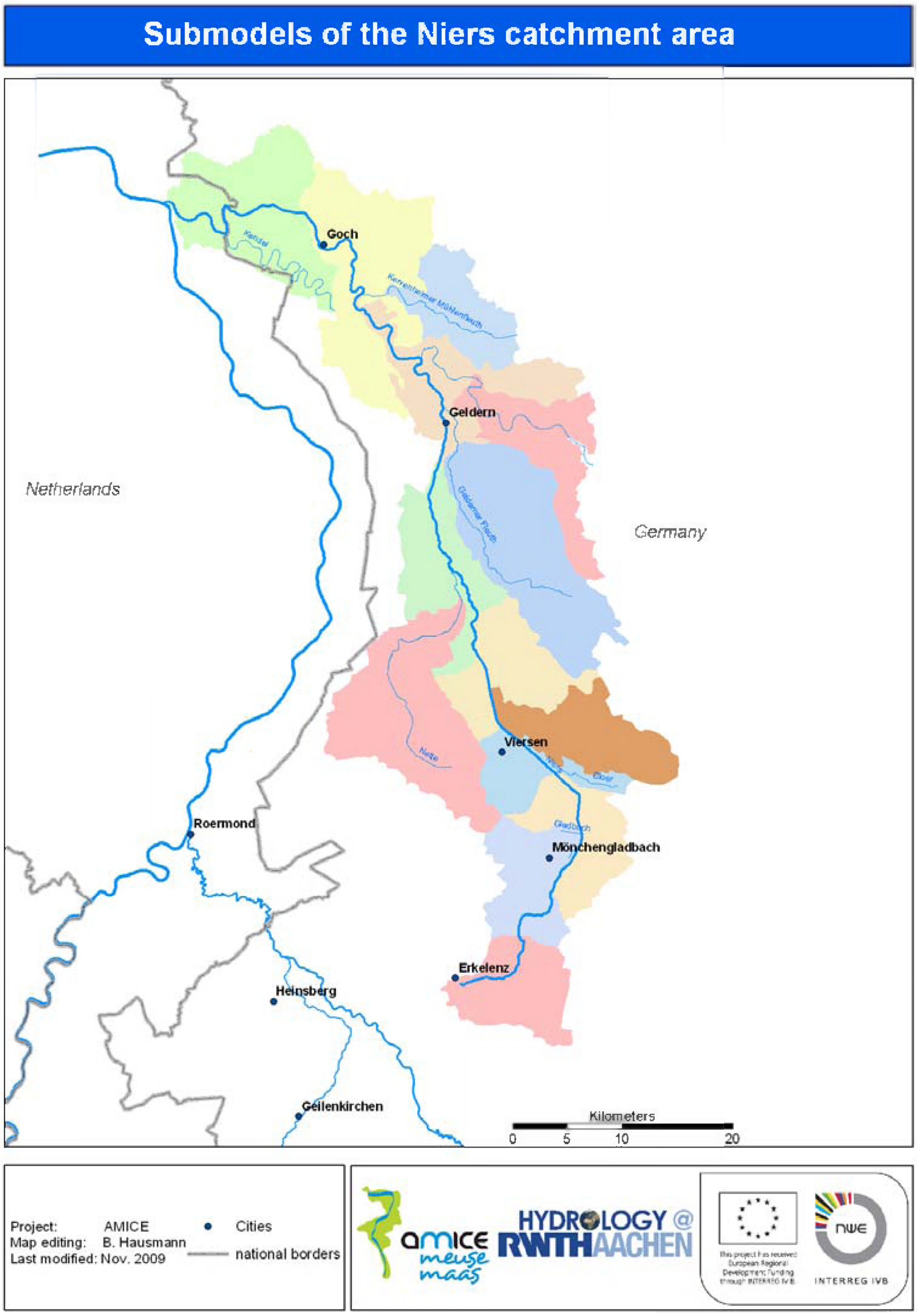


Figure 3: Overview over the submodels in the Niers catchment area

For all submodels the calibration and validation was carried out for single high-flow events with a time step of 30 minutes. Again all models have in common that the calibration did not specifically account for low flow periods so that it seemed to be questionable that the existing NASIM models would be able to carry out low flow simulations with sufficient accuracy.

Same as for the Rur models a variation of the time step would have destroyed the calibration. Because of this for both, the high flow simulations with a time step of one hour and the low flow simulations with a time step of one day using the E-OBS v.2

gridded dataset, the same models with a time step of 30 minutes were used. An aggregation of the results was performed afterwards.

GR4J model for the Niers basin

Like the GR4J model for the Rur the model for the Niers was set up in the framework of AMICE and was only used for the low flow simulations with a time step of one day using the E-OBS gridded dataset. The whole area up to gauge Goch was modelled with one element. Again areal mean values for the catchment area up to gauge Goch for precipitation and potential evapotranspiration needed to be calculated. Like mentioned above for the Rur basin the parameters were optimized by making use of the HYDROGRv50 Scilab toolbox from Julien Lerat. The model was again calibrated for low flows using the Nash-Sutcliffe criterion calculated on the logarithm transformed stream flow.

In contradiction to the GR4J model for the Rur basin we did not have to make use of additional routing functions for the Niers catchment. For the future scenarios the same calibration as for the state from 1961-1990 was used.

Appendix 5: More informations about hydrological simulation results

Belgian tributaries (Lesse & Vesdre)

Vesdre at Chaudfontaine

Monthly mean discharge

Transnational scenario

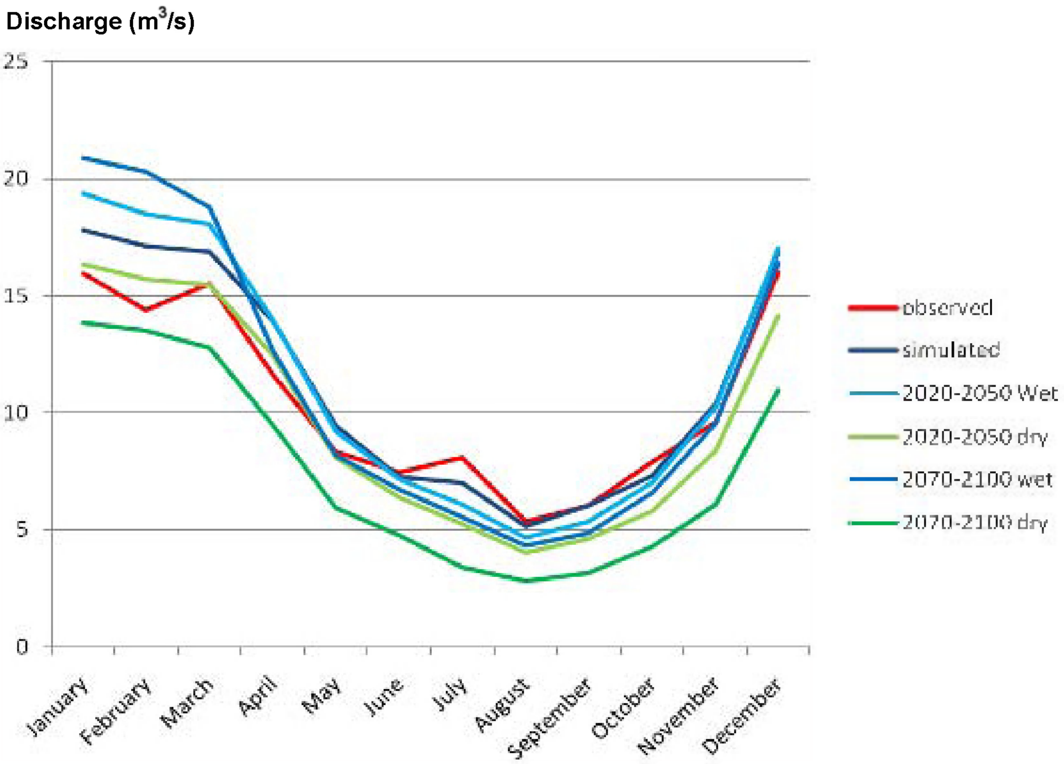


Figure 1: Evolution of m ean monthly discharge during a year for the Vesdre at Chaudfontaine for the different scenarios and time slices

For the end of the century a decrease in mean monthly discharge is predicted from May to November by the EPIC-Grid model for the two scenarios (dry and wet) and for all input data (different time slices). For the dry scenario, a decrease in mean monthly discharge is observed all year long, for the two time slices. The predicted changes in mean monthly discharge are between -51% (June, dry scenario for 2071-2100, using EPIC-Grid) and +19% (February, wet scenar io for 2071-2100, using EPIC-Grid)(see Table 1).

Month	Qobs (m3/s)	2020-2050wet	2020-2050Dry	2070-2100Wet	2070-2100Dry
January	16.0	9%	-8%	17%	-22%
February	14.4	8%	-8%	19%	-21%
March	15.5	7%	-9%	11%	-24%
April	11.6	0%	-11%	-9%	-32%
May	8.4	-2%	-14%	-13%	-37%
June	7.4	-1%	-12%	-7%	-35%
July	8.1	-13%	-25%	-21%	-52%
August	5.4	-10%	-21%	-16%	-45%
September	6.0	-11%	-24%	-19%	-48%
October	7.9	-4%	-20%	-10%	-41%
November	9.6	-1%	-20%	-8%	-41%
December	16.0	1%	-16%	-3%	-35%

Table 1: Change in mean monthly discharge for the Vesdre at Chaudfontaine

National scenario

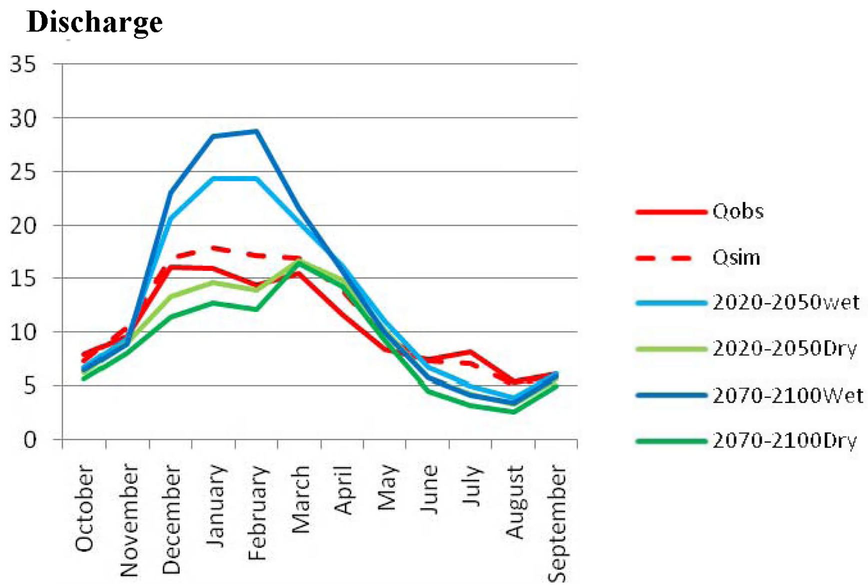


Figure 2 : Evolution of mean monthly flows during a year for the Vesdre at Chaudfontaine (National scenario).

For the end of the century a decrease in mean monthly discharge is predicted from June to August and from October to November by the EPIC-Grid model for all scenarios (dry and wet) and for all input data (2 time slices).
For the dry scenario, a decrease in mean monthly discharge is observed all year long, for the two time slices , except in April for both time slice and in May for 2020-2050. The predicted changes in mean monthly discharge are between -55% (July, dry scenario for 2071-2100, using EPIC-Grid) and +68% (February, wet scenario for 2071-2100, using EPIC-Grid)(see Table 2).

Month	Qobs	2020-2050wet	2020-2050Dry	2070-2100Wet	2070-2100Dry
January	15.96	37%	-18%	59%	-29%
February	14.39	42%	-19%	69%	-29%
March	15.53	20%	-10%	28%	-2%
April	11.59	16 %	7%	13%	2%
May	8.35	16%	8%	5%	-3%
June	7.44	-8%	-21%	-21%	-37%
July	8.10	-28%	-38 %	-41%	-55%
August	5.37	-24%	-35%	-33%	-50%
September	6.04	1%	-7 %	-4%	-19%
October	7.89	-9%	-14%	-12%	-23%
November	9.62	-11%	-14%	-15%	-23%
December	16.02	22%	-20%	36%	-32%

Table 2: Change in mean monthl y discharge for the Vesdre at Chaudfontaine for the two time slices (2021-2050 & 2071-2100) and the two scenarios (wet & dry)

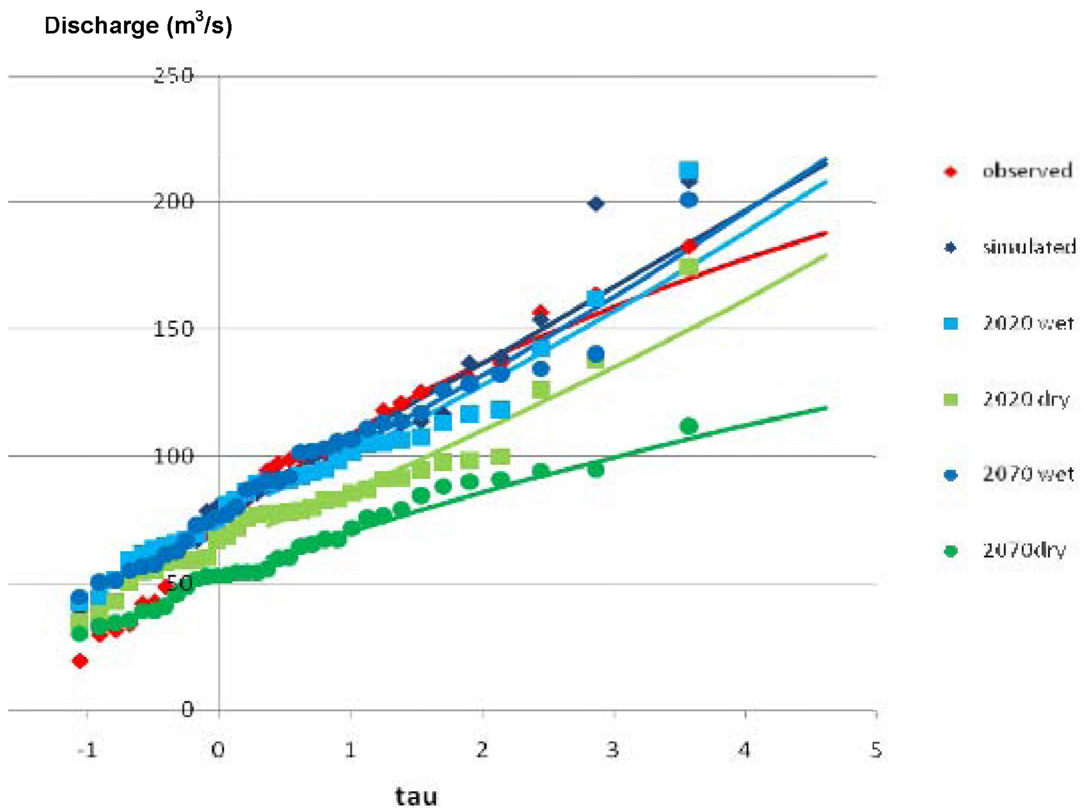
Maximum daily discharge

Transnational scenario

Concerning the Vesdr e maximum daily discharge the best fit depends upon the scenario (wet/dry) and the time slice (2020-2050/2070-2100).

For the data sets relative to the reference period (observed / simulated), the best fit is the Weibull distribution. This is in line wi th the study of Dautrebande et al. (2006). In the case of scenarios 2020-2050 wet and dr y and 2070-2100 wet , the best fit is t he gamma inverse distribution and for the scenario 2070-2100 dry it is the gamma.

Figure 3: Maximum daily discharges for the Vesdre at Chaudfontaine.



T	Qobs	Qsim	2020-2050wet	2020-2050Dry	2070-2100Wet	2070-2100Dry
100	188	192	208	179	217	119
50	176	181	185	159	193	111
25	163	167	163	140	169	102
10	143	147	135	116	139	89.4
5	124	128	114	98.1	117	78.5
2	88.7	92.7	84.8	72.9	86.2	60.1

Table 3: Maximum daily discharges (m3/s) for the Vesdre at Chaudfontaine for the two time slices (2021-2050 & 2071-2100) and for the two scenarios (wet & dry)

T	Qobs	Qsim	2020-2050wet	2020-2050Dry	2070-2100Wet	2070-2100Dry
100	155-221	159-225	130-286	111-246	131-303	99.0-140
50	147-206	152-210	127-243	109-209	129-256	93.2-129
25	138-188	142-193	121-205	104-176	124-214	87.0-117
10	123-163	127-167	110-160	94.1-138	112-166	77.7-101
5	107-140	112-145	97.6-131	83.9-112	99.5-134	69.2-87.8
2	74.8-103	78.6-107	75.4-94.3	64.8-81.0	76.3-96.0	53.4-66.8

Table 4: Confidence interval (95%) for the maximum daily discharges for the Vesdre at Chaudfontaine for the two time slices (2021-2050 & 2071-2100) and for the two scenarios (wet & dry)

Finally, Table 5 presents ratios for flood discharge for the different scenarios and time slices in comparison with the reference period.

T[y]	Qobs	2020-2050wet	2020-2050Dry	2070-2100Wet	2070-2100Dry
100	188	8%	-7%	13%	-38%
50	176	2%	-12%	7%	-39%
25	163	-2%	-16%	10%	-39%
10	143	-8%	-21%	-5%	-39%
5	124	-11%	-23%	-9%	-39%
2	88.7	-9%	-21%	-7%	-35%

Table 5: Change in the maximum daily discharges for the Vesdre at Chaudfontaine for the two time slices (2021-2050 & 2071-2100) and the two scenarios (wet & dry)

The predicted changes in maximum daily discharge for a recurrence interval of 100 years are between + 13% (wet scenario for 2071-2100, using EPIC-Grid) and -38% (dry scenario for 2071-2100, using EPIC-Grid).

National scenario

Concerning the Vesdre daily discharge the best fit is the Weibull distribution.

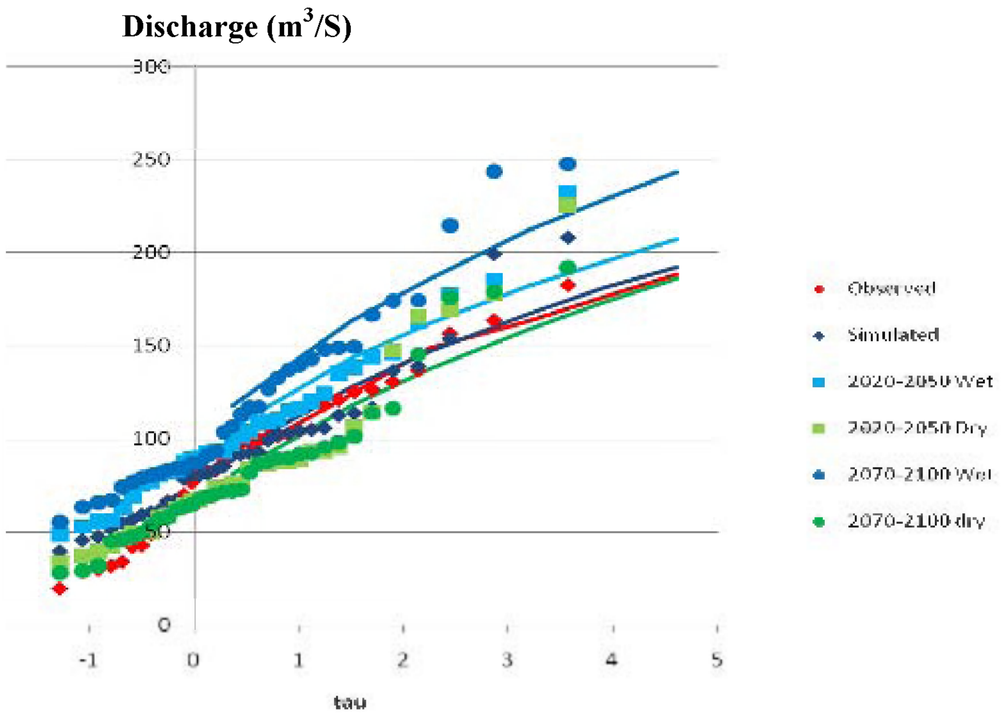


Figure 4: Maximum daily discharges for t he Vesdre at Chaud fontaine (National scenario).

T[y]	Qobs	Qsim	2020-2050wet	2020-2050Dry	2070-2100Wet	2070-2100Dry
100	188 192 207			200 243 186		
50	176	181 195		186	228 173	
25	163	167 182		170	212 159	
10	149	147 162		146	186 138	
5	124	128 143		123	163 118	
2	88.7	92.7 106		83.7	118	81.3

Table 6: Maximum daily discharges (m3/s) for the Vesdre at Chaudfontaine for the two time slices (2021-2050 & 2071-2100) and the two scenarios (wet & dry)

T	Qobs	Qsim	2020-2050wet	2020-2050Dry	2070-2100Wet	2070-2100Dry
100	155 - 221	159 - 225	175 - 239	159 - 241	202 - 283	150 - 222
50	147 - 206	152 - 210	167 - 224	150 - 222	192 - 264	142 - 205
25	138 - 188	142 - 193	157 - 207	139 - 200	180 - 243	132 - 186
10	135 - 183	127 - 167	142 - 182	122 - 169	161 - 211	116 - 159
5	107 - 140	112 - 145	126 - 160	104 - 143	142 - 183	100 - 135
2	74.8 - 103	78.6 - 107	91.7 - 121	68.4 - 98.9	100 - 136	67.3 - 95.4

Table 7: 95% Confidence interval (95%) for the maximum daily discharges for the Vesdre at Chaudfontaine for the two time slices (2021-2050 & 2071-2100) and for the two scenarios (wet & dry)

T	Qobs	2020-2050wet	2020-2050Dry	2070-2100Wet	2070-2100Dry
100	188	8%	4%	27%	-3%

50	176	8%	3%	26%	-4%
25	163	9%	2%	27%	-5%
10	143	10%	-1%	27%	-6%
5	124	12%	-4%	27%	-8%
2	88.7	14%	-10%	27%	-12%

Table 8: Change in the maxi mum daily dis charges for the Vesdr e at Chaudfontaine for the two time slices (2021-2050 & 2071-2100) and the two scenarios (wet & dry)

The predicted changes in maxim um daily di scharge for a recurrence interval of 100 years are between +26% (w et scenario for 2071-2100, using EPIC-Grid) and -3% (dry scenario for 2071-2100, daily time step, using EPIC-Grid).

Maximum hourly discharges

Transnational scenario

In the case of hourly data, the best fit is the Weibull distribution.
The predicted changes in maximum hourly discharge for a recurrence interval of 100 years are between +26.5% (wet scenario for 2071-2100, step, using RS-PDM) and -19% (dry scenario for 2071-2100, using RS-PDM).

T[y]	Qobs	2020-2050wet	2020-2050Dry	2070-2100Wet	2070-2100Dry
100	264	8%	-10%	-27%	-19%
50	246	8%	-10%	-25%	-20%
25	227	7%	-11%	-23%	-21%
10	198	6%	-11%	-21%	-22%
5	170	5%	-12%	18%	-23%
2	120	2%	-14%	11%	-26%

Table 9: Change in the maximum hourly disc harges for the Vesdre at Chaudfontaine for the two time slices (2021-2050 & 2071-2100) and the two scenarios (wet & dry)

National scenario

In the case of hourly data, the best fit is the Weibull distribution.
The predicted changes in maximum hourly discharge for a recurrence interval of 100 years are between +89% (w et scenario for 2071-2100, using RS-PDM) and -20% (dry scenario for 2071-2100, using RS-PDM).

T	Qobs	2020-2050wet	2020-2050Dry	2070-2100Wet	2070-2100Dry
100	278	59%	-11%	89%	-20%
50	260	57%	-12%	87%	-20%
25	240	55%	-12%	84%	-20%
10	209	53%	-12%	81%	-19%
5	181	49%	-13%	76%	-19%
2	128	42%	-15%	66%	-19%

Table 10. Change in the maximum hourly discharges for the Vesdre at Chaudfontaine for 2021-2050 & 2071-2100 and the two scenarios (wet & dry)

Low-flows

Transnational scenario

For the reference data (observed and sim ulated) and the scenario 2070- 2100 dry, the best fit is the Weibull distribution, for the other scenarios it is the gamma one.

T	Qobs	Qsim	2020-2050wet	2020-2050Dry	2070-2100Wet	2070-2100Dry
50	1.31	1.18 1.38 1.1			1.3	0.669
25	1.54	1.39 1.53 1.23 1.45 0.814				
10	1.89	1.73 1.78 1.46 1.69 1.06				
5	2.23	2.06 2.03 1.7			1.95	1.31
2	2.87	2.68 2.59 2.23 2.52 1.79				

Table 11: MAM7 values (m3/s) for the V esdre at Chaudfontaine for the two time slices (2021-2050 & 2071-2100) and for the two scenarios (wet & dry).

T	Qobs	Qsim	2020-2050wet	2020-2050Dry	2070-2100Wet	2070-2100Dry
50	0.972-1.66	0.852-1.50	1.11-1.66	0.845-1.35	1.03-1.58	0.455-0.88
25	1.19-1.88	1.06-1.71	1.26-1.79	0.983-1.47	1.18-1.71	0.592-1.04
10	1.57-2.22	1.42-2.04	1.52-2.03	1.22-1.69	1.44-1.95	0.837-1.28
5	1.93-2.53	1.77-2.35	1.79-2.27	1.47-1.92	1.71-2.19	1.09-1.52
2	2.62-3.12	2.44-2.93	2.35-2.83	2.00-2.46	2.27-2.76	1.60-1.98

Table 12: Confidence interval (95%) fo r the MAM7 values for the Vesdre at Chaudfontaine for the two time slices (2021-2050 & 2071-210 0) and for the two scenarios (wet & dry)

For the dry scenario, a decrease in the MAM7 value is predicted for every time slice and for every return period.

T[y]	Qobs	2020-2050wet	2020-2050Dry	2070-2100Wet	2070-2100Dry
50	1.31	17%	-7%	10%	-43%
25	1.54	10%	-12%	4%	-41%
10	1.89	3%	-16%	-2%	-39%
5	2.23	-1%	-17%	-5%	-36%
2	2.87	-3%	-17%	-6%	-33%

Table 13: Change in the MAM7 values for the Ves dre at Chaudfontaine for t he two time slices (2021-2050 & 2071-2100) and the two scenarios (wet & dry)

National scenario

For the reference data (observed and simulated) and the scenario 2070- 2100 dry, the best fit is the Weibull distribution, for the other scenarios it is the gamma one.

T	Qobs	Qsim	2020-2050wet	2020-2050Dry	2070-2100Wet	2070-2100Dry
50	1.31	1.22 1.31 0.918			1.41	0.766
25	1.54	1.43 1.54 1.1			1.62	0.931
10	1.89	1.77 1.9		1.42	1.97 1.21	
5	2.23	2.1	2.24	1.73 2.3		1.49
2	2.87	2.72 2.88 2.33 2.89 2.04				

Table 14: MAM7 values (m3/s) for the Vesdre at Chaudfontaine for the two time slices (2021-2050 & 2071-2100) and the two scenarios (wet & dry).

T	Qobs	Qsim	2020-2050wet	2020-2050Dry	2070-2100Wet	2070-2100Dry
50	0.972-1.66	0.890-1.55	0.97-1.66	0.633-1.20	1.07-1.75	0.516-1.02
25	1.19-1.88	1.10-1.76	1.19-1.88	0.812-1.40	1.29-1.96	0.672-1.19
10	1.57-2.22	1.46-2.09	1.57-2.22	1.13-1.71	1.66-2.28	0.950-1.47
5	1.93-2.53	1.81-2.39	1.94-2.54	1.45-2.00	2.01-2.58	1.24-1.74
2	2.62-3.12	2.47-2.96	2.62-3.13	2.09-2.57	2.66-3.12	1.81-2.26

Table 15: Confidence interval (95%) for the MAM7 values for the Vesdre at Chaudfontaine for the two time slices (2021-2050 & 2071-2100) and for the two scenarios (wet & dry)

For the dry scenario, a decrease in the MAM7 value is predicted for every time slice and for every return period.

T	Qobs	2020-2050wet	2020-2050Dry	2070-2100Wet	2070-2100Dry
50	1.31	7%	-25%	16%	-37%
25	1.54	8%	-23%	13%	-35%
10	1.89	7%	-20%	11%	-32%
5	2.23	7%	-18%	10%	-29%
2	2.87	6%	-14%	6%	-25%

Table 16: Change in MAM7 values for the Vesdre at Chaudfontaine for the two time slices (2021-2050 & 2071-2100) and the two scenarios (wet & dry)).

Lesse at Gendron

Mean monthly discharge

Transnational scenario

The figure 5 presents the evolution of m ean monthly discharge for the Lesse at Gendron for the different scenarios and time slices.

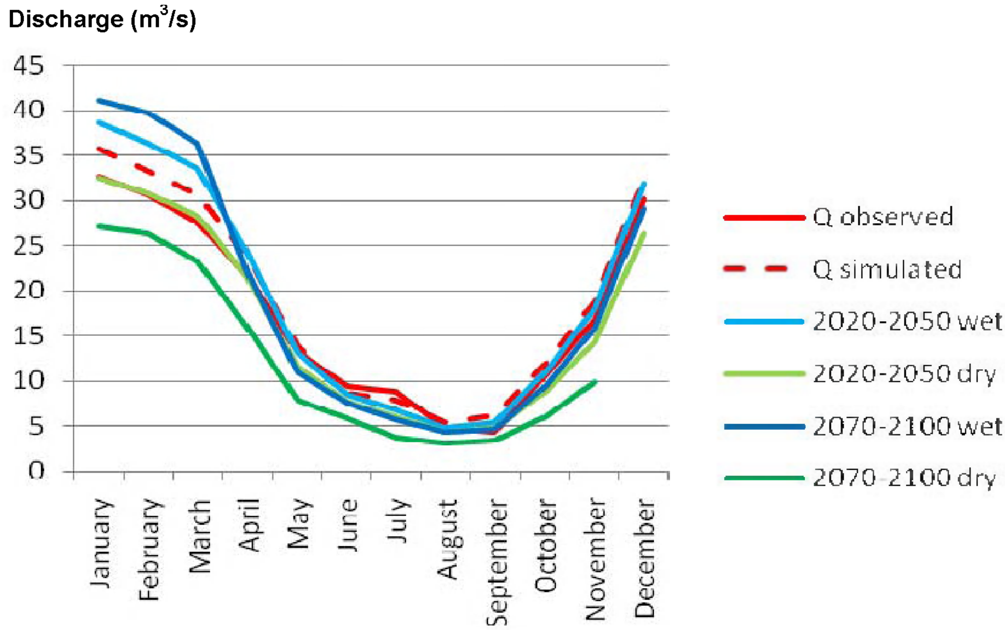


Figure 5: Evolution of mean monthly discharge during a year for the Lesse.

For the end of the century a decrease in mean monthly discharge is predicted from April to December by the EPIC-Grid model for all scenar ios (dry and wet) and for all input data (different ti me slice). For t he dry scenario, a decrease in mean monthly discharge is observed all year long, for the two time slices. The predicted changes in mean monthly discharge are between -52% (July, dry scenario for 2071-2100, using EPIC-Grid) and +19% (February, wet scenario for 2071-2100, using EPIC-Grid).

Month	Qobs	2020-2050wet	2020-2050Dry	2070-2100Wet	2070-2100Dry
January	32.7	8%	-9%	15%	-24%
February	30.7	9%	-7%	19%	-21%
March	27.6	9%	-8%	19%	-24%
April	21.7	2%	-10%	-7%	-33%
May	13.3	-5%	-16%	-22%	-43%
June	9.5	-1%	-11%	-12%	-32%
July	8.9	-14%	-25%	-28%	-52%
Augustus	4.7	-11%	-21%	-21%	-44%
September	4.4	-13%	-23%	-25%	-46%
October	10.6	-9%	-27%	-21%	-49%
November	16.8	-4%	-24%	-16%	-48%
December	16.0	1%	-16%	-3%	-35%

Table 18: Change in the m ean monthly discharges for t he Lesse at Gendron for the two time slices (2021-2050 & 2071-2100) and the two scenarios (wet & dry)

National scenario

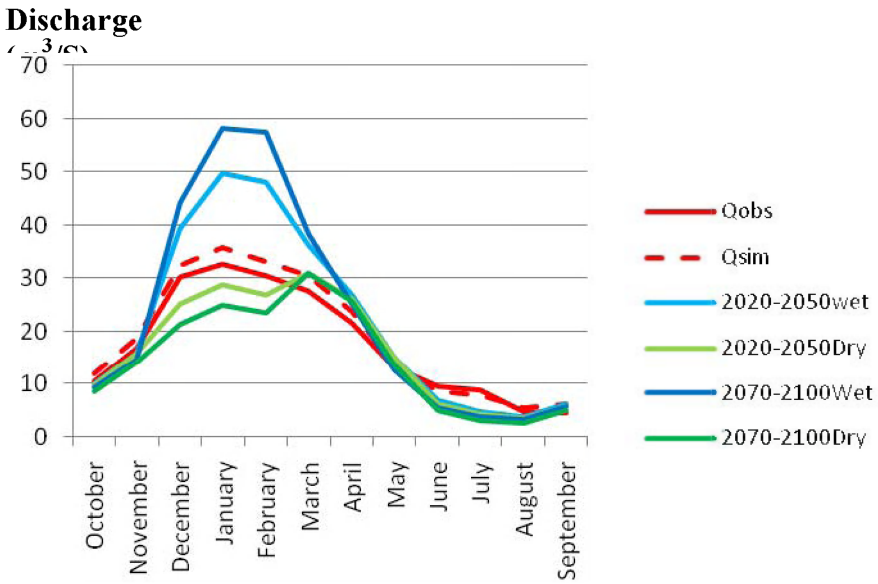


Figure 7: Mean monthly dischar ges (m3/s) for the Lesse at Gendron for the two time slices (2021-2050 & 2071-2100) and the two scenarios (wet & dry)

For the end of the century a decrease in the mean monthly disc harge is predicted from June to August and from October to No vember by the EPIC-Grid model for all scenarios (dry and wet) and for all input data (different time slice).
For the dry scenario, a decrease in mean monthly discharge is observed all year long, for the two time slices , except in April for both ti me slice and in May for 2020-2050.
The predicted changes in mean monthly discharge are between -55% (July, dry scenario for 2071-2100, usi ng EPIC-Grid) and +68% (February, wet scenario for 2071-2100, using EPIC-Grid)(see table 17).

Month	Qobs	2020-2050wet	2020-2050Dry	2070-2100Wet	2070-2100Dry
January	32.60	37%	-18%	59%	-29%
February	30.59	42%	-19%	69%	-29%
March	27.48	20%	-1%	28%	-2%
April	21.58	16%	7%	13%	2%
May	13.21	16%	8%	5%	-3%
June	9.42	-8%	-21%	-21%	-37%
July	8.81	-28%	-38%	-41%	-55%
Augustus	4.69	-24%	-35%	-33%	-50%
September	4.37	1%	-7%	-4%	-19%
October	10.58	-9%	-14%	-12%	-23%
November	16.73	-11%	-14%	-15%	-23%
December	30.12	22%	-20%	36%	-32%

Table 19: Change in the m ean monthly discharges for t he Lesse at Gendron for the two time slices (2021-2050 & 2071-2100) and the two scenarios (wet & dry)

Maximum daily discharge

Transnational scenario

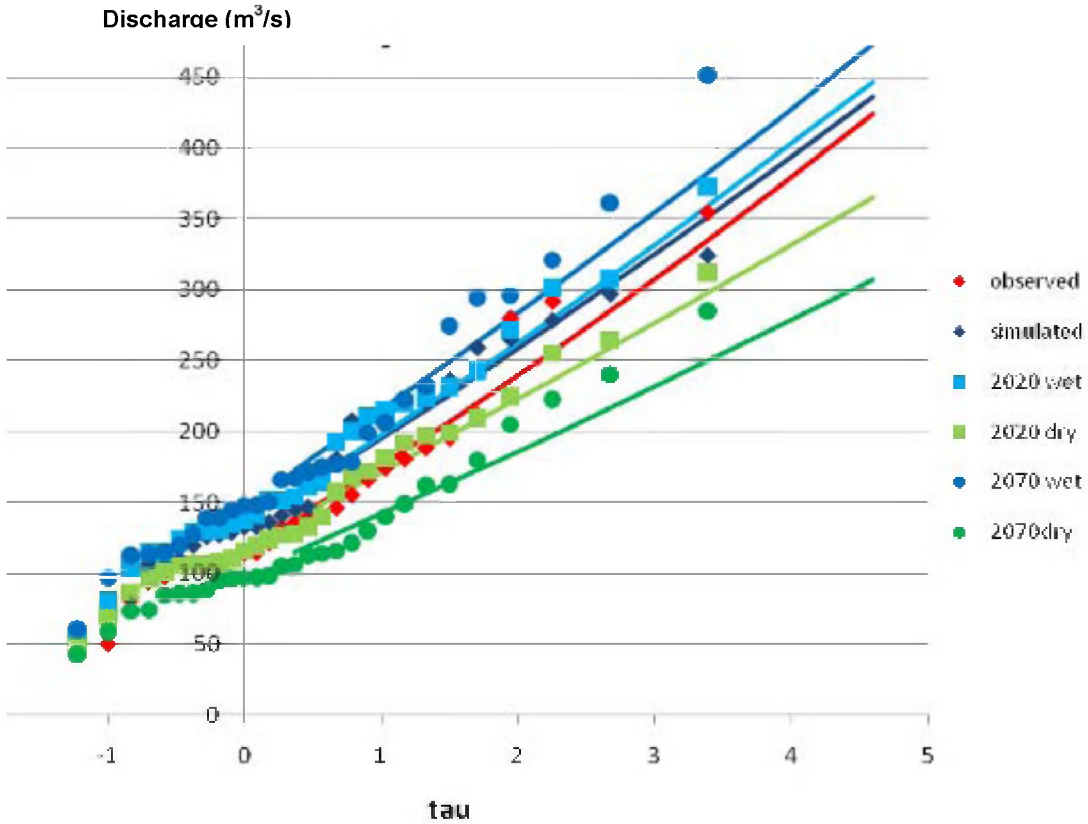


Figure 18: Maximum daily discharges for the Lesse.

Concerning the Less e maximum daily discharge, the lognor mal fit is the best distribution for both scenarios (dry/wet) and both time slices (2020-2050/2070-2100).

T	Qobs	Qsim	2020-2050wet	2020-2050Dry	2070-2100Wet	2070-2100Dry
100	424 436 447			365 473 307		
50	372	387 396		326	420 274	
25	321	338 345		287	369 241	
10	256	275 279		236	301 197	
5	207	226 229		197	249 164	
2	138	156 157		138	173 115	

Table 20: Maximum daily discharges (m3/s) for the Lesse at Gendron for the two time slices (2021-2050 & 2071-2100) and the two scenarios (wet & dry)

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T	Qobs	Qsim	2020-2050wet	2020-2050Dry	2070-2100Wet	2070-2100Dry
100	278-570	299-573	304-591	257-473	328-618	215-400
50	255-489	276-498	280-512	238-414	303-538	198-349
25	230-421	251-426	254-436	217-357	276-462	181-300
10	194-317	215-335	217-342	210-340	237-366	156-239
5	164-249	184-269	185-273	162-232	203-295	134-193
2	113-162	131-181	131-183	117-159	146-201	96.8-132

Table 21: Confidence interval (95%) for the maximum daily discharges for the Lesse at Gendron for the two time slices (2021-2050 & 2071-2100) and for the two scenarios (wet & dry)

T[y]	Qobs	2020-2050wet	2020-2050Dry	2070-2100Wet	2070-2100Dry
100	424	3%	-16%	8%	-30%
50	372	2%	-16%	9%	-29%
25	321	2%	-15%	9%	-29%
10	256	1%	-14%	9%	-28%
5	207	1%	-13%	10%	-27%
2	138	1%	-12%	11%	-26%

Table 22: Change in the maximum daily di scharges for the Lesse at gendron for the two time slices (2021-2050 & 2071-2100) and for the two scenarios (wet & dry)

The predicted changes in maxim um discharge for a recurrence interval of 100 years are between +8,5% (wet scenar io for 2071-2100, daily time step, using EPI C-Grid) and -30% (dry scenario for 2071-2100, daily time step, using EPIC-Grid).

National scenario

Concerning the Lesse maximum daily disc harge, the lognormal distribution fits the best for both scenarios (dry/wet) and both time slices (2020-2050/2070-2100).

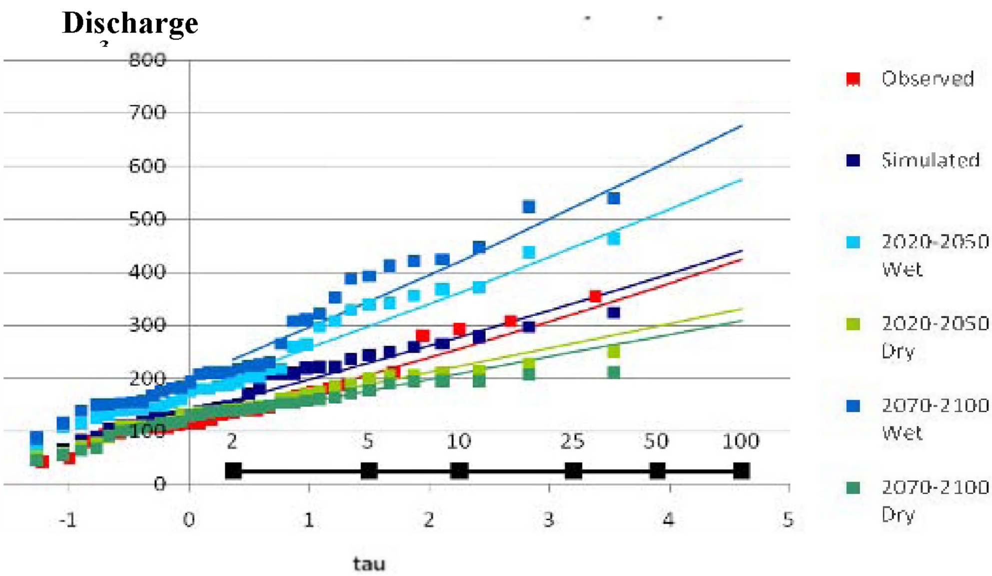


Figure 19: maximum daily discharge for the Lesse (National scenario).

T	Qobs	Qsim	2020-2050wet	2020-2050Dry	2070-2100Wet	2070-2100Dry
100	424 440 575			330 677 309		
50	372	390 510		298	599 279	
25	321	342 446		265	522 249	
10	256	279 362		223	421 209	
5	207	230 298		189	345 177	
2	138	159 205		137	235 129	

Table 23: Maximum daily discharges (m3/s) for the Lesse at Gendron for the two time slices (2021-2050 & 2071-2100) and the two scenarios (wet & dry)

T	Qobs	Qsim	2020-2050wet	2020-2050Dry	2070-2100Wet	2070-2100Dry
100	314-565	408-742	249-411	476-879	233-384	314-565
50	288-492	374-645	230-365	436-761	216-341	288-492
25	261-422	339-552	212-319	394-649	199-299	261-422
10	223-334	289-435	184-261	334-509	173-245	223-334
5	190-269	246-350	161-216	284-407	151-203	190-269
2	136-183	175-236	120-155	200-271	113-146	136-183

Table 24: Confidence interval (95%) for the maximum daily discharges for the Lesse at Gendron for the two time slices (2021-2050 & 2071-2100) and for the two scenarios (wet & dry)

T	Qobs	2020-2050wet	2020-2050Dry	2070-2100Wet	2070-2100Dry
100	424	31%	-25%	54%	-30%
50	372	31%	-24%	54%	-28%
25	321	30%	-23%	53%	-27%
10	256	30%	-20%	51%	-25%
5	207	30%	-18%	50%	-23%
2	138	29%	-14%	48%	-19%

Table 25: Change in the maximum daily discharges for the Lesse at Gendron for the two time slices (2021-2050 & 2071-2100) and the two scenarios (wet & dry)

The predicted changes in maximum hourly discharge for a recurrence interval of 100 years are between + 53% (wet scenario for 2071-2100, us ing EPIC-Grid) and -30% (dry scenario for 2071-2100, using EPIC-Grid).

Maximum hourly discharge

Transnational scenario

In the case of hourly data, the best adj ustment law to the sets of data is the lognormal one.
The predicted changes in maxim um discharge for a recurrence interval of 100 years are between +55% (wet scenario for 2071- 2100, hourly time step, using RS-PDM) and -10% (dry scenario for 2071-2100, hourly time step, using RS-PDM).

T[y]	Qobs	2020-2050wet	2020-2050Dry	2070-2100Wet	2070-2100Dry
100	472	19%	-2%	55%	-10%
50	414	19%	-2%	52%	-11%
25	357	18%	-2%	49%	-12%
10	284	18%	-2%	45%	-13%
5	230	17%	-2%	40%	-14%
2	153	17%	-3%	33%	-16%

Table 26: Change in the maximum hourly discharges for the Lesse at gendron for the two time slices (2021-2050 & 2071-2100) and for the two scenarios (wet & dry)

National scenario

In the case of hourly data, the best fit is the lognormal distribut ion for the observed data and in the other cases is the gamma distribution.
The predicted changes in maxim um hourly discharge for a recurrence interval of 100 years are between +84% (w et scenario for 2071-2100, using RS-PDM) and -29% (dry scenario for 2071-2100, using RS-PDM).

T	Qobs	2020-2050wet	2020-2050Dry	2070-2100Wet	2070-2100Dry
100	503	60%	-23%	84%	-29%
50	436	59%	-22%	83%	-28%
25	371	58%	-21%	83%	-28%
10	290	56%	-20%	82%	-26%
5	230	52%	-18%	81%	-25%
2	148	48%	-14%	79%	-21%

Table 27: Change in the maximum hourly di scharges for the Lesse at Gendron for the two time slices (2021-2050 & 2071-2100) and the two scenarios (wet & dry)

Low-flows

Transnational scenario

For all the scenarios, the best fit to the MAM7 values is the Weibull distribution.

T	Qobs	Qsim	2020-2050wet	2020-2050Dry	2070-2100Wet	2070-2100Dry
50	0.427	1.16	1.16 0.968		1.11	0.66
25	0.564	1.34	1.34 1.13 1.28 0.795			
10	0.82	1.64 1.63 1.4			1.56	1.02
5	1.1	1.92	1.9	1.65	1.82 1.24	
2	1.73	2.43 2.4		2.13	2.31 1.67	

Table 28: MAM7 values (m3/s) for the Le sse at Gendron for the two ti me slices (2021-2050 & 2071-2100) and the two scenarios (wet & dry)

T	Qobs	Qsim	2020-2050wet	2020-2050Dry	2070-2100Wet	2070-2100Dry
50	0.21-0.643	0.85-1.47	0.852-1.46	0.692-1.24	0.816-1.40	0.44-0.88
25	0.32-0.807	1.04-1.65	1.04-1.64	0.858-1.41	0.995-1.57	0.567-1.02
10	0.547-1.09	1.35-1.93	1.34-1.91	1.14-1.66	1.29-1.83	0.794-1.25
5	0.817-1.39	1.65-2.18	1.64-2.16	1.41-1.89	1.58-2.07	1.03-1.46
2	1.43-2.02	2.21-2.65	2.19-2.61	1.92-2.33	2.10-2.51	1.49-1.86

Table 29: Confidence interval (95%) for the MAM7 values for the Lesse at Gendron for the two time slices (2021-2050 & 2071 -2100) and for the tw o scenarios (wet & dry)

For all the scenarios, a decrease in the MAM7 value is predicted; it is comprised between 0% and 43%.

T[y]	Qobs	2020-2050wet	2020-2050Dry	2070-2100Wet	2070-2100Dry
50	0.427	0%	-17%	-4%	-43%
25	0.564	0%	-16%	-4%	-41%
10	0.82	-1%	-15%	-5%	-38%
5	1.1	-1%	-14%	-5%	-35%
2	1.73	-1%	-12%	-5%	-31%

Table 30: Change in MAM7 values for the Lesse at Gendron for the two time slices (2021-2050 & 2071-2100) and the two scenarios (wet & dry)

National scenario

For all the scenarios, the best fit to the MAM7 values is the Weibull distribution.

T	Qobs	Qsim	2020-2050wet	2020-2050Dry	2070-2100Wet	2070-2100Dry
50	0.426	1.1	1.34	0.976	1.41	0.87
25	0.562	1.29	1.52	1.14	1.59	1.02
10	0.817	1.59	1.59	1.41	1.86	1.27
5	1.1	1.88	2.07	1.67	2.11	1.52
2	1.72	2.41	2.54	2.15	2.56	1.97

Table 31: MAM7 values (m3/s) for the Lesse at Gendron for the two time slices (2021-2050 & 2071-2100) and the two scenarios (wet & dry)

T	Qobs	Qsim	2020-2050wet	2020-2050Dry	2070-2100Wet	2070-2100Dry
50	0.215-0.638	0.814-1.39	1.06-1.63	0.718-1.23	1.13-1.69	0.632-1.11
25	0.325-0.800	1.00-1.58	1.25-1.8	0.885-1.40	1.32-1.86	0.785-1.26
10	0.551-1.08	1.07-1.64	1.26-2.06	1.17-1.66	1.62-2.11	1.05-1.50
5	0.819-1.38	1.62-2.13	1.85-2.30	1.44-1.90	1.90-2.33	1.30-1.73
2	1.43-2.00	2.2-2.62	2.36-2.73	1.96-2.34	2.39-2.73	1.79-2.15

Table 32: Confidence interval (95%) for the MAM7 values for the Lesse at Gendron for the two time slices (2021-2050 & 2071 -2100) and for the tw o scenarios (wet & dry). For all the scenarios, a decrease in the MAM7 value is predicted; it is comprised between -21% and 28%.

T	Qobs	2020-2050wet	2020-2050Dry	2070-2100Wet	2070-2100Dry
50	1.4	22%	-11%	28%	-21%
25	1.58	18%	-12%	23%	-21%
10	1.84	0%	-11%	17%	-20%
5	2.09	10%	-11%	12%	-19%
2	2.52	5%	-11%	6%	-18%

Table 33: Change in the MAM7 values f or the Lesse at Gendron for the two time slices (2021-2050 & 2071-2100) and the two scenarios (wet & dry)

Flemish part

Model results are given in digital format to FHR. In Table 34 statistics for the control period and scenario's are summarized. The averages are the average over the 30 year period.

	Control period	Scenario		
		low	middle	high
Average yearly discharge	278	191	255	313
Average winter discharge (dec-feb)	445	270	465	701
Average summer discharge (jul-sep)	113	33	52	29
10%-percentile of daily values	50	14	21	12
90%-percentile of daily values	665	515	676	871

Table 34 – Average yearly and seasonal discharge (m³/sec)

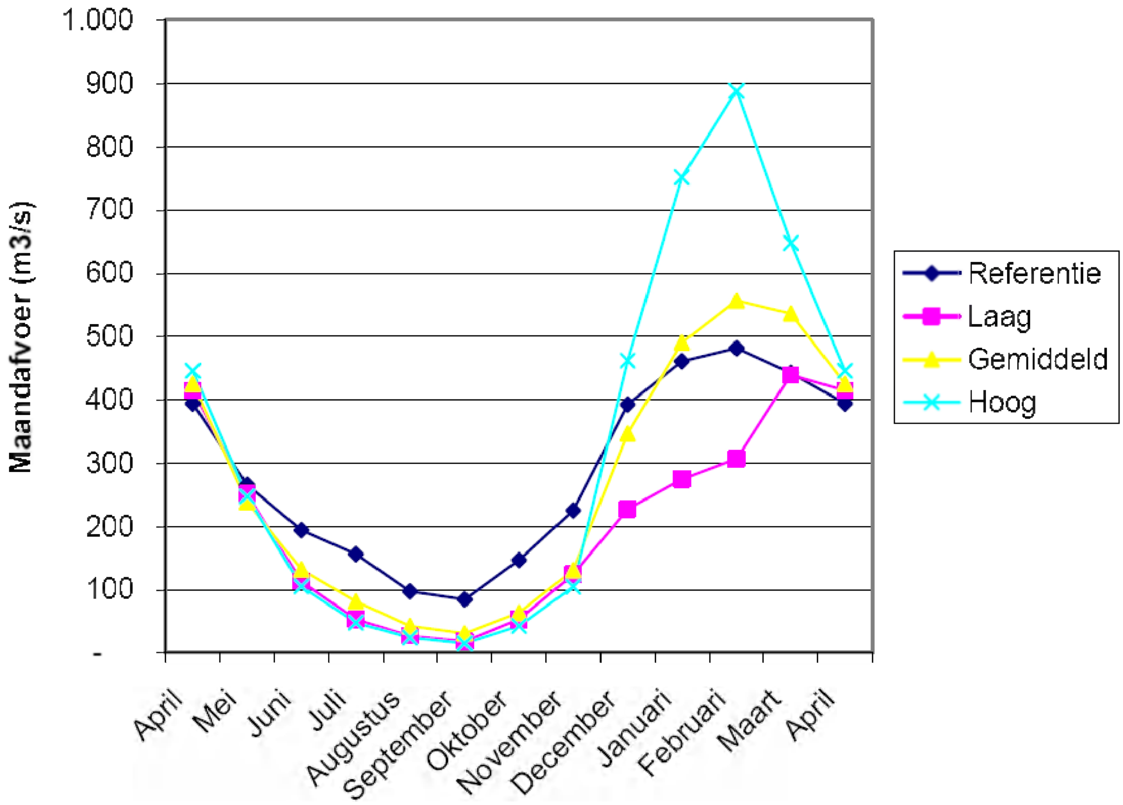


Figure 20: Monthly average discharge for control run (referentie) and scenarios

<u>Analysis</u>

The average yearly discharges for the low scenario are significantly lower for the low scenario and significantly higher for the higher scenario compared to the actual situation. All scenarios are unambiguous for future summer discharge. The average summer discharge becomes lower than half discharge in the control period.
February has the highest monthly discharge, except for the low scenario where this is in March. Explanation can be the higher influence of the base flow in the low, dryer, scenario. The high scenario results in an average winter discharge are almost double of the discharge in the control period. Maximum average yearly discharge is 1335

m³/sec in the control period and 1040 m³/sec, 1428 m³/sec and 1938 m³/sec in the low, middle and high scenario respectively.
In all scenarios September has the lowest discharge. The average is 15 m³/sec in the high and 18 m³/sec in the low scenario, in spite of a comparable reduction of rainfall during summer. The lower discharge in the high scenario is a result of the higher ETo which is a consequence of the higher temperature in the high scenario. Rainfall during winter is still contributing to discharge in April in the high scenario. Also dry periods affect the discharge where October is a low discharge month (< 100 m³/sec).
An important remark has to be made for low flows: as indicated earlier the calibration of the HBV model is done with a focus on high water applications. De Wit et al. (2007) suggest that influence of winter rainfall in average summer discharge is underestimated.

Peak discharge

Table 35 indicates the maximum daily discharge during the highest high water in each series for the control period and each of the scenarios with the HBV hydrological model and with SOBEK. The values clearly indicate the influence of wave damping which is realistically simulated with SOBEK.

Scenario	HBV (m³/sec)	SOBEK (m³/sec)	Decrease (%)
Reference (1995)	2975	2660	10,6
Low	1872	1656	11,5
Middle	3164	2832	10,5
High	4335	3880	10,5

Table 35 – Highest discharge for control period and scenarios with HBV and SOBEK and relative decrease of calculated discharge with SOBEK.

German tributaries (Niers & Rur)

For the simulations with hourly time step only the hydrological model NASIM was used. As mentioned in previous chapters the precipitation data for the German tributaries to the Meuse from the Partners' hourly database are assigned to areas of in mean several hundred kilometers. But the equipartition of the precipitation over the whole area may only conditionally be assumed. In (Verworn, 2008) area depending reduction factors of statistical precipitation values were determined. These reduction factors were calculated using the results from statistical evaluations. In doing so not single events but all events of a certain period of time were included in the evaluation, thus also events with uniform rainfall over the whole area or events where the maximum was not located at the center of reference (i.e. the measuring point). We regard this to be an argument for the validity of the results not only for statistical rainfall values but also for continuous measurements of precipitation. But the resulting factors do not only depend on the size of the assigned area but also on the duration of the specific event. The dependency on the return period was mentioned to be of inferior relevance. In principle for continuous measurements of precipitation for every single event an assignment to a duration would be necessary. But this would be complex and error-prone. Instead we used reduction factors for typical durations (depending on the size of the assigned area). These reduction factors approximately represent the minimum necessary reduction for the specific assigned area. For events with smaller durations there will still be an overestimation of the assigned precipitation. The described approach has shown to deliver improved results not only for mean values but also for extreme values.

For the simulations with daily time step besides NASIM the GR4J model was used. In this case the evaluations additionally comprised the low-flow relevant variables. Since data from the E-OBS gridded database are mean areal values no reduction of the precipitation data was performed.

Niers at Goch

Simulations with daily time step using the E-OBS gridded dataset

In Figure 21 a comparison of the simulated and observed mean monthly discharges for the period 1961-1990 is illustrated. The simulations with NASIM show an underestimation in the summer half-year from June to November and an overestimation from December to April. The highest relative deviation occurs in January and is at about 28%. The results of the GR4J-model are the opposite. Here we have an overestimation during the summer half-year and an underestimation during the winter half-year. The maximum deviation is at about 22% and occurs in July. Using NASIM a Nash-Sutcliffe coefficient of 0,64 could be obtained, using GR4J 0,83.

In Figure 21 B the simulated winter maxima values for both models are confronted with the observed ones. Concerning the sum of squared standardized deviations NASIM shows slightly better results than the GR4J model. As Figure 21 C shows this is also confirmed by the discharges for different recurrence intervals (maximum likelihood fitting of the Gumbel distribution). The NASIM results show a very good agreement with the discharges calculated using the observed values. The GR4J results are slightly worse and show a constant undershooting.

In Figure 21 D the simulated summer AM7-values for both models are opposed to the observed ones. It is obvious that NASIM is not able to reproduce the observed values with sufficient accuracy since the variance cannot be represented. The GR4J results are predominant, although the deviations to the observed values are compared to the winter maxima values larger. However, concerning the summer AM7 discharges for several recurrence intervals (maximum likelihood fitting of the Lognormal distribution) there is a very good agreement with the discharges calculated using the observed values (see Figure 21 E).

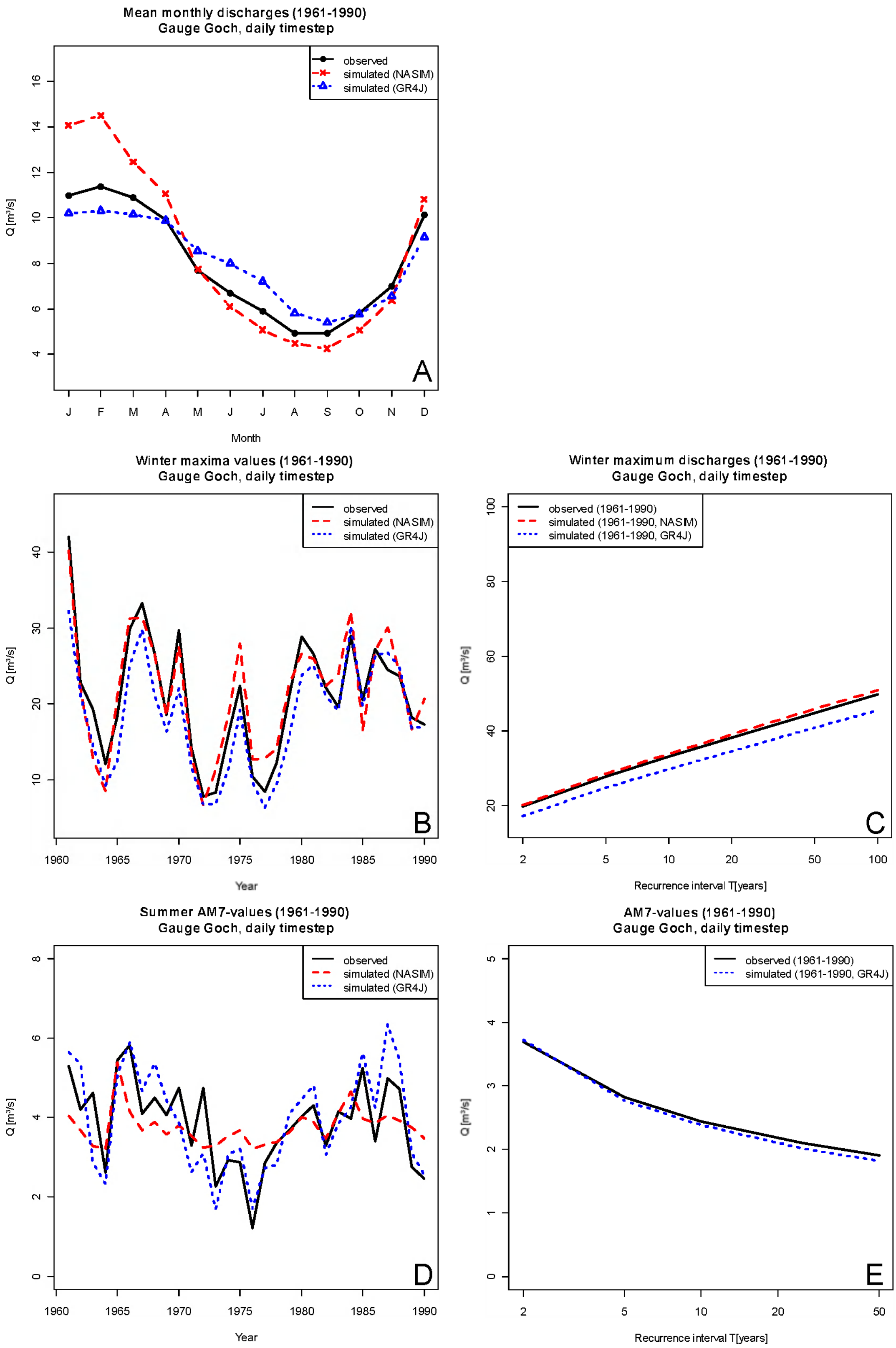


Figure 21: Adaptation quality of simulati ons with daily time step for gauge Goch (Niers)

National scenarios

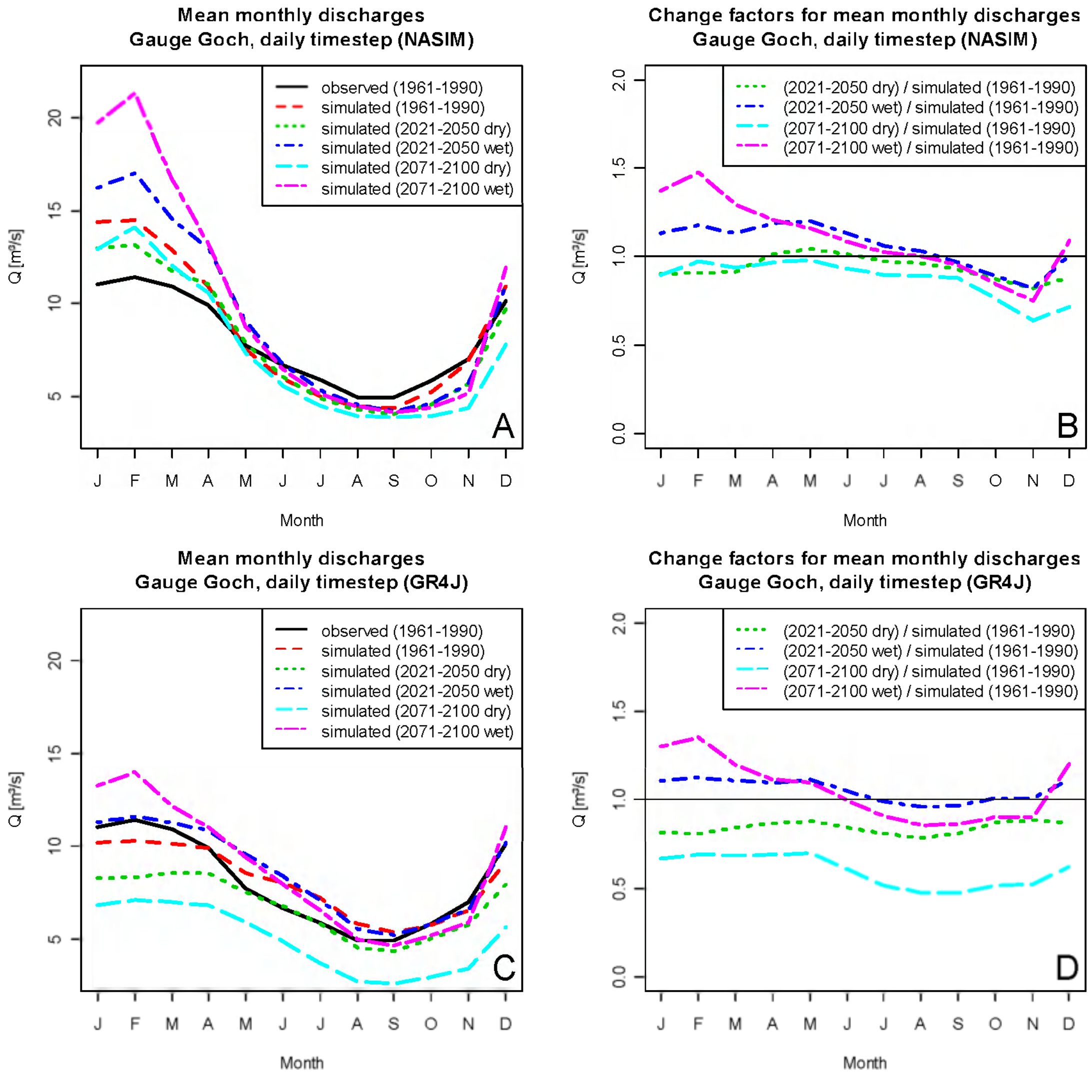


Figure 22: Predicted mean monthly discharges and change factors for gauge Goch (Niers) for a time step of 1 day, national scenarios

In Figure 22 A and B one can see the NASIM results for the mean monthly discharges and for the predicted change factors (obtained by dividing the future climate value by the simulated value for 1961-1990). The highest change factor with almost 1,5 is predicted for February for the wet scenario for 2071-2100. For September to November for all scenarios and both future time slices a decrease in predicted. The strongest decrease with a change factor of about 0,75 is predicted for November for the dry scenario for 2071-2100, which is the only future simulation where a decrease for the whole year is predicted.

	NASIM	GR4J	observed
1961-1990	8,50	7,70	7,98
2021-2050 dry	8,06	6,79	-
2021-2050 wet	9,38	8,60	-
2071-2100 dry	7,62	4,97	-
2071-2100 wet	10,15	8,80	-

Table 36: Simulated and observed mean discharges [m³/s] for gauge Goch (Niers) for daily time steps, national scenarios

In Figure 22 C and D the GR4J results ar e shown. Compared to the NASIM results for both, the absolute and relativ e changes, the predicted increases are weaker and the predicted decreases are higher. The hig hest increase is at about 35% predicted for February for the wet scenario for 2071-2100. It is striking that f or the dry scenario for 2071-2100 an all the year de crease of at least 30% is predicted. Concerning the dry scenarios in contrast to NASIM the GR4J model predicts a strong further decrease of the mean monthly discharges between the middle and the end of the century. In Table 36 an overview over the mean discharges is given.

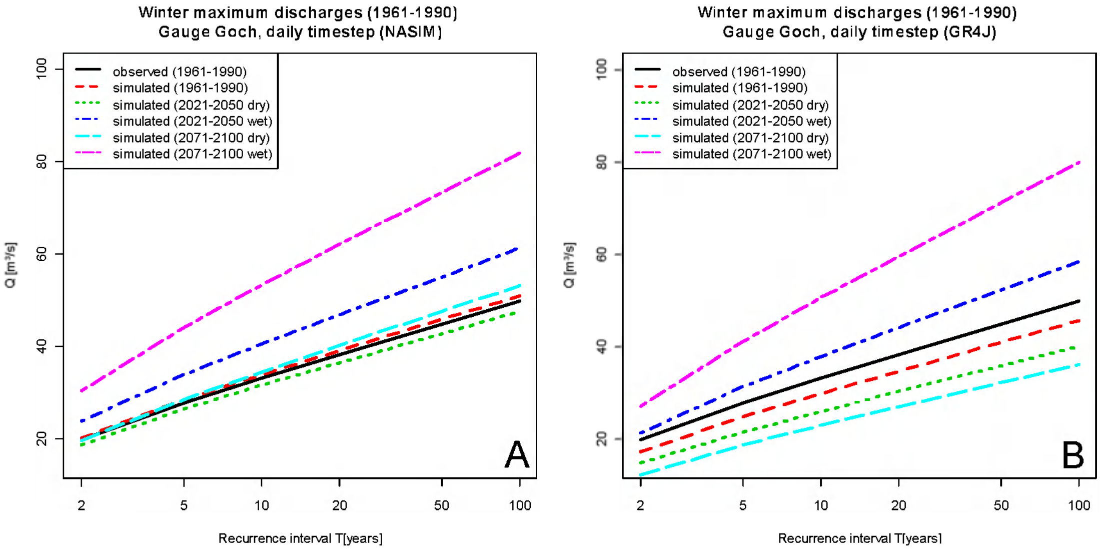


Figure 23: Winter maximum dis charges for different recurrence intervals for gauge Goch (Niers), national scenarios

In Figure 23 winter maximum dis charges for different recurrence intervals are shown (left side: NASIM, right side: GR4J). As mentioned above, NASIM reproduces the discharge behavior for different recurrence intervals be tter than GR4J. Concerning the wet sc enarios the results do not diffe r much between both models. For the dry scenarios NASIM predicts higher dischar ges. For the dry scenario for 2071-2100 NASIM predicts higher discharges than for the dry scenario for 2021-2050 and also than for 1961-1990. This is di fferent to the results from GR4J. The GR4J model predicts for both, the dry and wet scenar ios, a monotonic inc rease respectively decrease until the end of the century.

In Figure 24 summer AM7 discharges for di fferent recurrence intervals are shown . Since NASIM is not able to reproduce the behavior with sufficient accuracy, only the GR4J-results are illustrated. Only for the wet scenario for 2021-2050 a slight increase is predicted. For the dry as well as for the wet scenarios a decrease from the middle to the end of the century is forecasted. For the dry scenario for 2071-2100 compared to 1961-1990 nearly a bisection of the values is projected.

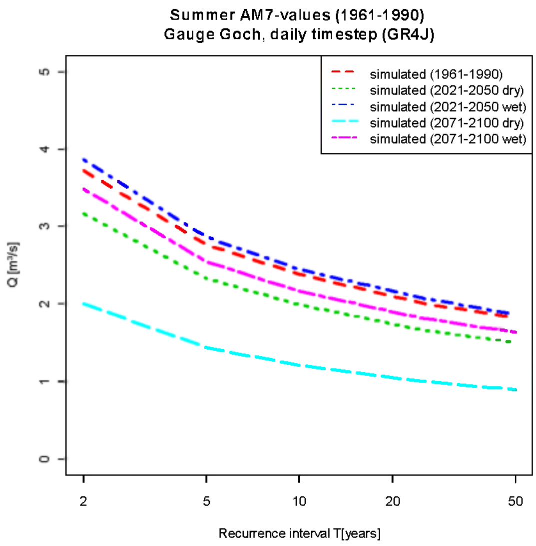


Figure 24 : Predicted summer AM7-values for different recurrence intervals (GR4J) for gauge Goch (Niers), national scenarios

<u>Transnational scenarios</u>

In Figure 25 A and B one can see the NASIM results for the mean monthly discharges and the predicted changes factors. The highest change factor with 1,13 is predicted for February for the wet scenario for 2071-2100. For May to December for both scenarios and both future time slices a decrease in predicted. The strongest decrease with a change factor of 0,57 is predicted for December for the dry scenario for 2071-2100. For the dry scenarios a year-round decrease is predicted.

In Figure 25 C and D the GR4J results are shown. It is eye-catching that for all future scenarios a year-round decrease is predicted. The strongest decrease with a change factor of 0,23 is predicted for September for the dry scenario for 2071-2100. Compared to the NASIM results GR4J predicts smaller change factors.

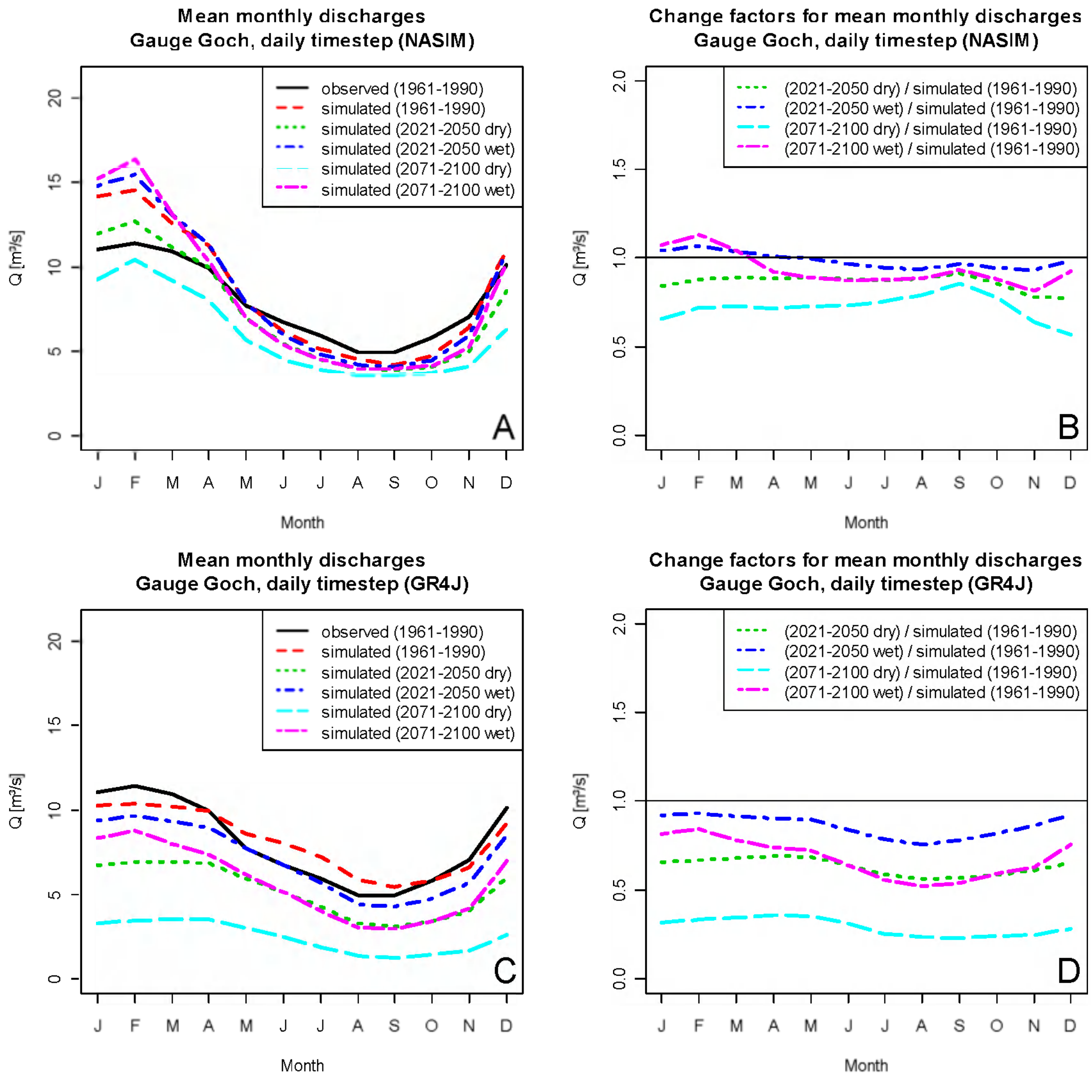


Figure 25: Predicted mean m onthly discharges and change factors for gauge Goch (Niers) for a time step of 1 day, transnational scenarios

In Figure 26 winter maximum discharges for different recurrence intervals are shown. NASIM predicts higher winter maximum disc harges for both scenarios and for both future time slices than GR4J. In contr adiction to GR4J NASIM predicts a further increase until the end of the century for th e wet scenarios. Both models predict for the wet scenarios a monotonic decrease until the end of the century. For a recurrence interval of 100 years the bandwidth of t he predicted changes is between +19% (NASIM, wet scenario for 2071-2100) and -64% (GR4J, dry scenario for 2071-2100).

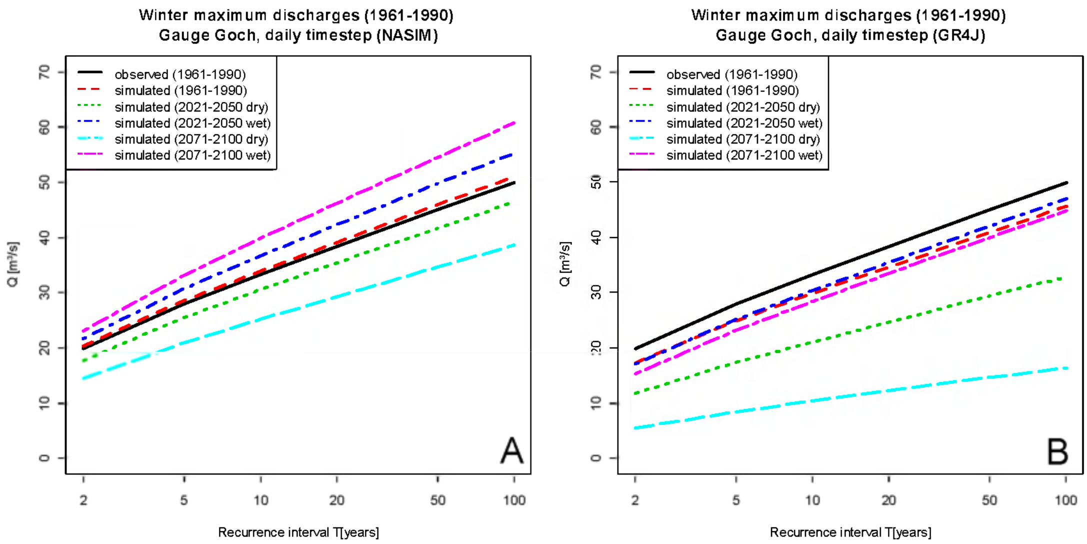


Figure 26: Winter maximum discharges for different recurrence intervals for gauge Goch (Niers), transnational scenarios

In Figure 27 summer AM7 discharges for different recurrence intervals are shown. Since NASIM is not able to reproduce the behavior with sufficient accuracy only the GR4J-results are illustrated. For all future projections decreases are predicted. For a recurrence interval of 50 years the simulated decreases are between 20% (wet scenario for 2021-2050) and 75% (dry scenario for 2071-2100).

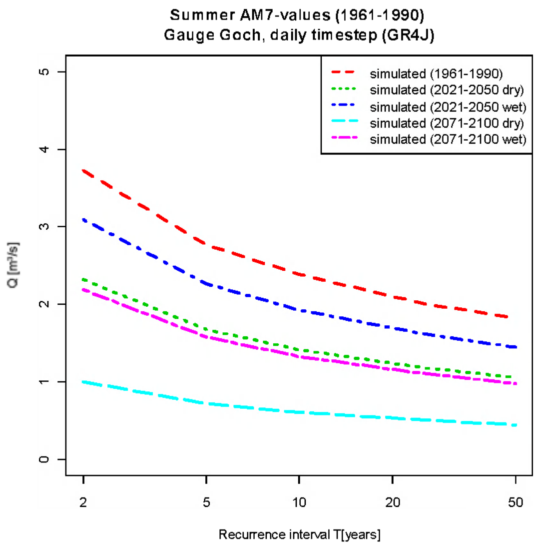


Figure 27: Predicted summer AM7-values for different recurrence intervals (GR4J) for gauge Goch (Niers), transnational scenarios

Simulations with hourly time step using NASIM

In Figure 28 a comparison of the simulated and observed mean monthly discharges for the period from 1971-2000 is illustrated. The seasonal cycle is reproduced with good quality. The simulations show a slight underestimation from May to November (except August) and an overestimation from December to April. The highest relative deviation occurs in February and is at about 17%. A Nash-Sutcliffe coefficient of 0,68 was obtained.

In Figure 28 B the simulated winter maxima values are compared to the observed ones. It can be stated that the winter maximum values of each year are only partly reproduced by the simulations. The reason for this may be the very coarse resolution of the input precipitation and temperature signals.

Nevertheless, as Figure 28 C shows, due to very similar mean values and variances for simulated and observed values the discharges for different recurrence intervals are reproduced with good accuracy (maximum likelihood fitting of the Gumbel distribution). For long recurrence intervals the overestimation of the simulated values becomes larger.

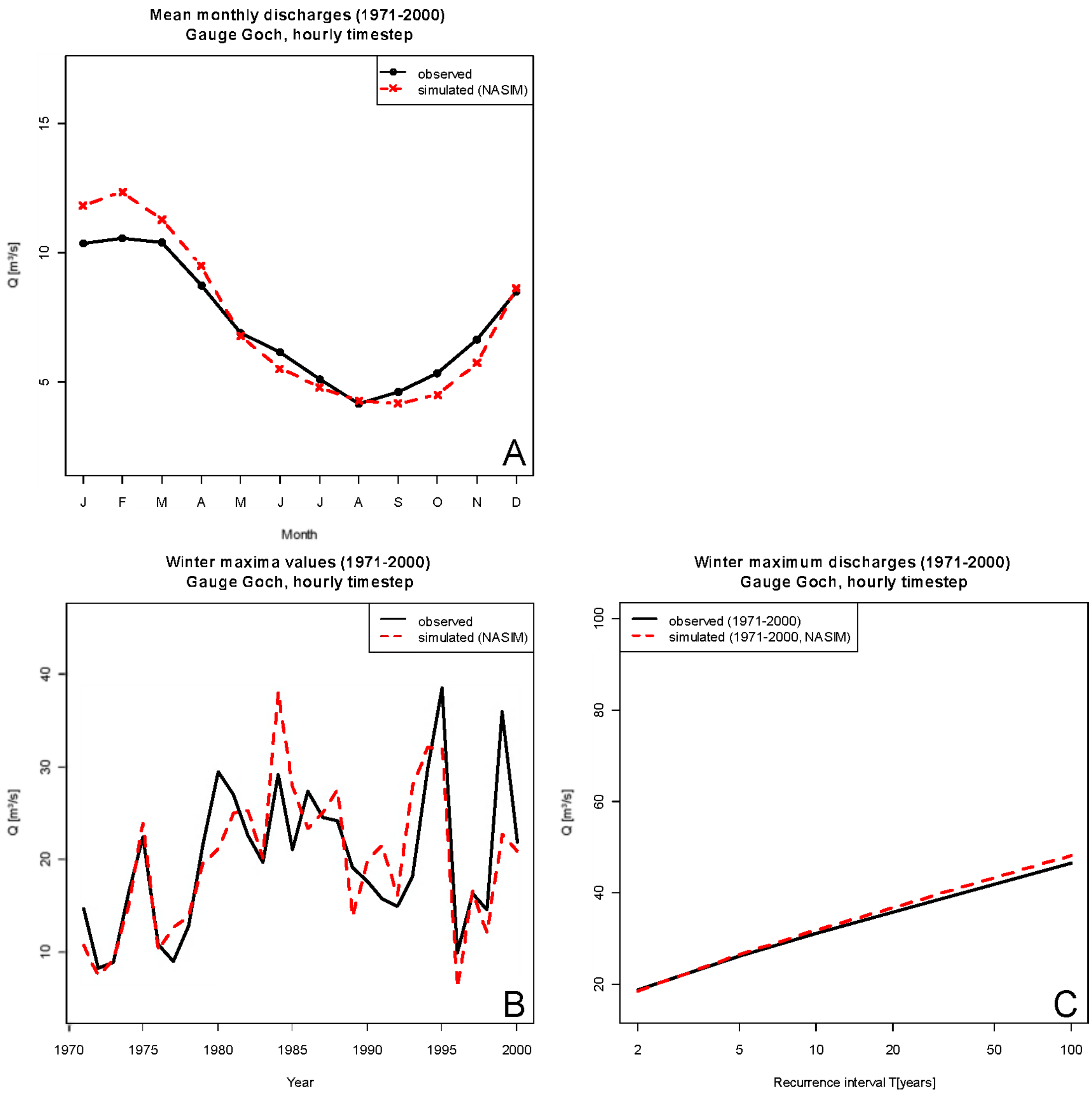


Figure 28: Adaptation quality of simulations with hourly time step for gauge Goch (Niers) using NASIM

<u>National scenarios</u>

In Figure 29 A and B the NASIM results for the mean monthly discharges and for the predicted change factors are illustrated. The highest increase with a change factor of almost 1,5 is predicted for February for the wet scenario for 2071-2100. For October and November for both scenarios and both future time slices a decrease is predicted. The strongest decrease with a change factor of about 0,78 is predicted for November for the dry scenario for 2071-2100. For both dry scenarios a decrease is predicted for the whole year. In Table 37 an overview of the mean discharges is given.

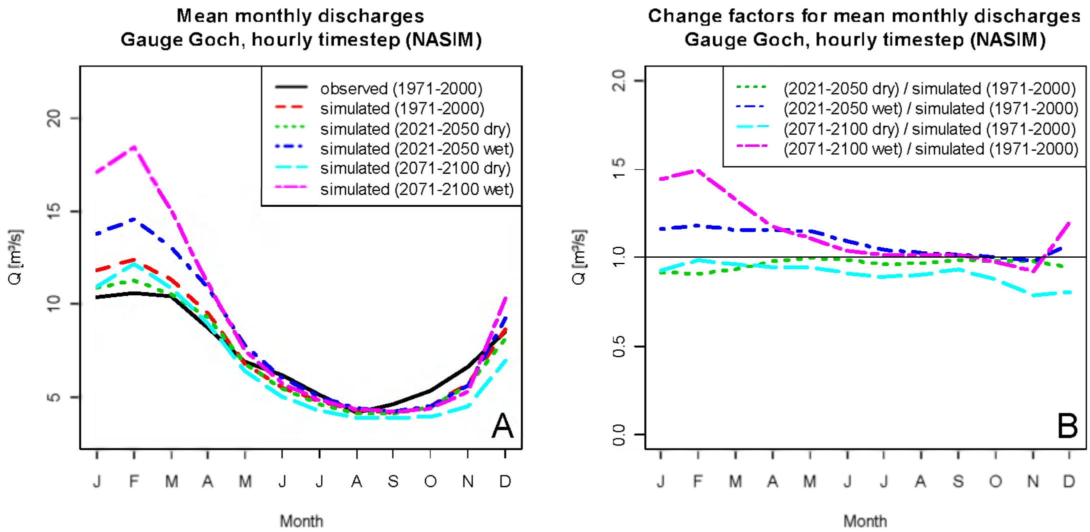


Figure 29: Predicted mean monthly discharges and change factors for gauge Goch (Niers) for a time step of 1 hour using NASIM, national scenarios

	NASIM	*observed*
1971-2000	**7,42**	**7,27**
2021-2050 dry	**7,07**	**-**
2021-2050 wet	**8,22**	**-**
2071-2100 dry	**6,78**	**-**
2071-2100 wet	**8,97**	**-**

Table 37: Simulated and observed mean discharges [m³/s] for gauge Goch (Niers) for a time step of 1 hour using NASIM, national scenarios

In Figure 30 winter maximum discharges for different recurrence intervals based upon the NASIM results are shown. For the dry scenario for 2071-2100 NASIM predicts higher discharges than for the dry scenario for 2021-2050 and also than for 1971-2000. This tendency is equal to the results using the E-OBS gridded dataset with time steps of one day. For the wet scenarios a monotonic increase until the end of the century is predicted. When comparing maximum discharges predicted for the wet scenario for 2071-2100 to values for 1971-2000 the increase for the different recurrence intervals is between 60% and 80%.

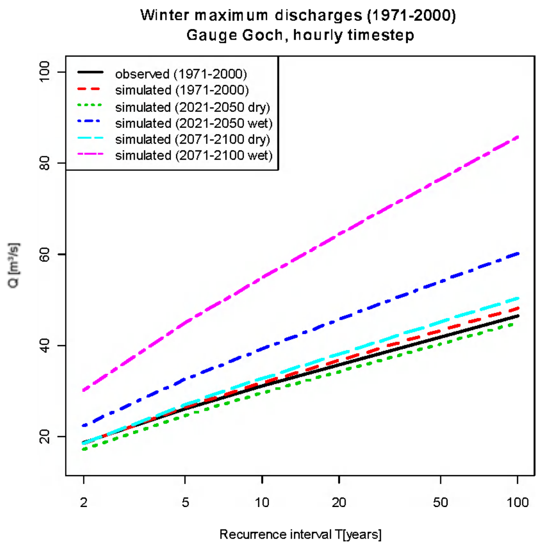


Figure 30: Winter maximum discharges for gauge Goch (Niers) for different recurrence intervals for a time step of 1 hour using NASIM, national scenarios

Transnational scenarios

In Figure 31 A and B one can see the NASIM results for the mean monthly discharges and the predicted change factors. The highest change factor with 1,15 is predicted for February for the wet scenario for 2071-2100. For May to December for the dry and the wet scenarios and for both future time slices a decrease in predicted. The strongest decrease with a change factor of 0,62 is predicted for December for the dry scenario for 2071-2100. For the dry scenarios a year-round decrease is predicted for both future time slices.

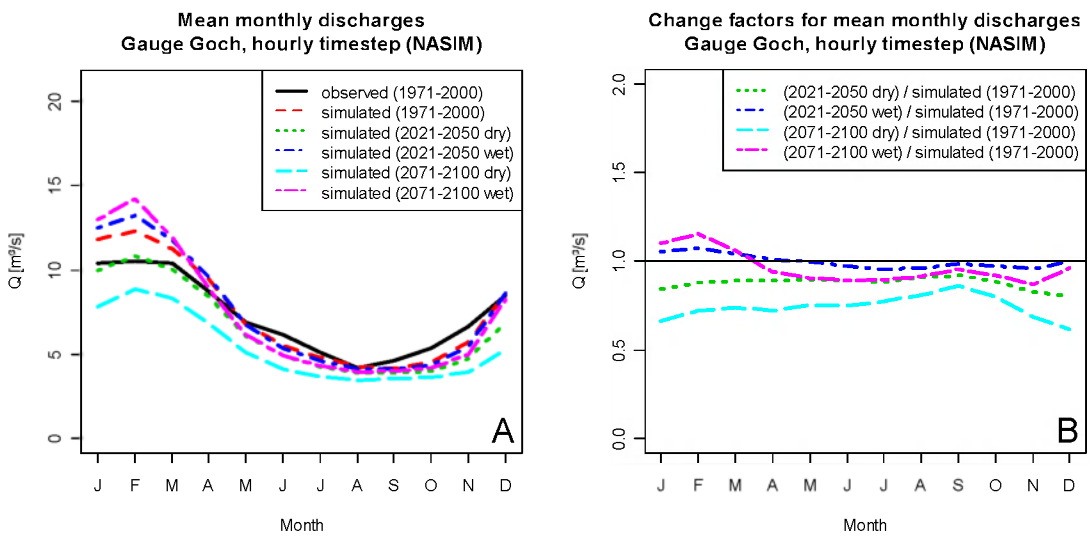


Figure 31: Predicted mean monthly discharges and change factors for gauge Goch (Niers) for a time step of 1 hour using NASIM, transnational scenarios

In Figure 32 winter maximum discharges for different recurrence intervals are shown. For the wet and for the dry scenario an intensification until the end of the century (i.e. a monotonic increase for the wet and a monotonic decrease for the dry scenario) is simulated. For a recurrence interval of 100 years the bandwidth of the predicted changes is between +24% (wet scenario for 2071-2100) and -29% (dry scenario for 2071-2100).

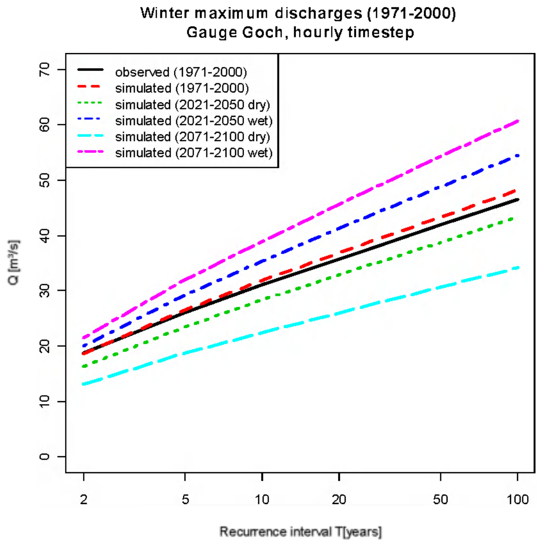


Figure 32: Winter maximum discharges for gauge Goch (Niers) for different recurrence intervals for a time step of 1 hour using NASIM, transnational scenarios

Rur at Stah

Simulations with daily time step using the E-OBS gridded dataset

In Figure 33 A the simulated and observed mean monthly discharges for the period from 1961-1990 are opposed. The simulations with NASIM show an underestimation from March to October and an overestimation from November to February. The highest relative deviation occurs in July and is at about 8%. The results of the GR4J-model outperform NASIM and are closer to the observed. Here we have an overestimation from May to November and an underestimation from December to April. The maximum deviation is at about 5% and occurs again in July. Using NASIM a Nash-Sutcliffe coefficient of 0,86 could be obtained, using GR4J 0,90.

In Figure 33 B the simulated winter maxima values for both models are confronted with the observed ones. Like for gauge Goch concerning the sum of squared standardized deviations NASIM shows slightly better results than the GR4J model. As can be seen in Figure 33 C this is not obviously confirmed by the discharges for different recurrence intervals (maximum likelihood fitting of the Gumbel distribution). For small recurrence intervals the NASIM results show a better agreement with the discharges calculated using the observed values than the GR4J results, but this changes for longer recurrence intervals.

In Figure 33 D a comparison of the simulated and observed summer AM7-values for the period from 1961-1990 is illustrated. The NASIM results show for almost all years an underestimation of the observed values. The observed values cannot be reproduced with sufficient accuracy. The GR4J results are predominant, although the deviations to the observed values are larger compared to the winter maxima values. As one can see in Figure 33 E the simulated summer AM7 discharges are slightly overestimated for small recurrence inte rvals (maximum likelihood fitting of the Lognormal distribution) and underestimated for larger recurrence intervals. The larger the recurrence intervals gets, the larger the deviation becomes.

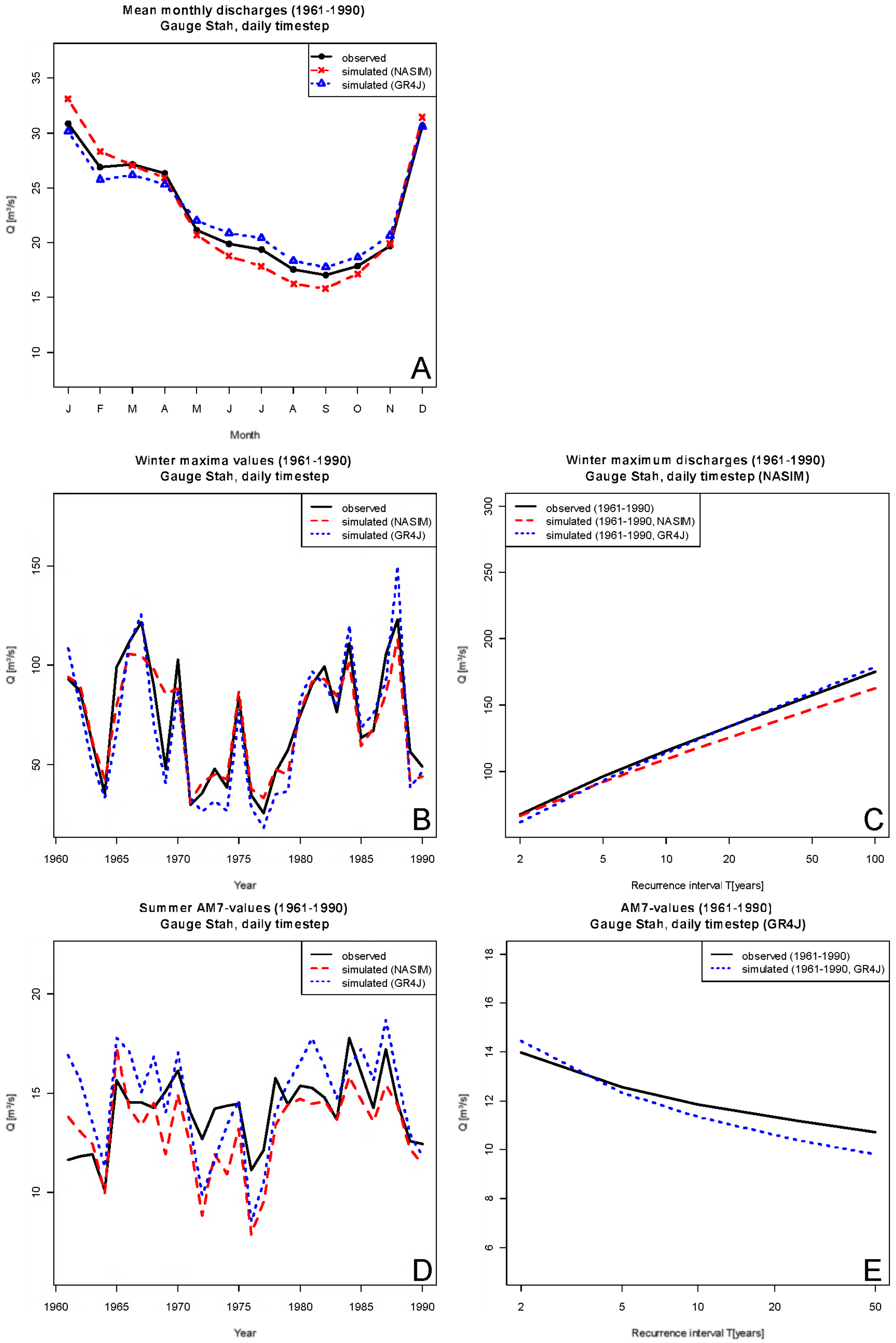


Figure 33: Adaptation quality of simulations with daily time step for gauge Stah (Rur)

National scenarios

In Figure 34 A and B the NASIM results for the predicted mean monthly discharges and for the predicted change factors are shown. The highest increase with a change factor of 1,71 is predicted for February for the wet scenario for 2071-2100. For May to November for both scenarios and both future time slices a decrease is predicted. The strongest decrease with a change factor of 0,63 is predicted for June for the dry scenario for 2071-2100. For both dry scenarios an all the year round decrease is predicted. As mentioned in previous chapters, within the period from 2030-2050 water is taken from the Rur to create a lake by filling the remaining pit with water. This of course has impacts on the mean monthly discharges. As a first approximation one may assume that the mean monthly discharges for the scenarios for 2021-2050 are decreased by this measure by about 2/3*2,5 m³/s (see Figure 34).

The latter is of course also valid for the GR4J results which are shown in Figure 34 C and D. Like for NASIM the highest increase following the results of GR4J with a change factor of 1,75 is predicted for February for the wet scenario for 2071-2100. The strongest decrease with a change factor of about 0,62 is again predicted for June for the dry scenario for 2071-2100. In table 38 an overview over the mean discharges is given.

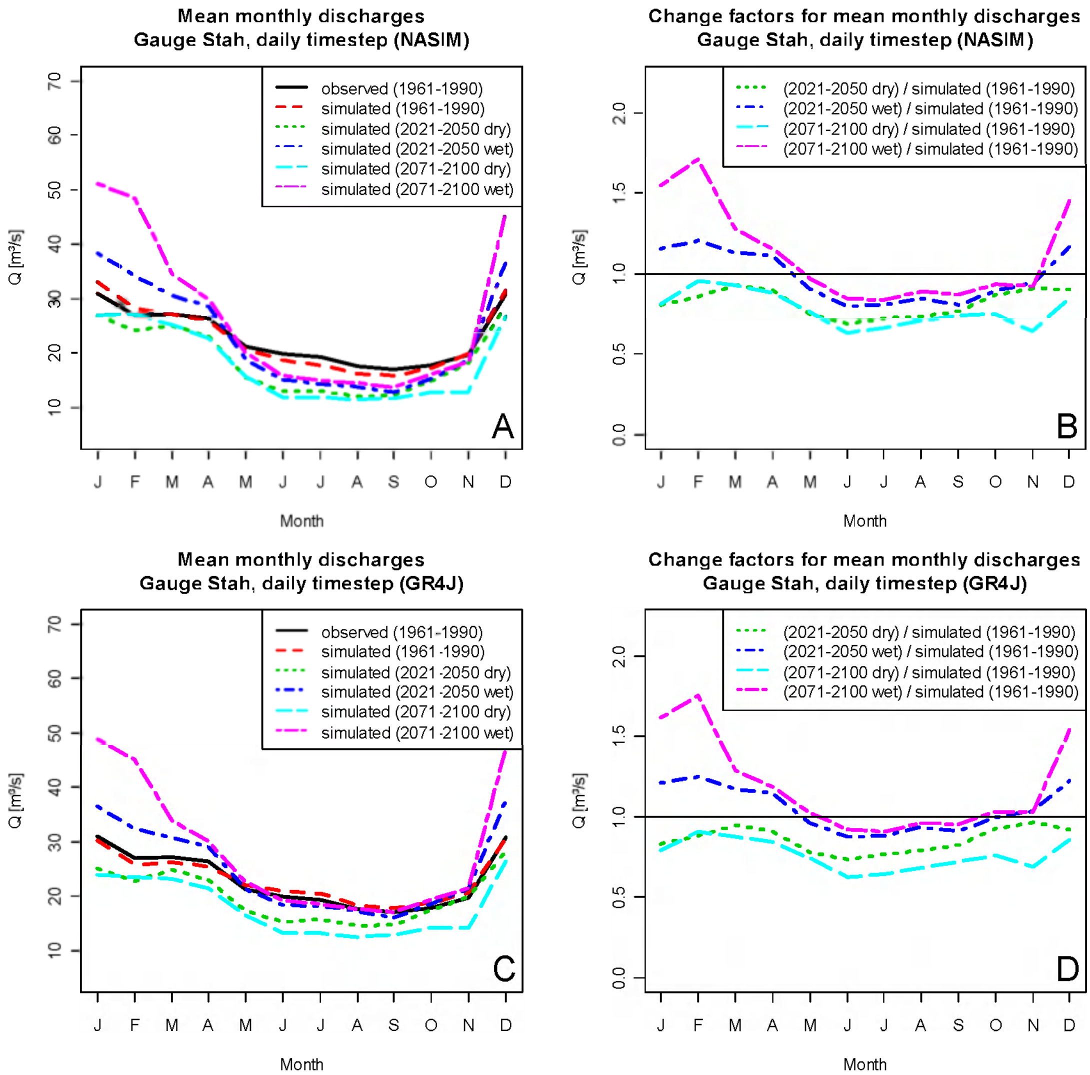


Figure 34: Predicted mean monthly discharges and change factors for gauge Stah (Rur), national scenarios

	NASIM	*GR4J*	*observed*
1961-1990	**22,76**	**23,05**	**22,84**
2021-2050 dry	**18,89**	**19,85**	**-**
2021-2050 wet	**23,11**	**24,72**	**-**
2071-2100 dry	**18,10**	**17,84**	**-**
2071-2100 wet	**26,89**	**28,31**	**-**

Table 38: Simulated and observ ed mean discharges [m³/s] for gauge Stah (Rur) for the daily time step, national scenarios

In Figure 35 winter maximum discharges for different recurrence inter vals are illustrated (left side: NASIM, right side: GR4J). As mentioned above the withdrawal of water for the creation of the lake starts in 2030. In order not to violate the basic assumptions of extreme value statistics for the calculation of discharges for different recurrence intervals, in pr inciple one would have to adjus t either the values from

2021 to 2029 or only take the values from 2030 to 2050 into consideration. Comparative calculations have shown that the effect of both is very small in the case of winter maximum discharges. For all recurrence intervals the deviations in the results were less than 2% compared to taking all 30 (not adjusted) values between 2021 and 2050 into consideration.

The predictions for the future scenarios reveal large differences. Especially for the wet scenarios GR4J predicts higher discharges for all recurrence intervals than NASIM. Both models have in common that for the wet scenarios an intensification until the end of the century is predicted. For the dry scenario for the end of the century both models predict a slight increase of winter maximum discharges compared to 1961-1990. Concerning the dry scenario for the middle of the century both models show an increase for small recurrence intervals and a decrease for larger recurrence intervals.

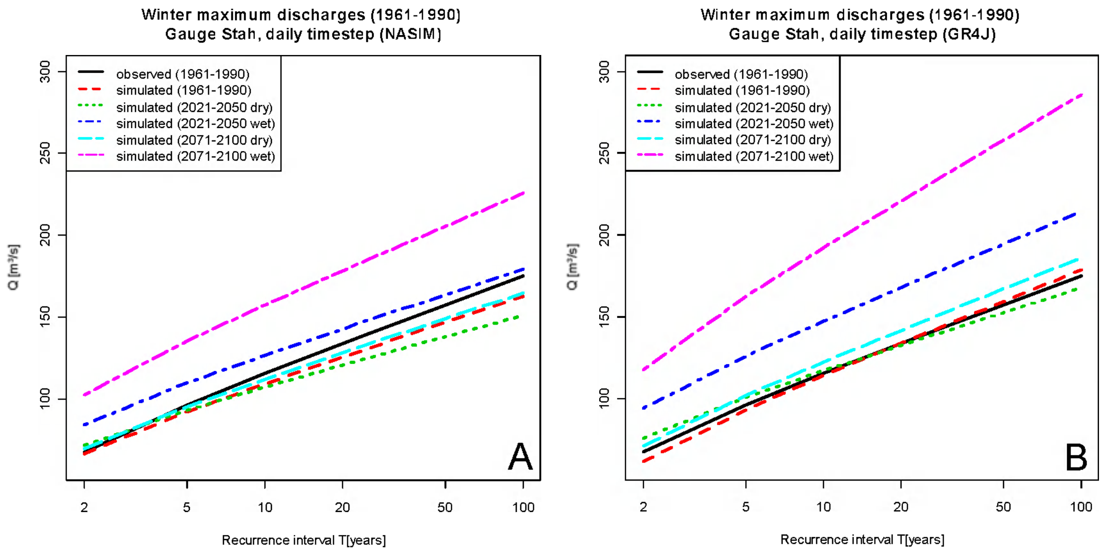


Figure 35: Winter maximum discharges for different recurrence intervals for gauge Stah (Rur), national scenarios

In Figure 36 summer AM7 discharges for different recurrence intervals are shown. The summer AM7 discharges are of course much smaller than the winter maximum values. Thus, the impact of the withdrawal of water is much bigger. Because of this in contrast to the calculation of the winter maximum values here we have to conclude that there is a significant inhomogeneity in the time series. Thus we have taken only the extreme values from 2030-2050 into consideration for the statistical extreme value analysis for the scenarios from 2021-2050. For comparison reasons we used for the extreme value analysis of all other simulations only the last 21 values as well.

Since GR4J clearly outperforms NASIM only the results from GR4J are shown. The withdrawal of water leads at least for the dry scenarios to smaller discharges at the middle of the century than at the end. Without the withdrawals this would be different. With the exception of the recurrence interval of 50 years for the wet scenario for 2071-2100 for both scenarios of both future time slices and for all recurrence intervals a decrease in the summer AM7-values is predicted. In comparison to 1961-1990 the dry scenario for 2071-2100 shows, depending on the recurrence interval, a decrease between 24% and 32%.

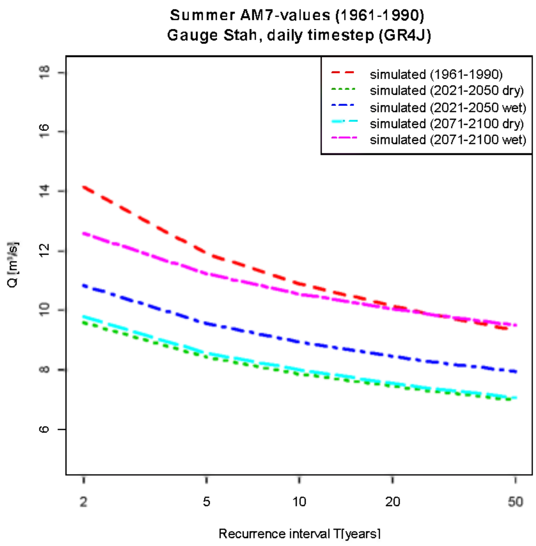


Figure 36: Predicted summer AM7-values for different recurrence intervals (GR4J) for gauge Stah (Rur), national scenarios

Transnational scenarios

In Figure 37 A and B the NASIM results for the mean monthly discharges and for the predicted change factors are shown. The highest increase with a change factor of 1,11 is predicted for February for the wet scenario for 2071-2100. For March to December for all future projections a decrease is predicted. The strongest decrease with a change factor of 0,41 is predicted for December for the dry scenario for 2071-2100. For both dry scenarios an all the year round decrease is predicted. As mentioned above the withdrawal of water for the creation of the lake has of course impacts on the mean monthly discharges.

The latter is of course also valid for the GR4J results which are shown in Figures 37 C and D. Concerning the change factors both models show comparable results. Like for NASIM the highest increase following the results of GR4J with a change factor of 1,06 is predicted for February for the wet scenario for 2071-2100. For March to November for all future projections a decrease is predicted. The strongest decrease with a change factor of about 0,37 is predicted for December for the dry scenario for 2071-2100.

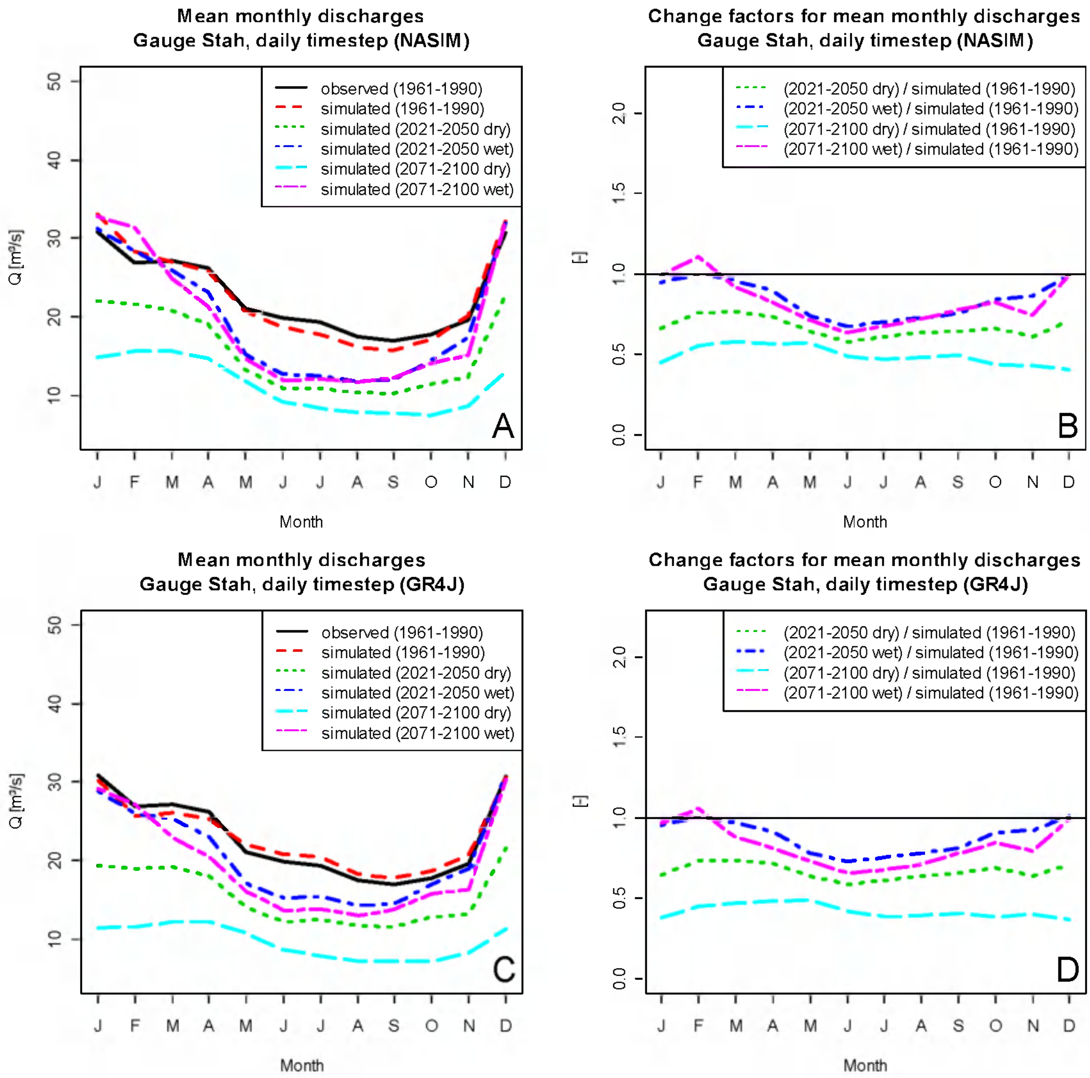


Figure 37: Predicted mean monthly discharges and change factors for gauge Stah (Rur), transnational scenarios

In Figure 38 winter maximum discharges for different recurrence intervals are shown. As mentioned earlier the withdrawal of water for the creation of the lake starts in 2030. Comparative calculations again have shown that the effect of either adjusting the values from 2021 to 2029 or only taking the values from 2030 to 2050 into consideration is very small in the case of winter maximum discharges.

It is striking that the results for the dry scenario for the end of the century show a very strong decrease. For a recurrence interval of 100 years the changes are between +7% (GR4J, wet scenario for 2071-2100) and -57% (dry scenario for 2071-2100).

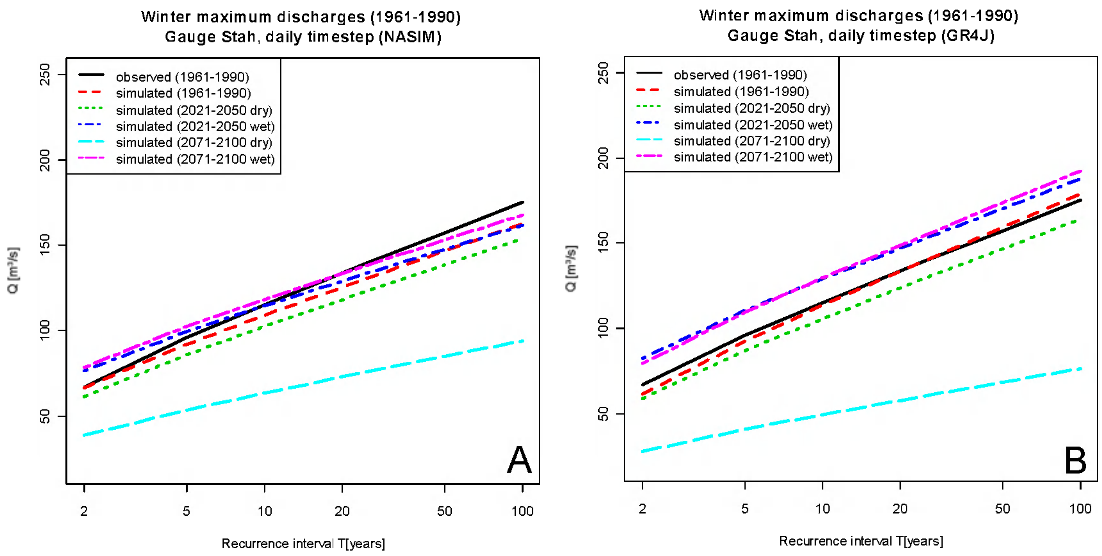


Figure 38: Winter maximum disc harges for different recurrence intervals for gauge Stah (Rur), transnational scenarios

In Figure 39 summer AM7 discharges for di fferent recurrence intervals are shown . The impact of the withdrawal of water is much bigger than for the winter maximum discharges. As for the national s cenarios we have taken for all s imulations only the last 21 values into consideration.

Since GR4J clearly outperforms NASIM only the results from GR4J are shown. For all future projections decreases are predict ed. For a recurrence interval of 50 years the decreases are between -20% (wet scenario for 2071-2100) and -91% (dry scenario for 2071-2100).

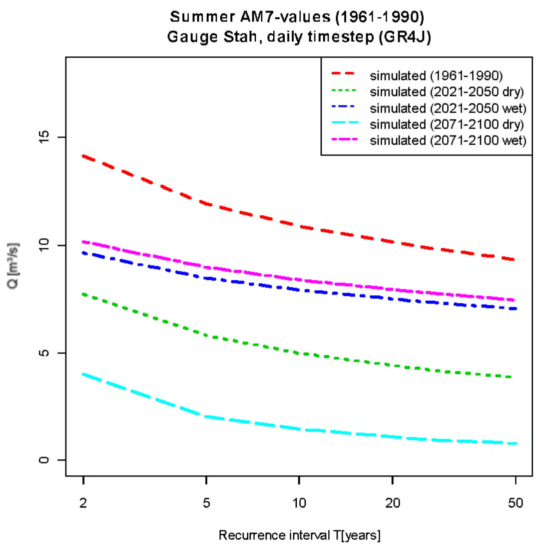


Figure 39: Predicted summer AM7-values for different recurrence intervals (GR4J) for gauge Stah (Rur), transnational scenarios

Simulations with hourly time step using NASIM

In Figure 40 A the simulated and observed mean monthly discharges for the period from 1971-2000 are opposed. The seasonal cycle is recreated with good quality. The simulations show a constant underestimation over the whole year. The highest relative deviation occurs in November and is at about 12% . A Nash- Sutcliffe coefficient of 0,81 was obtained.

In Figure 40 B the simulated winter maxima values are compared with the observed ones. Especially the events in 1975 and 1984 are overestimated by the simulations. Same as for the simulations for gauge Goch the reason for this may be mainly the fact that some pointwise measurements have been assumed to be uniformly distributed over partly large areas for the simulations. Without using the above mentioned reduction factors for the pointwise measurements the tendency of overestimating the observed winter maximum discharges would have been considerably higher. The ability of predicting extreme values would have strongly been degraded by this.

As Figure 40 C shows the winter maximum discharges for different recurrence intervals are constantly overestimated. The relative deviation is for a recurrence interval of two years at about 10% and diminishes for higher recurrence intervals.

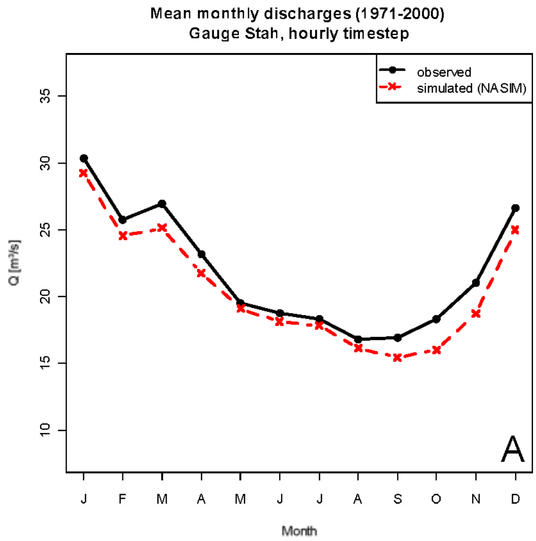
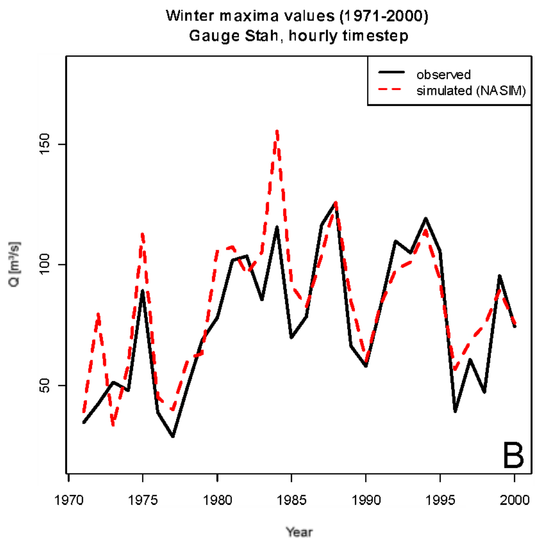
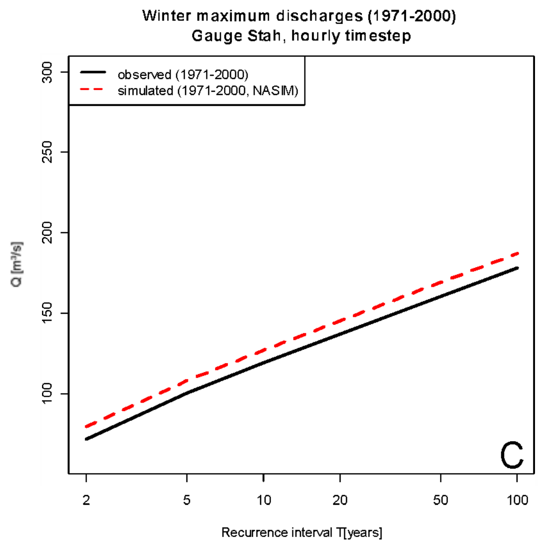


Figure 40: Adaptation quality of simulations with hourly time step for gauge Stah (Rur) using NASIM





<u>National scenarios</u>

In Figure 41 A and B a comparison of the NASIM results and the observed values for the mean monthly discharges and for the predicted change factors (obtained by dividing the future climate value by the simulated value for 1971-2000) are illustrated. The highest increase with a change factor of about 1,8 is predicted for February for the wet scenario for 2071-2100. For May to November for both scenarios and both future time slices a decrease in predicted. The strongest decrease with a change factor of about 0,65 is predicted for June and November for the dry scenario for 2071-2100. For the dry scenarios a decrease is predicted for both future time slices for all months of the year.

The results for 2021-2050 are of course again influenced by the withdrawal of water for the creation of the lake. As a first approximation one may again assume that the mean monthly discharge for the scenarios from 2021-2050 is decreased by this measure by about 2/3*2,5 m³/s (see Figure 41). In table 39 an overview over the mean discharges is given.

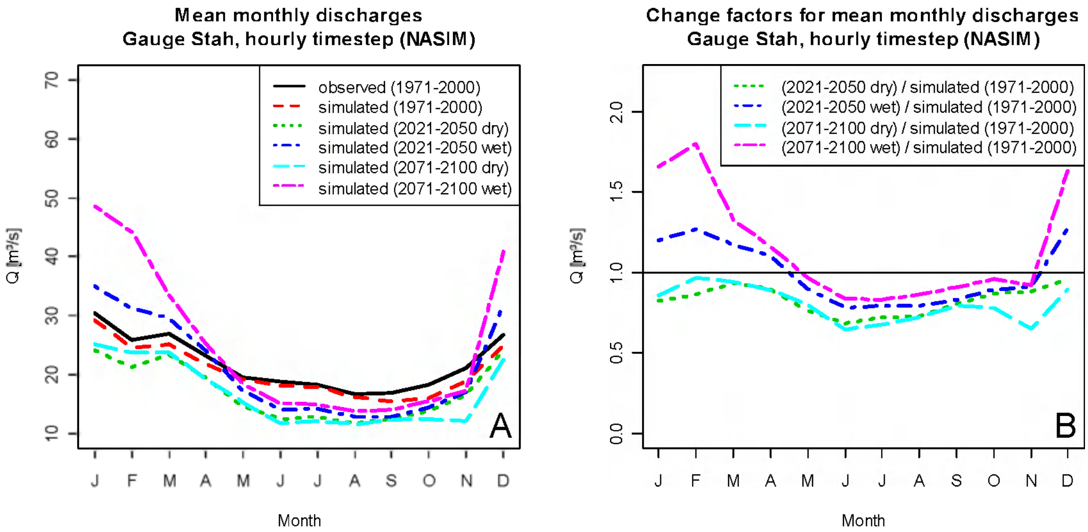


Figure 41: Predicted mean monthly discharges and change factors for gauge Stah (Rur) for a time step of 1 hour using NASIM, national scenarios

	NASIM	***observed***
1971-2000	**20,55**	**21,86**
2021-2050 dry	**17,17**	**-**
2021-2050 wet	**21,09**	**-**
2071-2100 dry	**16,77**	**-**
2071-2100 wet	**24,97**	**-**

Table 39: Simulated and observed mean discharges [m³/s] for gauge Stah (Rur) for a time step of 1 hour using NASIM, national scenarios

In Figure 42 the winter maximum discharges for different recurrence intervals using NASIM are shown. Comparative calculations again showed that the impact of adjusting the values from 2021-2029 or of only taking the values from 2030-2050 into account on the results of the extreme value analysis is very small.

For the dry scenario for 2071-2100 NASIM predicts higher discharges than for the dry scenario for 2021-2050. For the wet scenarios a monotonic increase until the end of the century is predicted. For a recurrence interval of 100 years the predicted changes are between +51% (wet scenario for 2071-2100) and -7% (dry scenario for 2021-2050).

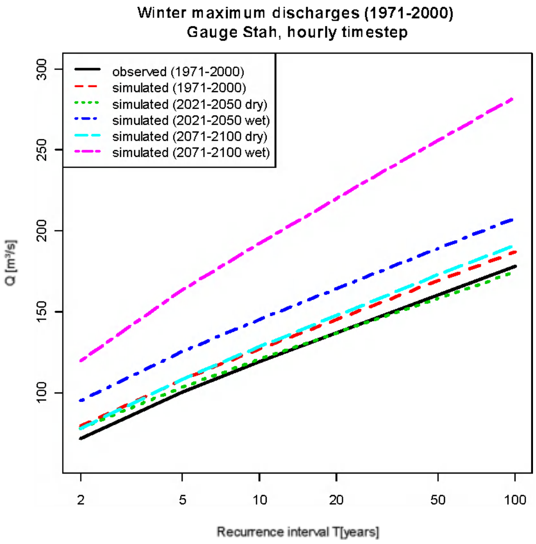


Figure 42: Winter maximum discharges for gauge Stah (Rur) for different recurrence intervals for a time step of 1 hour using NASIM, national scenarios

<u>Transnational scenarios</u>

In Figure 43 A and B the NASIM results for the mean monthly discharges and for the change factors are shown. The highest increase with a change factor of 1,13 is predicted for February for the wet scenario for 2071-2100. For March to November for all future projections a decrease is predicted. The strongest decrease with a change factor of 0,43 is predicted for December for the dry scenario for 2071-2100. For the dry scenarios an all the year round decrease is predicted. As mentioned above for the period from 2030-2050 water is taken from the Rur to create a lake by filling the remaining pit with water. This of course has impacts on the mean monthly discharges.

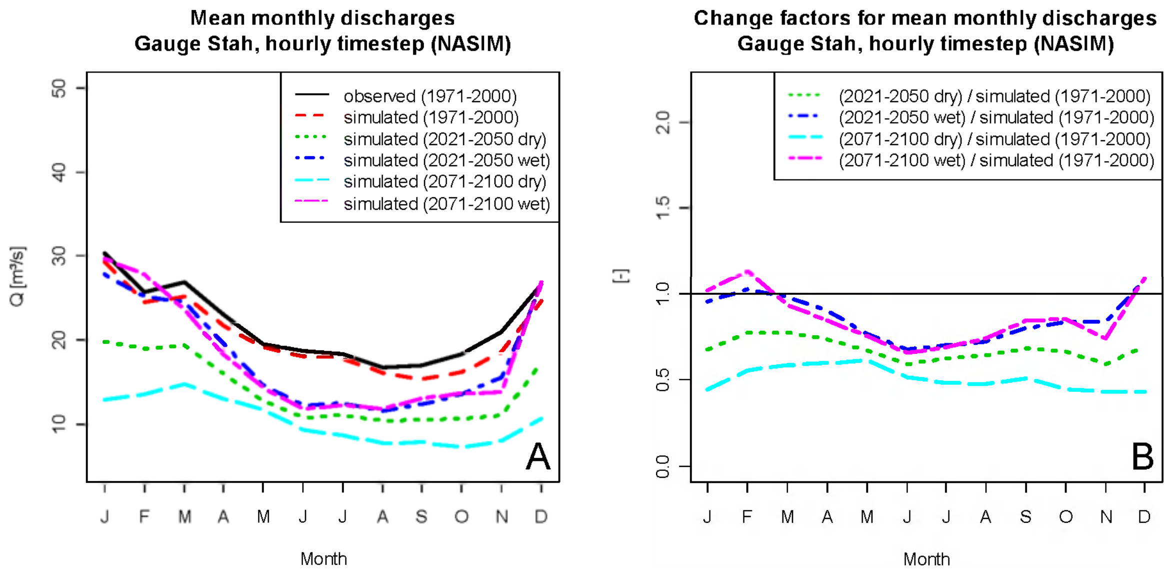


Figure 43: Predicted mean monthly discharges and change factors for gauge Stah (Rur) for a time step of 1 hour using NASIM, transnational scenarios

In Figure 44 the winter maximum discharges for different recurrence intervals using NASIM are shown. Comparativ e calculations showed that the impact of the water extraction on the results of the extreme value analysis is very small.

For the wet and for the dry scenarios a monotonic increase until the end of the century is predicted. For a re currence interval of 100 y ears the predicted c hange is between +10% (wet scenario for 2071-2100) and -39% (dry scenario for 2071-2100).

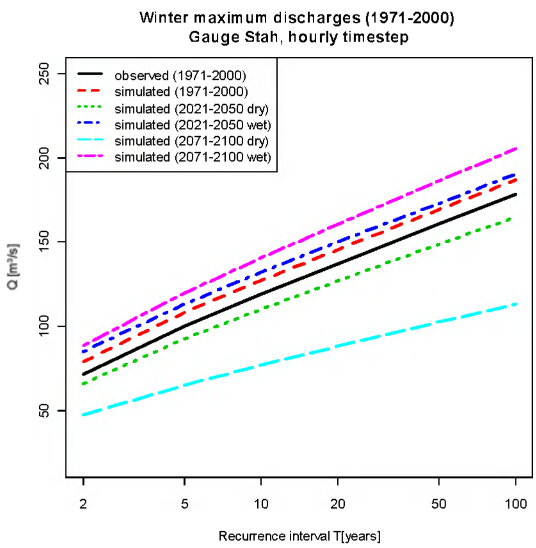


Figure 44: Winter maximum discharges fo r gauge Stah (Rur) for different recurrence intervals for a time step of 1 hour using NASIM, transnational scenarios

French tributaries (Aroffe, Chiers, Meuse, Vence)

River Aroffe has a very specific catchment basin with major karst phenomenons (losses). This basin has been used to validate the results obtained on other rivers. Indeed, similar results on this peculiar river would indicate that discharge variations are consequences of the model and not the rainfall variation.

If the Chiers, Meuse and Vence have a standard error below 5%, correlation will be deemed good. Between 5 and 10 %, correlation is deemed satisfactory. Between 10 and 15 %, it is deemed poor. Above 15%, it is bad.

In general, during the winters, the correlation between the 3 river beds is good. But that is not the case in spring and autumn : the influence of evapotranspiration plays a major role in the appearance of floods during these two seasons. However, the majority of floods happen during the winter season. We have thus concentrated our analysis on this period.

Results could be improved. An assessment of the whole Meuse river basin and of a wider flood panel could lead to more detailed results, especially for spring and autumn.

<u>Hourly maximum discharge - transnational scenario</u>

Correlation between the three rivers is good. For the “wet” scenarii, the river basins reacts in the same proportions as the rainfall modifications. For the “dry” scenarii, the river basins discharges display much bigger deviations.

<u>Hourly maximum discharge - national scenario</u>

Correlation between the three rivers is good, with the exception of medium floods for the timeframe 2071-2100 for which correlation is deemed poor. In general, river basins display important deviations.

Appendix 6: Discharge values for Qhx (winter maximum hourly discharge values)

T[y]	Meuse **St-Mihiel**	Meuse **Stenay**	Meuse **Montcy**	Meuse **Chooz**	Meuse **Sint Pieter**	Lesse **Gendron**	Vesdre **Chaudfontaine**	Rur **Stah (1971-2000)**	Niers **Goch (1971-2000)**
2	272	284	482	690	1574 1671	153 81.4	120 73.7	71,63 79,37	18,74 18,62
5	387	380	654	940	1898 1902	230 144	170 100	100,13 108,12	26,15 26,54
10	486	445	767	1100	2142 2155	284 194	198 114	119,00 127,16	31,05 31,79
25	507	520	900	1300	2466 2542	357 267	227 129	142,85 151,21	37,25 38,42
50	571	586	1018	1500	2710 2780	414 328	246 138	160,54 169,05	41,84 43,33
100	614	645	1124	1650	2955 3019	472 395	264 147	178,10 186,76	46,41 48,21
250					3278 3334			201,22 210,08	52,41 54,64
1250					3800 3844			241,74 250,94	62,94 65,90

Table 1: Observed and simulated winter maximum hourly discharge values (in m3/s) as a function of the recurrence interval T[y] for different sub-basins of the Meuse river basin. Period 1961-1990.

T[y]	Meuse St-Mihiel	Meuse Stenay	Meuse Montcy	Meuse Chooz	Meuse Sint Pieter	Lesse Gendron	Vesdre Chaudfontaine	Rur Stah (1971-2000)	Niers Goch (1971-2000)
2	306 261	318 272	542 463	776 663	1876 1545	95.1 79.3	75.2 63.3	85,32 66,34	20,18 16,38
5	435 372	428 365	736 628	1058 903	2193 1728	169 141	105 87.7	113,40 92,68	29,11 23,49
10	546 452	500 414	861 714	1235 1024	2494 2004	229 190	121 101	132,00 110,12	35,03 28,20
25	569 472	568 471	982 814	1460 1210	2885 2417	316 261	138 115	155,49 132,16	42,50 34,15
50	640 549	656 564	1140 979	1680 1443	3157 2644	389 321	149 124	172,92 148,51	48,04 38,57
100	875 751	722 620	1259 1081	1848 1587	3430 2872	469 387	159 132	190,22 164,73	53,55 42,95
250	Not calculated	Not calculated	Not calculated	Not calculated	3791 3173	Not calculated	Not calculated	213,00 186,10	60,79 48,72
1250	Not calculated	Not calculated	Not calculated	Not calculated	4374 3659	Not calculated	Not calculated	252,91 223,54	73,49 58,83

Table 2: Simulated winter **maximum hourly discharge** values (in m3/s) as a function of the recurrence interval T[y] for different sub-basins of the Meuse river basin. Period **2021-2050**, wet scenario and dry scenario. **Transnational climate scenarios**

T[y]	Meuse St-Mihiel	Meuse Stenay	Meuse Montcy	Meuse Chooz	Meuse Sint Pieter	Lesse Gendron	Vesdre Chaudfontaine	Rur Stah (1971-2000)	Niers Goch (1971-2000)
2	242 234	344 333	433 399	451 416	1817 1785	122 70.9	99.5 60.0	94,89 77,64	22,49 17,32
5	514 491	703 672	252 243	429 415	2108 2114	201 108	145 84.8	125,13 103,51	32,60 24,73
10	614 593	338 327	582 562	837 808	2381 2424	254 131	171 98.2	145,15 120,65	39,29 29,63
25	396 365	683 629	979 902	450 415	2734 2820	319 159	198 113	170,44 142,29	47,74 35,82
50	778 717	1157 1066	527 504	916 875	2987 3093	365 179	216 122	189,21 158,35	54,01 40,42
100	1350 1290	581 555	1012 967	1485 1419	3241 3366	411 199	233 131	207,84 174,29	60,23 44,98
250	Not calculated	Not calculated	Not calculated	Not calculated	3578 3727	Not calculated	Not calculated	232,36 195,28	68,43 50,99
1250	Not calculated	Not calculated	Not calculated	Not calculated	4121 4309	Not calculated	Not calculated	275,34 232,06	82,79 61,51

Table 3: Simulated winter **maximum hourly discharge** values (in m3/s) as a function of the recurrence interval T[y] for different sub-basins of the Meuse river basin. Period **2021-2050**, wet scenario and dry scenario. **National climate scenarios**

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T[y]	Meuse **St-Mihiel**	Meuse **Stenay**	Meuse **Montcy**	Meuse **Chooz**	Meuse **Sint Pieter**	Lesse **Gendron**	Vesdre **Chaudfontaine**	Rur **Stah (1971-2000)**	Niers **Goch (1971-2000)**
2	346 243	360 253	613 430	877 616	2028 1314	108 68	81.6 54.5	88,42 47,78	21,68 13,10
5	492 346	483 339	831 584	1195 839	2475 1680	202 124	118 77.0	119,73 65,36	31,84 18,75
10	625 396	573 363	987 625	1416 897	2863 1979	281 169	138 89.3	140,46 76,99	38,56 22,51
25	653 413	651 412	1125 712	1673 1060	3339 2286	398 236	159 102	166,66 91,691	47,06 27,24
50	727 504	746 517	1296 898	1910 1323	3675 2516	499 293	173 111	186,09 102,60	53,37 30,75
100	994 689	821 569	1431 991	2100 1455	4013 2747	611 356	186 119	205,38 113,43	59,62 34,24
250	Not calculated	Not calculated	Not calculated	Not calculated	4459 3051	Not calculated	Not calculated	230,77 127,68	67,86 38,83
1250	Not calculated	Not calculated	Not calculated	Not calculated	5177 3543	Not calculated	Not calculated	275,28 152,66	82,30 46,88

Table 4: Simulated winter **maximum hourly discharge** values (in m3/s) as a function of the recurrence interval T[y] for different sub-basins of the Meuse river basin. Period **2071-2100**, wet scenario and dry scenario. **Transnational climate scenarios**

T[y]	Meuse **St-Mihiel**	Meuse **Stenay**	Meuse **Montcy**	Meuse **Chooz**	Meuse **Sint Pieter**	Lesse **Gendron**	Vesdre **Chaudfontaine**	Rur **Stah (1971-2000)**	Niers **Goch (1971-2000)**
2	228 174	325 248	360 272	375 284	1963 1964	148 65.7	117 57.2	119,87 77,87	30,16 18,53
5	474 360	648 492	238 181	405 308	2295 2403	239 99.4	172 78.8	163,47 108,26	45,02 27,07
10	580 442	319 243	549 419	790 602	2595 2753	297 121	203 90.4	192,34 128,39	54,86 32,72
25	329 249	568 430	814 616	374 283	2950 3180	370 146	236 103	228,82 153,82	67,29 39,85
50	647 489	962 728	486 369	845 641	3221 3498	421 165	258 111	255,88 172,68	76,52 45,15
100	1245 945	535 406	933 708	1370 1040	3495 3817	472 182	278 118	282,74 191,40	85,67 50,40
250	Not calculated	Not calculated	Not calculated	Not calculated	3856 4237	Not calculated	Not calculated	318,11 216,06	97,73 57,32
1250	Not calculated	Not calculated	Not calculated	Not calculated	4439 4918	Not calculated	Not calculated	380,09 259,26	118,86 69,44

Table 5: Simulated winter **maximum hourly discharge** values (in m3/s) as a function of the recurrence interval T[y] for different sub-basins of the Meuse river basin. Period **2071-2100**, wet scenario and dry scenario. **National climate scenarios**

Appendix 7: Discharge values for Qdx (winter maximum daily discharge values)

T[y]	Meuse **St-Mihiel**	Meuse **Stenay**	Meuse **Montcy**	Meuse **Chooz**	Meuse **Sint Pieter**	Lesse **Gendron**	Vesdre **Chaudfontaine**	Rur **Stah (NASIM)**	Niers **Goch (NASIM)**
2	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	138 159	88.7 92.7	67,27 66,42	19,77 20,28
5	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	207 230	124 128	96,16 92,16	27,83 28,47
10	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	256 279	149 147	115,30 109,20	33,16 33,90
25	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	321 342	163 167	139,47 130,74	39,90 40,75
50	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	372 390	176 181	157,40 146,71	44,90 45,83
100	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	424 440	188 192	175,20 162,57	49,87 50,88
250	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	198,64 183,45	56,40 57,53
1250	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	239,72 220,04	67,85 69,17

Table 6: Observed and simulated winter maximum daily discharge values (in m3/s) as a function of the recurrence interval T[y] for different sub-basins of the Meuse river basin. Period 1961-1990.

T[y]	Meuse St-Mihiel	Meuse Stenay	Meuse Montcy	Meuse Chooz	Meuse Sint Pieter	Lesse Gendron	Vesdre Chaudfontaine	Rur Stah (NASIM)	Niers Goch (NASIM)
2	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	157 138	84.8 72.9	76,70 61,40	21,71 17,77
5	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	229 197	114 98.1	99,47 86,11	30,66 25,40
10	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	279 236	135 116	114,56 102,47	36,60 30,46
25	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	345 287	163 140	133,61 123,14	44,09 36,84
50	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	396 326	185 159	147,75 138,47	49,65 41,58
100	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	447 365	208 179	161,79 153,70	55,17 46,28
250	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	180,26 173,74	62,43 52,47
1250	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	212,64 208,86	75,16 63,32

Table 7 : Simulated winter **maximum daily discharge** values (in m3/s) as a function of the recurrence interval T[y] for different sub-basins of the Meuse river basin. Period **2021-2050**, wet scenario and dry scenario. **Transnational climate scenarios**

T[y]	Meuse St-Mihiel	Meuse Stenay	Meuse Montcy	Meuse Chooz	Meuse Sint Pieter	Lesse Gendron	Vesdre Chaudfontaine	Rur Stah (NASIM)	Niers Goch (NASIM)
2	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	205 137	106 83.7	84,19 71,71	23,96 18,79
5	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	298 189	143 123	109,56 92,93	33,93 26,49
10	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	362 223	162 146	126,36 106,99	40,53 31,59
25	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	446 265	182 170	147,59 124,74	48,87 38,03
50	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	510 298	195 186	163,3 137,91	55,05 42,81
100	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	575 330	207 200	178,96 150,98	61,19 47,55
250	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	199,54 168,19	69,28 53,79
1250	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	235,61 198,36	83,45 64,74

Table 8: Simulated winter **maximum daily discharge** values (in m3/s) as a function of the recurrence interval T[y] for different sub-basins of the Meuse river basin. Period **2021-2050**, wet scenario and dry scenario. **National climate scenarios**

T[y]	Meuse St-Mihiel	Meuse Stenay	Meuse Montcy	Meuse Chooz	Meuse Sint Pieter	Lesse Gendron	Vesdre Chaudfontaine	Rur Stah (NASIM)	Niers Goch (NASIM)
2	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	173 115	86.2 60.1	78,78 39,02	22,96 14,50
5	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	249 164	117 78.5	102,62 53,81	33,04 20,92
10	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	301 197	139 89.4	118,41 63,60	39,72 25,18
25	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	369 241	169 102	138,35 75,96	48,15 30,55
50	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	420 274	193 111	153,15 85,14	54,41 34,54
100	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	473 307	217 119	167,84 94,25	60,62 38,50
250	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	187,18 106,24	68,80 43,71
1250	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	221,07 127,25	83,13 52,84

Table 9: Simulated winter **maximum daily discharge** values (in m3/s) as a function of the recurrence interval T[y] for different sub-basins of the Meuse river basin. Period **2071-2100**, wet scenario and dry scenario. **Transnational climate scenarios**

T[y]	Meuse St-Mihiel	Meuse Stenay	Meuse Montcy	Meuse Chooz	Meuse Sint Pieter	Lesse Gendron	Vesdre Chaudfontaine	Rur Stah	Niers Goch
2	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	235 129	118 81.3	102,25 69,63	30,38 19,66
5	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	345 177	163 118	135,30 95,00	44,14 28,60
10	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	421 209	186 138	157,18 111,80	53,25 34,52
25	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	522 249	212 159	184,83 133,02	64,76 42,00
50	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	599 279	228 173	205,34 148,77	73,30 47,55
100	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	677 309	243 186	225,70 164,40	81,78 53,06
250	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	252,51 184,98	92,94 60,31
1250	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	299,49 221,04	112,50 73,02

Table 10: Simulated winter **maximum daily discharge** values (in m3/s) as a function of the recurrence interval T[y] for different sub-basins of the Meuse river basin. Period **2071-2100**, wet scenario and dry scenario. **National climate scenarios**

Appendix 8: Discharge values for MAM7 (Minimum 7-days (April-Sept.) discharge values)

	Meuse St-Mihiel	Meuse Stenay	Meuse Montcy	Meuse Chooz	**Meuse Sint Pieter**	Lesse Gendron	Vesdre Chaudfontaine	Rur Stah	Niers Goch
1961-1990	3.04 3.70	8.43 8.51	19.4 24.6	29.4 29.0	54 46	1.77 2.40	2.85 2.66	14,44 14,38	3,86 3,94
2021-2050	2.41 1.85	6.16 5.40	17.0 14.6	25.8 21.7	40 31	2.37 2.10	2.84 2.31	9,74 8,10	3,29 2,48
2071-2100	1.81 1.31	4.24 3.95	13.7 10.1	19.1 15.3	27 16	2.27 1.66	2.86 2.03	10,28 5,21	2,35 1,07

Table 1: Observed and simulated Mean Annual Minimum 7-days (April-Sept.) discharge values (in m3/s). Period 1961-1990, 2021-2050, 2071-2100, wet scenario and dry scenario.

T[y]	Meuse St-Mihiel	Meuse Stenay	Meuse Montcy	Meuse Chooz	**Meuse Sint Pieter**	Lesse Gendron	Vesdre Chaudfontaine	Rur Stah	Niers Goch
2	2.76 3.34	7.80 8.04	18.2 23.4	27.5 29.3	52 38	1.73 2.43	2.87 2.68	14,34 14,11	3,69 3,72
5	1.87 2.28	5.60 6.71	13.2 17.8	20.0 21.8	39 26	1.10 1.92	2.23 2.06	13,04 11,90	2,82 2,77
10	1.53 1.87	4.72 5.25	11.1 15.4	17.0 18.6	33 21	0.82 1.64	1.89 1.73	12,40 10,88	2,44 2,38
25	Not calculated	Not calculated	Not calculated	Not calculated	28 17	0.564 1.34	1.54 1.39	11,76 9,90	2,10 2,02
50	Not calculated	Not calculated	Not calculated	Not calculated	25 15	0.427 1.16	1.31 1.18	11,36 9,31	1,91 1,82

Table 2: Observed and simulated Minimum 7-days (April-Sept.) discharge values (in m3/s) as a function of the recurrence interval T[y] for different sub-basins of the Meuse river basin. Period 1961-1990.

T[y]	Meuse St-Mihiel	Meuse Stenay	Meuse Montcy	Meuse Chooz	**Meuse Sint Pieter**	Lesse Gendron	Vesdre Chaudfontaine	Rur Stah	Niers Goch
2	2.34 1.82	5.89 5.19	16.3 14.0	24.1 20.3	31 25	2.40 2.13	2.59 2.23	9,63 7,74	3,09 2,32
5	1.73 1.40	4.56 4.07	12.7 10.9	17.9 15.1	21 17	1.90 1.65	2.03 1.70	8,47 5,80	2,27 1,68
10	1.47 1.22	3.99 3.58	11.1 9.57	15.3 12.9	18 14	1.63 1.4	1.78 1.46	7,92 4,99	1,93 1,42
25	Not calculated	Not calculated	Not calculated	Not calculated	14 11	1.34 1.13	1.53 1.23	7,38 4,25	1,62 1,19
50	Not calculated	Not calculated	Not calculated	Not calculated	13 10	1.16 0.97	1.38 1.1	7,04 3,84	1,45 1,06

Table 3: Simulated **Minimum 7-days** (April-Sept.) **discharge** values (in m3/s) as a function of the recurrence interval T[y] for different sub-basins of the Meuse river basin. **Period 2021-2050**, wet scenario and dry scenario. **Transnational climate scenarios**

T[y]	Meuse St-Mihiel	Meuse Stenay	Meuse Montcy	Meuse Chooz	**Meuse Sint Pieter**	Lesse Gendron	Vesdre Chaudfontaine	Rur Stah	Niers Goch
2	2.11 2.07	5.47 5.36	14.8 14.4	22.0 21.9	38 21	2.54 2.15	2.88 2.33	10,83 9,58	3,86 3,17
5	1.56 1.51	4.22 4.08	11.4 11.0	16.2 16.0	26 14	2.07 1.67	2.24 1.73	9,55 8,42	2,86 2,33
10	1.33 1.29	3.69 3.55	9.95 9.56	13.8 13.6	21 11	1.59 1.41	1.9 1.42	8,93 7,87	2,45 1,99
25	Not calculated	Not calculated	Not calculated	Not calculated	17 9	1.52 1.14	1.54 1.10	8,32 7,32	2,08 1,67
50	Not calculated	Not calculated	Not calculated	Not calculated	15 8	1.34 0.98	1.31 0.92	7,95 6,99	1,86 1,50

Table 4: Simulated **Minimum 7-days** (April-Sept.) **discharge** values (in m3/s) as a function of the recurrence interval T[y] for different sub-basins of the Meuse river basin. Period **2021-2050**, wet scenario and dry scenario. **National climate scenarios**

T[y]	Meuse St-Mihiel	Meuse Stenay	Meuse Montcy	Meuse Chooz	Meuse Sint Pieter	Lesse Gendron	Vesdre Chaudfontaine	Rur Stah	Niers Goch
2	1.80 1.31	4.02 3.74	13.2 9.55	18.1 14.2	22 13	2.31 1.67	2.52 1.79	10,17 4,01	2,19 1,00
5	1.41 0.99	3.00 2.80	10.6 7.05	13.8 10.4	16 9	1.82 1.24	1.95 1.31	8,96 2,05	1,58 0,72
10	1.25 0.86	2.57 2.41	9.43 6.02	11.9 8.87	13 7	1.56 1.02	1.69 1.06	8,38 1,45	1,33 0,61
25	Not calculated	Not calculated	Not calculated	Not calculated	11 6	1.28 0.79	1.45 0.81	7,81 1,00	1,11 0,51
50	Not calculated	Not calculated	Not calculated	Not calculated	9 5	1.11 0.66	1.3 0.67	7,46 0,78	0,98 0,45

Table 5: Simulated **Minimum 7-days** (April-Sept.) **discharge** values (in m3/s) as a function of the recurrence interval T[y] for different sub-basins of the Meuse river basin. **Period 2071-2100**, wet scenario and dry scenario. **Transnational climate scenarios**

T[y]	Meuse St-Mihiel	Meuse Stenay	Meuse Montcy	Meuse Chooz	Meuse Sint Pieter	Lesse Gendron	Vesdre Chaudfontaine	Rur Stah	Niers Goch
2	1.31 1.25	3.80 3.69	9.55 9.04	13.1 12.4	38 10	2.56 1.97	2.89 2.04	12,60 9,80	3,48 2,00
5	1.05 1.00	3.09 2.89	7.54 7.06	10.3 9.96	26 7	2.11 1.52	2.3 1.49	11,22 8,57	2,55 1,44
10	0.94 0.89	2.69 2.55	6.67 6.21	9.10 8.88	21 6	1.86 1.27	1.97 1.21	10,56 7,99	2,17 1,21
25	Not calculated	Not calculated	Not calculated	Not calculated	17 4	1.59 1.02	1.62 0.93	9,90 7,42	1,82 1,00
50	Not calculated	Not calculated	Not calculated	Not calculated	15 4	1.41 0.87	1.41 0.77	9,49 7,07	1,63 0,89

Table 6: Simulated **Minimum 7-days** (April-Sept.) **discharge** values (in m3/s) as a function of the recurrence interval T[y] for different sub-basins of the Meuse river basin. Period **2071-2100**, wet scenario and dry scenario. **National climate scenarios**