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].

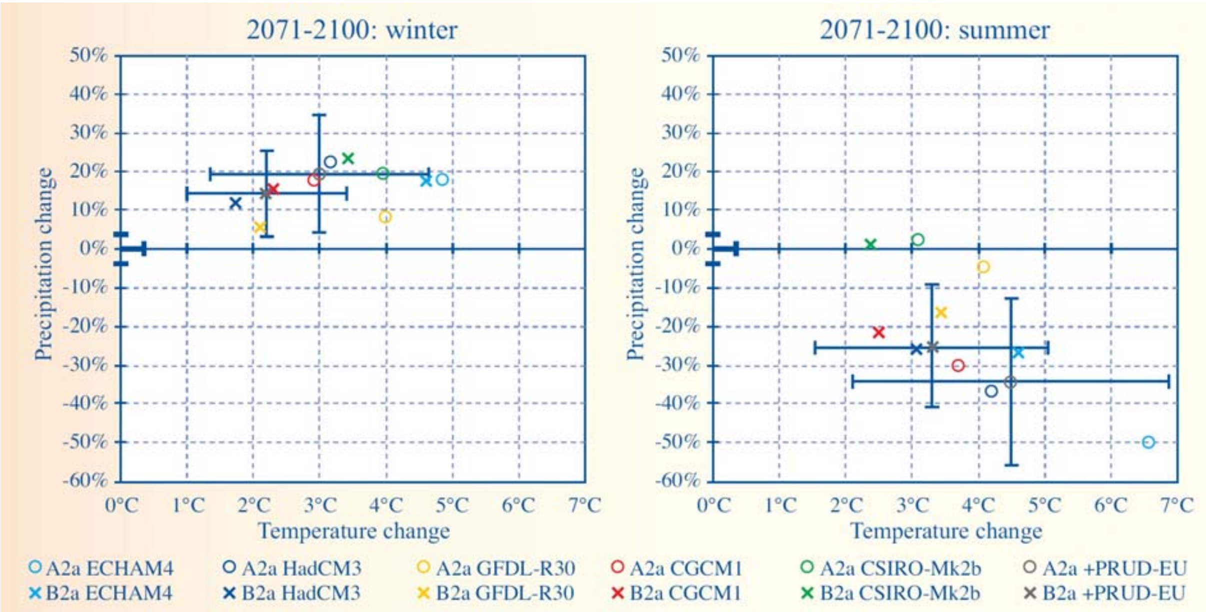

Figure 1: Average evolution of temperatures and precipitations in Belgium between the control period 1961-1990 and the period 2071-2100. The projections are represented for 2 scenarios of emissions (○ : « evolution including few modifications» and × : «evolution oriented to a sustainable development»),5 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 covers whole Europe. The simulations cover the period between 1960 and 2000 in three realizations and the predicted evolution between 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 realization has equal probability to occur. The CCLM results will be mentioned later again.

In (Kropp et al., 2009) the Regional Climate Model CCLM was used for marker-scenario (A1B). For the limitation of the uncertainty, it was tried, wherever possible, to make use of comparative calculations with the RCM STAR. Here CCLM and Star were based on the same results of the same ECHAM5/MPI-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 simulations 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 temperature and precipitation following CCLM and STAR are shown. All models show an increase in mean temperature, but the increase following STAR is much higher, independently of the scenario (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 results 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 chain 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) climate 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. Additionally monthly values are computed. All experiments were driven following 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. Afterwards, the results of this REMO run were used for another REMO run with a spatial resolution of about 10 km. The inner model area contains Germany, Austria and Switzerland. The complete basins of the Rhine and the Elbe are contained. Using this double nesting method has the advantage that there are no large scale-jumps.

For the projection of possible climate conditions in the 21st century, the SRES emission scenarios A1B, B1 and A2 have 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.

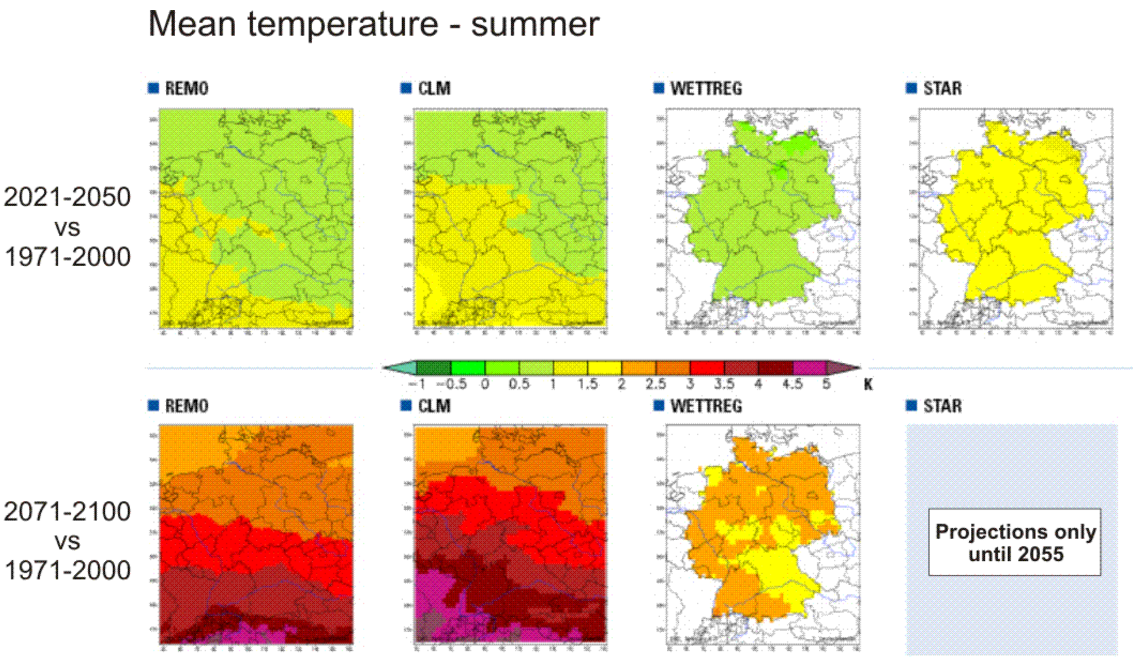

Figure 2 : Differences in temperatures for the summer season between projections of 2071-2100 and 2021-2050 compared to 1971-2000 (on the basis of DWD)

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.

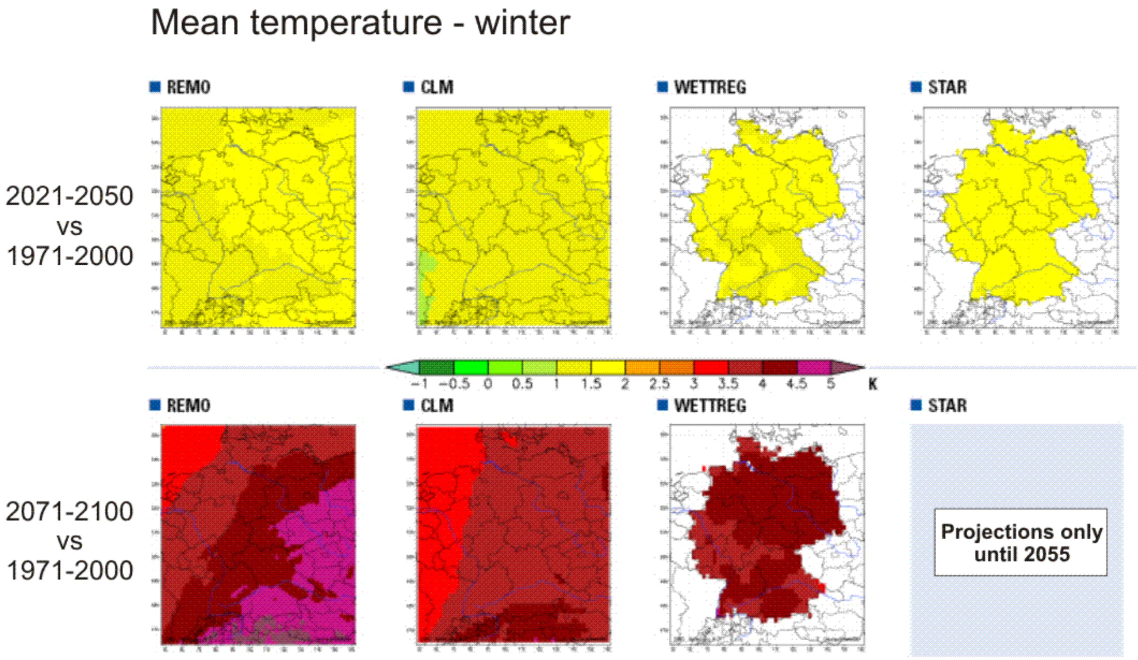

Figure 3: Differences in temperatures for the winter season between projections of 2071-2100 and 2021-2050 compared to 1971-2000 (on the basis of DWD).

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.

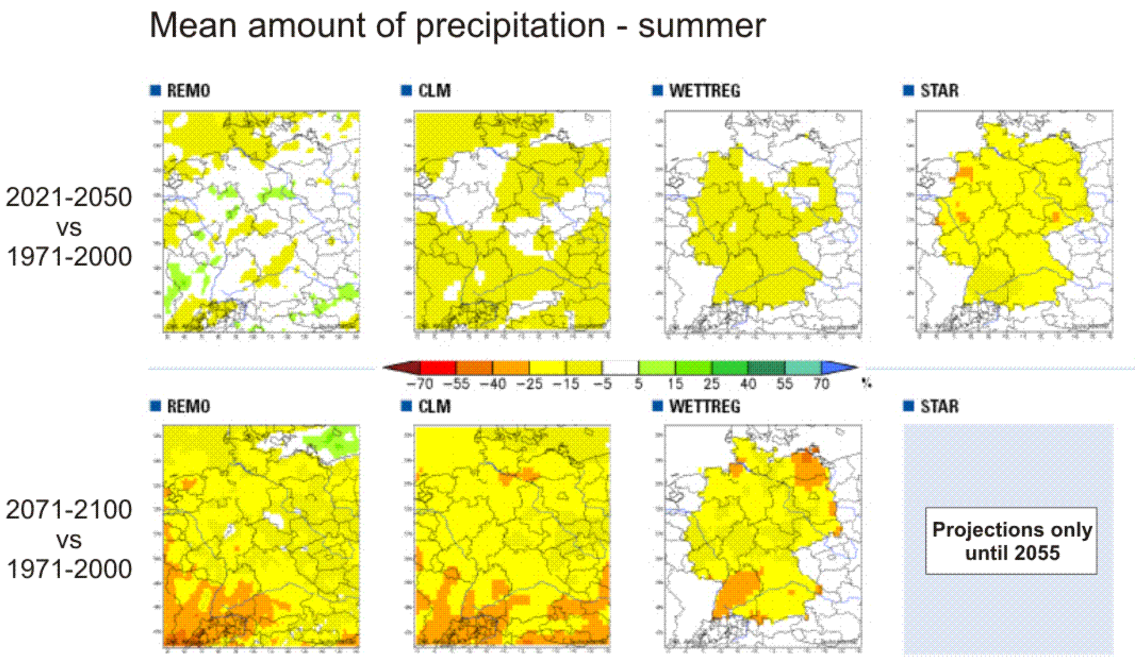

Figure 4: Differences in precipitation amount for the summer season between projections of 2071-2100 and 2021-2050 compared to 1971-2000 (on the basis of DWD).

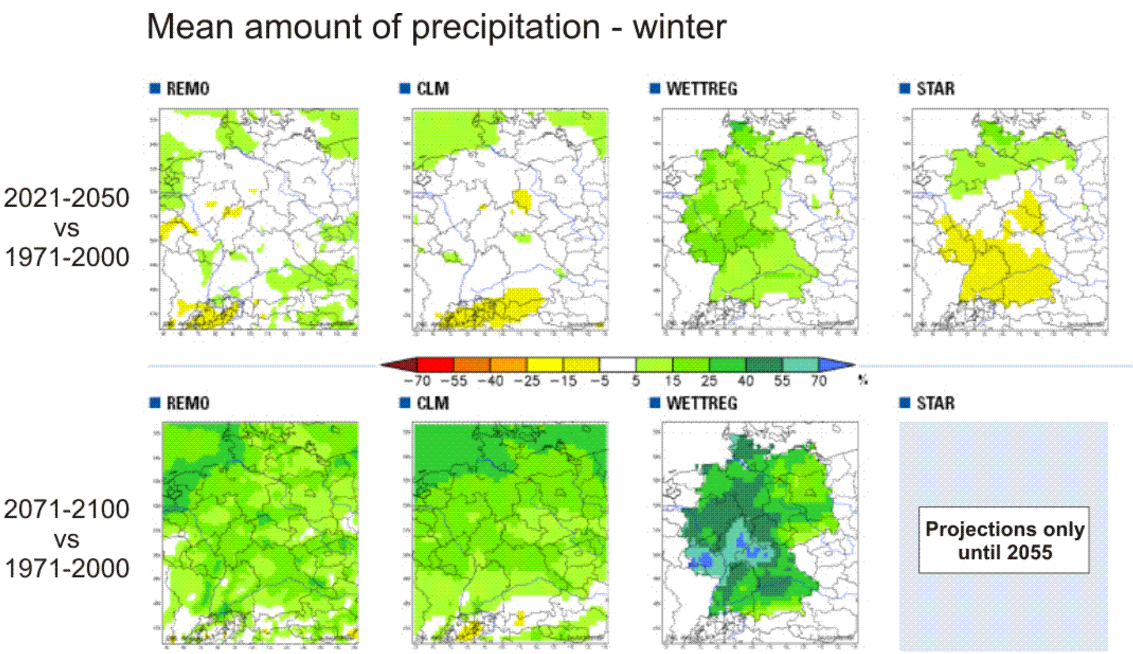

Figure 5: Differences in precipitation amount for the winter season between projections of 2071-2100 and 2021-2050 compared to 1971-2000 (on the basis of DWD).

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.

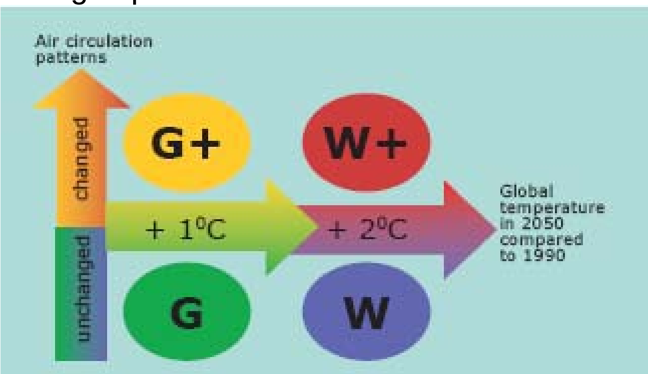

Figure 6. Schematic overview of the four KNMI ’06 climate scenarios (KNMI, 2009)

Table 4. Climate change in the Netherlands around 2050, compared 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.

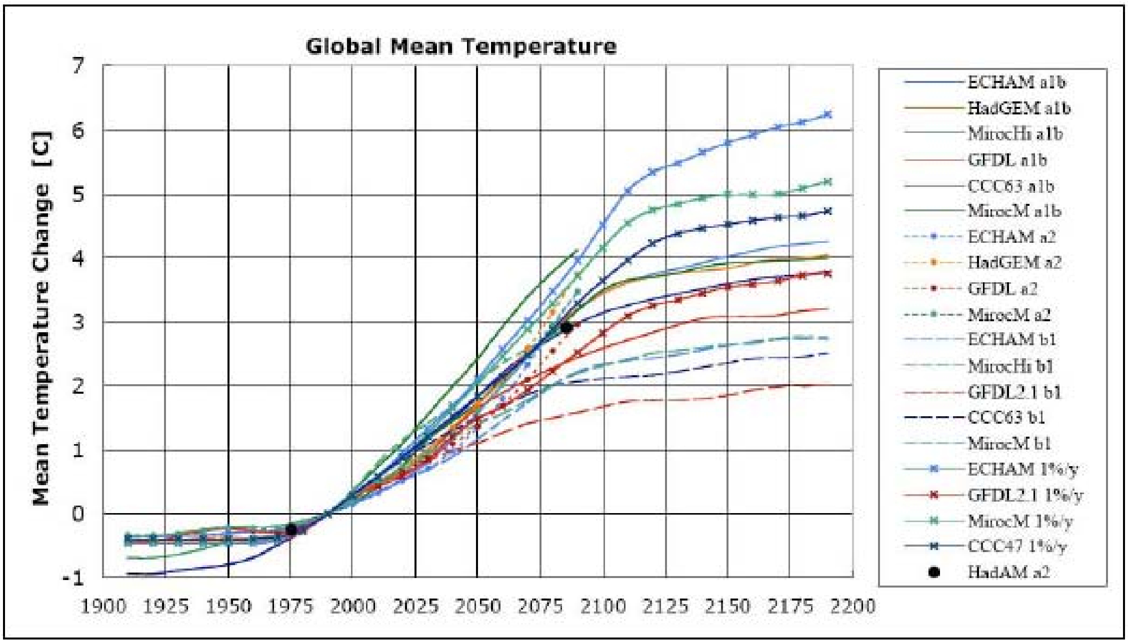

Figure 7. Time series of global mean temperature change for a wide range of GCM simulations, all driven by four different greenhouse gas emission scenarios (SRES B1, A1B, A2 and a scenario with 140 years of 1% CO2 increase per year)

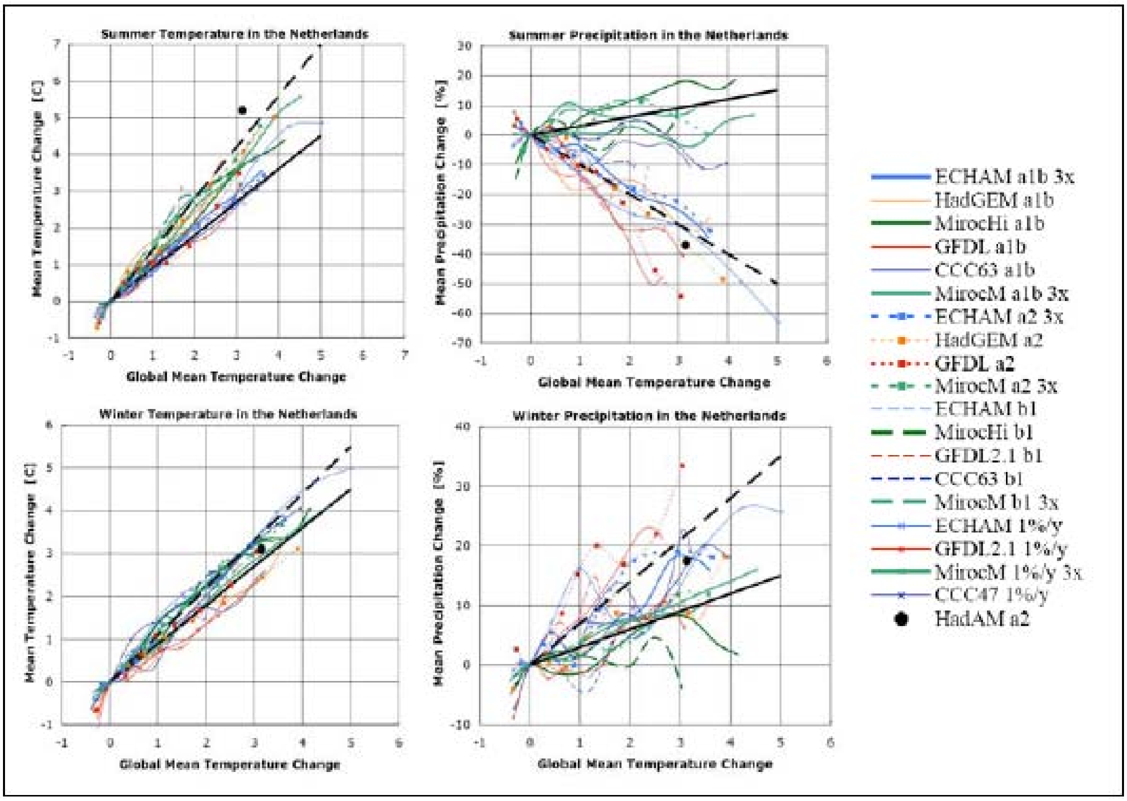

Figure 8. Projected change of seasonal mean temperature (left) and precipitation (right) for summer (top) and winter (bottom) in the Netherlands as function of global mean temperature rise, as simulated for the period 1990-2200. The black straight lines indicate fixed scaling relationships. The black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

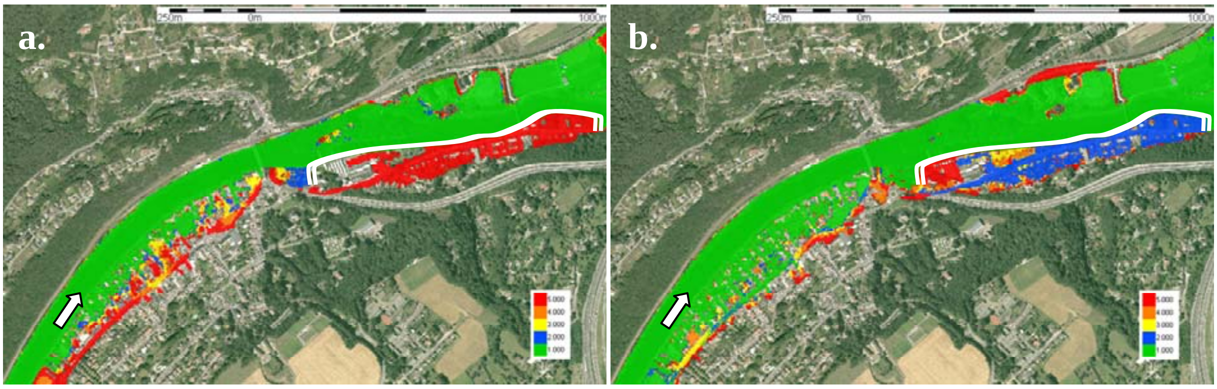

Figure 1: Comparison of flood extension for return periods 25 (a.) and 100 years (b) and the increases of 5, 10, 15 and 30% for the town of Tilff.

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 Figure 2 (a.) and Q100 + 30% (red zone on the Figure 2 (b.) for which there is an increase in the flooded area in comparison with the (Q25 and Q100) base scenario.

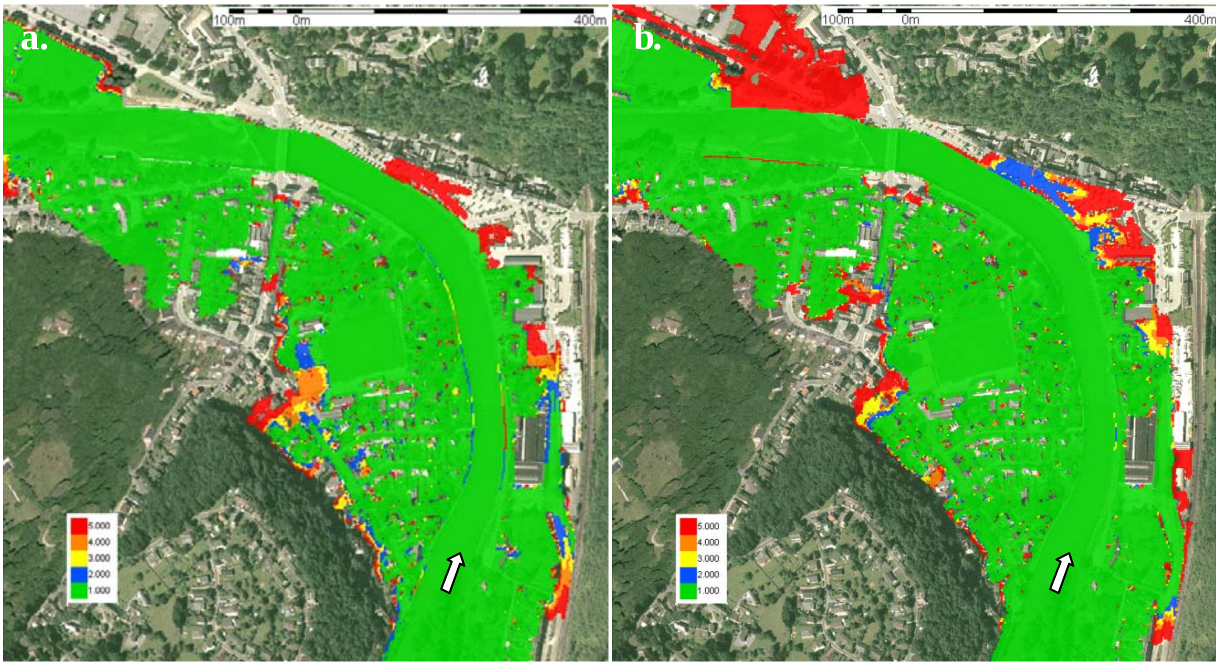

Figure 2 : Comparison of flood extension for return periods 25 (a.) and 100 years (b) and the increases of 5, 10, 15 and 30% for the town of Esneux.

Another way to express the hydraulic impact induced by increasing discharge is to represent the water depth difference between climate change scenarios and the current situation. The following pictures (Tilff: Figure 3 and Esneux: Figure 4) express the results by a classification of water heights differences 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.

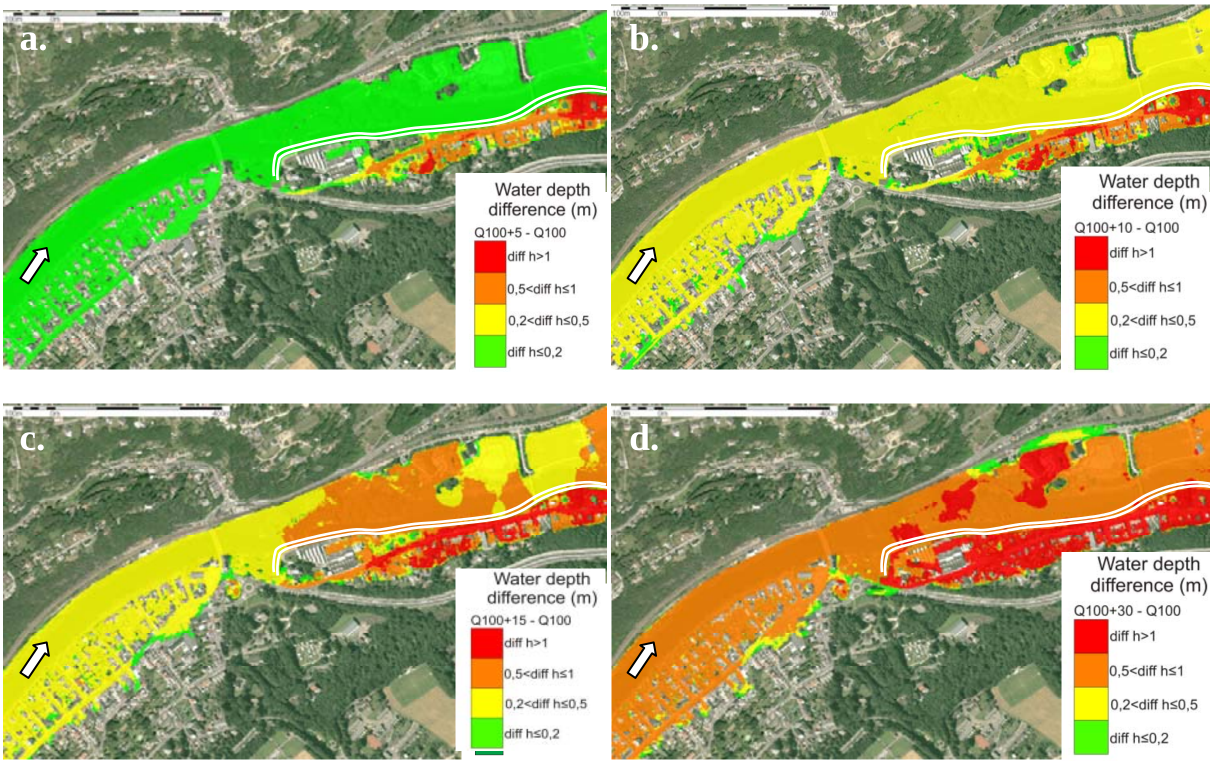

Figure 3: Water depth difference with respect to the current Q100 flood (without any climate change) in the town of Tilff. a. Q100+,5 b. Q100+10, c. Q100+15, d.Q100+30.

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.

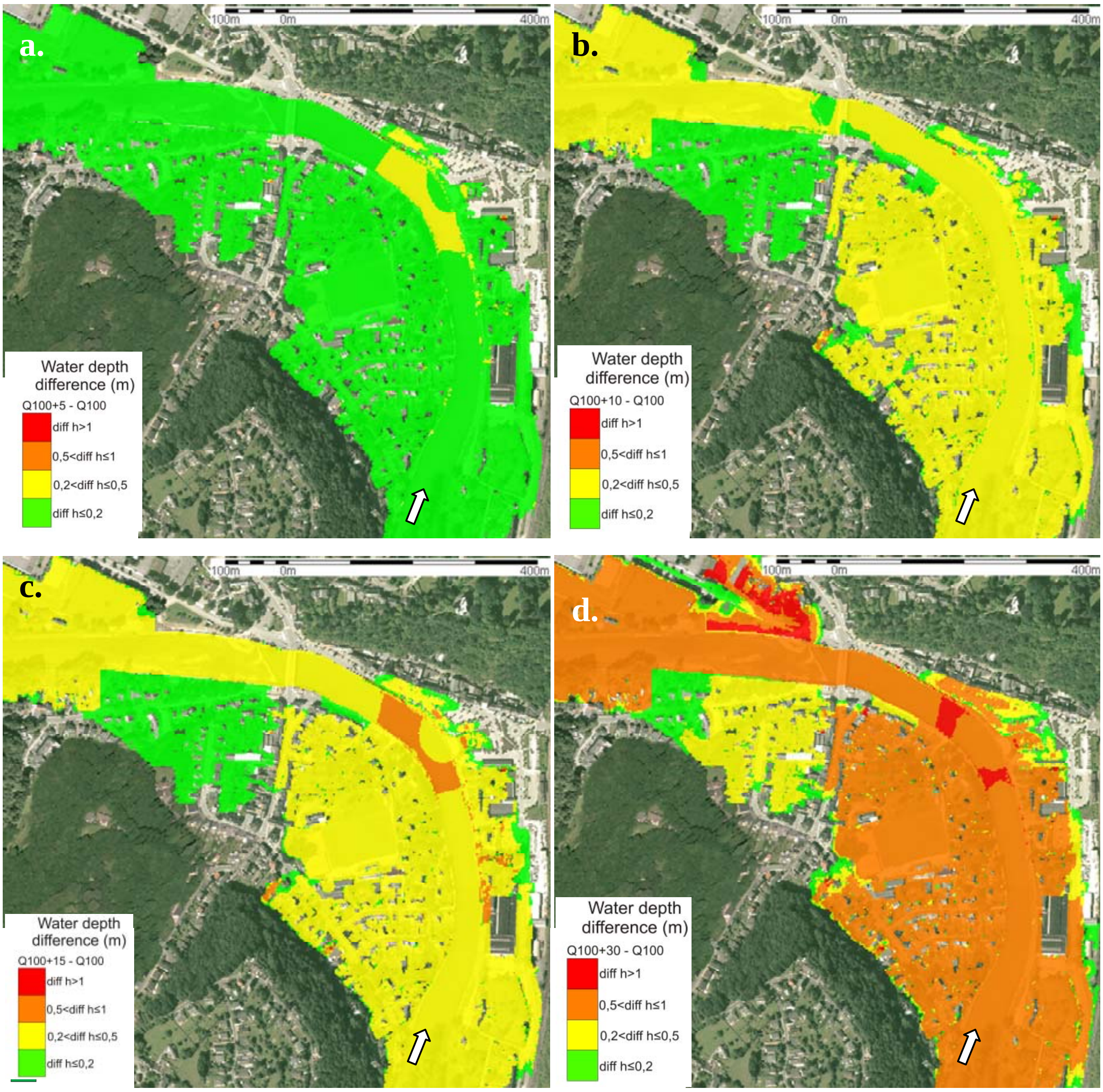

Figure 4: Water depth difference with respect to the current Q100 flood (without any climate change) in the town of Esneux. a. Q100+5, b. Q100+10, c. Q100+15, d.Q100+30

References

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[2] Commission Nationale Climat. Cinquième communication nationale de la Belgique à la Convention-Cadre des Nations Unies sur les Changements climatiques. 135, 2009.

[3] d'Ieteren, E., W. Hecq, R. D. Sutter and D. Leroy. Effets du changement 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 km^2.

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 five submodels that cover the area that is illustrated 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 consists of several hundred elements. At present no model for the area upstream of the reservoir Staubecken Obermaubach (see Figure 1) was available. Within subsequent action 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 calculations were carried out for gauge Stah, which is located just a few kilometers downstream 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 were handed over calibrated and validated. Concerning this no modifications were undertaken by the Academic and Research Department Engineering Hydrology. The calibration and validation had been carried out by the Water Board Eifel-Rur or subcontractors. The models for the Wurm and Rur were calibrated and validated for a time period of at least two years. This was done manually and not following automatic optimization algorithms. For the Inde the calibration and validation was carried out for single high-flow events. The time step for all models is 15 minutes. All models have in common that the calibration did not specifically account for low flow periods. Due to this is seemed to be questionable that the existing NASIM models would be able to carry out low flow simulations with sufficient accuracy.

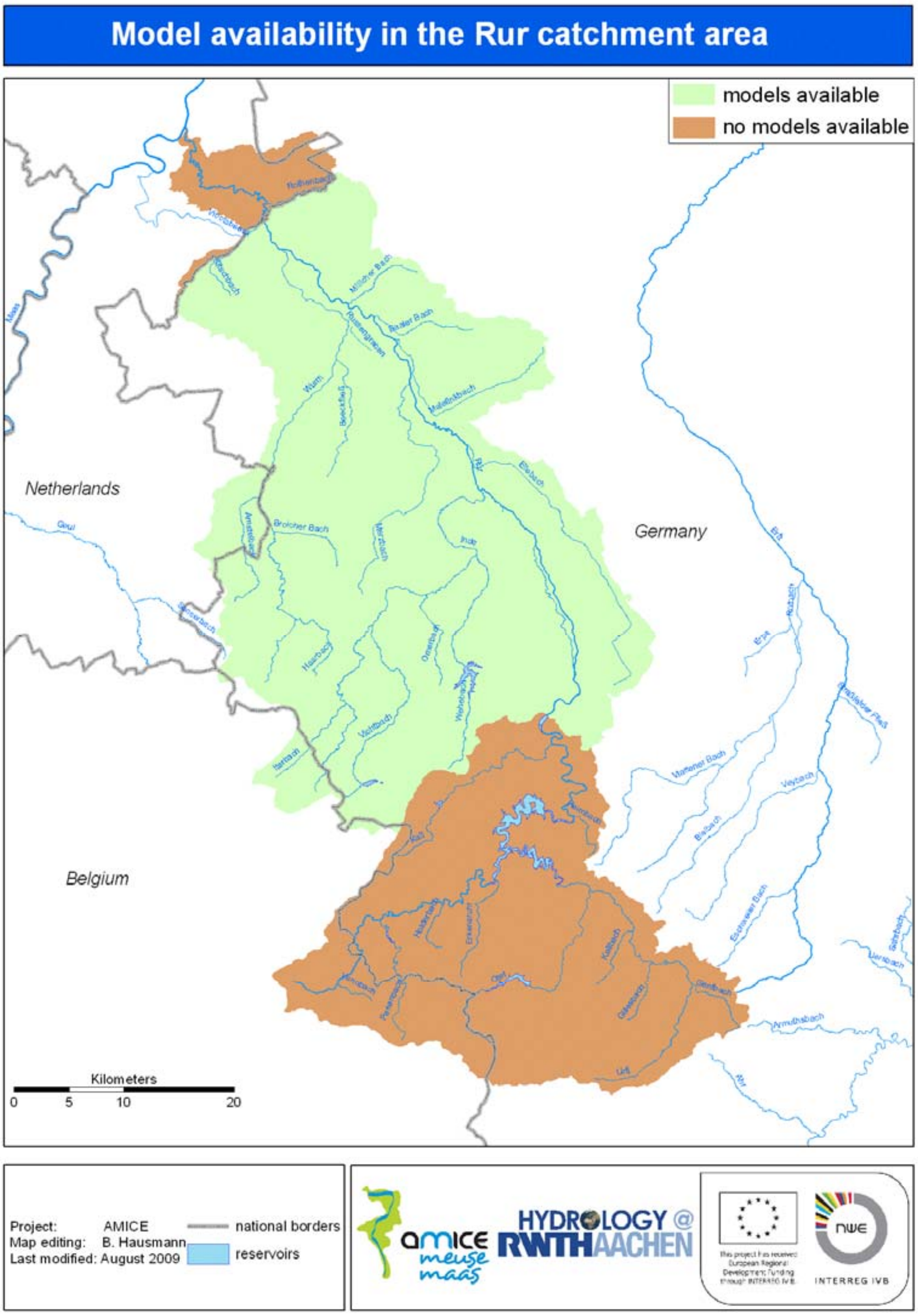


Figure 1: Model availability in the Rur catchment area

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 m³ inside the reservoir. The thrush discharge was assumed to be between 0,1 m³/s and 5,0 m³/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 m³. 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.

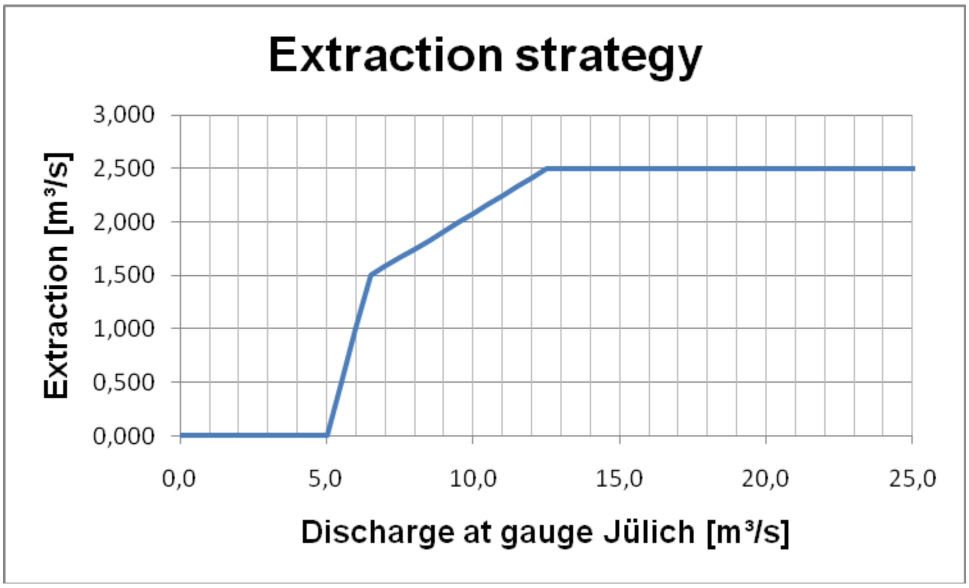


Figure 2: Extraction strategy for the filling of the lake in the mining area “Inden”

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).

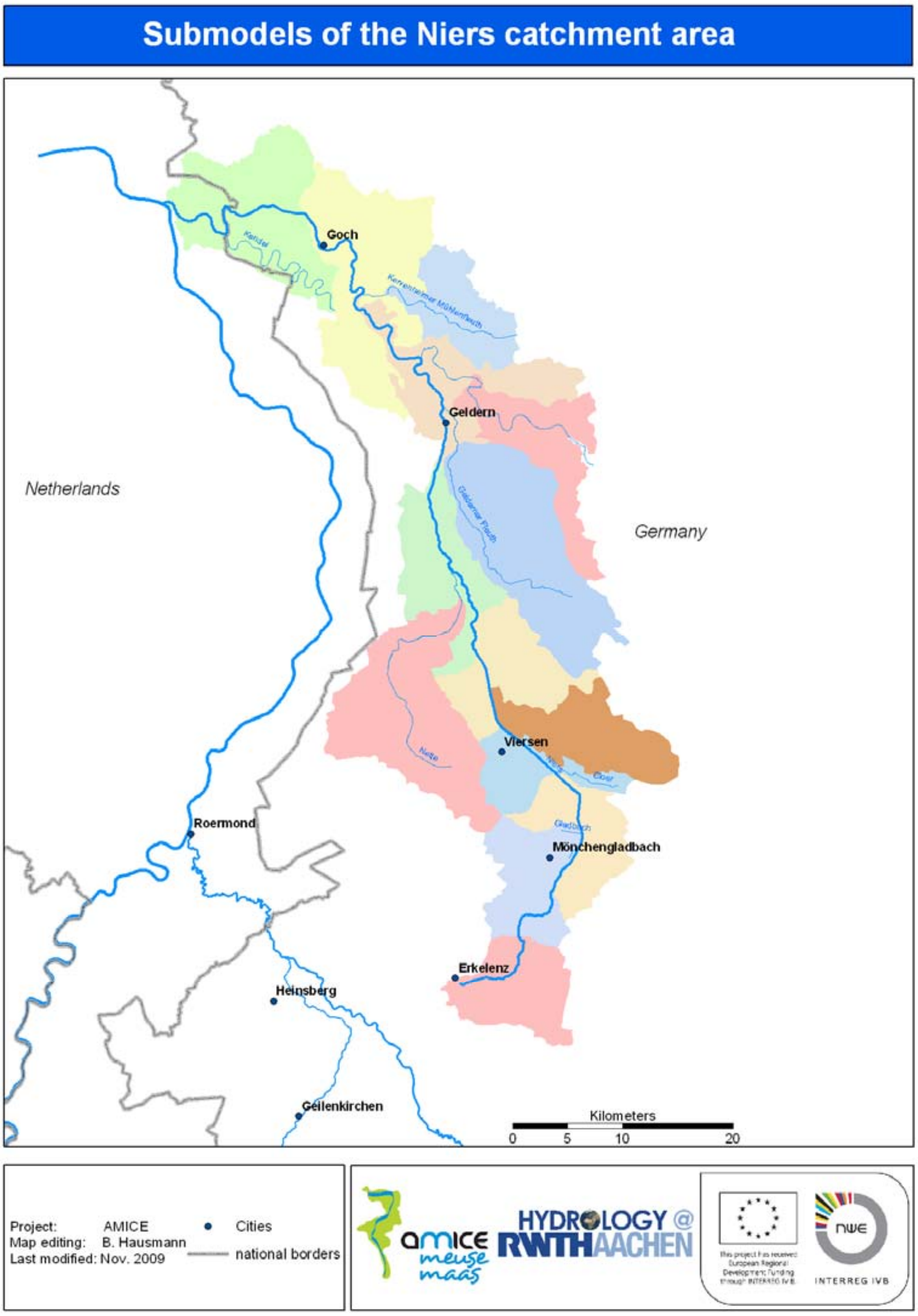


Figure 3: Overview over the submodels in the Niers catchment area

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

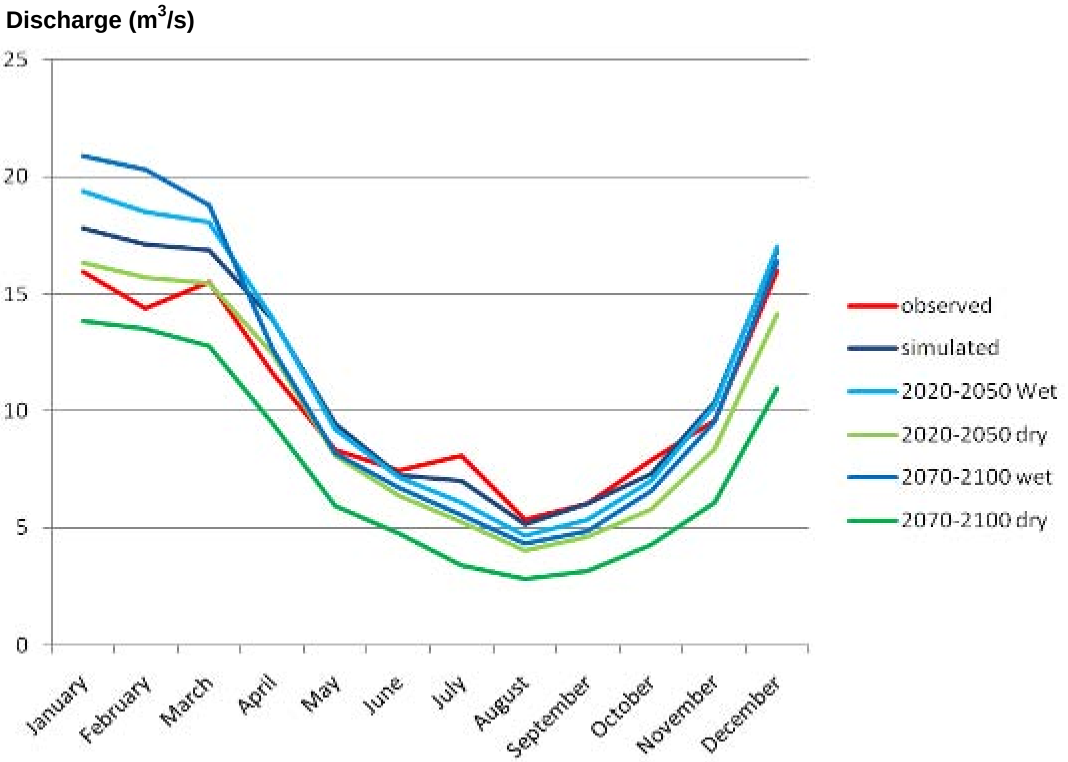


Figure 1: Evolution of mean monthly discharge during a year for the Vesdre at Chaudfontaine for the different scenarios and time slices

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 scenario 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

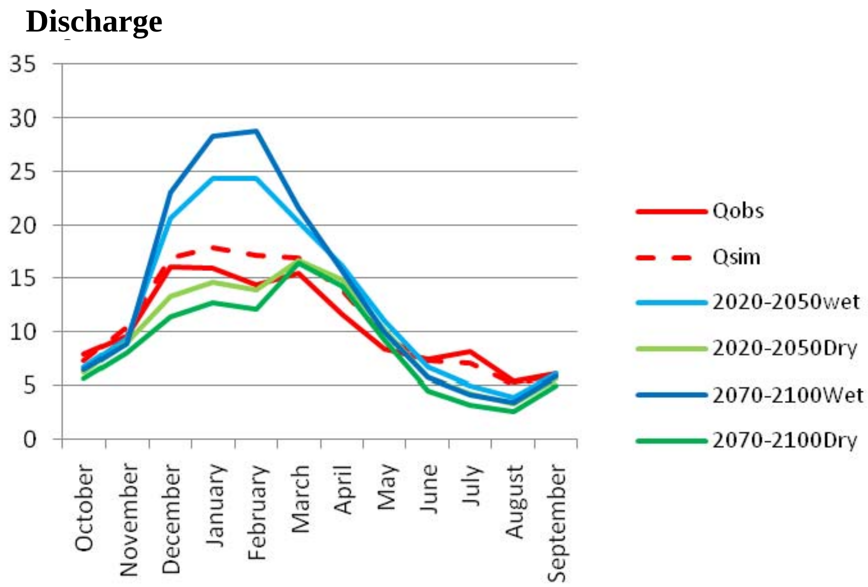


Figure 2 : Evolution of mean monthly flows during a year for the Vesdre at Chaudfontaine (National scenario).

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 monthly discharge for the Vesdre at Chaudfontaine for the two time slices (2021-2050 & 2071-2100) and the two scenarios (wet & dry)

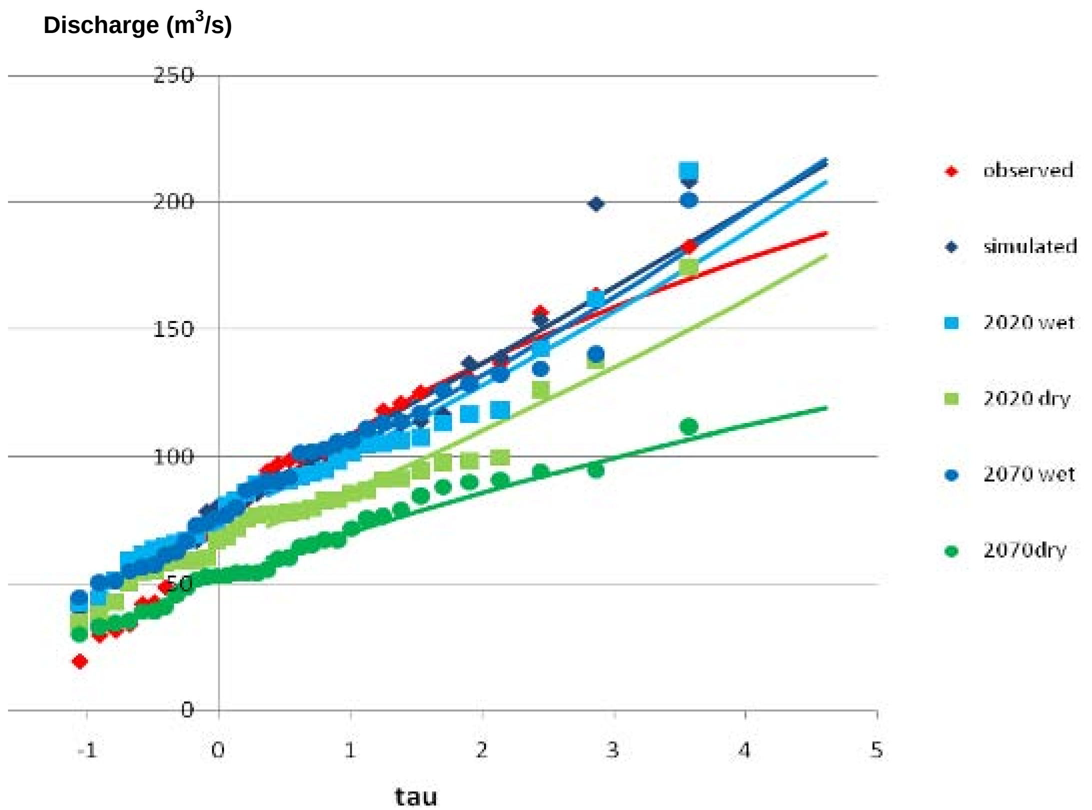
Maximum daily discharge

Transnational scenario

Concerning the Vesdre 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 with the study of Dautrebande et al. (2006). In the case of scenarios 2020-2050 wet and dry and 2070-2100 wet, the best fit is the 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.

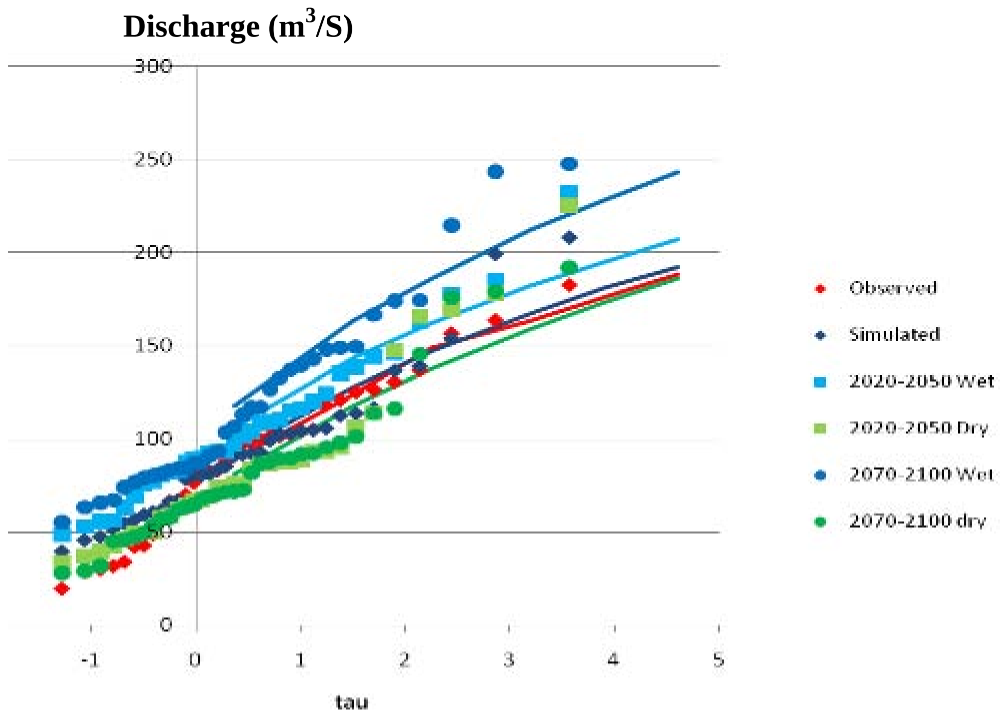


Figure 4: Maximum daily discharges for the Vesdre at Chaudfontaine (National scenario).

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 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 +26% (wet 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 discharges 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% (wet 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 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	1.18	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 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
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%) 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[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 Vesdre at Chaudfontaine for the 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 mean monthly discharge for the Lesse at Gendron for the different scenarios and time slices.

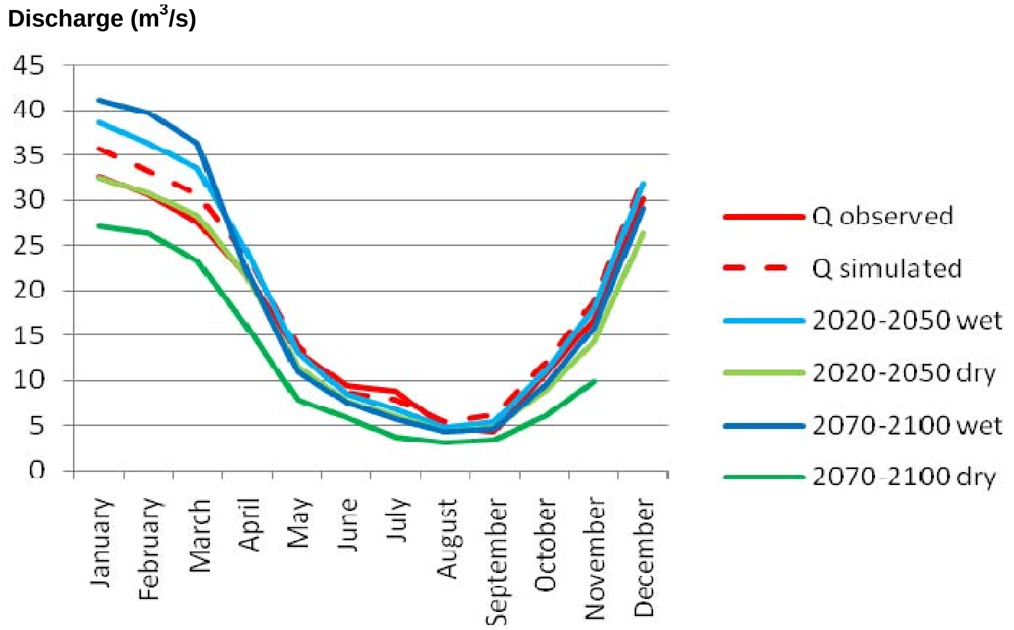


Figure 5: Evolution of mean monthly discharge during a year for the Lesse.

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 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. 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 mean monthly discharges for the Lesse at Gendron for the two time slices (2021-2050 & 2071-2100) and the two scenarios (wet & dry)

National scenario

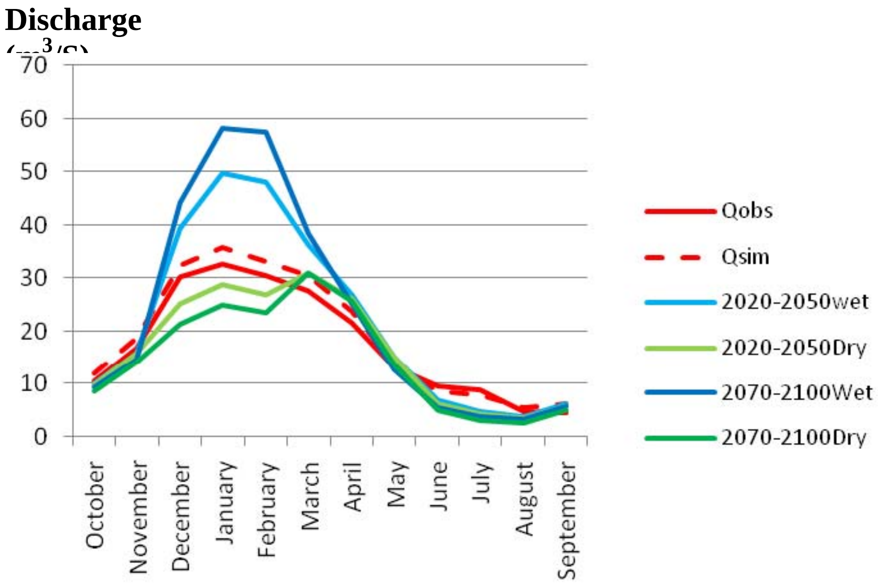


Figure 7: Mean monthly discharges (m3/s) for the Lesse at Gendron for the two time slices (2021-2050 & 2071-2100) and the two scenarios (wet & dry)

For the end of the century a decrease in the mean monthly 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 (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 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 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 mean monthly discharges for the Lesse at Gendron for the two time slices (2021-2050 & 2071-2100) and the two scenarios (wet & dry)

Maximum daily discharge

Transnational scenario

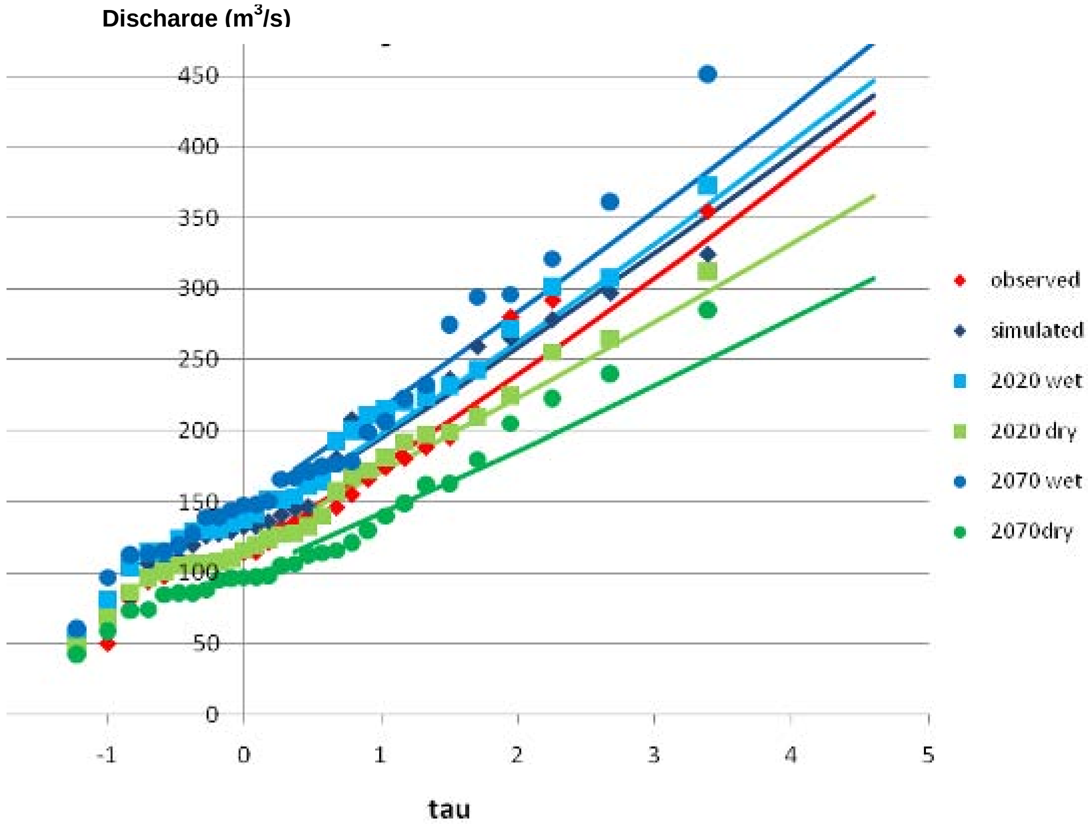


Figure 18: Maximum daily discharges for the Lesse.

Concerning the Lesse maximum daily discharge, the lognormal 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 discharges 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 maximum discharge for a recurrence interval of 100 years are between +8,5% (wet scenario for 2071-2100, daily time step, using EPIC-Grid) and -30% (dry scenario for 2071-2100, daily time step, using EPIC-Grid).

National scenario

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

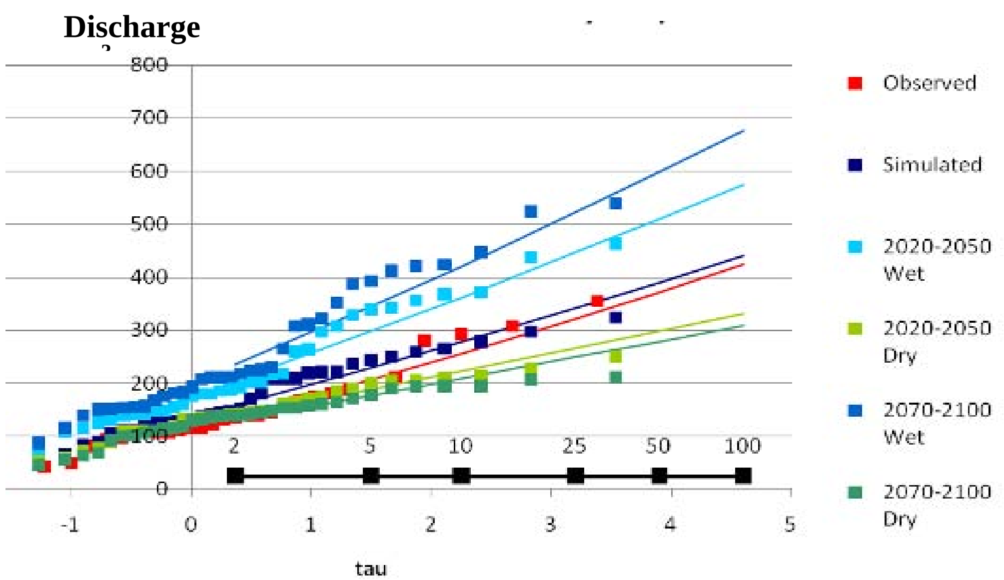


Figure 19: maximum daily discharge for the Lesse (National scenario).

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, using 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 adjustment law to the sets of data is the lognormal one.
The predicted changes in maximum 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 distribution for the observed data and in the other cases is the gamma distribution.
The predicted changes in maximum hourly discharge for a recurrence interval of 100 years are between +84% (wet 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 discharges 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 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	0.21-0.643	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 two 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 two 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 for 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)

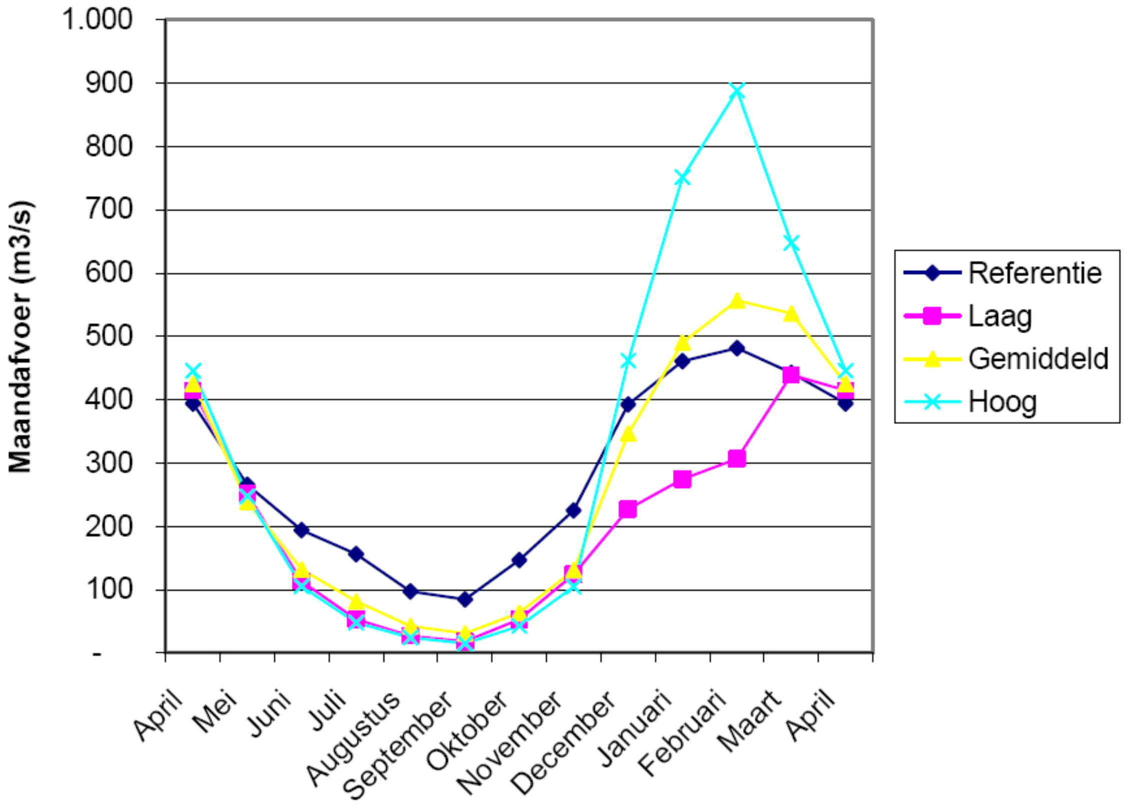


Figure 20: Monthly average discharge for control run (referentie) and scenarios

Analysis

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).

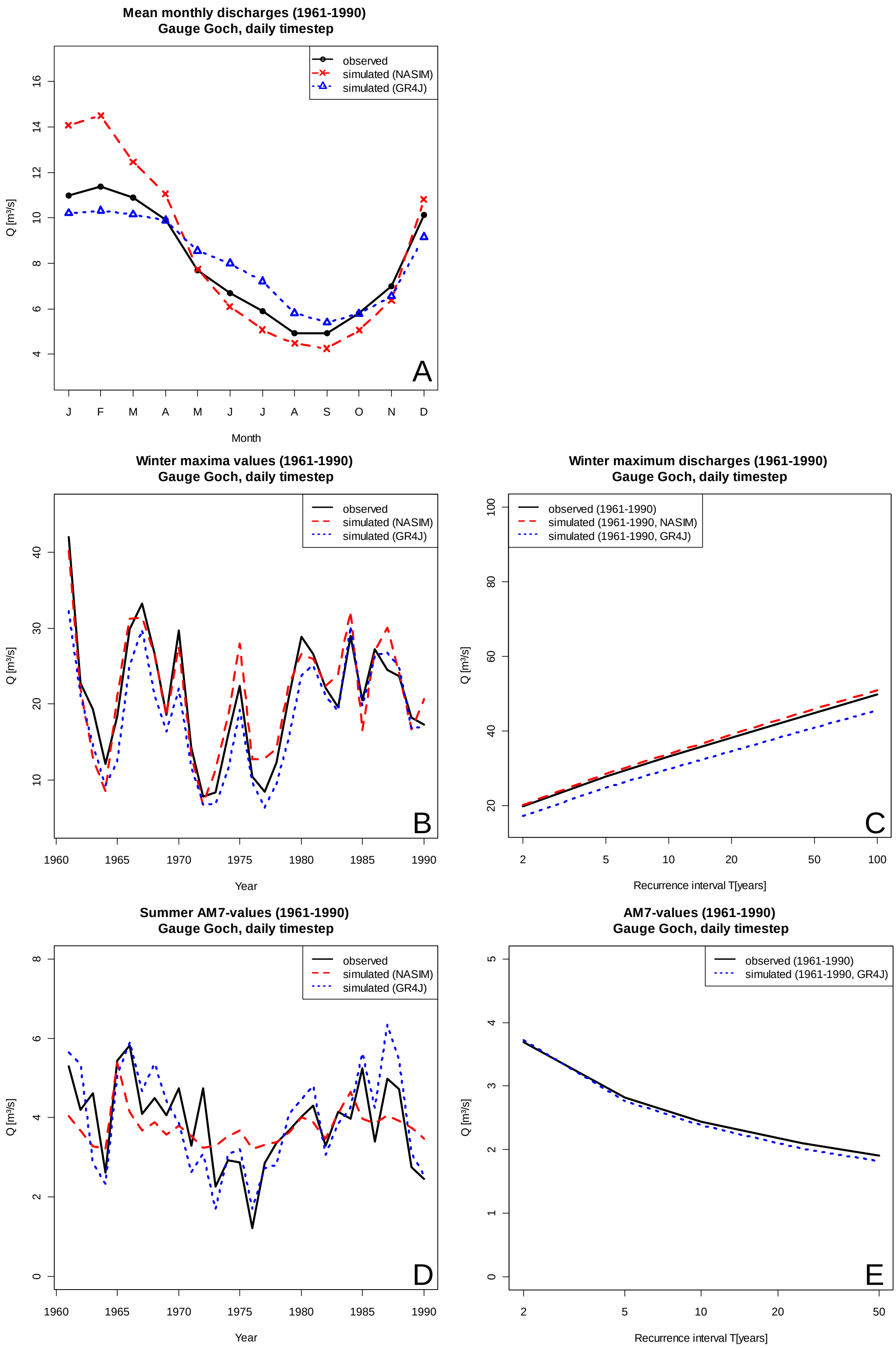


Figure 21: Adaptation quality of simulations with daily time step for gauge Goch (Niers)

National scenarios

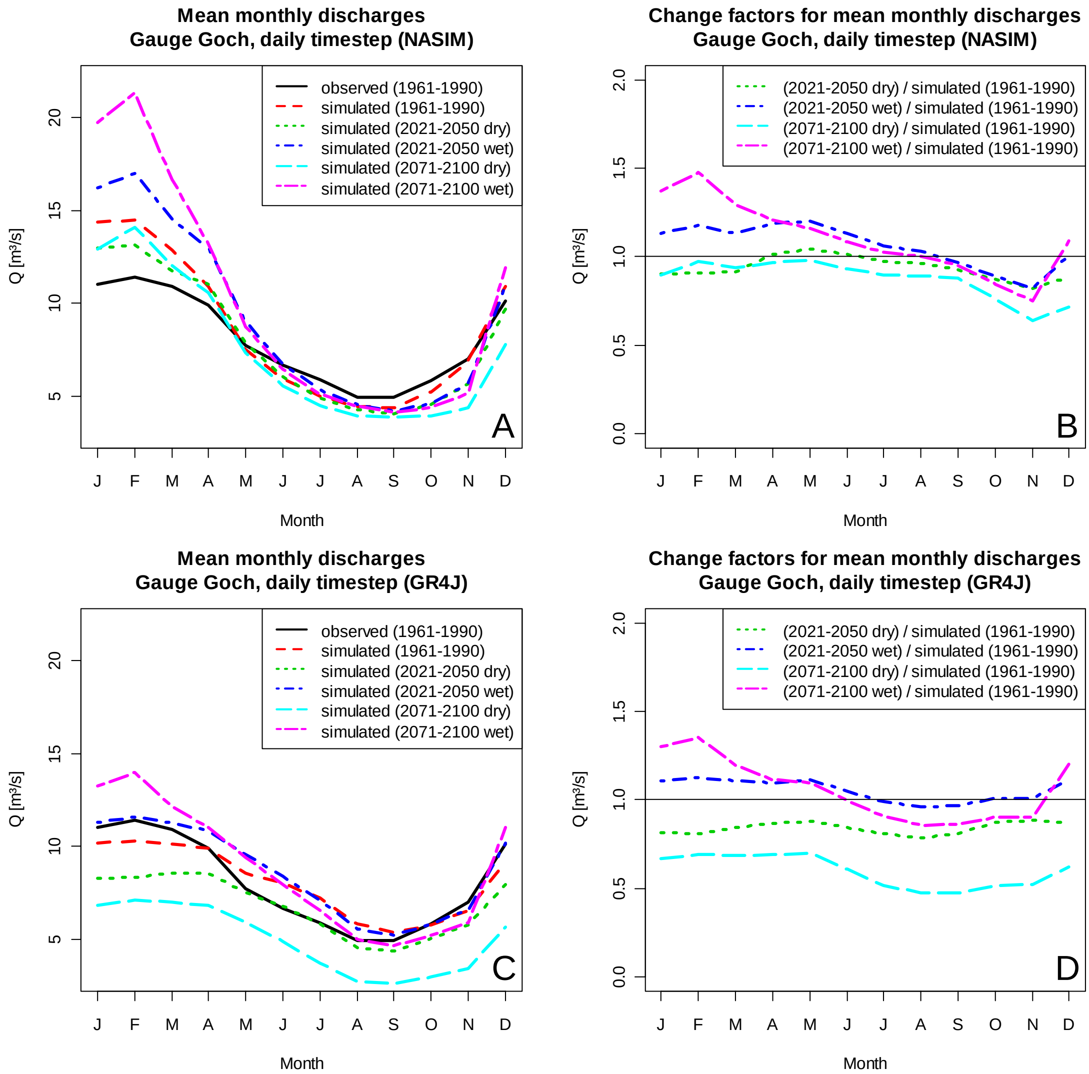


Figure 22: Predicted mean monthly discharges and change factors for gauge Goch (Niers) for a time step of 1 day, national scenarios

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 are shown. Compared to the NASIM results for both, the absolute and relative changes, the predicted increases are weaker and the predicted decreases are higher. The highest increase is at about 35% predicted for February for the wet scenario for 2071-2100. It is striking that for the dry scenario for 2071-2100 an all the year decrease 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.

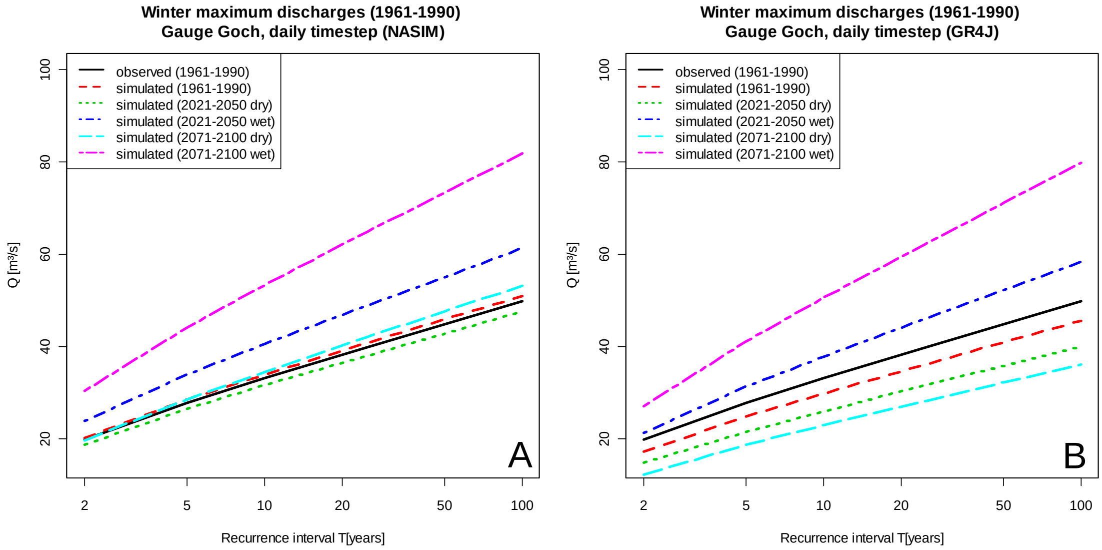


Figure 23: Winter maximum discharges for different recurrence intervals for gauge Goch (Niers), national scenarios

In Figure 23 winter maximum discharges for different recurrence intervals are shown (left side: NASIM, right side: GR4J). As mentioned above, NASIM reproduces the discharge behavior for different recurrence intervals better than GR4J. Concerning the wet scenarios the results do not differ much between both models. For the dry scenarios NASIM predicts higher discharges. 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 different to the results from GR4J. The GR4J model predicts for both, the dry and wet scenarios, a monotonic increase respectively decrease until the end of the century.

In Figure 24 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. 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.

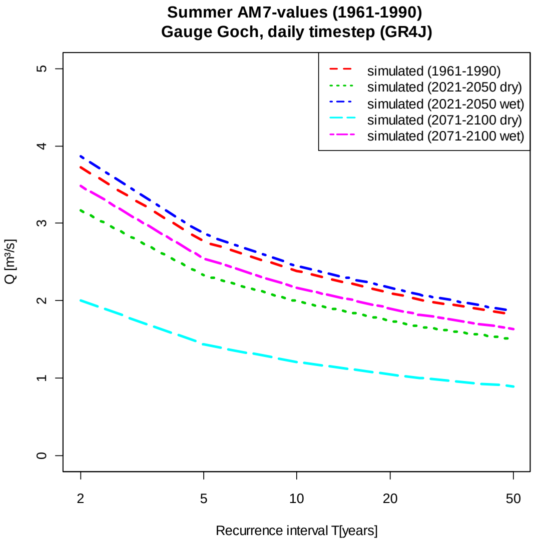


Figure 24 : Predicted summer AM7-values for different recurrence intervals (GR4J) for gauge Goch (Niers), national scenarios

Transnational scenarios

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.

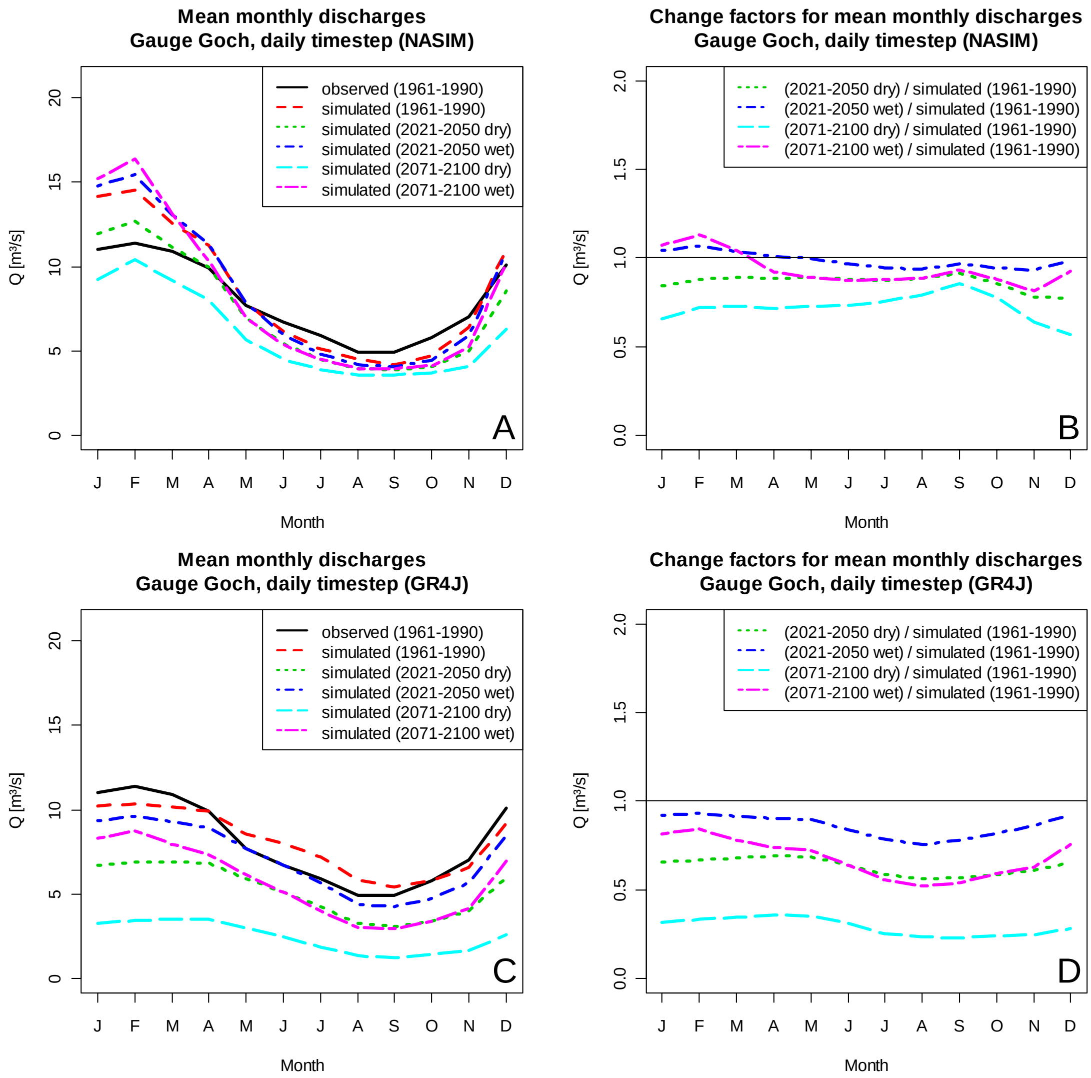


Figure 25: Predicted mean monthly discharges and change factors for gauge Goch (Niers) for a time step of 1 day, transnational scenarios

In Figure 26 winter maximum discharges for different recurrence intervals are shown. NASIM predicts higher winter maximum discharges for both scenarios and for both future time slices than GR4J. In contradiction to GR4J NASIM predicts a further increase until the end of the century for the 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 the predicted changes is between +19% (NASIM, wet scenario for 2071-2100) and -64% (GR4J, dry scenario for 2071-2100).

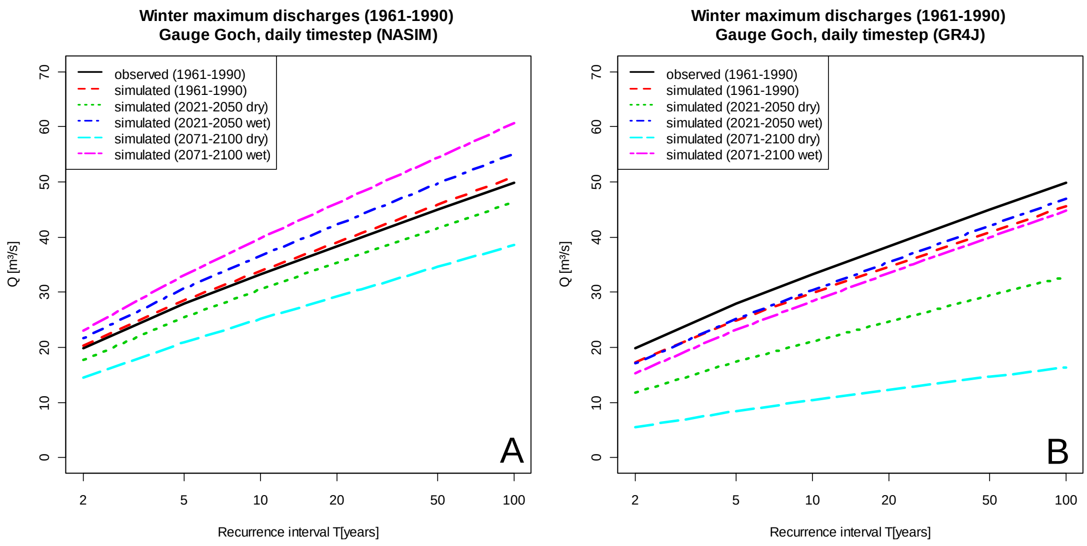


Figure 26: Winter maximum discharges for different recurrence intervals for gauge Goch (Niers), transnational scenarios

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).

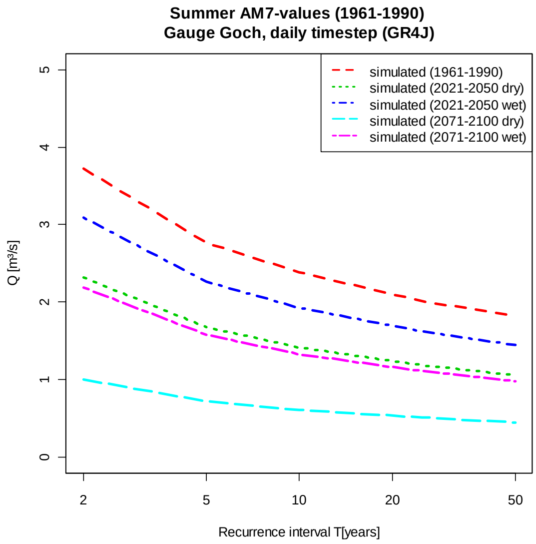


Figure 27: Predicted summer AM7-values for different recurrence intervals (GR4J) for gauge Goch (Niers), transnational scenarios

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.

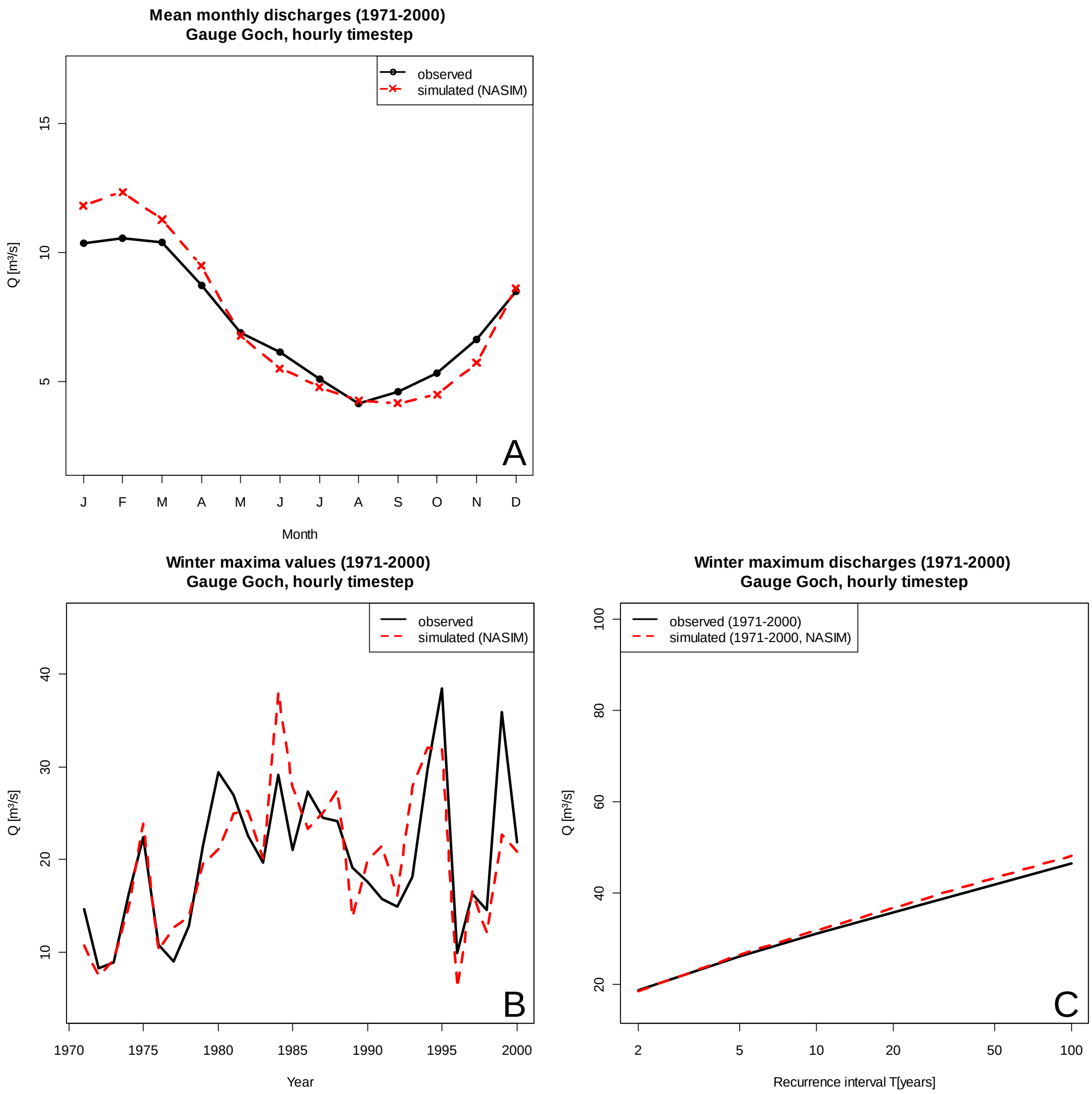


Figure 28: Adaptation quality of simulations with hourly time step for gauge Goch (Niers) using NASIM

National scenarios

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.

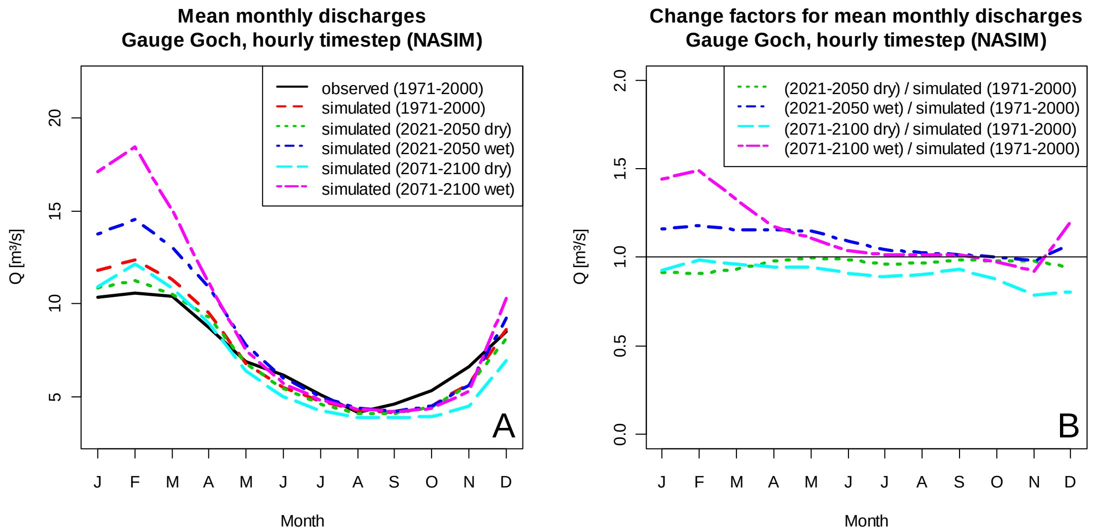


Figure 29: Predicted mean monthly discharges and change factors for gauge Goch (Niers) for a time step of 1 hour using NASIM, national scenarios

	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%.

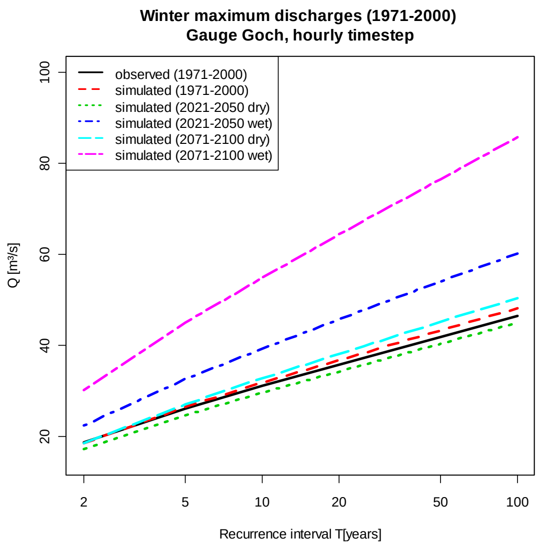


Figure 30: Winter maximum discharges for gauge Goch (Niers) for different recurrence intervals for a time step of 1 hour using NASIM, national scenarios

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.

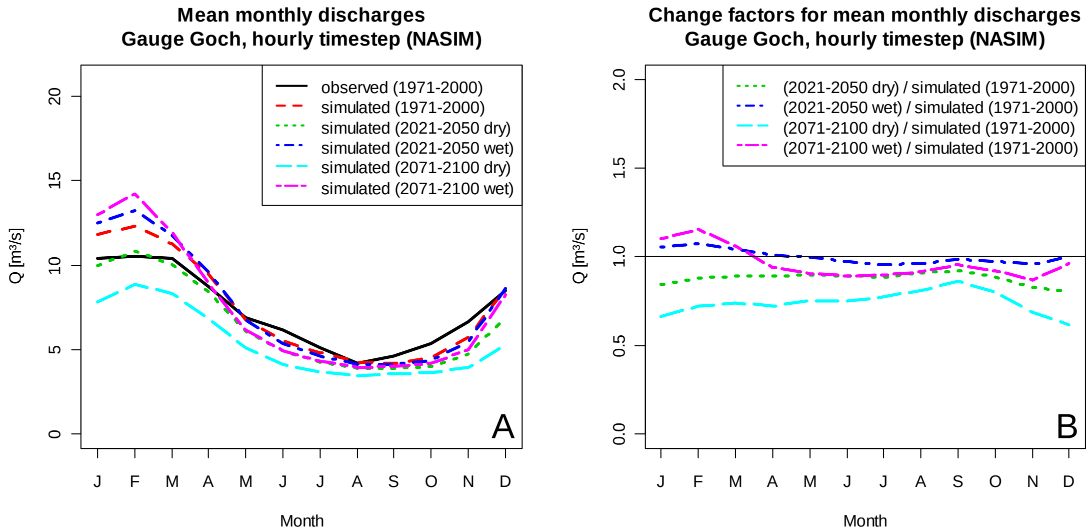


Figure 31: Predicted mean monthly discharges and change factors for gauge Goch (Niers) for a time step of 1 hour using NASIM, transnational scenarios

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).

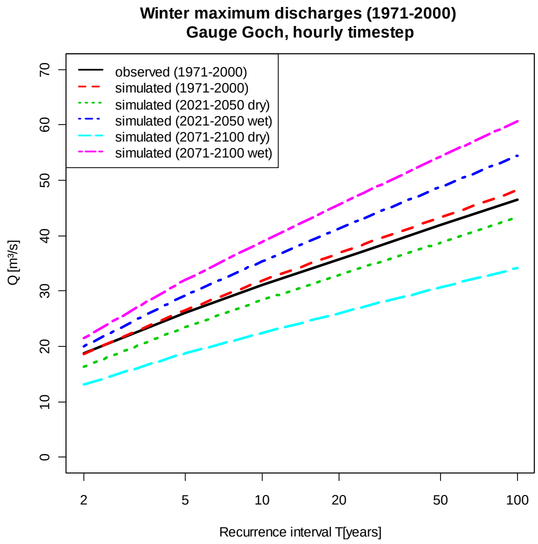


Figure 32: Winter maximum discharges for gauge Goch (Niers) for different recurrence intervals for a time step of 1 hour using NASIM, transnational scenarios

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 intervals (maximum likelihood fitting of the Lognormal distribution) and underestimated for larger recurrence intervals. The larger the recurrence intervals gets, the larger the deviation becomes.

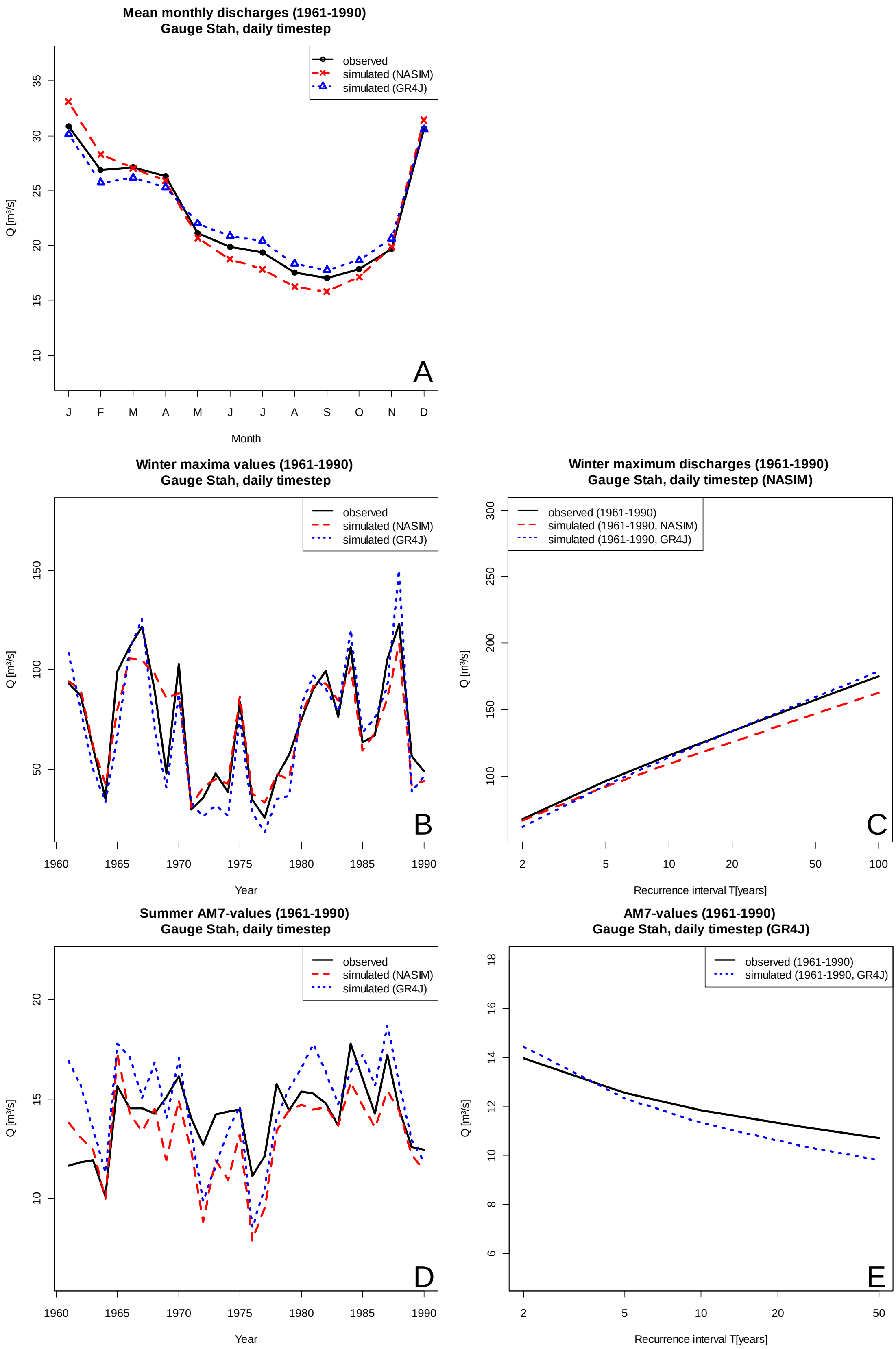


Figure 33: Adaptation quality of simulations with daily time step for gauge Stah (Rur)

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 m^3/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.

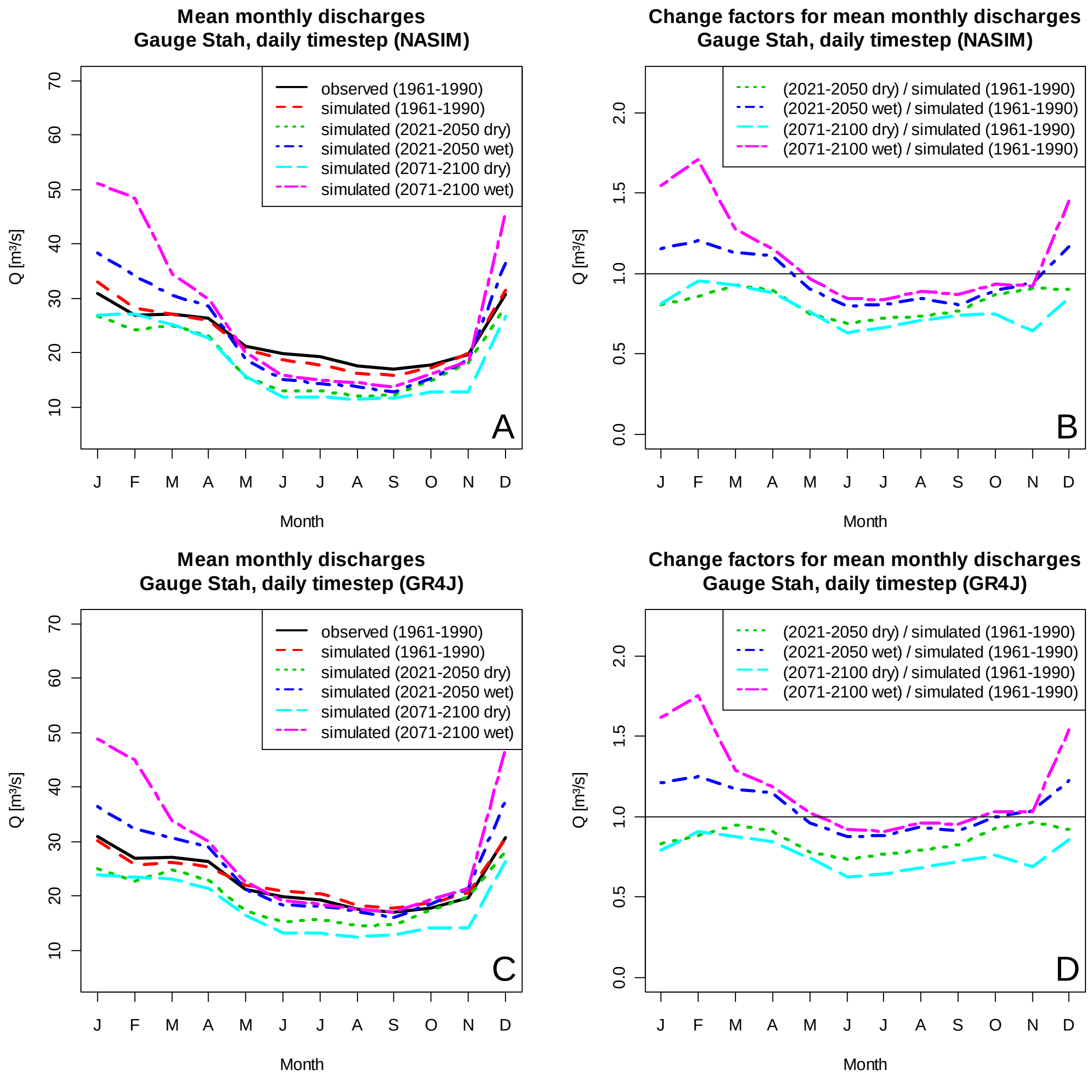


Figure 34: Predicted mean monthly discharges and change factors for gauge Stah (Rur), national scenarios

	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 observed mean discharges [m³/s] for gauge Stah (Rur) for the daily time step, national scenarios

In Figure 35 winter maximum discharges for different recurrence intervals 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 principle one would have to adjust 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.

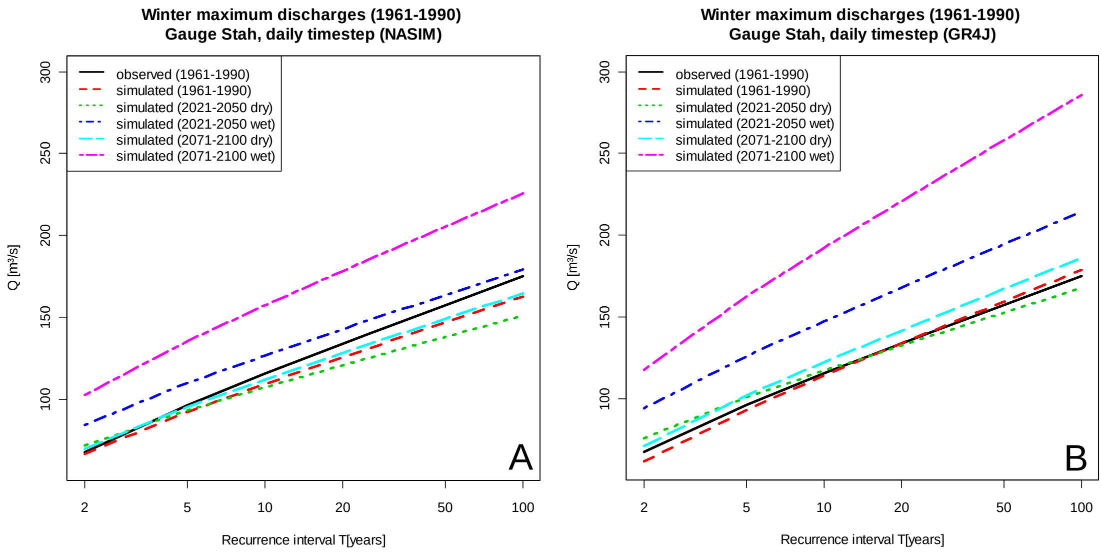


Figure 35: Winter maximum discharges for different recurrence intervals for gauge Stah (Rur), national scenarios

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%.

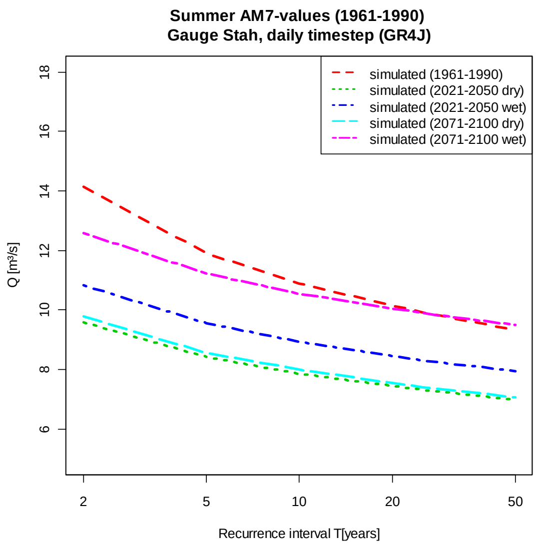


Figure 36: Predicted summer AM7-values for different recurrence intervals (GR4J) for gauge Stah (Rur), national scenarios

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.

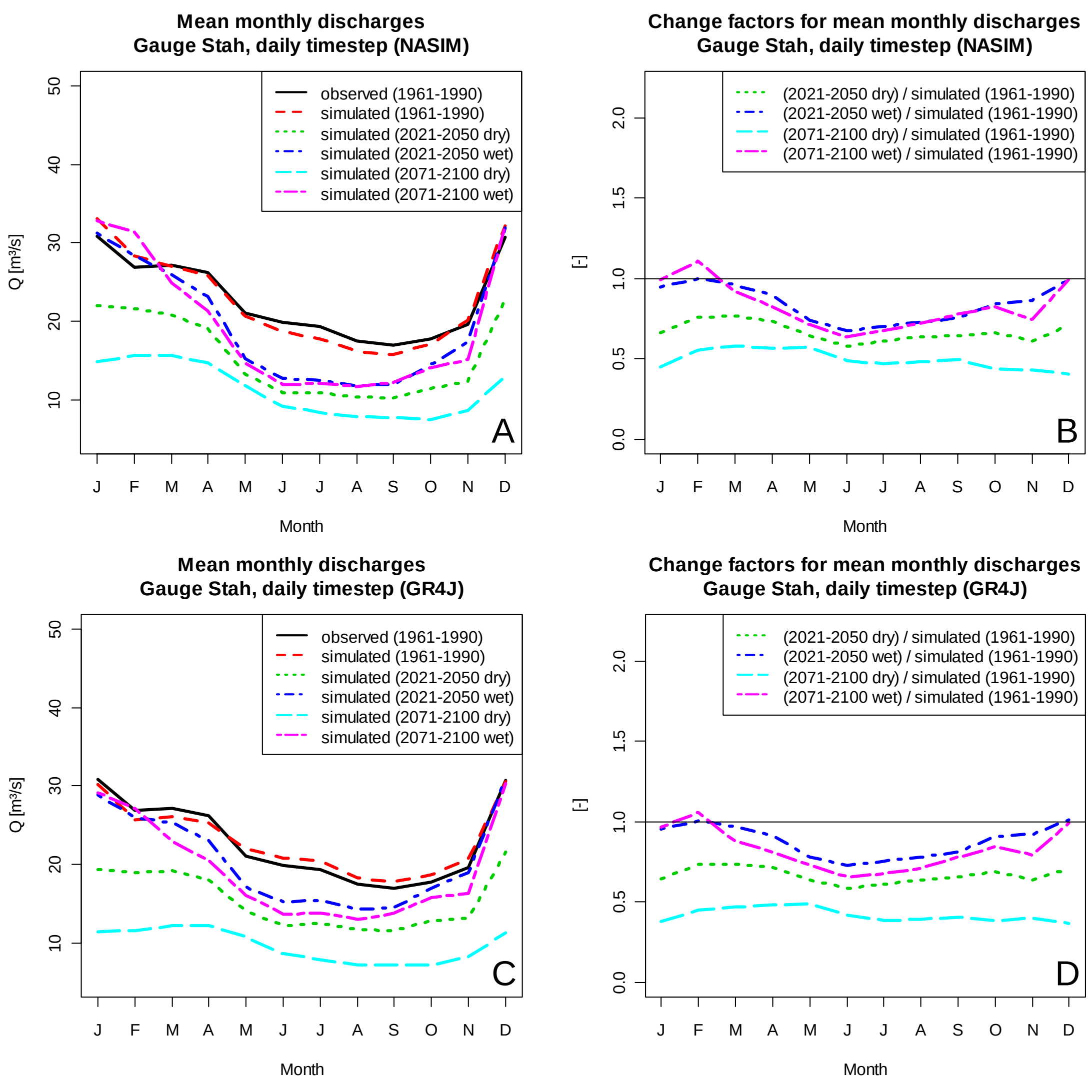


Figure 37: Predicted mean monthly discharges and change factors for gauge Stah (Rur), transnational scenarios

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).

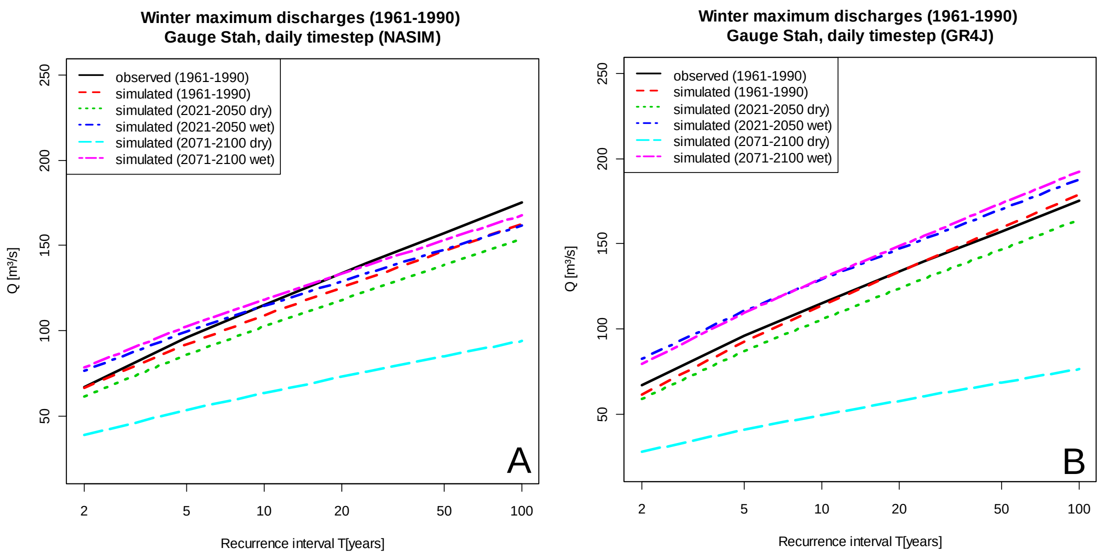


Figure 38: Winter maximum discharges for different recurrence intervals for gauge Stah (Rur), transnational scenarios

In Figure 39 summer AM7 discharges for different recurrence intervals are shown. The impact of the withdrawal of water is much bigger than for the winter maximum discharges. As for the national scenarios we have taken for all simulations 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 predicted. For a recurrence interval of 50 years the decreases are between -20% (wet scenario for 2071-2100) and -91% (dry scenario for 2071-2100).

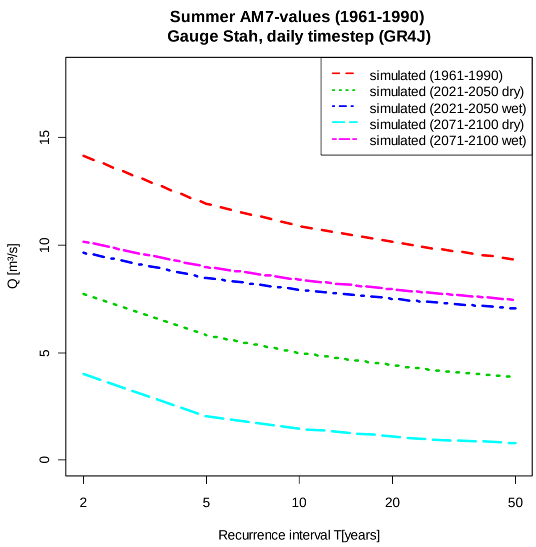


Figure 39: Predicted summer AM7-values for different recurrence intervals (GR4J) for gauge Stah (Rur), transnational scenarios

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.

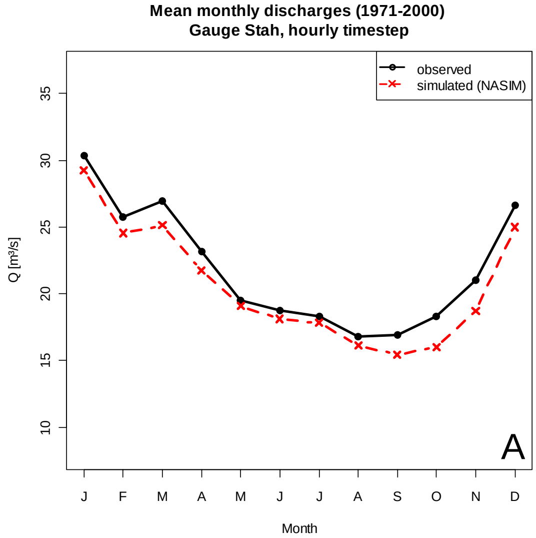
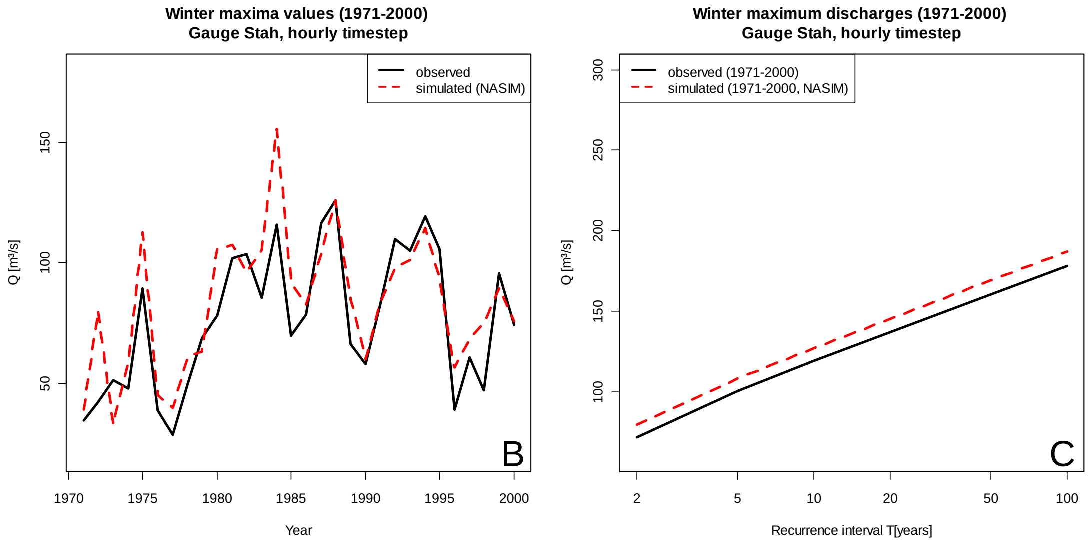


Figure 40: Adaptation quality of simulations with hourly time step for gauge Stah (Rur) using NASIM



National scenarios

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.

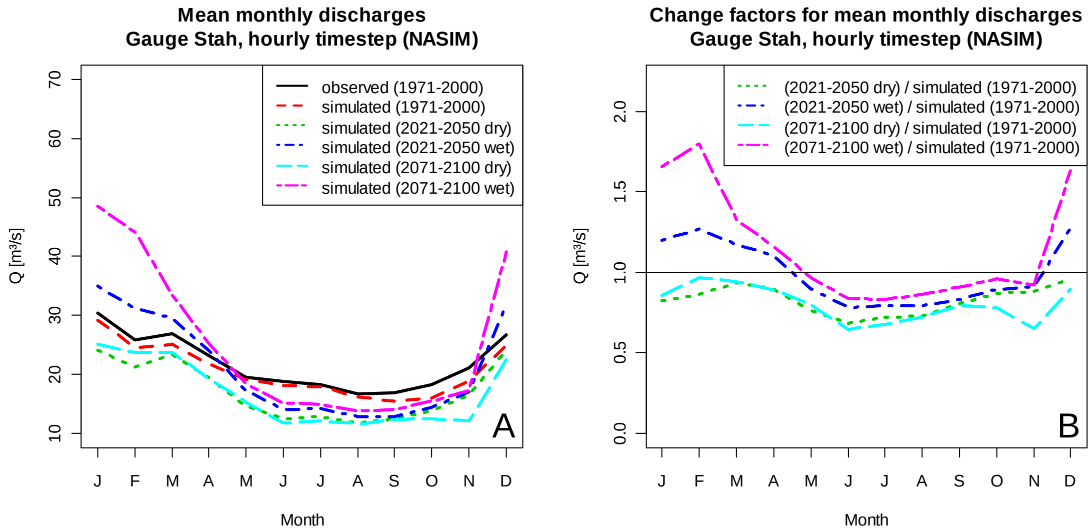


Figure 41: Predicted mean monthly discharges and change factors for gauge Stah (Rur) for a time step of 1 hour using NASIM, national scenarios

	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).

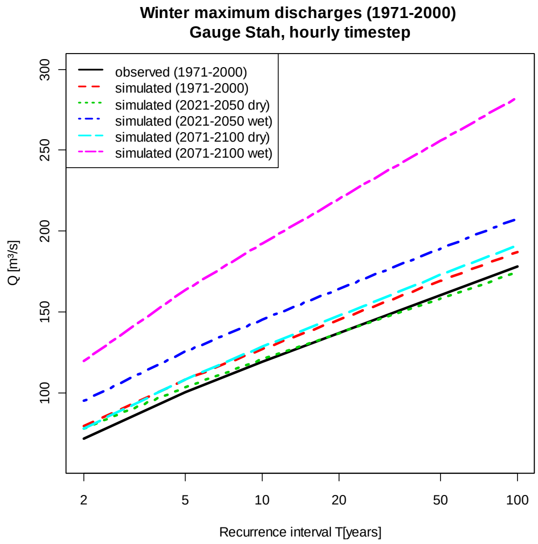


Figure 42: Winter maximum discharges for gauge Stah (Rur) for different recurrence intervals for a time step of 1 hour using NASIM, national scenarios

Transnational scenarios

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.

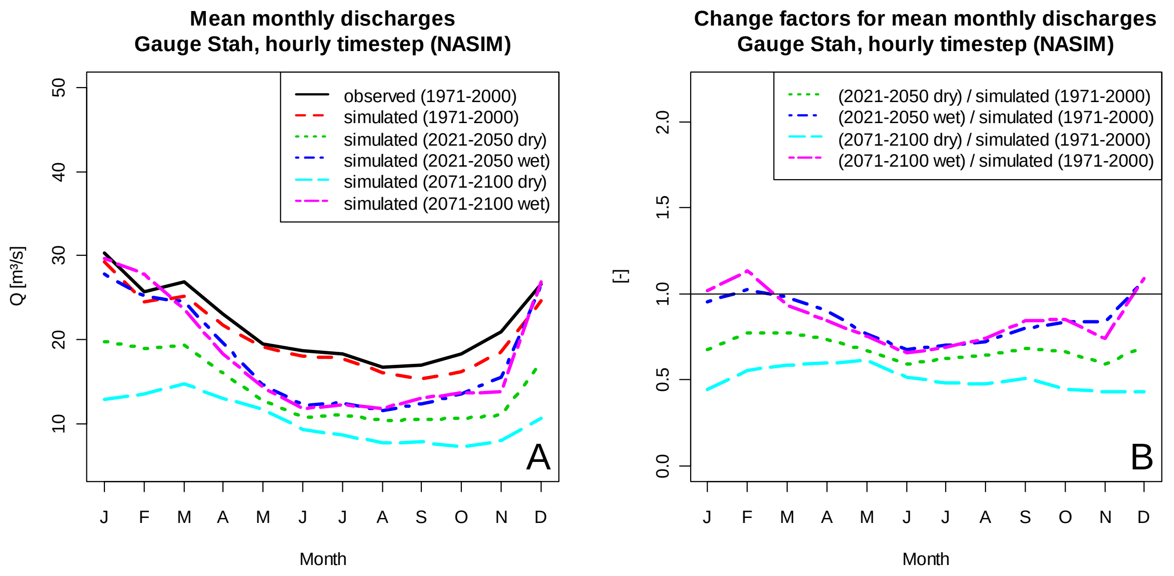


Figure 43: Predicted mean monthly discharges and change factors for gauge Stah (Rur) for a time step of 1 hour using NASIM, transnational scenarios

In Figure 44 the winter maximum discharges for different recurrence intervals using NASIM are shown. Comparative 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 recurrence interval of 100 years the predicted change is between +10% (wet scenario for 2071-2100) and -39% (dry scenario for 2071-2100).

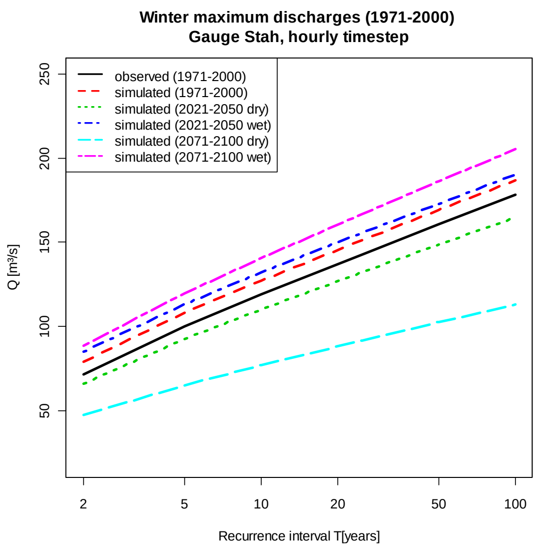


Figure 44: Winter maximum discharges for gauge Stah (Rur) for different recurrence intervals for a time step of 1 hour using NASIM, transnational scenarios

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.

Hourly maximum discharge - transnational scenario

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.

Hourly maximum discharge - national scenario

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	781	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**