

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

WP1 report summary – Actions 1 & 3



INTRODUCTION

The need to build common climate and hydrological scenarios

The AMICE Project provides the opportunity to use common scenarios, tools and methods to evaluate measures and elaborate strategies that can finally be comparable between countries. The AMICE Project, which will last 4 years, is divided in 5 Work Packages (see Figure 1).

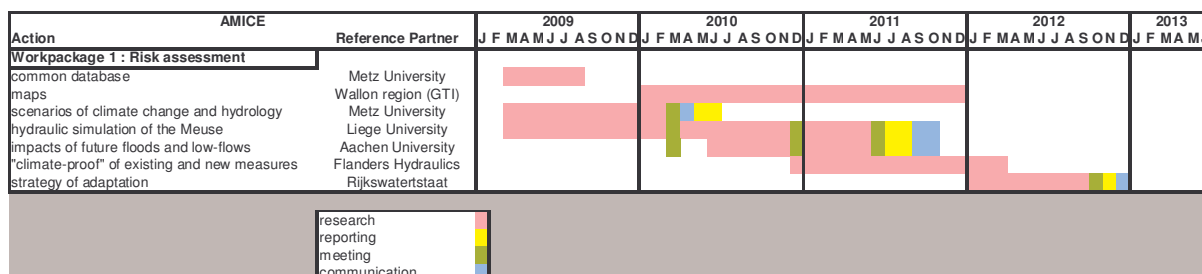


Figure 1. AMICE organisation of WP1

The objectives of Work Package 1 are planned to be carried-out in 9 Actions. The present report details methods and results from Actions 1 and 3 which have been carried-out in 2009 and supervised by the University of Metz.

The objective of **Action 1** is to improve the sharing of knowledge on the present and future characteristics of the hydrological behaviour of the Meuse river basin through the organization of existing documents into an online database and their translation in English, French, Dutch or German when required.

The **Action 3** is dedicated to the study of downscaled climate simulations for 2021-2050 and 2071-2100 time slices and their consequences in terms of floods and low-flows on the Meuse river basin. It aims at answering the following questions:

- Which discharges can be expected on the river Meuse and main tributaries according to the predicted climate evolution?
- How the return period, duration, extent of floods and low-flows will change from now to 2021-2050 and 2071-2100 time slices?

Conclusions of studies formerly undertaken by the International Meuse Commission highlight the risks of increased frequency of floods in winter (extreme events in particular) and decreasing of low flows in summer. The IMC also insists on the need to agree on common scenarios in order to improve coordination of water management policies.

The transnational cooperation within the AMICE Project will result in basin-wide scenarios on climate change and discharges, used as input for the adaptation strategy.

The analysis was based on existing climate simulations from meteorological institutes (Météo-France, KNMI, etc), national and EU research programs (PRUDENCE, ENSEMBLES, ADAPT, etc), bibliographies and interviews of users and experts invited to meetings and did not include new production or acquisition of climate simulations.

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

It is extremely important to emphasize that the AMICE adaptation strategy will respond to two scenarios – the most suitable we could find but not the only possible ones – with their assumptions and uncertainties. The scenarios represent what could, most likely, happen on the Meuse basin.

THE MEUSE RIVER BASIN: a major link between Belgium, France, Germany, Luxembourg and the Netherlands

The Meuse river basin is one of the most densely populated areas of Western Europe and a major geographic link between Belgium, France, Germany, Luxembourg and the Netherlands. The five European countries have been working together in the International Meuse Commission (IMC), since 2002.

The river itself is navigable and provides drinking water for more than 5 million inhabitants.

The main characteristics of the Meuse Basin are:

- **River length : 900 km**
- **Drainage area : 35 000 km²**
- **Number of inhabitants : 9 millions**

The Meuse flows from south to north. It takes its source in France on the Plateau de Langres (384 m.a.s.l.). After running 355 km along a mostly agricultural and forestry land, the Meuse leaves the French sub-basin (10 120 km²) and enters Belgium.

It runs through the Ardennes in the Province of Namur where it successively receives the Lesse and the Sambre in the city of Namur and then through the Province of Liège where it receives the Houyoux and the Ourthe. The Meuse leaves the Walloon Region at Visé. After a turn in the Netherlands via Maastricht, it acts as a border between Belgium and the Netherlands in the Province of Limburg. One third of the Meuse river basin area is located in the Walloon Region, let approximately 12 000 km².

As far as the German sub-basins are concerned, the Rur and Niers are the most important tributaries of the Meuse and represent respectively 7% and 4% of its hydrographical basin. The Rur is the only tributary which can be controlled by a total of 6 reservoirs, having a storage volume of about 300 million m³, located in the upstream part of the catchment area. The reservoirs are operated for drinking water production, increasing low flows and mitigating floods. Within the Niers basin, due to a very flat topography downstream, flood control measures are necessary. The retention is done, besides the natural one within the floodplains, via regulated flood retention basins and dikes along the rivers for small and middle size floods.

Eventually, the Meuse enters the Netherlands at Eijsden, south of Maastricht. The Dutch part of the Meuse river basin has a drainage area of 7 700 km². Several large cities are located next to or close to the Meuse river, such as Roermond, Venlo, Nijmegen and 's-Hertogenbosch. From Eijsden to Borgharen, the Meuse is called "Upper" Meuse (Bovenmaas). At Borgharen, the Meuse water is divided over the "Border" Meuse (Grensmaas), which forms the natural border with Belgium, and the Julianakanaal next to it which has been constructed for navigation. The water pursues its course to the North Sea through the Bergsche Maas and the Nieuwe Waterweg and eventually meets the Rhine at the Rhine-Meuse estuary. Here, water levels are mainly determined by sea tides and to a considerably lesser extent by discharges.

The **climate** of the Meuse river basin is semi-oceanic for the French river basin, with fairly regular rainfall throughout the year (approximately 80mm/month) and maritime and wet temperate in Belgium and the Netherlands due to its latitude and proximity to the sea. There is a gradient in precipitation, with the Ardennes receiving more rainfall than the rest of the basin. The **hydrological regime** of the Meuse is unimodal (only one low flows period each year in summer, and one high flows period in winter). Its discharges fluctuate considerably with seasons: it reached 3000 m³/s in the winter of 1993 in Liege and can be as low as 10-40 m³/s in the summer season. Classed as a rain-fed river, it has no glacier and little groundwater storage capacity to buffer precipitations.

It is thus extremely sensitive to any evolution of climate.

Nine gauging stations selected in 4 countries for hydrological simulations

Figure 2 presents the set of gauging stations selected by the AMICE Partners for the hydrological simulations:

- Four stations are located on the French part of the Meuse river basin: Saint-Mihiel; Stenay; Montcy-Notre-Dame; Chooz.
- One is located at the Walloon/Dutch border: Sint Pieter;
- Four stations are located on Walloon and German right-side tributaries : Gendron (the Lesse river), Chaudfontaine (the Vesdre river), Stah (the Rur river) and Goch (the Niers river).



Figure 2. Gauging stations of the Meuse river basin selected for hydrological simulations

For each selected station, hydrological simulations were realized in order to estimate the evolution of high-flows and low-flows discharges during the 21st century.

Besides a control run (1971-200 or 1961-1990), two reference periods were simulated: **2021-2050 and 2071-2100**. The adaptation strategy and knowledge are proposed both for the medium-term situation, the most useful for policy makers who have to define urgent adaptation measures, and for the long-term situation, for which climate trends are more pronounced. The 30 years span was used because data are usually available for a 30 years long reference period, as most discharges monitoring stations have been installed in the 1960's or 1970's.

ANALYSIS and SYNTHESIS OF LITERATURE on future climate and hydrological scenarios on the Meuse basin

Sharing knowledge through a Transnational Online Reference Database

The first action of the AMICE Project has consisted in the implementation of a tool for sharing bibliographic references in order to pool knowledge. This tool is called the AMICE “TORD” (Transnational Online References Database) and each Partner can view and add references dealing with the Meuse, climate change and other topics of interest to AMICE.

Queries can be formulated through keywords, authors and publishers. Two ways of querying are available (quick & power search). A system of categories based on issues of the AMICE Project has also been developed to refine the researches of references. Nine categories were created, comprising 45 sub-categories. The first two categories pertain to language and geographic area. The seven other categories are optional and give information on topics. Thanks to this system it is possible to refine the search for bibliographic references and to have an overview of the most (and less) represented subjects in the AMICE “TORD”.

Since December 2009, hosting and administration of the TORD have been maintained by EPAMA and the database is now accessible on the official website of the AMICE Project (www.amice-project.eu/biblio). Early 2010, eight months after its start, the AMICE TORD comprised about 800 references and more than 1.000 authors are quoted.

A need for regional studies on the Meuse river basin confirmed by the bibliographical analysis

According to this preliminary work, gaps in knowledge have been established. The most complete studies on climate change impacts on the hydrology of the Meuse river was carried out by De Wit *et al.*¹ and Leander *et al.*². Conclusions of the paper deal with the possible increase of extreme events, both high and low flows, and the need to detail further impacts.

In France, no study focused specifically on the Meuse basin as most researches have been conducted at the national scale. The French Ministry of Environment has selected the Meuse basin as one of the pilot basins for climate impact studies.

In Germany, no studies concerning the impacts of climate change on the water balance and discharges have been undertaken neither for the Rur nor the Niers basin area.

The AMICE Project will thus provide new findings and detailed information at the regional scale on the Meuse river basin.

Downscaling Global Climate Models (GCMs) for regional simulations

For producing future anthropogenic climate simulations, the most widely used method consists in running Global Climate Models (GCM). GCMs have the ability to simulate the global atmospheric circulation of the Earth, climatic forcing of the ocean and ocean/atmosphere interactions. Because of their low spatial and temporal resolutions (grid boxes of hundreds square kilometers and daily timestep) it is not possible to use them for hydrological impact

¹ De Wit M.J.M., van den Hurk B., Warmerdam P.M.M., Torfs P.J.J.F., Roulin E., van Deursen W.P.A., (2007). Impact of climate change on low-flows in the River Meuse. *Climatic change*, 82, pp 351-372.

² Leander R., Buishand A., van den Hurk B.J.J.M., de With M.J.M., (2008). Estimated changes in flood quantiles of the river Meuse from resampling of regional climate model output. *Journal of hydrology*, 351, pp 331-343.

studies usually performed at the mesoscale (10 000 – 100 km²) and for short timesteps (especially for high flows).

Numerical regionalization (or downscaling) techniques have been developed by modellers to generate regional climate information. One can use high-resolution GCMs or regional climate model (RCM) nested in a GCM. Due to inadequacy between RCMs outputs and observed climatological records, postprocessing methods have to be implemented on RCMS outputs.

A need for new climate and hydrological scenarios for the AMICE Project

In order to build up a transnational climate scenario, an inventory of all climate experiments known and used by the AMICE Partners has been performed. Different conclusions were drawn from this benchmarking exercise:

- > The lack of tailored (i.e. bias corrected) climate simulations at the Meuse basin scale
- > Most of the climate simulations are available only beyond 2050
- > The existence of a large uncertainty in ensemble climate simulations
- > Insufficient time to perform bias corrections for an ensemble of climate simulations

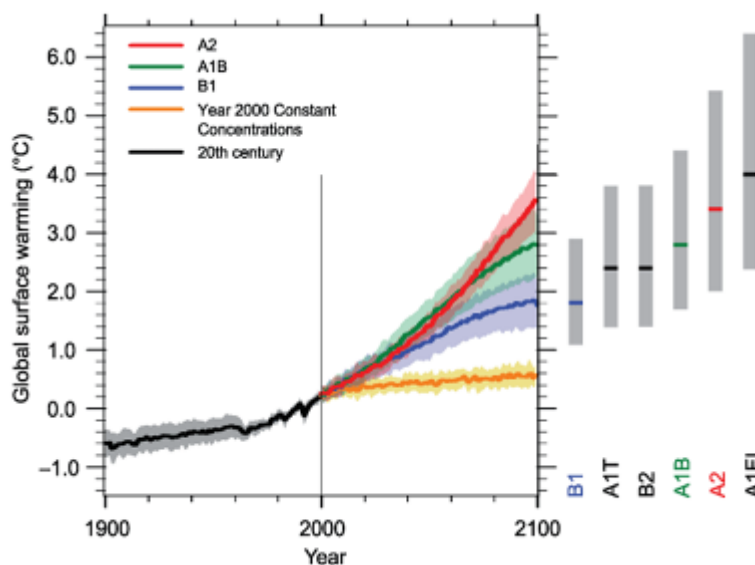
Similarly to climate evolution, a synthesis of the literature was conducted about impacts of climate change on the hydrology of the Meuse. This bibliographical analysis led to the conclusion that existing national scenarios were generally too heterogeneous and too sporadic to be used at the basin scale and claimed for the creation of new climate and hydrological scenarios for the AMICE Project. To this end, the optimal and most pragmatic solution for producing a common transnational climate scenario was **to apply the delta change approach** to existing national climate scenarios.

The selection of two scenarios to take into account uncertainties

The greenhouse gases (GHG) emission scenarios commonly used in climate change studies have been developed by the Intergovernmental Panel on Climate Change (IPCC) since 1996 and they have been described in the Special Report on Emission Scenarios (SRES). For each group of scenarios, one scenario of reference has been selected by the IPCC (A1B, A2, B1 and B2 – see Figure 3). These scenarios are the most used for GCM simulation and for impact studies of climate change.

For AMICE, **two scenarios are used: a dry scenario and a wet scenario** based on A2 and A1B. A1B and A2 emission scenarios are respectively an average scenario and a more pessimistic scenario. Consequently impact studies produced by AMICE present a wide range of variation in air temperature and precipitation to take into account uncertainties in economic and demographic evolution.

Figure 3. Evolution of the global surface warming during the 21st century for different emission scenarios (IPCC, 2001).



PRODUCTION OF FUTURE CLIMATE SCENARIOS

The Delta change approach: forcing present climatology with future anthropogenic scenarios to simulate future climatology

The delta change approach (Figure 4) is the method selected by the AMICE Partners for producing climate scenarios with high resolution time series. Seasonal trends (Δ in % for rainfall change and Δ in °C for air temperature variation in winter, spring, summer, autumn) have been provided by national meteorological institutes for the 2021-2050 and 2071-2100 periods based on GCM/RCM simulations forced with IPCC emission scenarios. The seasonal trends have then been used to force the present climatology on the 1961-1990 or 1971-2000 periods.

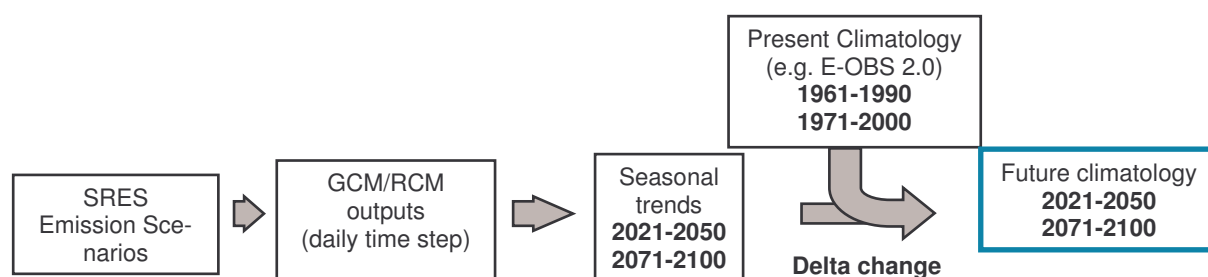


Figure 4. The Delta change approach

This post processing method has been implemented to create one wet and one dry climate scenarios for each period and for each national sub-basin.

The Partners used specific numerical experiments to derive the seasonal trends for the wet and dry scenarios:

- For France, ARPEGE-Climat A1B and A2 simulations,
- For Wallonia, CCI-HYDR Perturbation tool,
- For Germany, WETTREG for the wet scenario and CLM for the dry scenario,
- For Netherlands and Flanders, EU PRUDENCE project.

Putting together national scenarios towards the construction of a transnational scenario

Seasonal trends obtained with the delta change approach for each national sub-basin presented important heterogeneities. In order to maintain downstream consistency of discharges, especially at boundaries, a transnational scenario was established by weighting national trends according to the drainage area of each sub-basin (see Table 1). Results are shown in Figure 5.

	Drainage area (km ²)	Weighting coefficient
France	10 120	0,31
Walloon	10 880	0,33
Flanders & Netherlands	8 662	0,26
Germany	3 338	0,10
Transnational Meuse	33 000	1,0

Table 1. Weighting coefficients used to create the transnational seasonal trends

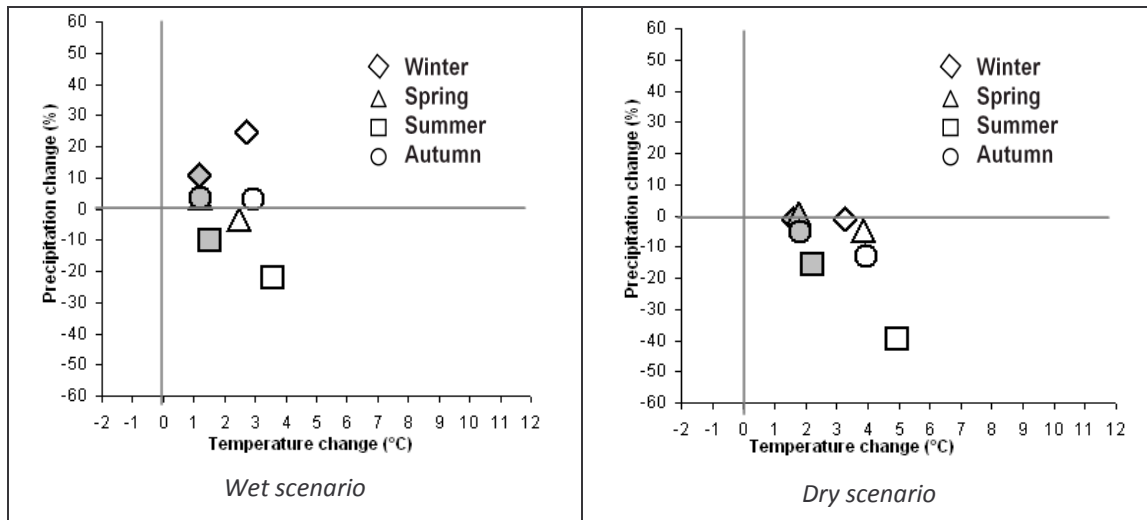


Figure 5. Seasonal trends in precipitation (%) and air temperature (°C) for the transnational climate scenarios and for the two time slices (grey: 2021-2050 - white: 2071-2100)

In order to check the consistency of the methodology used, AMICE Project values for the transnational scenarios were compared to the RCM (Regional Climate Model) simulations produced by the EU PRUDENCE project, a European-scale investigation on the regionalization of climate model conducted just before the AMICE Project. Both results are matching closely which reinforces the methodology used (see Figure 6).

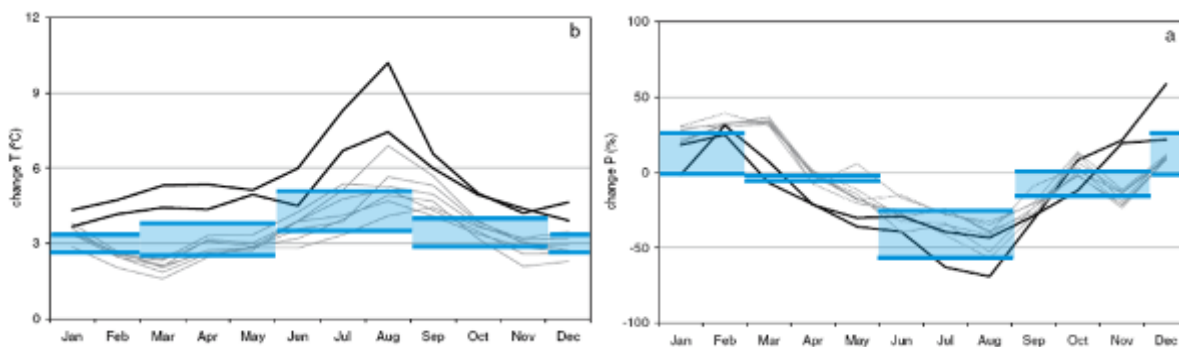


Figure 6. AMICE transnational wet and dry scenarios (blue bandwidths) vs PRUDENCE RCM simulations (black and grey curves) - 2071-2100 (from De Wit et al., 2007)

PRODUCTION OF FUTURE HYDROLOGICAL SCENARIOS

National hydrological models to calculate river discharges

For the hydrological simulations, each Partner has used its own rainfall-runoff models :

- In France, EPAMA and the University of Metz used the AGYR and GR4J models,
- In Wallonia, ULg - Gembloux Agro-Bio Tech used the model EPIC-Grid,
- In the Flemish part of Belgium, the Flanders Hydraulic Research used TOPModel and MIKE11 Maas,
- In Wallonia, Gembloux Agro-Bio Tech used the EPIC-Grid model,
- In the Netherlands, the Rijkswaterstaat used the HBV model,
- In Germany, the RWTH used the NASIM and GR4J models.

Beyond their differences, these models basically use the same input climate data (air temperatures, potential evapotranspiration and precipitation). Some of them require characteristics of the basin and river (slope, land cover, percentage of sealed surface...) to calculate the river discharges.

A common choice of variables to describe high flows and low flows

For achieving the WP1 objectives, the Partners decided to work on a set of common hydrological impact variables (HIV).

For low flows, the selected single variable is the MAM7 (Minimum Annual Mean 7-days discharge values) between April and September. It was calculated for several return periods: 2-5-10-25-50 years. For high flows two common variables were selected: the Qdx (annual winter daily maximum discharge value) and Qhx (annual winter hourly maximum discharge value). The corresponding return periods are 2-5-10-25-50-100 (+250-1250 for downstream). Results of simulations conducted in the AMICE Project are presented for a 100-year return period and therefore written Qdx_{100} and Qhx_{100} .

Applying statistical distribution functions to evaluate return periods of extreme discharges

In order to define the values of discharges for different return periods, a statistical distribution needs to be fitted to observed and simulated discharge series.

The sampling method of annual maximum discharges is the most common method used to evaluate quantiles of high-flow discharges. Once the sample of discharges is created, a theoretical statistical distribution is fitted to the set of observed or simulated annual maximum discharge series. For the AMICE Project, most of the time, the parameters of the theoretical statistical distributions were estimated through the maximum-likelihood method. Different theoretical statistical distributions (Gumbel, Weibull, etc.) were used for calculating the quantiles of annual winter hourly maximum discharge value (Qhx_{100}), and the Log-normal or Weibull/Gamma distributions for the summer minimum discharge series (MAM7). For each gauging station, the selection of the theoretical statistical distributions was made according to the fitting quality between observed and calculated quantiles.

In order to characterize the possible evolution of the future climate-induced changes of the Meuse river high flows and low-flows, a climate change factor was calculated at the 9 aforementioned gauging-stations for:

- the two time slices : 2021-2050 and 2071-2100,
- the transnational wet and dry climate scenarios
- the national climate scenarios

The climate change factor is defined as: $Q_{\text{simulated (scenario)}} / Q_{\text{simulated (present climate)}}$. Therefore, a value above 1 means an increase of the present discharge value whereas a value below 1 means a decrease of the present discharge value.

Table 2 shows the values of the climate change factor obtained for the 9 selected Meuse sub-basins. Values of the transnational (i.e. France, Belgium, Germany and Netherlands) scenarios for the two main impact variables: $Q_{hx_{100}}$ for high flows and MAM7 for low flows.

		Meuse St- Mihiel	Meuse Stenay	Meuse Montcy	Meuse Chooz	Meuse Sint- Pieter	Lesse Gendron	Vesdre Chaufontaine	Rur Stah	Niers Goch
MAM7	2021- 2050	0.79 0.61	0.73 0.64	0.88 0.75	0.88 0.74	0.82 0.65	1.00 0.83	1.17 0.93	0.68 0.56	0.84 0.63
	2071- 2100	0.60 0.43	0.50 0.47	0.71 0.52	0.65 0.52	0.60 0.33	0.96 0.57	1.10 0.67	0.71 0.36	0.60 0.27
$Q_{hx_{100}}$	2021- 2050	1.12 0.96	1.12 0.96	1.12 0.96	1.12 0.96	1.14 0.95	1.19 0.98	1.08 0.90	1.02 0.88	1.11 0.89
	2071- 2100	1.27 0.89	1.27 0.89	1.27 0.89	1.27 0.89	1.33 0.91	1.55 0.90	1.27 0.81	1.10 0.61	1.24 0.71

Table 2. Climate change factors obtained for the minimum mean 7-days discharge series (MAM7) and the hourly winter centennial flood peak ($Q_{hx_{100}}$), wet and dry climate scenarios.

An expected increase in maximum discharge for the wet scenario

For the transnational climate scenario the change in maximum discharge is logically homogeneous across the basin: an increase in discharge is expected for the wet scenario and a decrease in discharge for the dry scenario. These trends are more pronounced for the end of the century.

More severe low-flows expected whatever the emission scenario

Climate change factors based on the Mean Annual Minimum 7-days discharge values (MAM7) were also calculated: the minimum discharge tends to decrease for both the wet and dry scenario, except in the Walloon part of the Meuse where a slight increase is calculated for the wet scenario. Trends are accentuated for the second simulated period (2071-2100).

A remaining gap in knowledge for extreme rainfalls on small basins

One of the main lacks in the AMICE Project is the study of extreme rainfalls on small basins. Extreme rainfalls concentrated on small-scale areas can create devastating mudfloods, triggering very costly damages locally. Contrary to large floods that happen mostly in winters, extreme rainfalls can occur anytime of the year.

As this phenomenon is very complex to understand and simulate, present knowledge enables only to mention that extreme rainfalls could be more frequent during the century.

AGREEING UPON FUTURE HYDROLOGICAL SCENARIOS

An increase of discharges in winter - A decrease of discharges in summer

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

Based on the results of Table 2 and on the representativeness of the Meuse tributaries, experts were consulted to define hydrological scenarios applicable for the whole Meuse basin. The AMICE Partners finally agreed upon the most extreme hydrological scenarios only. The latter were derived from the transnational wet climate scenario for high-flows and the transnational dry climate scenario for low-flows.

Those extreme hydrological scenarios are as follows:

- An increase in **Qhx₁₀₀** values of **+15% for 2021-2050** and **+30% for 2071-2100**
- A decrease in **MAM7** values of **-10% for 2021-2050** and **-40% for 2071-2100**

These hydrological scenarios will be used by Partners involved in the next actions, particularly the one dedicated to hydraulic modelling (Ac6) that has already started and that is coordinated by the University of Liege (ULg-HACH).

In order to reinforce the results obtained through the AMICE Project, Partners have agreed on the need to compare AMICE climate scenarios with the result of the EU FP6 project ENSEMBLES whose objective was to quantify the uncertainty in long-term predictions on climate change.

Title	Analysis of climate change, high-flows and low-flows scenarios on the Meuse basin WP1 report – Action 3
Authors	Drogue G., Fournier M., Bauwens A., Buiteveld H., Commeaux F., Degré A., De Keizer O., Detrembleur S., Dewals B., François D., Guilmin E., Hausmann B., Hissel F., Huber N., Lebaut S., Losson B., Kufeld M., Nacken H., Piroton M., Pontégnie D., Sohier C., Vanneuville W.
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Partners involved	UPVM, CETMEF, FHR, RWTH, RWS, ULg-HACH, ULg-Gx-ABT
Work package	1
Action	3

AMICE Adaptation of the Meuse to the Impacts of Climate Evolutions

is an INTERREG IVB North West Europe Project (number 074C).

Climate change impacts the Meuse basin creating more floods and more droughts. The river managers and water experts from 4 countries of the basin join forces in this EU-funded transnational project to elaborate an innovative and sustainable adaptation strategy. The project runs lasts from 2009 through 2012. To learn more about the project visit: www.amice-project.eu

The NWE INTERREG IV B Program

The Program funds innovative transnational actions that lead to a better management of natural resources and risks, to the improvement of means of communication and to the reinforcement of communities in North-West Europe.

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