Investing in Opportunities

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

INTERREG IVB

Effects of climate change on river Meuse

Hydraulic modelling from spring to mouth

WP1 report summary - Action 6

Université de Liège

EPAMA

RÉGION WALLONNE

Rijkswaterstaat
Ministerie van Infrastructuur en Milieu

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HYDRAULICS RESEARCH

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INTRODUCTION

The AMICE Project provides the opportunity to use common scenarios, tools and methods to evaluate measures against the impact of climate change on the Meuse river basin and elaborate strategies that can finally be comparable between countries.

The AMICE Project, planned to last from 2009 to 2012, is divided in 5 Work Packages.

The objectives of Work Package 1 are carried-out in 9 Actions. The present report details methods and results from Action 6, which has been carried-out in 2010 and 2011 and supervised by the University of Liege.

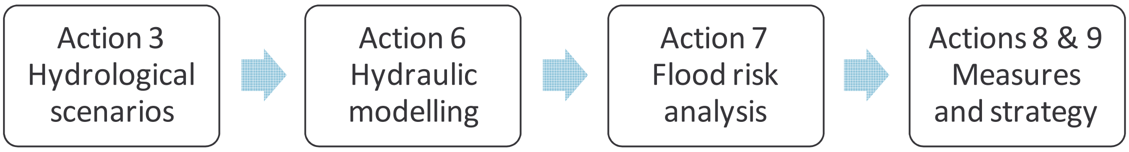


Figure 1: Hydraulic modelling is a key component of flood risk analysis and management.

This report follows a 1st work supervised by the University of Metz on Action 3. As a result of this preliminary work, all AMICE Partners have agreed to use the following scenarios for future floods and low-flows, taking into account the impacts of climate change:

- An increase in **HQ_{100} values** of **+15% for 2021-2050** and **+30% for 2071-2100,** where **HQ_{100}** stands for the river discharge for a 100 year return period flood,
- A decrease in MAM7 values of -10% for 2021-2050 and -40% for 2071-2100, where MAM7 stands for the mean annual 7-day minimum flow.

The need to build a consistent international hydraulic model to quantify the future consequences of floods under climate change

Hydraulic modelling is an essential step in the understanding of (future) consequences of floods. Accounting for the new climatic context, measures and strategies will then be set up to prevent impacts of flood events.

Hydraulic modelling is needed to quantify damage caused by floods. This type of models result in distributed information on water depths, flood duration and water velocities. This information can be used to develop measures and policies to diminish or even prevent damage caused by flooding. Besides, hydraulic modelling will prove itself useful through the whole AMICE project; its transboundary development could be used in many other studies around the world. Finally, the results of hydraulic modelling can serve communication purposes as it can be used to design maps of flood extents for public awareness.

Hydraulic models have already been developed in each country for the river Meuse and some of its tributaries. Although these models share some characteristics, this is not sufficient to provide directly consistent results for the whole river Meuse stretch. That is why the main objective of **Action 6** is to build a **consistent international hydraulic model**. The approach taken by Action 6 aims at coupling models and results from the different countries and establishing a common procedure to run them all in parallel.

The following steps have been followed in Action 6:

1. Collect information on existing models and sets of data used by each region and compare them,

2. Determine a methodology for a common hydraulic modelling: choice of consistent boundary conditions for the whole river course and how to run the simulation,

3. Run in parallel the hydraulic models from the different regions. Check the consistency of the results at the borders after a first run. If necessary, refine the boundary conditions to ensure consistency of the models across borders and compute a 2nd run for checking results.

4. Run the simulation for the AMICE wet scenarios and analyse the impact of climate change:

- at the river scale for different points and reaches: impacts on water level, on flooded areas and stored volume,
- at the local scale: draw maps of inundation extent for the wet scenarios, determine how the vulnerability of selected hotspots may evolve with climate change.

Consistency and differences between existing hydraulic models

Collecting information on the models and data used by each partner

Hydraulic models have already been developed for each region of the river Meuse. Nevertheless, **the hydraulic models along the Meuse do not use the discharges nor water levels from upstream or downstream models**, and some important **differences exist between models**, which definitely call for a more consistent transnational approach.

Basic notions on hydraulic modelling

Generally, different types of hydraulic models can be used, depending on the shape and the functioning of the river system.

Models can be either steady or unsteady. In the first type, it is considered that water discharge does not change with time. Thus, a unique statistical value of the maximum discharge is used (for the AMICE Project, Q_{100}). This kind of hypothesis is relevant in narrow valleys.

In the second type, water discharge can evolve with time: thus, hydrographs are used as upstream boundary conditions. In large flood plains where flood storage may occur, these models are more relevant as they can take into account the decrease in discharge due to water storage in the floodplains.

Also, models can be either 1D or 2D: in the first type, the water flow is supposed to follow a unique direction, whereas in the second type, the model can consider various flow directions in respect to the specific topography of the floodplain.

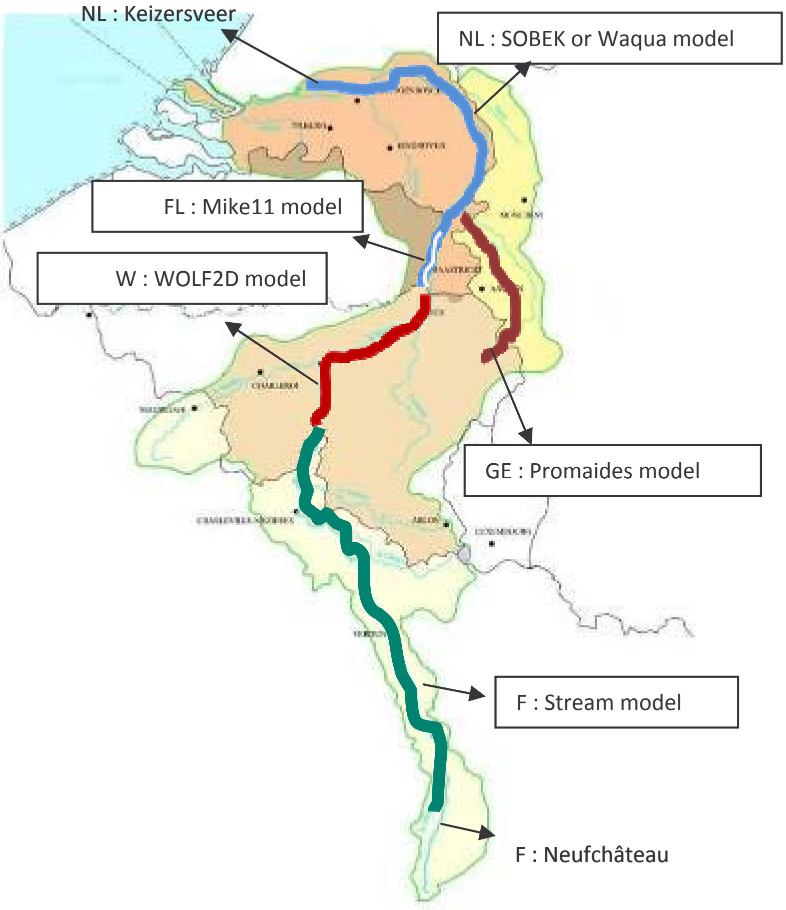
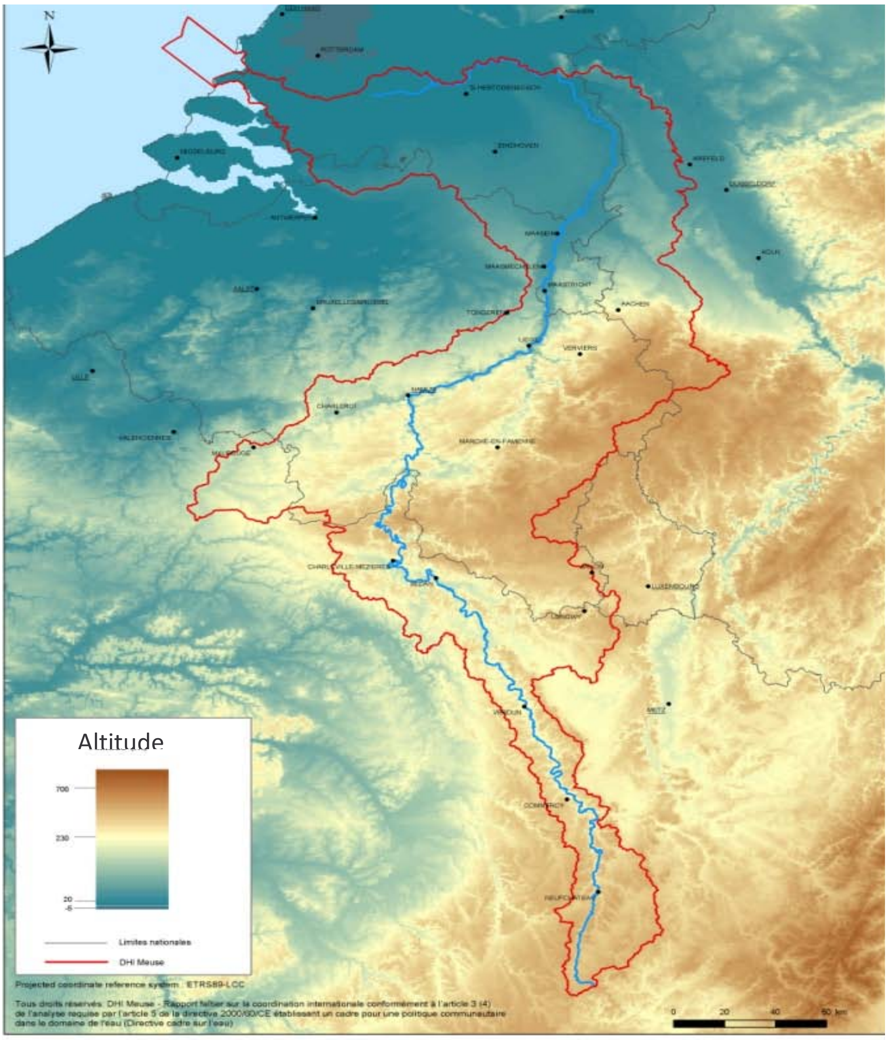


Figure 2: Covered reaches and corresponding hydraulic models.

When reviewing existing models, it appeared that:

- Existing models cover nearly the whole course of the river Meuse from spring to mouth. For Germany, the model is run on the Rur, one major tributary of the Meuse (see Figure 2).
- Significant differences exist between models reflecting differences in the characteristics of the basin, but also some specific needs of users :
  - in terms of spatial representation, the models range from fully one-dimensional, based on cross-sections in the river bed and in the floodplains (e.g., in The Netherlands), up to a fully two-dimensional description based on laser altimetry and sonar bathymetry (in Wallonia);
  - in terms of time description, models can be either unsteady or run in steady mode. France, Flanders, Germany and The Netherlands use unsteady models while Wallonia uses a steady one.

Those differences in the type of models used are consistent with the topography of the Meuse river basin (Figure 3). Indeed, the Meuse basin can be subdivided into three major geological zones. While the southern and northern parts are characterized by **wide floodplains**, in the central part of the Meuse basin, between Charleville-Mézières and Liege, the Meuse is captured in the Ardennes massif, characterized by **narrow steep valleys**. Those land characteristics are decisive elements during floods, as they determine the possibilities of **flood waves attenuation**. Thus, they determine the optimal procedure for hydraulic modelling in the different parts of the basin, particularly the choice between steady and unsteady modelling.



Projected coordinate reference system : ETRS89-LCC

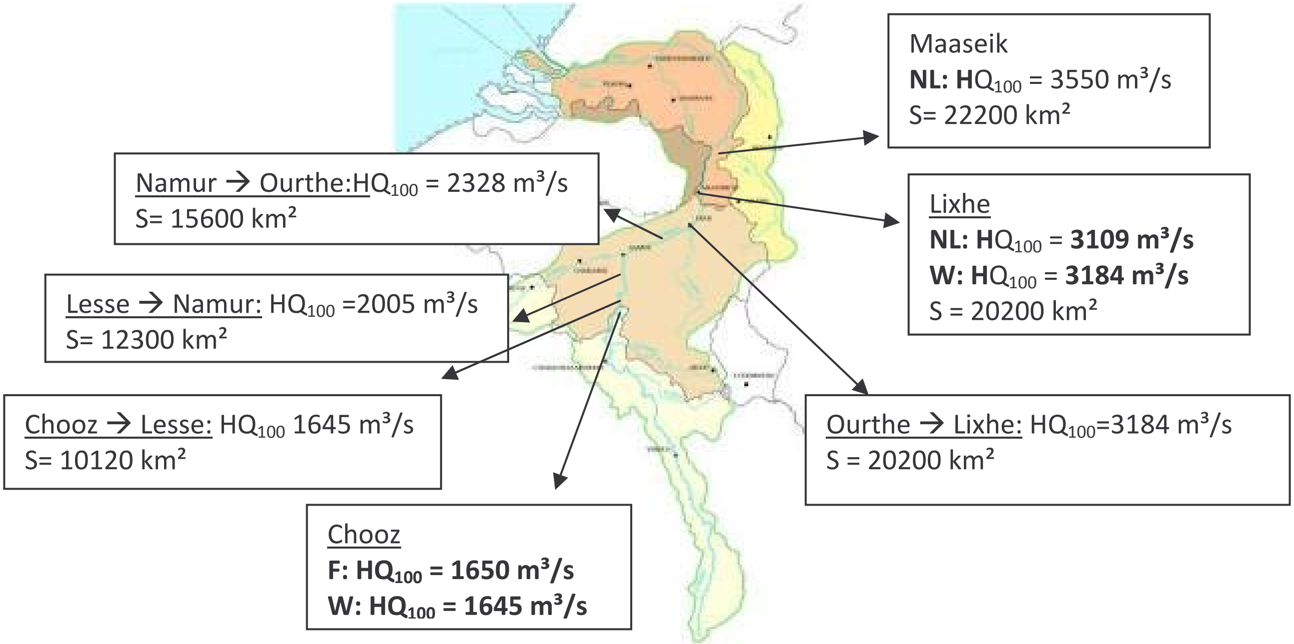
Tous droits réservés: DHI Meuse - Rapport faîtier sur la coordination internationale conformément à l'article 3 (4) de l'analyse requise par l'article 5 de la directive 2000/60/CE établissant un cadre pour une politique communautaire dans le domaine de l'eau (Directive cadre sur l'eau)

Figure 3: The Meuse basin

Ensuring continuity at the borders: boundary conditions

Hydraulic models need an upstream and downstream boundary condition, which can be constant for the use in steady models and time-dependent for the use in unsteady models. In general the upstream boundary condition is a discharge and the downstream boundary condition a water level. Water level can be calculated from discharge when the stage-discharge relationship is known.

Presently, each hydraulic model is based either on the outputs of rainfall-runoff models or on statistical hydrological data, derived from observations at the existing gauging stations.
All gauging stations of the Meuse basin have recorded historical data extending over a period ranging between 25 and 50 years and even 100 years at Borgharen (NL). These time series are the basis for calculating HQ_{100} , the upstream boundary conditions used for the hydraulic simulations. The HQ_{100} value at each border is summarized on the map below (Figure 4).
Differences in the set of hydrological data used proved to be small: statistical discharges at borders are found to differ by no more than 2% to 3% at Lixhe (border between Wallonia and the Netherlands) and less than 1% at Chooz (France-Wallonia border).


Maaseik
NL: **HQ**$_{100}$ = 3550 m³/s
S= 22200 km²

Namur → Ourthe:HQ_{100} = 2328 m³/s
S= 15600 km²

Lixhe
NL: HQ_{100} = 3109 m³/s
W: HQ_{100} = 3184 m³/s
S = 20200 km²

Lesse → Namur: HQ_{100} =2005 m³/s
S= 12300 km²

Chooz → Lesse: HQ_{100} 1645 m³/s
S= 10120 km²

Ourthe → Lixhe: HQ_{100}=3184 m³/s
S = 20200 km²

Chooz
F: HQ_{100} = 1650 m³/s
W: HQ_{100} = 1645 m³/s

Figure 4: HQ_{100} discharge and catchment area (S) for each considered reach of the Meuse.

Building a common methodology for hydraulic modelling

Once the consistency of hydrological values at national borders has been checked, a discrepancy still remains between steady and unsteady modelling approaches.

In order to ensure consistency between simulations in each region, the following approach has been followed:

1. Define consistent boundary conditions between region,
2. Determine a methodology to run simulations: either choose a full steady or unsteady approach and run simulations simultaneously, or run each model in parallel.

As far as the 1st step is concerned, the set of mathematical equations solved by models (Saint-Venant or shallow water equations) require a suitable boundaries conditions:

- **Upstream boundary conditions** are either the maximum discharge value HQ_{100} at the gauging station for steady models, or hydrographs for unsteady models**,**
- **Downstream boundary conditions** are usually water levels, determined thanks to the stage-discharge relationship.

For the Action 6 simulation, following boundary conditions were agreed upon:

- Measured data are used at the most upstream point, in Neufchâteau (discharge) and at the downstream limit at Keizersveer (water level).
- All other boundaries conditions depend on the results of the other models.

An important question to solve in the Action 6 of the AMICE Project was whether to run simultaneously all models and then use either a full steady or unsteady simulation for the whole course of the river Meuse, or to accommodate existing differences between models and run them in parallel.

The first approach seemed not satisfactory as it would have prevented an optimal use of available time.

Thus**,** the common modelling procedure agreed upon **combines unsteady and steady modelling**, depending on existing practice in each region and in accordance with the storage capacity of the floodplains, **while enabling parallel** (instead of sequential) **runs** of the models and **ensuring reasonable continuity of the results at the borders.**

Eventually, the chosen methodology was a two-step procedure. First, all hydraulic models were run separately based on measured or extrapolated data.

Then consistency of the simulation results at the borders between models has been checked, and, if necessary, a second run of (sub-) models has been undertaken. When a second run was necessary, the use of boundary conditions transferred from the adjacent models allowed restoring continuity across borders (Figure 5).

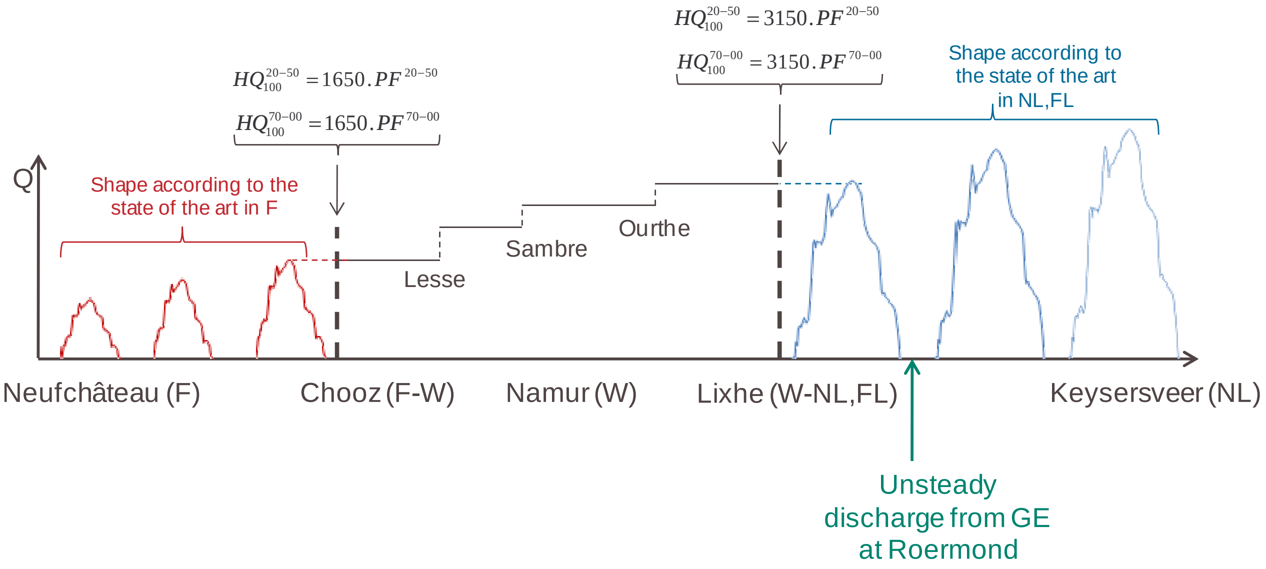


*Figure 5: Sketch for discharge repartition along the Meuse: unsteady models are used between Neufchâteau and Chooz and between Lixhe and Keizersveer, whereas a steady model is used between Chooz and Lixhe. *PF: Perturbation Factor*

Consistency check at the borders

Preliminary work: choosing comparison points and defining a common reference system to compare results

5 points were chosen for comparison of the models' results: Chooz at the French-Walloon border, Lixhe at the Walloon-Dutch border, Linne and Borgharen for the comparison of the Dutch and Flemish models, and eventually Roermond for the Dutch and German models.

Then, as coordinate systems and references for elevation measurement are different in each region, the spatial coordinates of comparison points chosen in the different countries had to be converted into a common projection system to perform comparisons between results of hydraulic models. Longitude and latitude were chosen as common coordinate system, whereas for the reference for elevation, the Belgian DNG (or TAW) was kept, for it was already shared by Wallonia and Flanders.

Running the simulation: observing differences after the first run at each border and finding how they could be reduced

After conducting the 1st simulation, the largest difference in water level, up to 1 meter, was detected between France and Wallonia. This gap resulted from three facts: a difference in the stage-discharge curves of the French model, used as downstream BC (Figure 6), a bathymetry of the river Meuse that was not updated in Wallonia and the need to correct the roughness parameter of the French model in the Walloon part. Once those parameters were fixed, the 2nd run showed a difference of only 10 cm. In Figure 6, the bathymetry in 2002 is denoted "modelled points in Wallonia 2002" and the updated bathymetry "modelled points in Wallonia 2007".

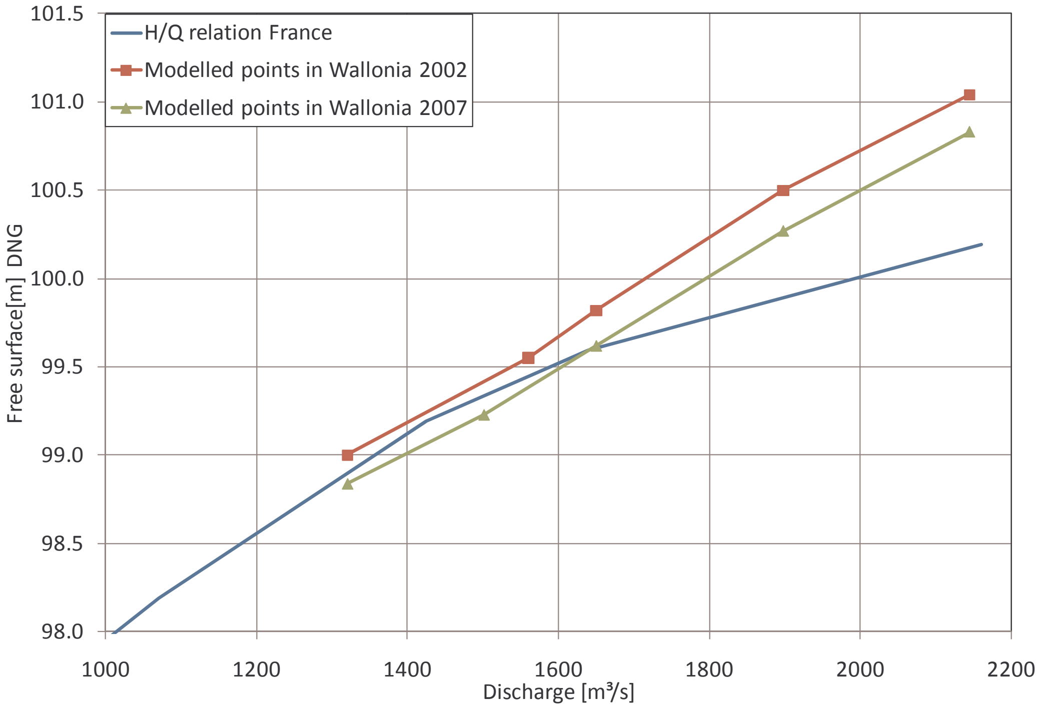


Figure 6: Gap between French and Walloon stage-discharge curves used downstream as BC.

The difference between Wallonia and the Netherlands was less than 20 cm after the 1st run. After a slight correction of the BC of the Walloon model, results proved to be consistent.

Between Flanders and the Netherlands, a 30 cm gap was detected as well as a difference in the peak discharges of both models. These were considered not significant enough to run the models a second time; besides, the inflow hydrographs respect the defined methodology. Finally, some small differences appear also in Borgharen due to the differences in the shape of the hydrographs.

Finally, Germany adjusted boundary conditions upstream on the Rur to fit the discharge at the two rivers' junction, in Roermond. This value corresponded to a HQ_{100} in the Meuse. The deviation of peak discharge and flood volume was eventually below 5%.

Results and analysis

After consistently running simulations from spring to mouth of river Meuse, the results have been analyzed at two complementary scales: the river scale and the local scale.

Analysing climate change impacts at the river scale

Hydrographs and peak discharges

First, peak discharges and, when possible hydrographs, which are output data of the hydraulic models, were determined for the HQ_{100}+15% and HQ_{100}+30% scenarios and analyzed. Following results on the general functioning of the Meuse basin could be derived from the simulation, though they are not linked to the consequences of climate change.

In France, hydrographs show that the water depth and flood duration gradually increase with the distance to spring, showing the impacts of the inputs of tributaries. On the contrary, in the Flemish-Dutch border region, between Borgharen and Linne, the maximum water depth decreases as a small damping takes place in floodplains, and there are no significant tributaries. The propagation time calculated is about 130 hours between Neufchâteau and the French-Belgian border, and about 20 hours between Borgharen and Linne.

Values of peak discharges were deduced from the hydrographs.
Figure 7 shows that the discharge grows gradually from spring to Givet. Second, the discharge grows by steps, corresponding to the major tributaries in Wallonia. Next, the contributions of tributaries are slightly damped between Lixhe and Roermond and finally some more damping occurs downstream due to the large flooded areas in the Netherlands.

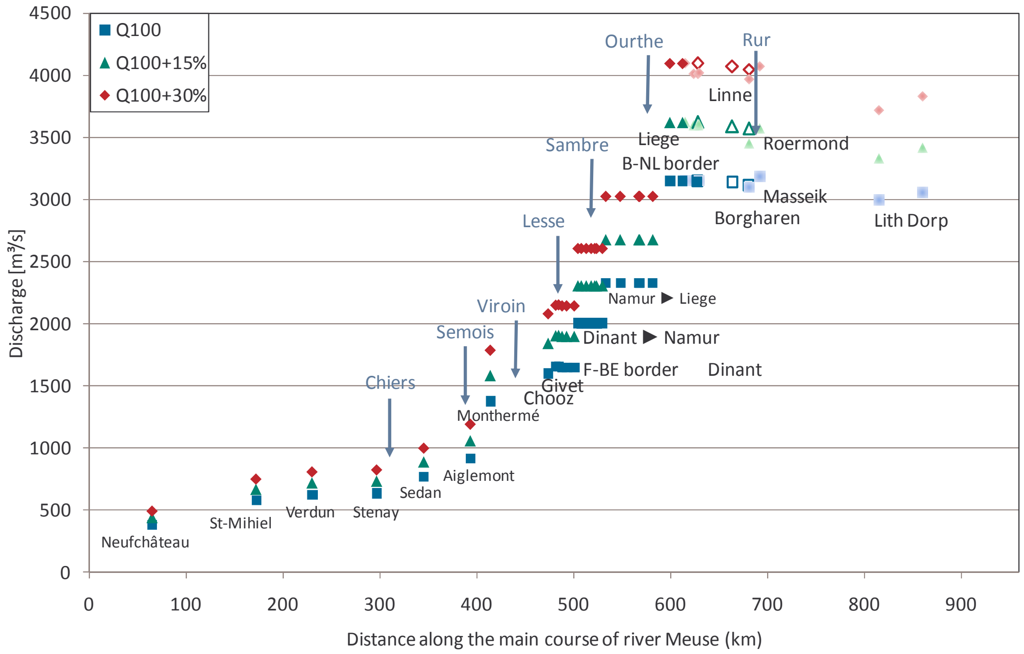


Figure 7: Peak discharge comparison from spring to mouth

Water depths, flooded area and stored volume

Then, thanks to the hydraulic modelling, other data could be compared. Results proved that the impacts of climate change can be significantly different in each region in respect to the natural functioning of the river.

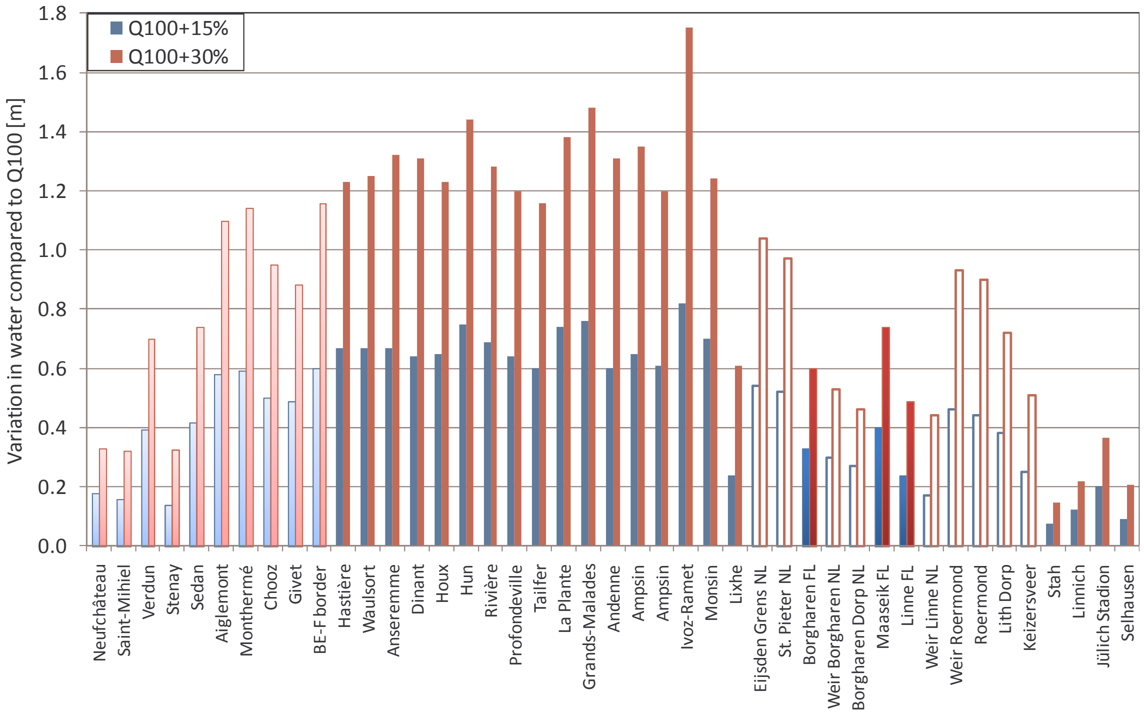


Figure 8 : Variation in water depth compared to HQ_{100} at extraction points

Analysis of changes in water depths at the chosen points along the reaches ended up with the following conclusions (see Figure 8):

- In the upper and lower parts of river Meuse, values went from +30cm (period 2021-2050) to +70 cm (period 2071-2100) whereas in the central and narrower part of the basin they reached +60 to +130 cm. This higher sensitivity of the water levels in respect to the increase of discharge in the central part is consistent with the valley topography.

- **Flooded areas and stored volume** were then displayed for each reach as their relative contribution to the total increase for HQ_{100}+30% in each country.
  - In France, the reaches between Verdun and Aiglemont were the most affected by the increase in discharge with climate change (each reach represents between 15 % and 30 % of the total increase of flooded area with climate change for the scenario HQ_{100}+30%).
  - In Wallonia, the part of the river located between Andenne and Monsin would be the most affected one (see Figure 9 – the Ivoz-Monsin reach, including the industrial area of Liege, would represents alone around 35% of the total increase of flooded area for the scenario HQ_{100}+30%).
  - In the Netherlands and Flanders, the reach between Lanaken and Kessenich is the most affected for both time horizons (approximately 35% of the total increase of stored volume), followed by the part of the river named “Zandmaas” (about 10%).

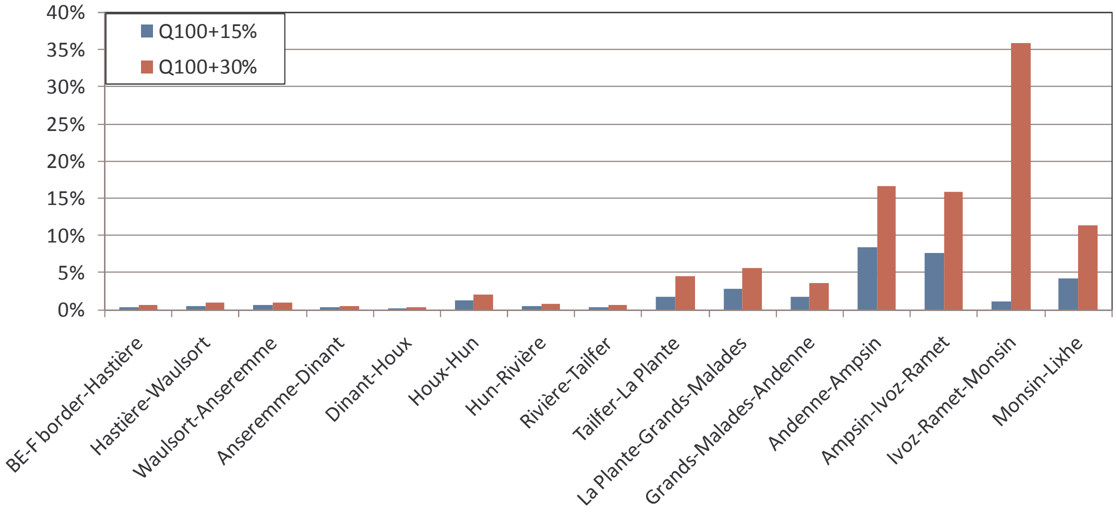


Figure 9 : Contributions of flooded areas per reach compared to the total increase in flooded area for HQ_{100}+30% in Wallonia

Analysing impacts of climate change on the flooding of strategic hotspots

In each country, strategic hotspots have been chosen to analyse the impact of climate change and resulting floods. For each spot, a potential flood hazards map for the three established scenarios was realised.

In France, the cities of Givet and Charleville-Mézières were severely impacted by the 1995 flood. Following this event, protections have been built (walls, embankments, short-cut, dynamic flood retention zone…). However, **under the AMICE wet scenario, the protections built will prove insufficient to protect the two cities**. Moreover, for Charleville-Mézières, strategic parts of the towns will be under water. For the city of Verdun, the impacts of climate change are limited in terms of flooded areas but the water depth could increase from 40 to 60 cm.

As far as Wallonia is concerned, its most important city **Liege** is currently protected against a 100-hundred year return period flood event. The simulations proved that **flooded area would greatly increase with the severity of the climate-change scenarios.**

The selected hotspot along the **Dutch-Flemish** border corresponds to a part of the Grensmaas. As dike break and overflow are not taken into account, the inundation map shows little differences in **flooded area.** Although the extension of the flooded area will hardly vary with climate change, **the water depths would be impacted**.

Finally, **for Germany**, the village Ophoven located on the downstream part of the Rur River, which was already vulnerable to floods, only sees its **situation worsen**.

Conclusions and outlook

Basin-wide harmonized hydrological data and hydraulic models

This report covers hydraulic modelling tasks performed in the context of the AMICE project. These tasks, part of the Work Package 1, Action 6, have enabled to develop a **common methodology for hydraulic modelling** and to conduct the **first coordinated flow simulation of river Meuse from spring to mouth**. In order to estimate the impacts of climate change in case of floods, the transnational consistent hydraulic modelling was then tested with the AMICE wet scenarios agreed upon in Action 3: HQ_{100}+15% for the 2021-2050 time horizon and HQ_{100}+30% for 2050-2071.

A strong spatial pattern in the sensitivity of river stages with respect to changes in flood discharge

The harmonized hydraulic **modelling conducted showed that the influence on the increase of the water depth of a similar change in flood discharge is found to be approximately twice as strong in the central part of the basin compared to the upper and lower parts**. This finding can be explained by the main characteristics of the Meuse basin: both the upper part and the lower part of the basin are characterized by relatively wide floodplains with large storage capacity; whereas in the central part, the river valleys are steeper and narrower, leading to limited storage capacity in the floodplains. As a result, river stages are indeed expected to show a higher sensitivity of water depth in the central part of the basin.

Also, the simulation emphasized how **some reaches may be severely affected by climate change in terms of increase of flooded areas,** such as the reach between Andenne and Monsin in Wallonia.

Potentially significant consequences in selected hotspots

Analysis of the selected hotspots in the different countries also revealed the following facts:

- Even if floods spread on a limited surface, they can have serious consequences when reaching key assets, for example in France.
- Although some sites seem to be well prepared and protected from current possible floods, namely in Wallonia, they could suffer greater damages considering an increased discharge due to climate change.

Title	Hydraulic modelling of the Meuse WP1 report – Action 6
Authors	Detrembleur S., Dewals B., Fournier M., Becker B., Guilmin E., Moeskops S., Kufeld M., Archambeau P., de Keizer O., Pontegnie D., Huber N.P., Vanneuville W., Buiteveld H., Schüttrumpf H. and Pirotton M.
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Lead partner	EPAMA
Partners involved	ULg-HACH, EPAMA, RWTH, RWS, FHR
Work package	1
Action	6

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

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