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Quantifying flood damages for climate-change adaptation on a transnational river basin

Case study from the AMICE project on the Meuse basin

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Abstract

The Meuse River basin is shared by five countries. Climate change in the future decades could either lead to a dryer or a wetter situation. In order to build an adaptation strategy that would cope with both scenarios and that is agreed at the international level, water experts have set-up the AMICE project. Quantifying the flood damages is an important part. It required much negotiation at every intermediary step, from the definition of climate scenarios, to the hydraulic modeling and the determination of the flood damage potential.

1 The challenges of transnational cooperation and climate change

Climate change is already taking place. But high uncertainties remain on the climate evolutions trends for the future decades. Depending on the Global Circulation Models (GCMs) chosen, North-West Europe would either become drier or wetter (EEA, 2007). Water managers are in need of better trends, especially when building water infrastructures designed to last over 50 years.

However, floods are a common phenomenon which is expected to be more hazardous in the future years due to climate change (EEA, 2007). As a consequence, adaptation strategies are necessary to counter the negative impacts of climate change and maintain our living standards. Within the AMICE project, the quantification of the climate change impacts will be done by a comparative analysis of risk. To meet the goals of a river basin wide consideration, it is understood as a central task to present a robust transnational flood risk assessment methodology, which is applicable and representative for the whole Meuse basin.

In general, the risk is often defined as the product of hazard and vulnerability. The hazard is hereby considered as the flood event and its probability of occurrence (or flood frequency). The vulnerabilities are then expressed in terms of damage potential assigned to this flood event. According to this definition of risk, the risk quantification is composed of the analysis of the hydrological scenarios, the hydraulic system and the determination of the damage potential.

The Meuse river basin is located in North-West Europe (see Fig.2). The basin is shared between France (most upstream part), Luxembourg, Belgium (Wallonia and Flanders), Germany and the Netherlands, where the Meuse flows into the North Sea. Three different languages are spoken on the Meuse territory. The catchment area is nearly 35,000 km² and we can reasonably assume that climate change impacts will be comparable for a part of the basin to another (Drogue et al., 2010). Within the International Meuse Commission, the idea arose to build up a common adaptation strategy and to share forces. However, each country had built its own national land-use datasets, damage functions and methodologies to model floods. These are so different that the figures produced by each country cannot be compared as it. Common or harmonized tools and references are needed as a first step.

The AMICE Project was created to respond to these challenges.

2 The AMICE Project

AMICE stands for Adaptation of the Meuse to the Impacts of Climate Evolutions. It involves 17 Partners: water managers, researchers, public authorities and associations. The Partners have been working together since 2009.

The Project has a total budget of 8.9 million € and is funded through the European Programme Interreg IV B (2.8 million €) as well as governments of the Meuse basin's countries.

The goals are to:

- propose an adaptation strategy, to deal with the future floods and low-flows, for the Meuse basin;
- implement measures that are good examples of adaptation;
- strengthen the international partnership of water experts that is initiated by the International Meuse Commission;
- communicate our results to other river basin managers, to the decision makers of the Meuse basin and to its inhabitants.

www.amice-project.eu

There are five workpackages, each representing one way of adapting to climate change:

- sharing knowledge to understand and quantify the impacts of climate change;
- make use of the nature's resilience to climate evolutions;
- improve the water infrastructures to deal with both higher or lower discharges;
- prepare for extreme events;
- communicate and raise awareness of the threats and solutions.

The present results are achievements of the Workpackage 1. The scientific lead is passing from one university or research institute to another, according to their field of expertise. Credits should be given to the University of Lorraine (climate and rainfall-runoff modeling), the University of Liège (hydraulic modeling) and the Institute of Aachen (impact assessment), as well as all AMICE Partners contributing outputs for their territories.

3 From climate scenarios to damage quantification

3.1 The AMICE climate scenarios

Many climate change studies are available that provide insights for the end of the century (ENSEMBLES, 2009). However, decision makers also need information on the short and medium terms. The AMICE Partners settled on two future periods: 2021-2050 and 2071-2100, each lasting 30 years which is most common in hydrological studies related to climate change. The climate of these two periods will be compared to the years 1971-2000, called the reference period.

For our purposes, air temperature and precipitations will be used. Potential evapotranspiration input was determined with the air temperature-based formula of Oudin et al. (2005). Annual means are not sufficiently accurate in hydrology which is influenced by inter-seasonal variability. Seasonal trends (in % for precipitations, in °C for temperatures) are of easy access and have been used within AMICE. Monthly or even daily data related to climate parameters would have been even better but such data were not validated and ready-to-use at the Meuse basin scale when AMICE work started. In order to get climate data for the two aforementioned time slices, the delta change approach (see Fig.1) has been used, which modifies the present climatology on the reference period through 8 seasonal perturbation factors (4 seasons x 2 climate parameters).

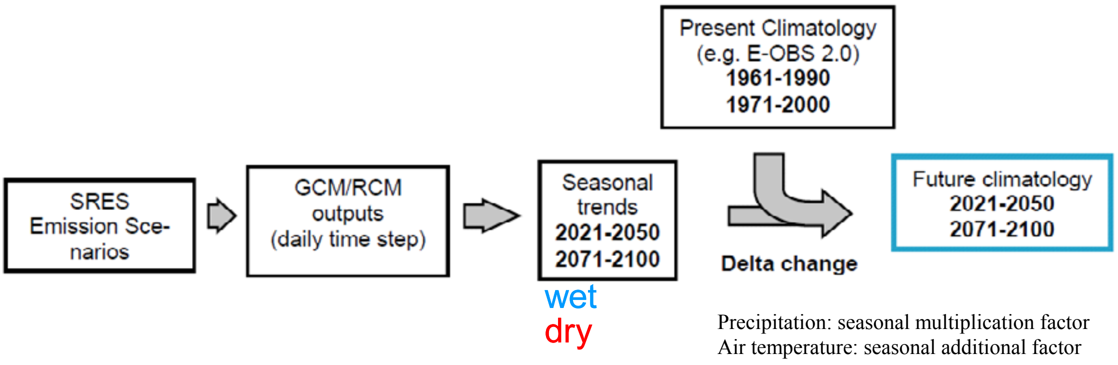

Fig. 1: The delta change approach (Drogue et al., 2010)

It soon turned out that there was no existing downscaled climate scenarios available on the international Meuse basin for both time slices. Each country had used its own assumptions and methods to produce scenarios for its national territory (The Netherlands and Flanders: PRUDENCE, 2006 – Germany: WETTREG, CLM, 2009 – Belgium: CCI-HYDR, 2008 – France: ARPEGE Climat, 2007). A transnational scenario was therefore needed.

All GCMs agree upon an increase of air temperature in Europe in the coming decades. Precipitation totals are either expected to increase or to decrease in the Meuse basin area, depending on the models (EEA, 2007). To take into account this uncertainty, we decided to work both on a "wet" and a "dry" climate scenario. These two scenarios encompass the wide range of possible futures.

Each country involved in AMICE provided seasonal trends of precipitations and air temperatures for the periods 2021-2050 and 2071-2100, and for both wet and dry climates. The seasonal perturbation factors from each country were weighted according to their drainage area within the Meuse basin in order to derive mean transnational climate change factors. This simple solution ensures that all countries' scenarios are taken into account (see Table 1) and assumes that each national scenario is transferable to another part of the Meuse basin.

Tab. 1: Weighting factors for each Meuse country (Drogue et al. 2010)

	Catchment area (km²)	**Weight**
France	10 120	0,31
Belgium	10 880	0,33
Netherlands	8 662	0,26
Germany	3 338	0,10
Transnational	**33 000**	**1,00**

Under the wet scenario, air temperatures are expected to increase by 1.3 °C to 2.9 °C with little difference between the seasons. Precipitations are expected to increase in winter (+10.9% in 2021-2050 and +24.7% in 2071-2100). Even under the wet scenario, precipitations are expected to decrease in summer (see Table 2)!

3.2 Rainfall-runoff modeling on the Meuse basin

What would be the consequence of such scenarios in terms of river discharges?

Once more, each country uses its own rainfall-runoff model and none is available that covers the whole Meuse basin with sufficient details (The Netherlands: HBV – Germany: NASIM - Flanders: TOPMODEL, MIKE 11 - Wallonia: PDM - France: AGYR). All models have been used and their results compared to check if discharges modifications are of the same range.

Tab. 2: Seasonal trends in precipitation (%) and air temperature (°C) for the national parts of the Meuse basin as well as for the transnational scenario ("Meuse") for the two time slices (2021-2050 & 2071-2100), (Drogue et al., 2010)

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

For floods, the partners agreed upon comparing their models' outputs on the hourly peak discharge of a 100 years return period flood (Q_{hx100}). Nine hydrological stations have been used (see Fig.2), four of them are on major tributaries: the Lesse and the Vesdre (Belgium), the Rur and the Niers (Germany).

On the Meuse River, models yielded comparable results. The Q_{hx100} would increase by 15% in 2021-2050 and by 30% in 2071-2100 under the wet scenario. No modification with the reference period appears under the dry scenario (Drogue et al., 2010).

Climate change studies also point out that flash floods are bound to increase in the future and that floods would not only become bigger but also more frequent (EEA, 2007). These were not included in AMICE for lack of statistics and because seasonal trends do not provide enough information on these phenomenon's.

Fig. 2: The International Meuse river basin and gauging stations Hydraulic modeling from spring to mouth

Four different hydraulic models exist on the Meuse River and an additional one is available on the Rur tributary. These models cover the full length of the river course, from its spring in France to its mouth in the Netherlands (see Fig.3). Nonetheless, these models have different characteristics, so that connecting them is not straightforward. Building a new transnational hydraulic model is also out of the scope of the project and would be of little added-value except nearby the borders.

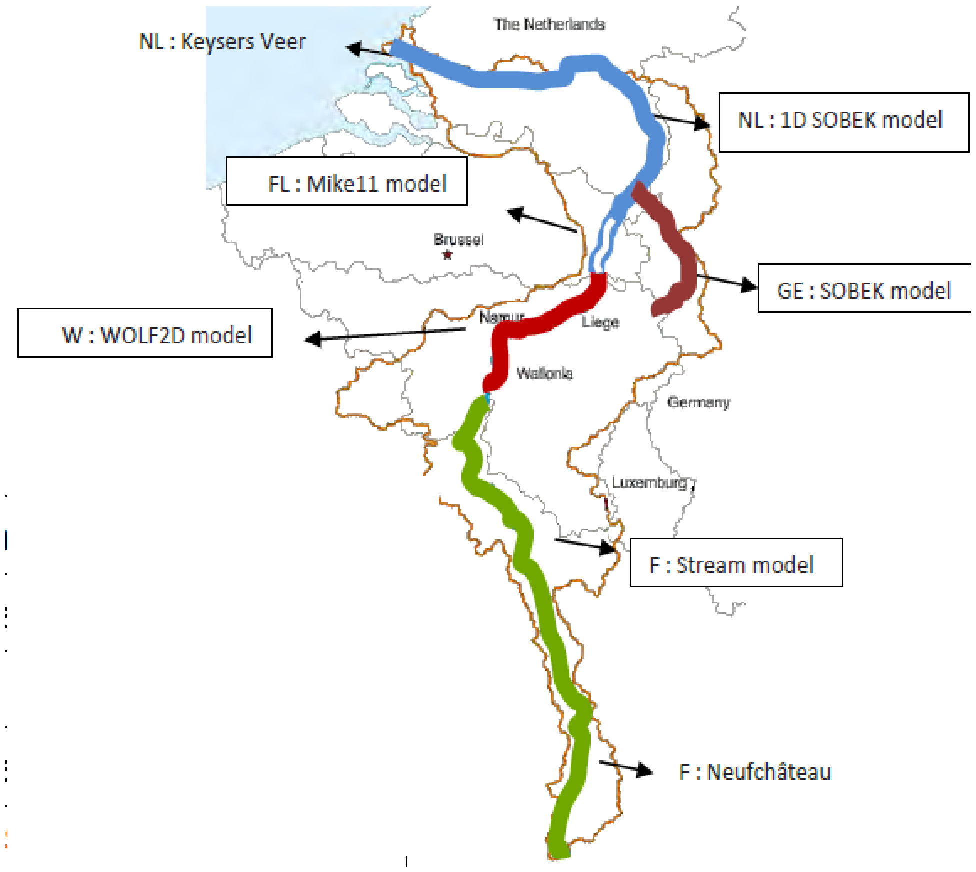

Fig. 3: River stretches covered by existing hydraulic models (Detrembleur et al., 2012)

A solution has therefore been developed to harmonize the input/output data at the boundaries between the existing models.

The hydraulic modeling has been conducted in three steps (Detrembleur et al., 2012).

- Each model has first been run independently, inflow discharges and downstream water depth being deduced from observed time series.
- Next, water depths computed by each model have been compared at the boundaries between models. This required a common geographical reference system (Longitude/Latitude and Belgian DNG/TAW). When discrepancies were detected, they have been analysed and corrected.

- Finally, a second run of the models has been performed, using boundary conditions provided by the upstream and downstream models.

This procedure has enabled to achieve the first harmonized simulation of inundation flows along the whole course of river Meuse, even across the borders.

Climate change is likely to worsen the severity of future floods. Compared to levels of the present 100-year flood, the expected increases in flood levels would reach, respectively for 2021-2050 and 2071-2100:

- between 30 cm and 70 cm in the southern and northern part of the basin, where floodplains are particularly wide,
- between 60 cm and 130 cm in the central part of the basin, between Sedan and Monsin, where the valley is more narrow (Ardennes massif).

The changes in inundation extents and volumes stored in the floodplains have also been analyzed.

3.3 Damage calculation methodologies

The determination of the flood damage potential requires four input parameters (see Fig. 4):

- the inundation depth and extent, resulting from river discharge modeling;
- the land-use in the flooded area;
- the damage function for each land-use category, which represents the susceptibility of the assets to inundation depth;
- the asset value in each land-use category.

The theory looks quite simple but it can get quite difficult when dealing with:

- a transnational river basin,
- strong climate change uncertainties.

Whereas the flood damage determination methodologies of all partners follow overall and comparable procedures, methodical details and input parameters often differ. Thus, a harmonization of the regional approaches into a methodology, valid and applicable for the whole Meuse basin is essential.

AMICE damage calculation is limited to direct tangible economic flood losses, at the scale of the international basin.

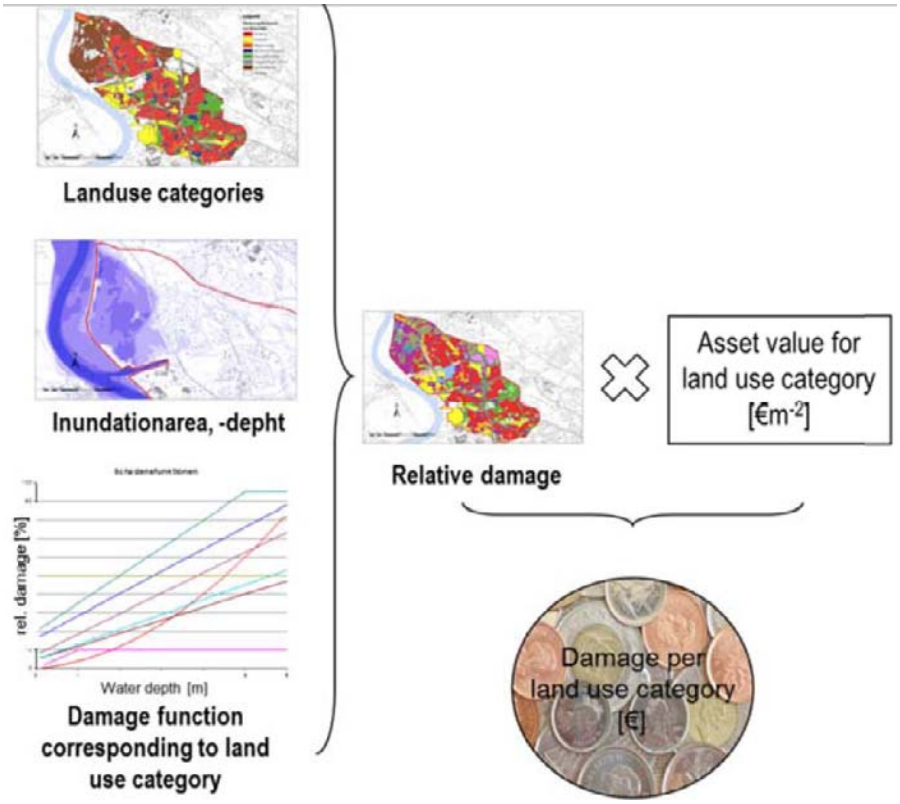

Fig. 4: Superposition of input parameters in AMICE flood damage assessment methodology (Sinaba et al., 2012).

3.3.1 Inundation depth

The inundation depths and extents of a future flood have been determined by the modeling described above. One of the parameters required for flood damage calculation is ready and coherent at the international level.

3.3.2 Land-use categories

There are numerous databases available on the Meuse river basin but none covers the whole basin, except the European Corine Land Cover (CLC) database. Its resolution is quite large (1:100000). As a consequence, the figures from the AMICE damage calculation will be quite coarse compared to regional assessments. Since our goal is to evaluate the impacts related to climate change, not the exact damage of one flood, the CLC database is deemed sufficient (Sinaba et al., 2012).

For the damage potential analysis, the CLC data have to be aggregated into suitable damage categories. The transcoding of the CLC classes into damage categories permits the assignment of specific damage functions and monetary asset values to the considered damage categories. The 6 categories used are Settlement, Industry, Traffic, Agriculture, Forests and Others. The Traffic category is badly represented in CLC because of the coarse resolution. To solve this, we assumed that 5% of the mobile assets under the category Settlement are in fact cars and should be counted under Traffic. In the same way, 10% of the immobile assets under the category Settlement are in fact roads and parking and should be counted under Traffic.

Land-uses will change between the reference period (1971-2000) and the future ones (2021-2050 and 2071-2100) as a result of human development, but there is too little information about these changes. Furthermore, AMICE would have needed data with enough details to identify changes taking place within the flood-prone area. Within AMICE, we assume that no modification will occur to the land-use of the Meuse basin.

3.3.3 Asset values

The monetary assessment is preferably realized by using the regional asset value, representing the regional situations. The asset values of neighbour territories are indeed very different depending on the wealth and density of communities. The national asset values, which have been derived on the bases of national or regional account systems, have to be aggregated to match the CLC categories within the floodplains (Sinaba et al., 2012).

All Partners agreed to use the year 2009 as the price reference.

3.3.4 Damage functions

Damage functions represent the susceptibility of assets to the impact of water depth. The AMICE partners explored literature to identify damage functions corresponding to our 6 CLC categories.

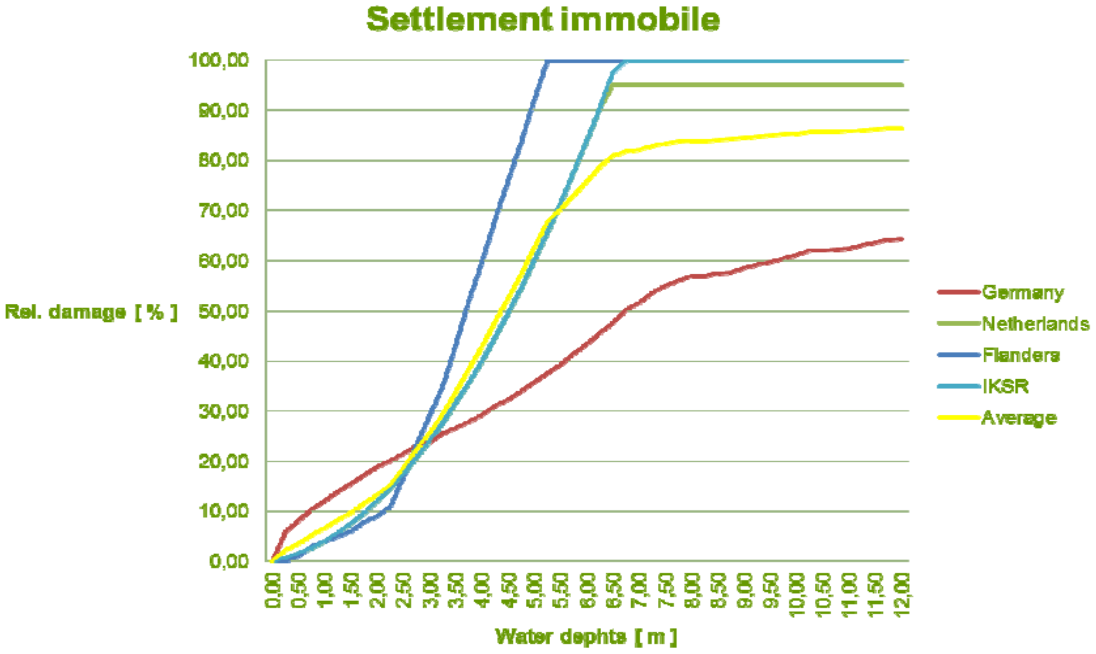

Fig. 5: Comparison of relative damage functions used in the Meuse countries for the category Settlement immobile (from AMICE – WP1 meeting – April 6th, 2011 – Aachen)

Damage functions can be built in two different ways (Sinaba et al, 2012):

- empirical derivation by means of real flood data and damage surveyed after flood events;
- synthetic data estimated from standardized property types;

and can result from the combination of functions from subcategories. Universality and transferability of these functions is often criticised.

A comparison of the regional damage functions revealed essential differences (see Fig. 5).

Thus, an assessment of potential damage for particular objects, which might be assumed to be identical across regional borders, would lead to different results as the applied damage functions differ. Therefore common damage functions (see Fig.6) are generated, with the intention that risk results are not biased by the use of regional damage functions.

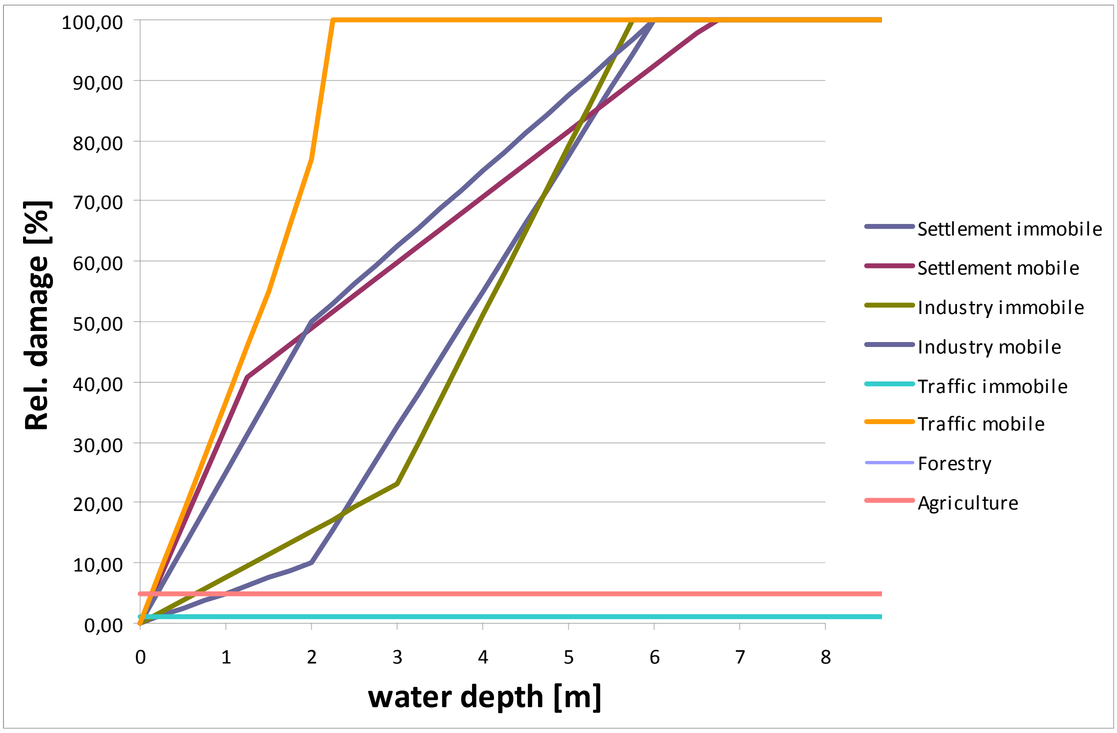

Fig. 6: Relative damage functions for the 6 CLC categories, for mobile or immobile assets, as used in the AMICE approach (Sinaba et al., 2012)

3.3.5 Partially common approach versus AMICE approach

Since damage functions can vary greatly, we decided to carry out a comparative analysis. The intention is to show the impacts of the variation of input parameters in damage calculation methodologies. The comparative analysis was conducted on the Rur basin and comprises three approaches: the existing origin regional approach, the partially common approach and the AMICE approach (Sinaba et al. 2012).

The regional approach is based on the specific region's available land use data, which are predominantly displayed in a higher resolution than the CORINE data. Thus the damage categories differ to the partially common and the AMICE approach.

The partially common approach is based on a common land use data set and the unified damage categories. The damage categories are linked with the regional damage functions and asset values.

Within the AMICE approach, the CLC based damage categories and common damage functions are applied.

In Fig.7, the results of the comparative analysis between the regional approach, the partially common approach and the transnational AMICE approach are depicted. The application of land use data with a courser resolution in the partially common approach results in a huge increase of damage, especially in the agricultural sector. With the adaptation of the input parameters (damage functions and asset values) to the transnational Meuse basin, a harmonization of the regional approaches were achieved, resulting in smoothed discrepancies.

The comparative analysis still has to be performed on other territories and conclusions may evolve.

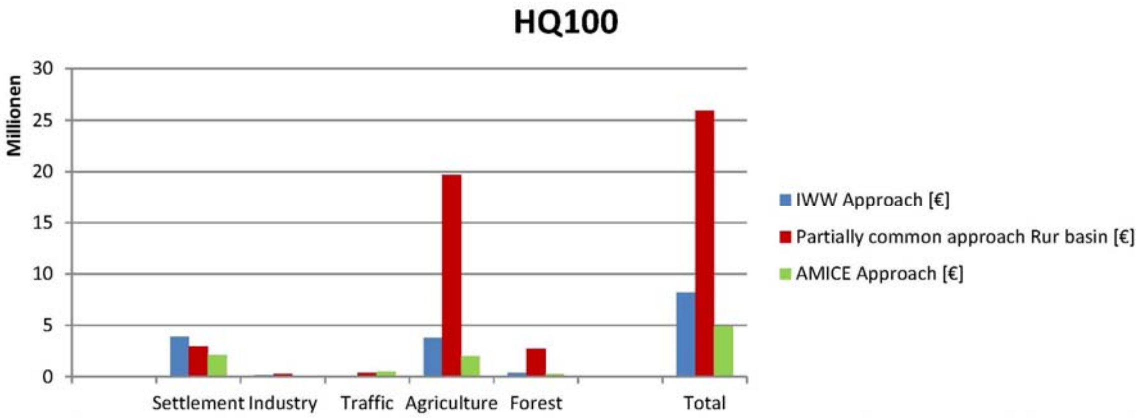

Fig. 7: Flood damages (in million Euros) for each category and for three approaches on the Rur basin. The river discharge would lead to a 100 years return period flood on the Meuse (reference period 1971-2000)

4 Forthcoming steps

The results of the hydraulic modelling and the results of the damage potential analysis will be combined to calculate the flood risk for the present state and the future scenarios. Due to the inaccuracies, simplifications and high inherent uncertainties of all input parameters in the overall chain of the risk calculation procedure, the absolute consideration of risk can lead to very uncertain results. Hence, within AMICE, a comparative risk analysis is conducted. The relative risk results will then be used to point-out:

- which reach of the Meuse is most affected due to future floods,
- which land-use category is most affected by higher floods related to climate change.

These two elements will help us identify where to act in priority and which actions have to be taken. The results will be included in the Meuse adaptation strategy.

Partners are also discussing how to display these results so the decision makers understand them easily and can take the right decisions. The scale used to draw these maps is of high importance. A high resolution could spark opposition from the local population and lead to downright refusal because of the high uncertainty related to climate change and modeling. The AMICE results for the wet scenario represent only one of the many possible futures. A low resolution would draw attention on the Meuse River and major cities, disregarding the tributaries and smaller communities where action should nonetheless be taken.

A parallel study is also undertaken on the topic of low-flows, which are quite a new threat for the Meuse. The damage calculation approach is completely different from the flood losses calculation, as impacts vary with the water uses. The focus is put on agriculture, energy production and inland navigation. Drinking water seems less directly affected by a low-flow situation as other water sources can be temporarily used such as water reservoirs or groundwater.

5 Conclusion

Transnational cooperation brings many benefits to the involved Partners. Models have been improved and updated. A method now exists for data to be exchanged between the national models. New methodologies and data become accessible. An effort to fit common data at the French-Belgium boundary was performed. Comparisons with the neighbour countries help criticize your own results and quickly understand inaccuracies.

There is still a lot that can be done on the Meuse basin: applying climate change scenarios to more tributaries, taking into account future land-use evolutions, studying the impacts not only on the economy but also on the environment and social organisations, etc. However, AMICE already achieved to build up a partnership of water experts that are willing to continue cooperation and to set common methodologies and processes for the whole Meuse basin.

6 References

Detrembleur et al. (2012), to be published: Effect of climate change on river Meuse, Hydraulic modelling from spring to mouth. AMICE – WP1 – Action 6 – technical report

Drogue et al. (2010): Analysis of climate change, high-flows and low-flows scenarios on the Meuse basin. AMICE - WP1 – Action 3 – technical report.

European Environment Agency (2007): Climate change and water adaptation issues. EEA Technical Report No 2/2007. Copenhagen - ISBN 978-92-9167-917-1

Oudin et al. (2005): Which potential evapotranspiration input for a rainfall-runoff model? Part 2 - Towards a simple and efficient PE model for rainfall-runoff modelling. J. Hydrol. 303(1-4), 290-306

Sinaba et al. (2012), to be published: Quantification of the impacts of future floods on the economy in the international Meuse basin. AMICE – WP1 – Action 7 – technical report

Van der Linden P., and J.F.B. Mitchell (eds.) (2009): ENSEMBLES: Climate Change and its Impacts: Summary of research and results from the ENSEMBLES project. Met Office Hadley Centre.

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