

# Adaptation of the Meuse to the Impacts of Climate Evolutions



The aim of this presentation is to give an overview of what has been achieved in Action 6 of the AMICE project : the hydraulic modeling of the river Meuse from spring to mouth.

# Content

- Hydraulic modelling within AMICE
- Existing models and modelling procedures
- Transnational modelling methodology
- Preliminary results: consistency check at the borders
- Inundation characteristics for 2021-2050 and 2071-2100

Contributors

WP1 partners & **hydraulic modellers:**

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Coordination

HACH-ULg: S. Detrembleur & B. Dewals

All this is a team work and most Partners of Workpackage 1 have been involved. Especially the hydraulic modellers, that are also present today, can provide additional insights on their tools and results.

# I - Hydraulic modelling within AMICE

Input:

Scenarios of climate change and hydrology

**WP1: Impacts of future floods and low-flows: an analysis of climate-change-induced floods and low-flows**

**WP2: Natural Water retention, an example of non-structural protection against future water-related risks**

**WP3: Control of water quantities, an example of structural protection against future water-related risks**

**WP4: Crisis management software, a preparedness measure against future water-related risks**

Output:

Common Strategy of Adaptation

Evaluation of measures based on cost-benefit analysis (CBA)

The evaluation of AMICE adaptation measures need to be consistent with standard approaches such as cost benefit analyses. To do so, we need to know the flood risk and especially the avoided flood risk. This requires the evaluation of the damage induced by the inundation. This damage depends on the hazard, involving hydrology with rainfall-runoff modeling, and hydraulic modeling providing inundation characteristics. Such a comprehensive approach enables to evaluate the wide range of adaptation measures we are interested in in the AMICE project.

# I - Hydraulic modelling within AMICE

Hazard modelling

Vulnerability modelling

## AC 3: Scenarios

FLOOD

## AC 6: Hydraulics

INUNDATION

## AC 7: Risk

DAMAGE

e.g. water retention  
(incl. large reservoirs)

e.g. enhanced river conveyance  
(maintenance dredging, dikes ...)

e.g. ban on building in floodplains,  
reduced vulnerability of assets ...

## AC 8,9: Evaluation of measures

Housing



Trade,  
industry

Forest,  
crops ...



Infra-  
structure



The hydraulic modelling task is a key part of the AMICE project and has numerous interactions with the rest of WP1 and the project itself. Action 6 takes into account the results from Action 3 and feeds the other parts of the Project with its results.

# Content

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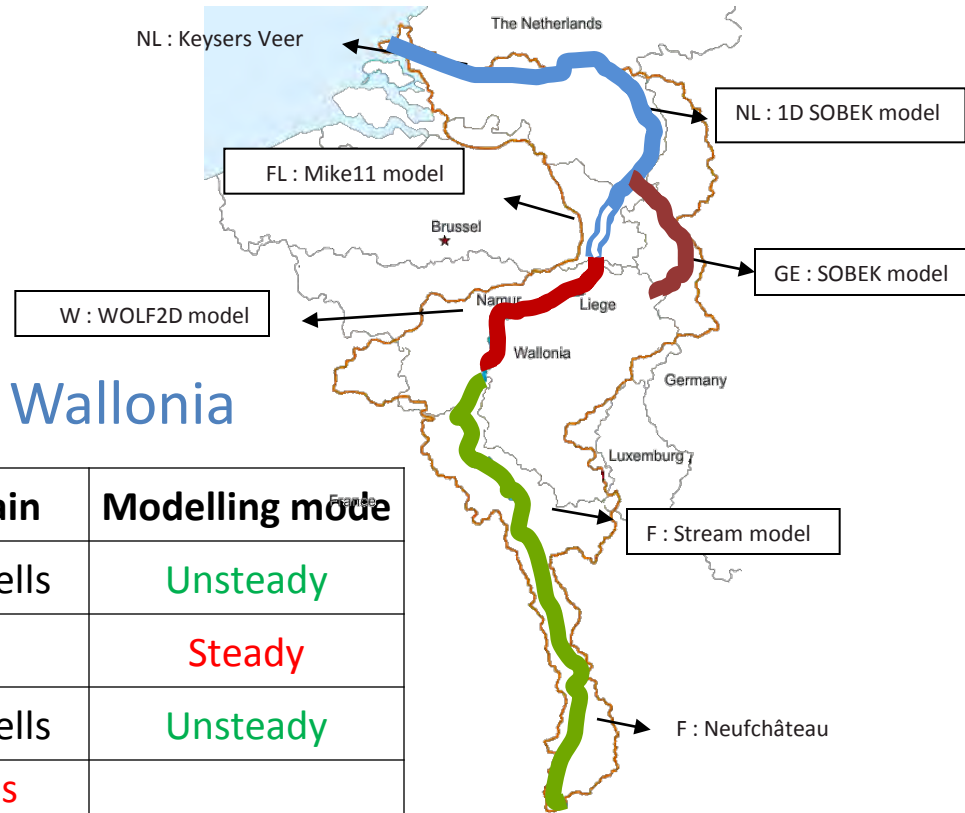
# II - Existing models and procedures

*in the perspective of elaborating a transnational modelling methodology*

Questionnaire

Hydraulic models available from spring to mouth

Steady modelling in Wallonia



	Main stream	Flood plain	Modelling mode
F	1D	Storage cells	Unsteady
W	2D ( $\Delta x = \text{max. } 5 \text{ m}$ )		Steady
FL	1D	Storage cells	Unsteady
NL	1D	1D Cross sections	Unsteady
	(2D Waqua / Not in AMICE)		
GE	1D	Storage cells	Unsteady

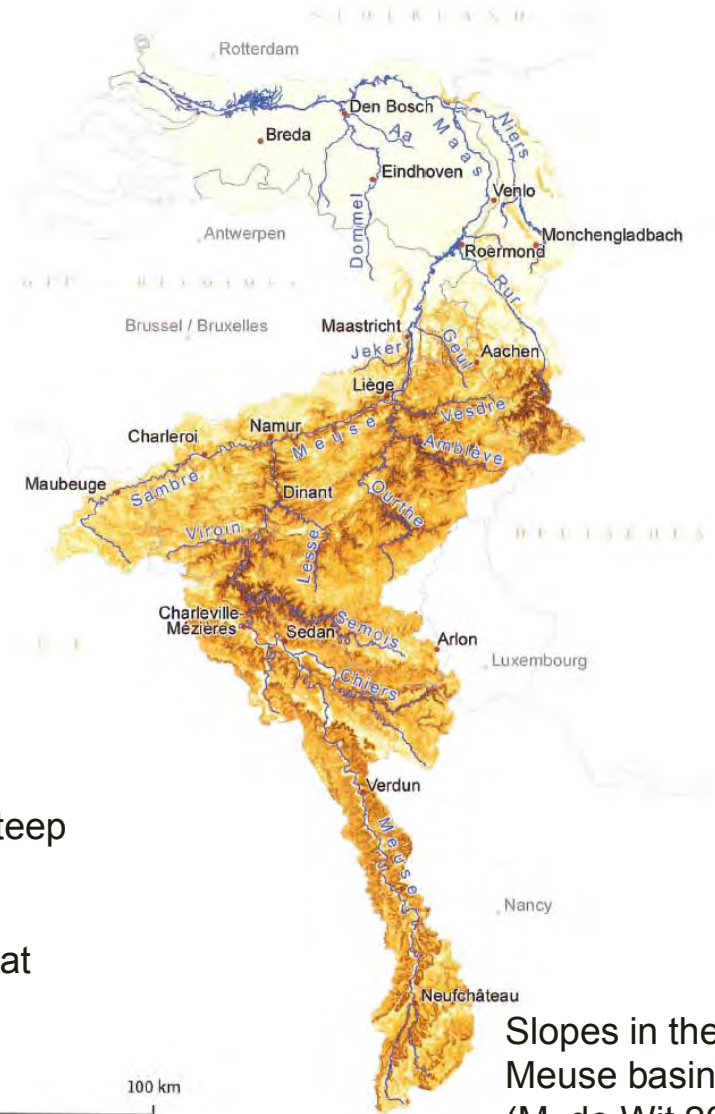
We have sent a questionnaire to the WP1 Partners and processed the results. It came out fast that hydraulic models exist on the river Meuse from Neufchâteau down to Keizersveer, so almost from spring to mouth. Nevertheless, they differ very much in their type.

Only Wallonia uses a complete 2 dimensional model with the complete shallow water equations and with a fine grid spacing of 5 meters. Our unsteady model *WOLF* is run in steady mode. This can be explained by the characteristics of the valley.

# II - Existing models and procedures

*in the perspective of elaborating a transnational modelling methodology*

No significant damping of the flood waves in the central part of the basin



Slopes in the Meuse basin (M. de Wit 2008)



The downstream part is nearly flat with large floodplains and a large storage capacity which is susceptible to damp the flood wave. An unsteady approach is necessary.

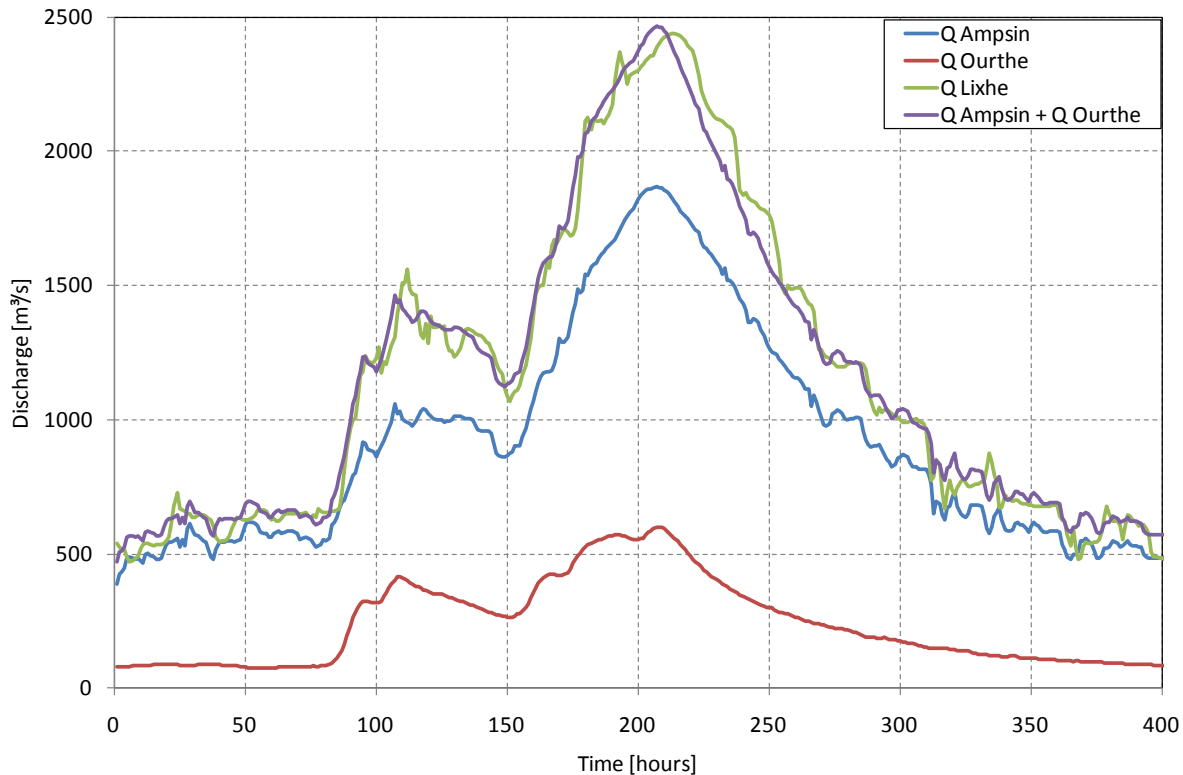
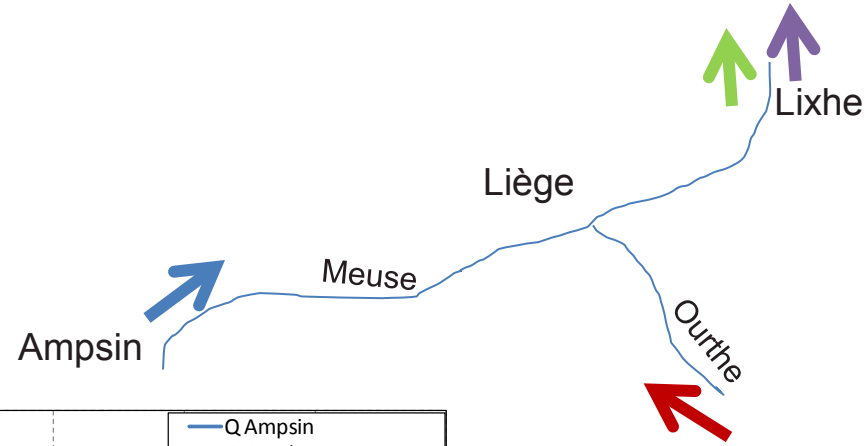
An unsteady model is relevant as well in the most upstream part.

In contrast, in the central part of the basin, especially where the river crosses the Ardennes, the valleys are much more narrow. We verified that the storage capacity is so small that you hardly have a damping of the flood wave. A steady approach makes senses.

# II - Existing models and procedures

*in the perspective of elaborating a transnational modelling methodology*

No significant damping of the flood waves



Measured hourly data at gauging stations

These are examples of measured hydrographs along the river Meuse nearby Liege during a flood event. The blue and red lines represent input discharges from the upstream reach and the tributary Ourthe. The green line represents the measured outflow downstream. The purple line is the sum of the inflows. You can see that along such a reach, there is no damping.

## II - Existing models and procedures *in the perspective of elaborating a transnational modelling methodology*

Outcomes of Ac3      Input data for AC6:

Common hydrological impact variable for high flows:  $Q_{hxa100}$  = annual maximum hourly discharge of 100 year return period (Q100)

Hydrological scenarios:  
increase in Q100 values of **+15% for 2021-2050** and  
**+30% for 2071-2100**

[Meeting in Metz 3 September 2009, Ac3 report June 2010]

The gauging stations we used on the Meuse basin have time series of more than 30 years. The Borgharen station has 100 years of measurements without a single day missing, even during World War 1 and World War 2.

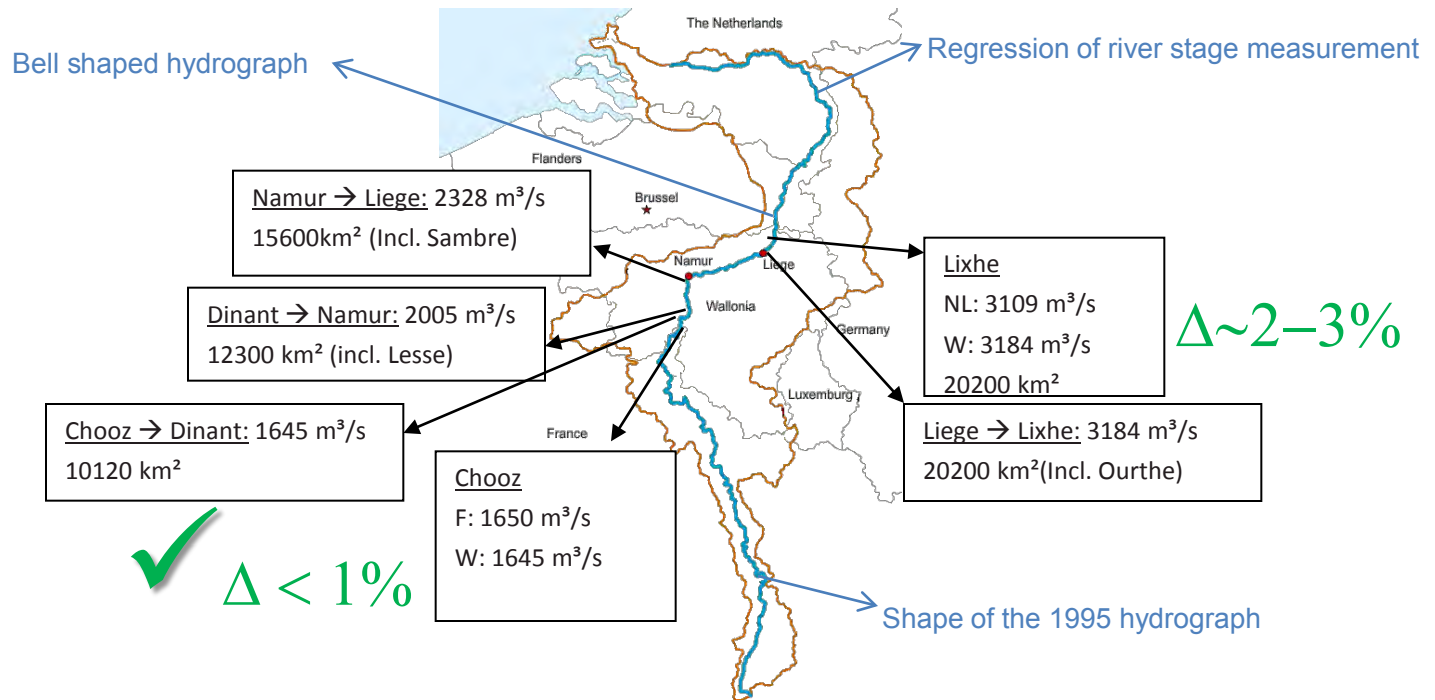
The statistical methods used to evaluate the Q100 value differ but nevertheless give consistent results.

There are also differences in the shapes of the hydrographs in the regions where unsteady models are used.

# II - Existing models and procedures

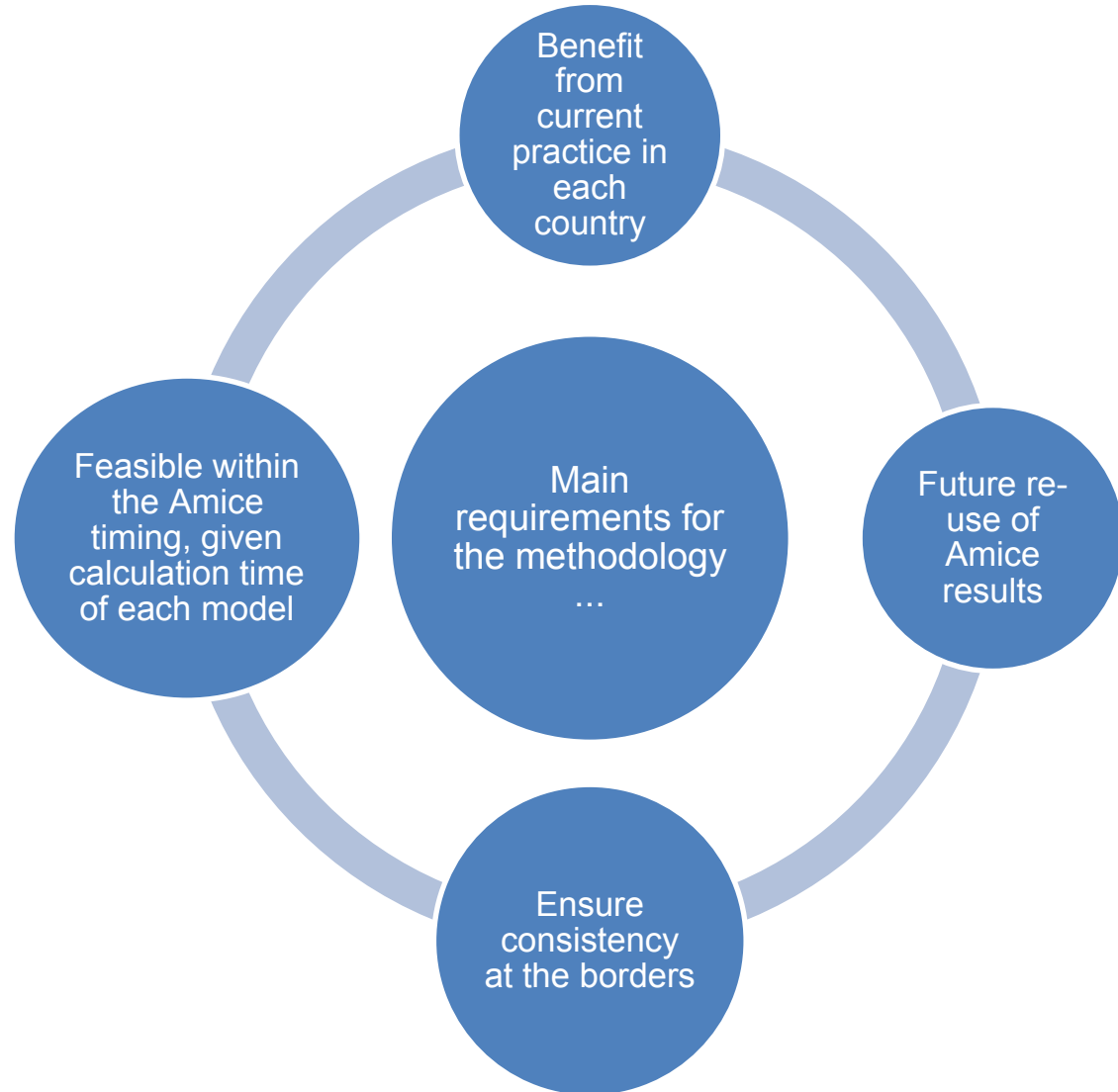
Main gauging stations have more than 30 years of measurements (100 years in Borgharen)

Applied statistical methods differ along the Meuse; Nevertheless reasonable agreement at the borders



# III - Transnational modelling methodology

*for consistent transnational modelling  
and sound comparison of models outputs*



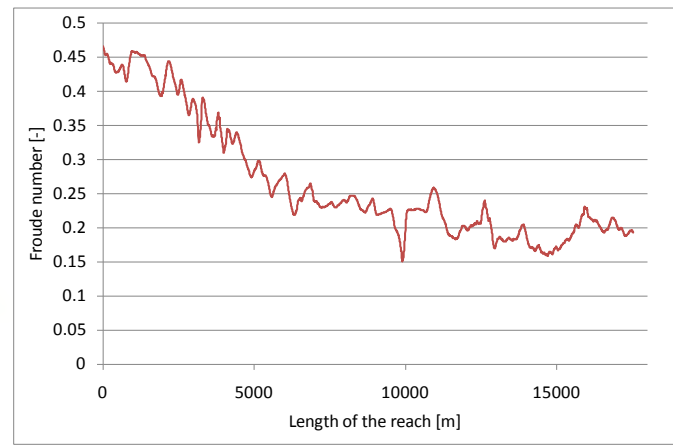
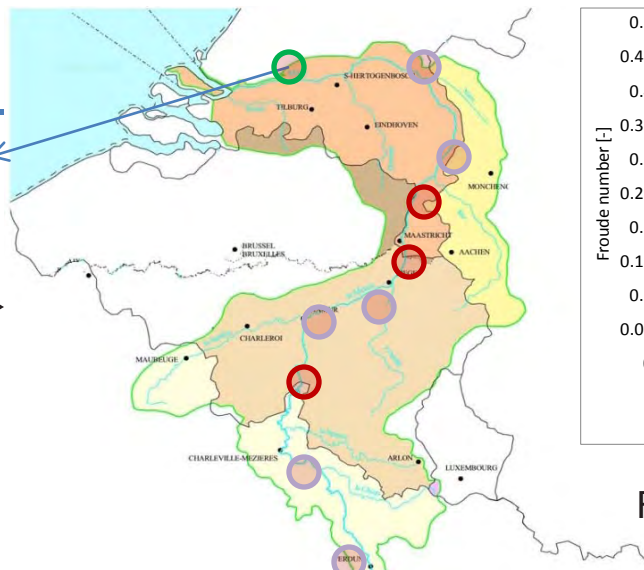
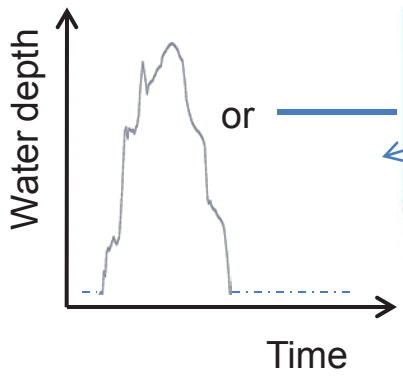
# Sequential vs. parallel runs of the models

The Meuse remains subcritical even for high flows ( $Fr < 1$ )

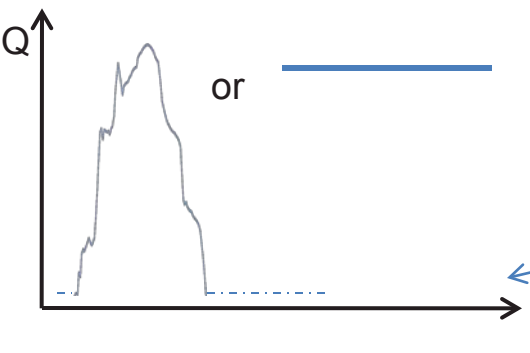
- Downstream BC = water depth
- Upstream BC = discharge

**No sense to run models sequentially**

- Measured data or scenarios at the outer limits
- Depends on the other models
- Discharge input from tributaries



Froude number along a reach of the Meuse in Wallonia for  $Q_{100}$

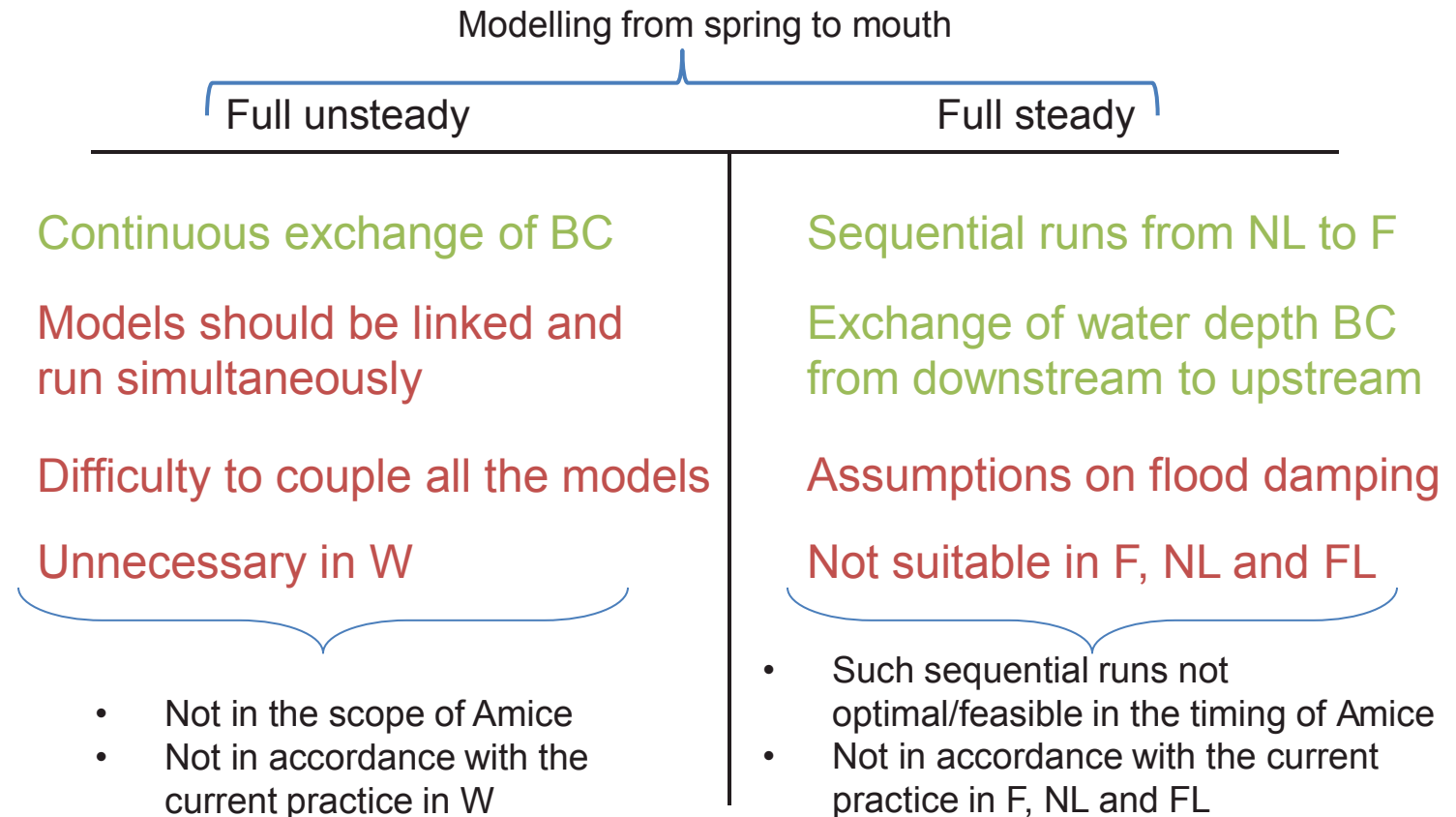


A main concern was whether to run the models sequentially or in parallel. To run a hydraulic modeling in subcritical regime, one need to define boundary conditions (BC) both upstream and downstream. So that makes no sense to run the models sequentially because if you run models from upstream to downstream, you miss the boundary conditions downstream of each model. The same applies if you wish to run a model sequentially from downstream.

# Steady vs. unsteady simulations ?

F, FL and NL models are unsteady, while the B model for inundation modelling is run in steady mode

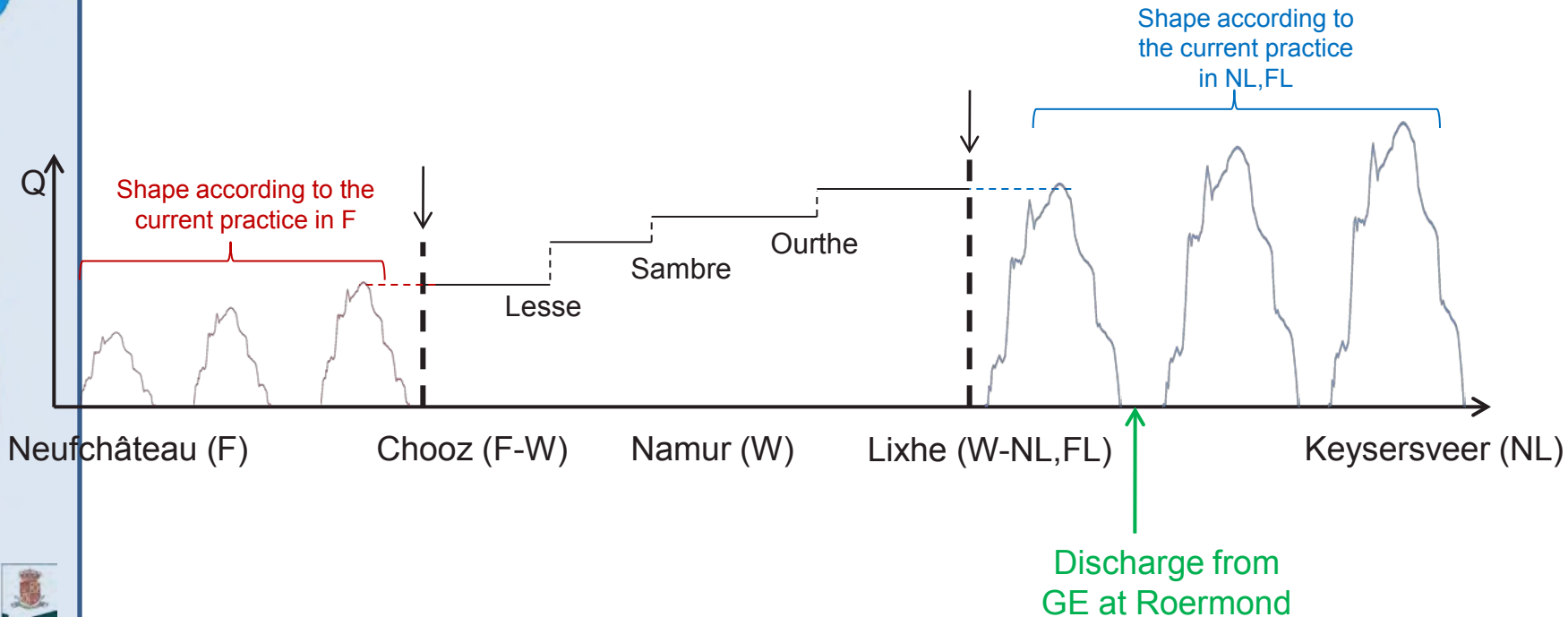
The common methodology to be followed in AC6 should accommodate this difference in modelling procedures



# Overall procedure

→ Trade-off methodology, combining unsteady and steady modelling, in accordance with

- existing practice in each region
- the storage capacity of the floodplains
- enabling parallel (instead of sequential) runs of the models
- ensuring reasonable continuity of the results at the borders



The peak discharge of the hydrograph used in France matches the uniform discharge used in the upstream reach of Wallonia, and the same applies between Wallonia and the Netherlands.

# Overall procedure

## First step

1<sup>st</sup> runs in parallel based on boundary conditions prescribed from **extrapolated available measured data** instead of transferred from one model to the next

## Second step

Consistency of the simulation results at the borders between models has been checked

A second run (limited in space) of models has been undertaken accounting for boundary conditions **transferred from the adjacent models**

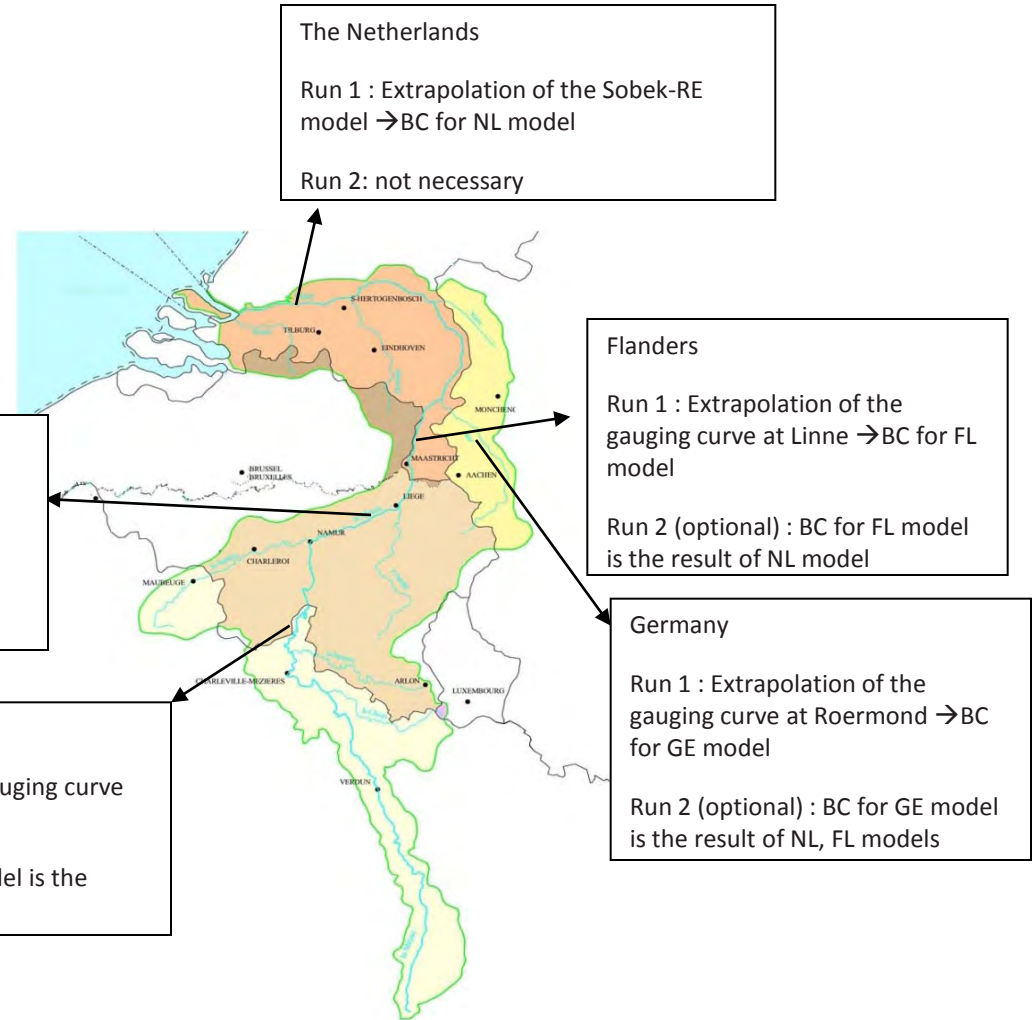


All models are run a first time using boundary conditions from extrapolated measured data. This is possible because we have high discharge values in the time series available.

With this methodology, we obtained finally consistent results at the borders.

# Handling boundary conditions

## Downstream



## Summary of the methodology

1. Working with a mixed unsteady and steady approach
2. Run the models in parallel to save time
3. Optional second run (with limited spatial extension) to ensure consistency at borders
4. Modelling  $Q_{100}$  discharge with the 2 *perturbation factors* obtained from Ac3 (based on the transnational WET climate scenario)



# IV - Consistency check at the borders

Coordinates of upstream and downstream boundaries of each model

Providing location of the comparisons points

- expressed in relevant projection systems
- translated into a common coordinate system WGS84: Lat/Long

Points are available in a .kml file (easily loaded by Google Earth)

	Chooz - FR		Chooz - W		Lixhe - W		Lixhe - NL		Borgharen - FL - NL		Roermond - GE		Roermond - NL		Linne - FL - NL	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
Lambert 1 [m]	777786	277445	777771	277428												
Lambert 72 [m]	182638	95515	182620	95500	243000	160930	242663	161676	243441	174107					258594	207578
Rijksdriehoek [m]					176103	306783	175810	307627	176724	319953	196687	356608	196687	356608	192331	353211
German coord system ?											2498735	5673585	2498735	5673585		
Long/Lat [°]	4.826	50.170	4.825	50.170	5.687	50.751	5.682	50.758	5.696	50.870	5.985	51.198	5.985	51.198	5.921	51.168

Offsets in altitude due to different system of reference :

$$Z_W = Z_F + 1.794 \text{ [m]} \rightarrow \text{Topographic measurement of the gauging station in Chooz}$$

$$Z_{W,FL} = Z_{NL} + 2.32 \text{ [m]} \rightarrow \text{Confirmed by both W and NL partners, as well as historical documents}$$

[http://nl.wikipedia.org/wiki/Tweede\\_Algemene\\_Waterpassing](http://nl.wikipedia.org/wiki/Tweede_Algemene_Waterpassing)

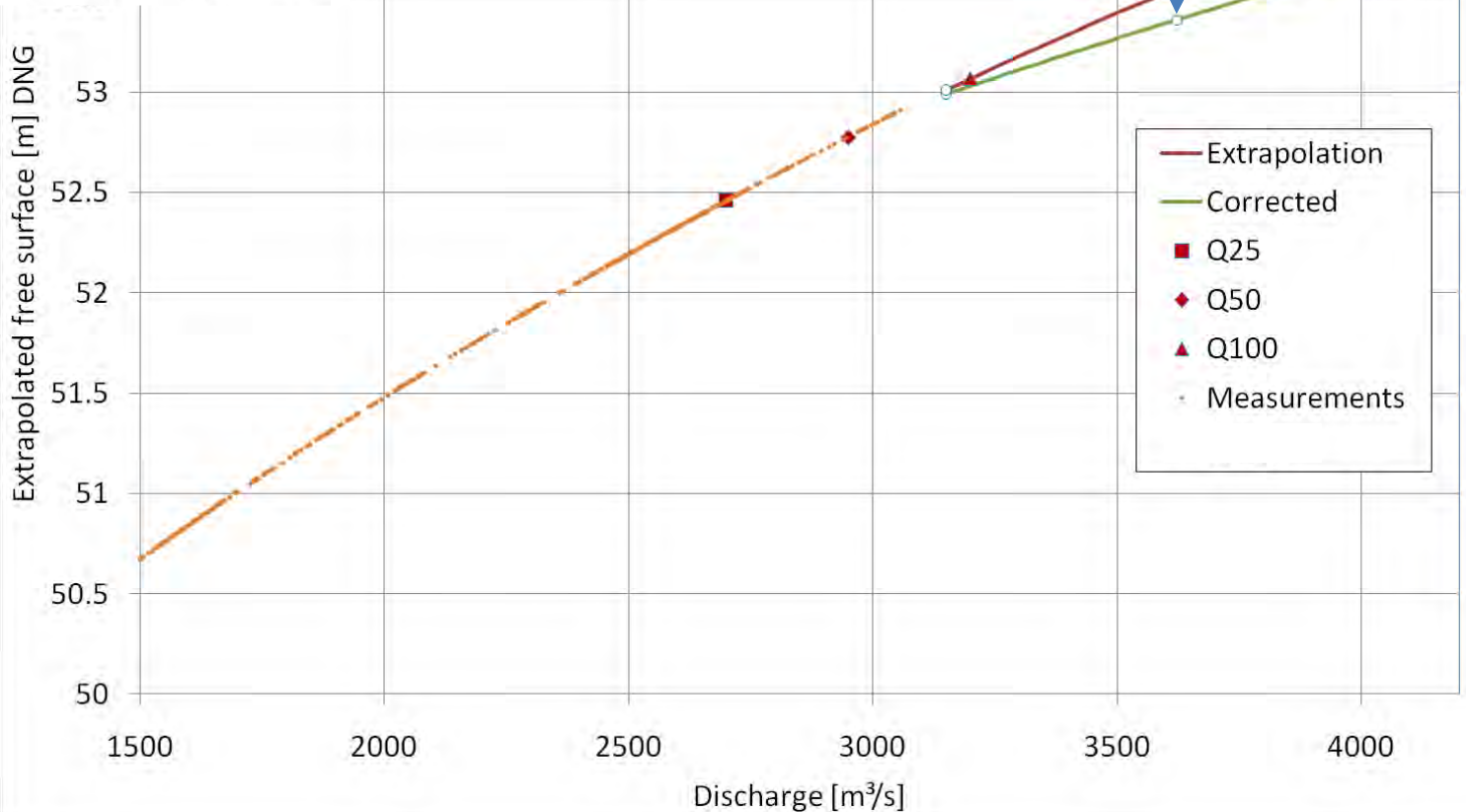
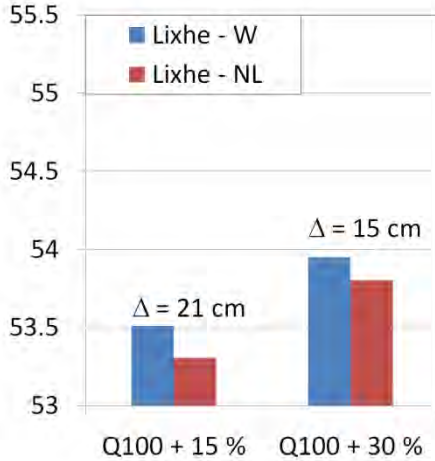
A first issue was to translate all gauging points in the same coordinate system because each region has a different one.

# Comparison at borders (NL/W) after 1<sup>st</sup> run

Free surface for Q100 (max historical discharge) are consistent (52.94 vs 52.99 m DNG)

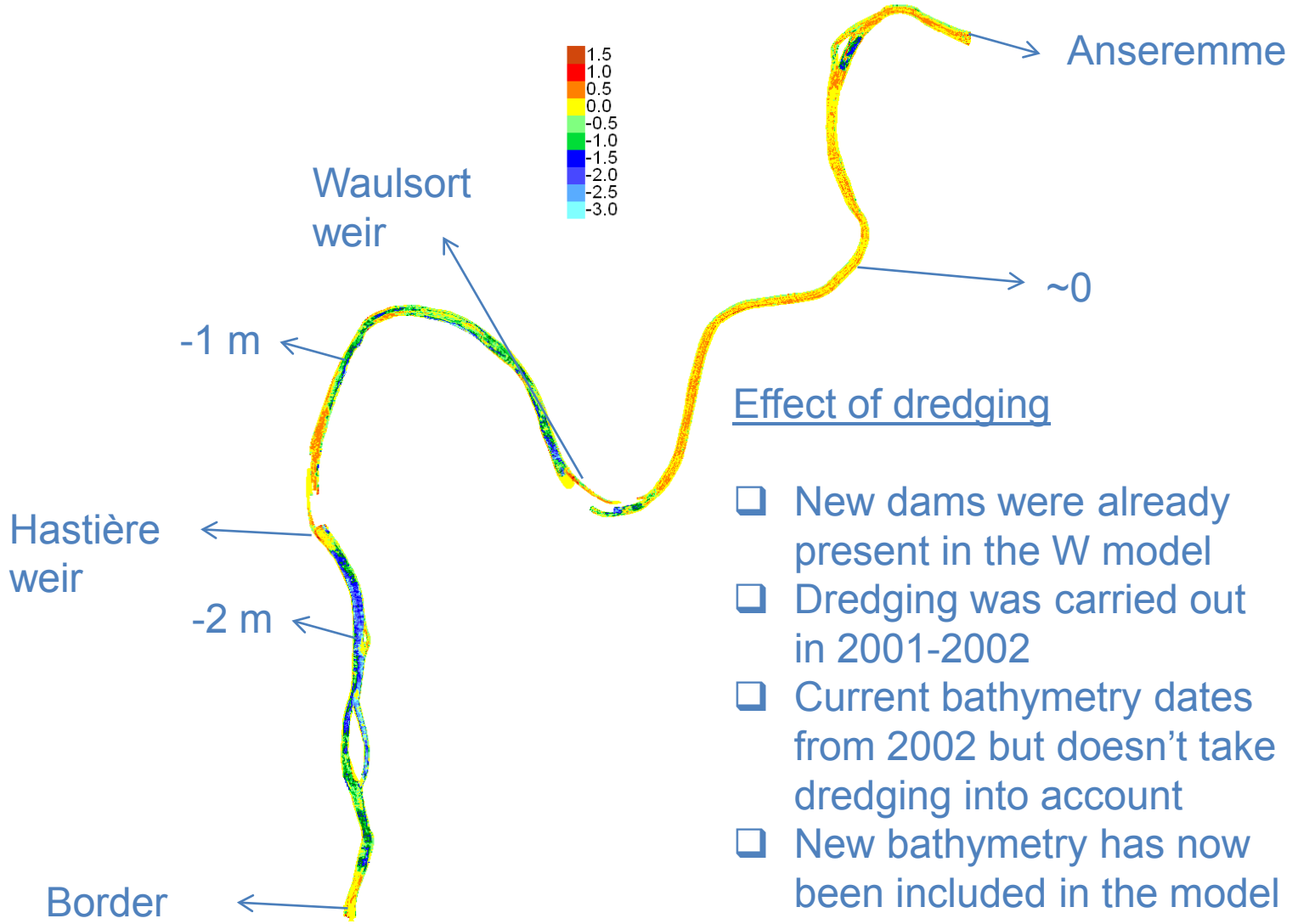
Extrapolation of the H-Q relation to be corrected in W

Second run needed



The red curve is the result of the Walloon 1st run. The green curve is provided by the Dutch model. We corrected our extrapolation and ran the model a second time.

# Comparison at borders (F/W)



## Effect of dredging

- New dams were already present in the W model
- Dredging was carried out in 2001-2002
- Current bathymetry dates from 2002 but doesn't take dredging into account
- New bathymetry has now been included in the model

Effect of dredging on bathymetry between 2002 and 2007 [m]

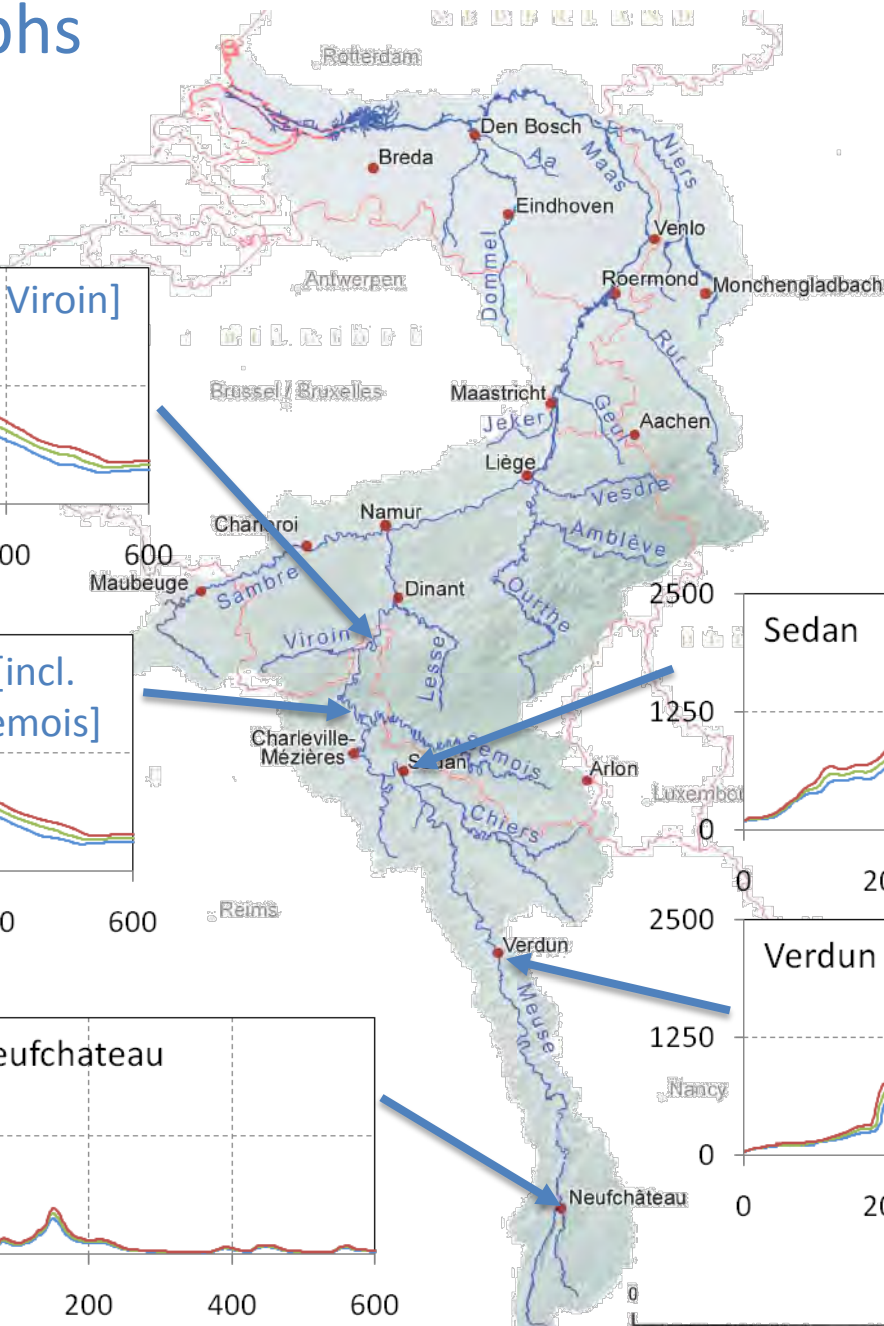
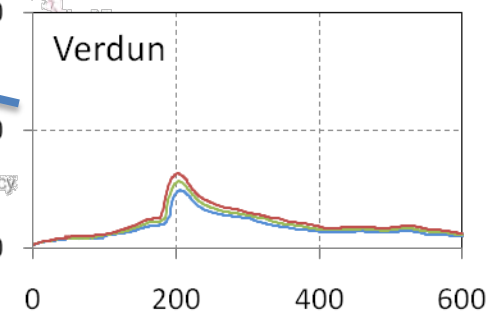
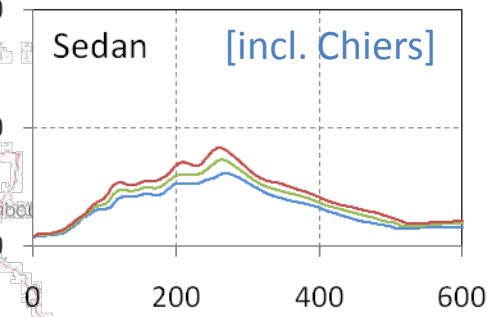
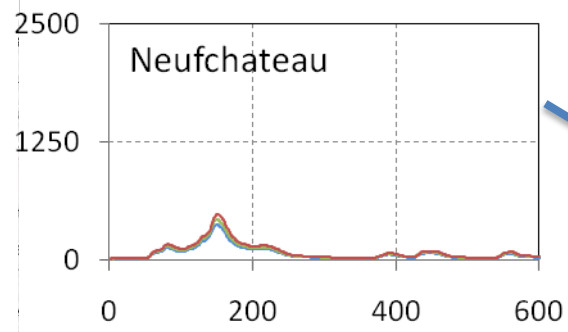
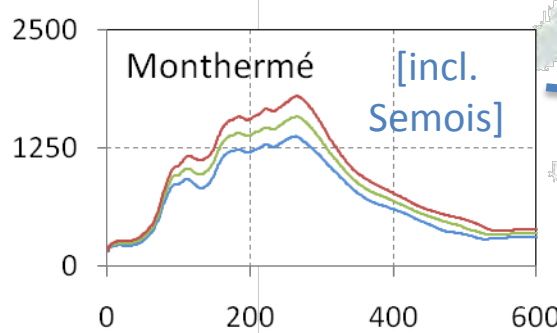
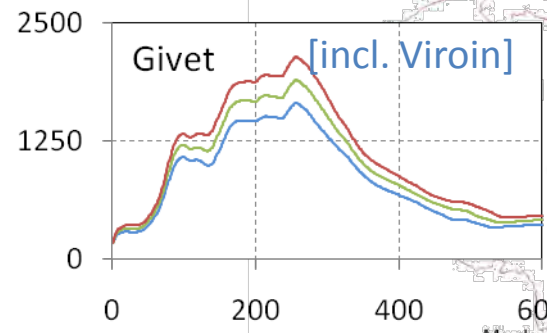
When comparing results between France and Wallonia, the dredging operations that had taken place in the border reach had important impact and a new bathymetry had to be included in the model.

## II - Preliminary results

- Hydrographs
- Maximum water levels
- Flooded areas  
[available so far for W, FL & NL]
- Volume stored in the floodplains  
[available so far for W, FL & NL]
- Detailed analysis of hotspots  
[to be presented in  
forthcoming AC6 report]



# Hydrographs



— Q100  
— Q100+15%  
— Q100+30%

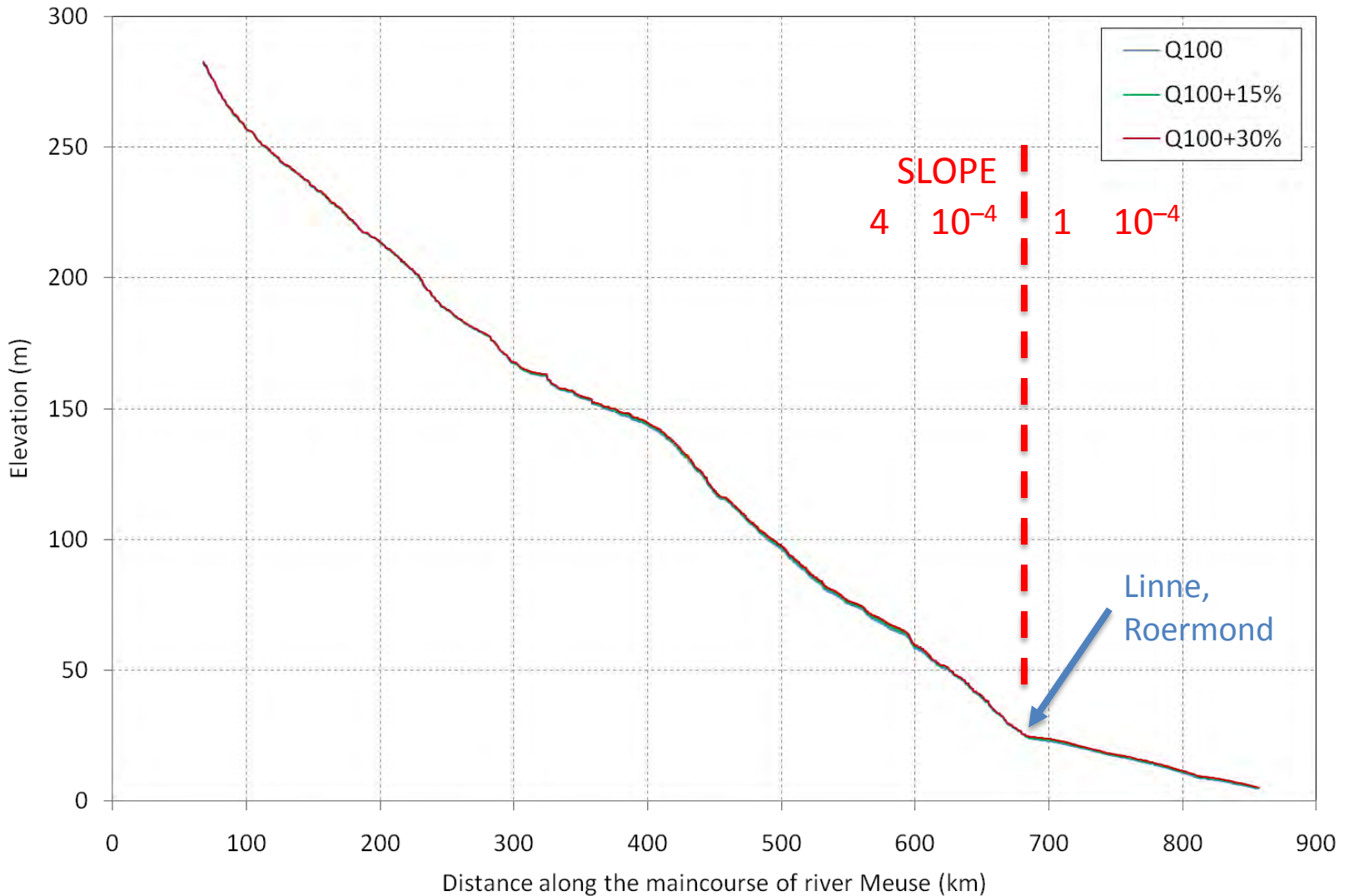


(M. de Wit 2008)

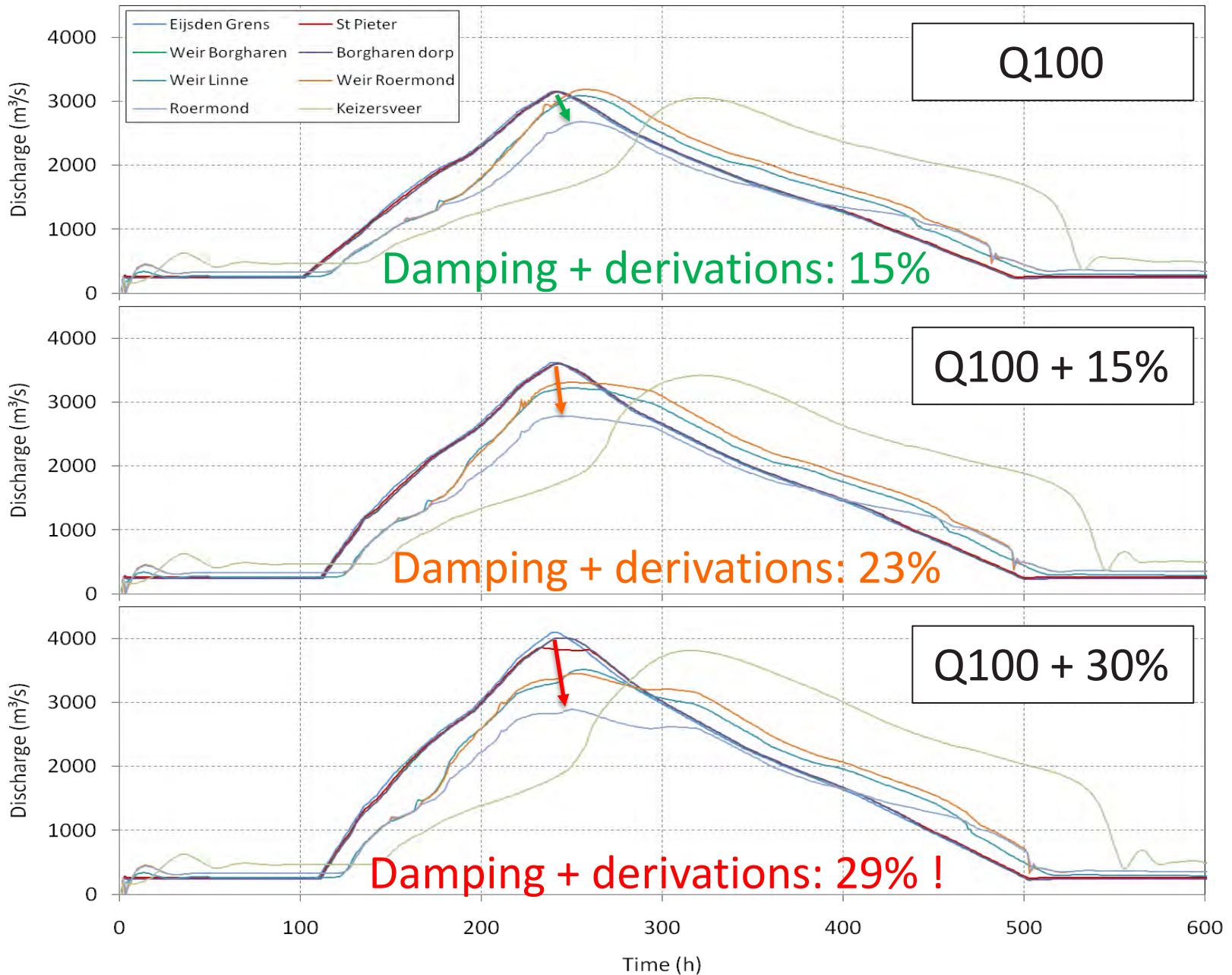


The hydrographs in France have the shape of a reference flood such as 1993 or 1995. As you move further downstream, the hydrographs increase in terms of peak discharge and you clearly see the inputs from the main tributaries. This monotonous increase shows that the tributaries have a higher impact than the damping effect of the floodplain.

# Maximum water elevation (m)

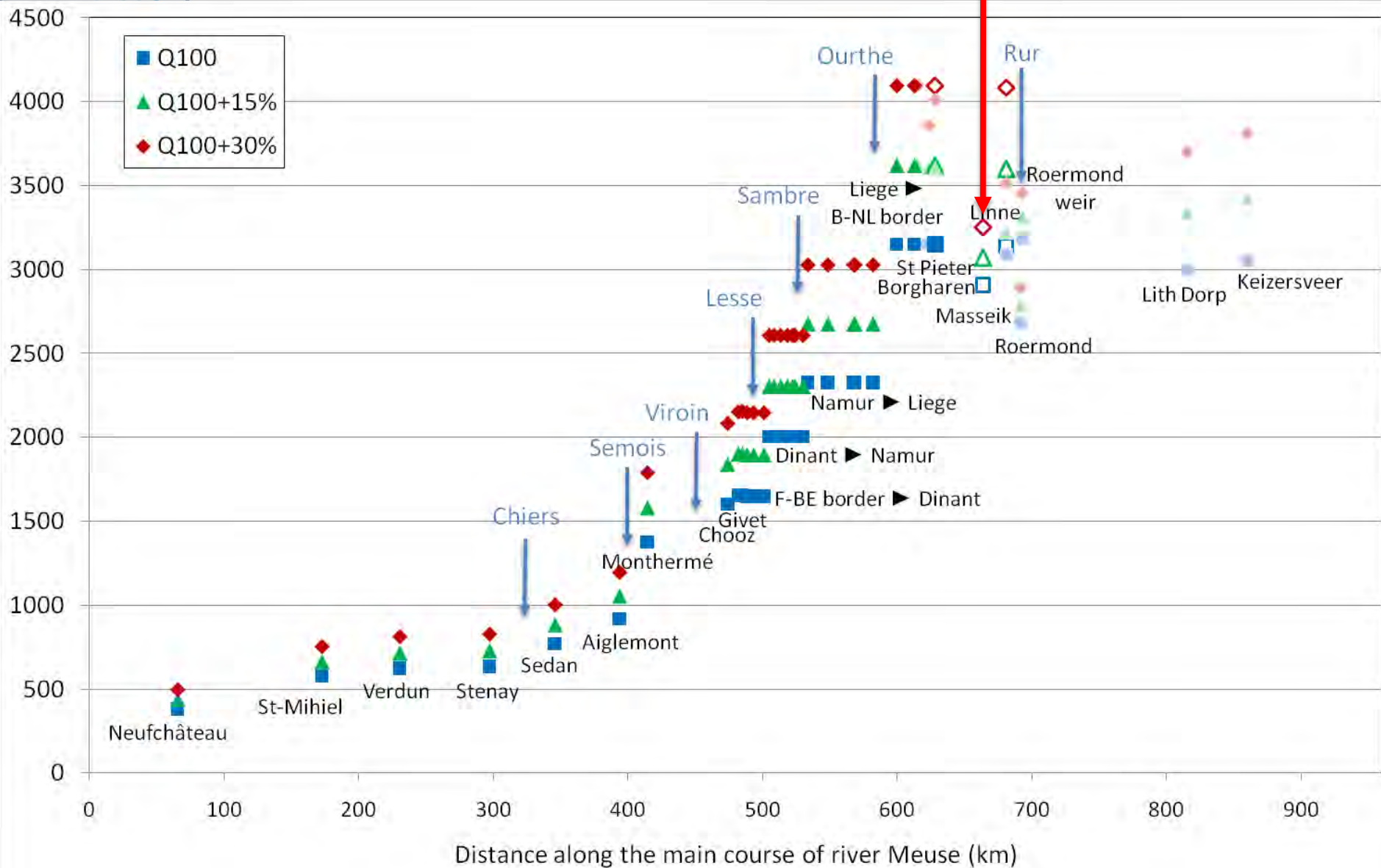


# Hydrographs in the NL



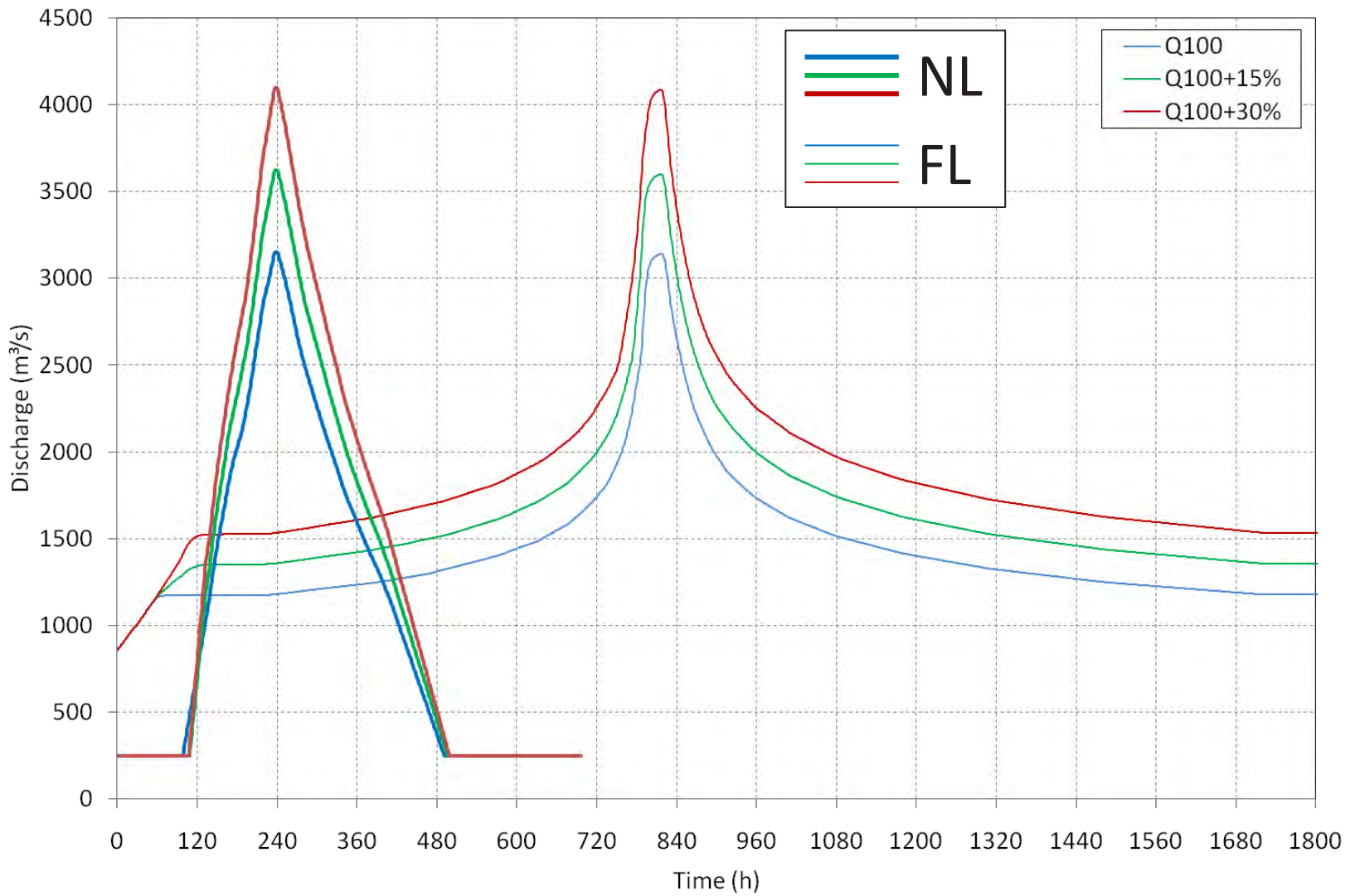
Here are the hydrographs as propagated by the Dutch model between Eijsden Grens and Keizersveer. Between Eijsden Grens and Roermond, you see there is a significant damping. The damping effect is twice bigger for Q100+30% than for Q100. This is explained by an increase of storage in the flood plain.

# Peak discharges (m<sup>3</sup>/s)



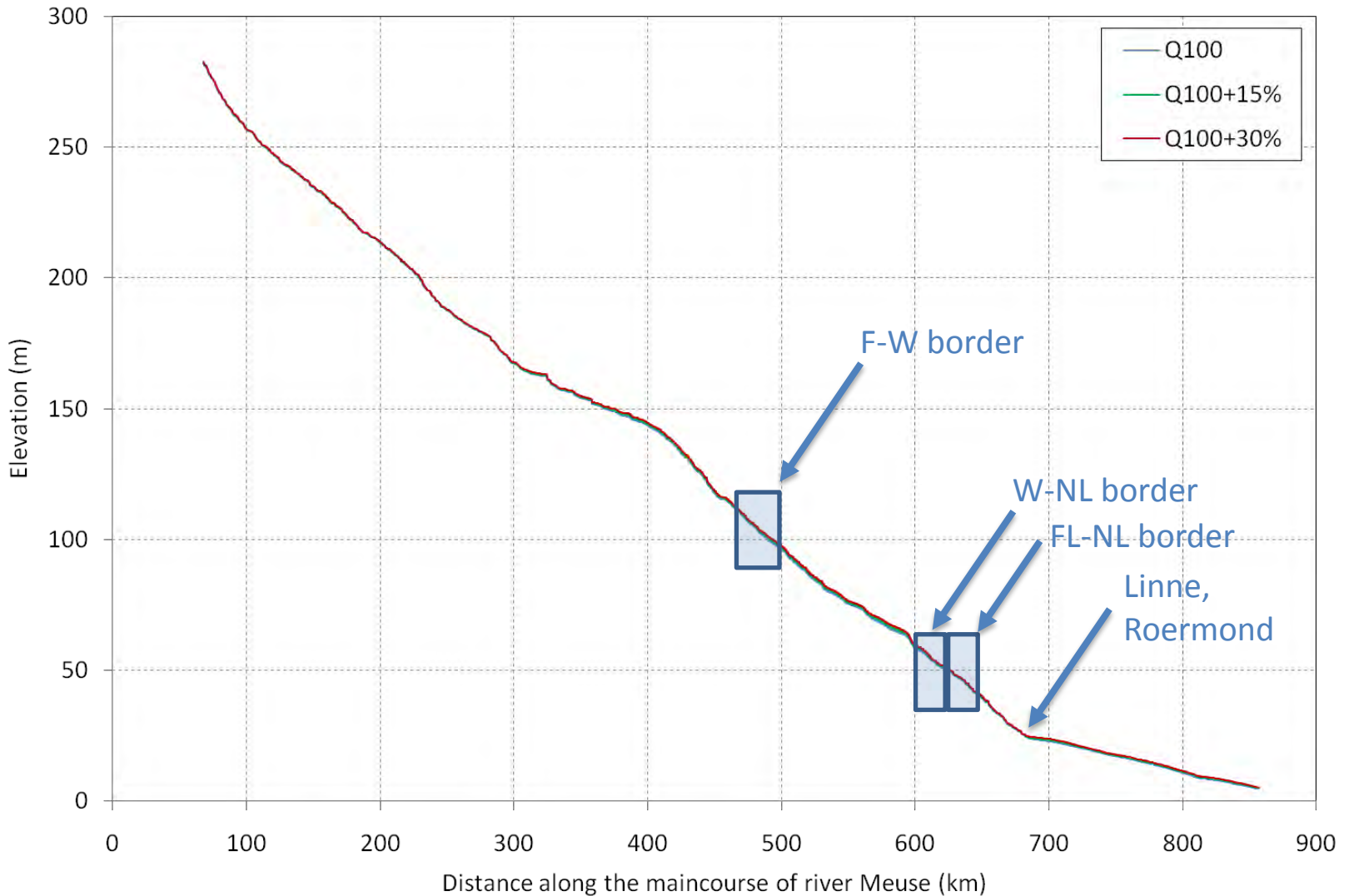
In this graph I have added a few points. The ones with a white background are the points obtained by the Flemish model. There is a rather low discharge in Maaseik. This is explained by a derivation of the water through the Oude Maas. The Flemish model seems to damp much less the hydrograph than the Dutch one. This may be related to the shape of the hydrograph.

# Hydrographs used in NL vs. FL

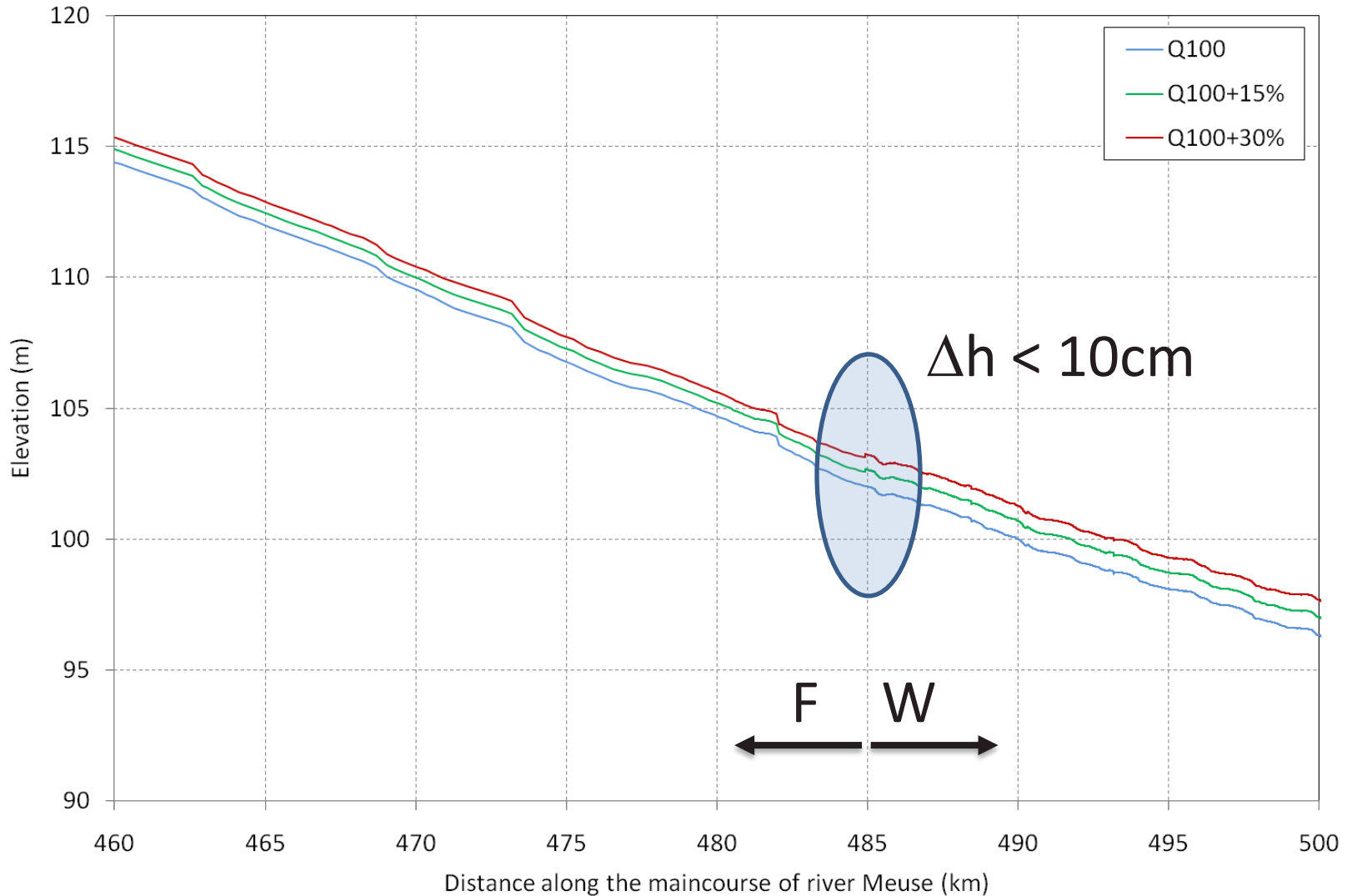


Though the peak discharge have been made consistent, the volume is totally different, the running time is totally different but the results are quite consistent in terms of water depth. This is because there is no big a difference in the volume above a certain threshold.

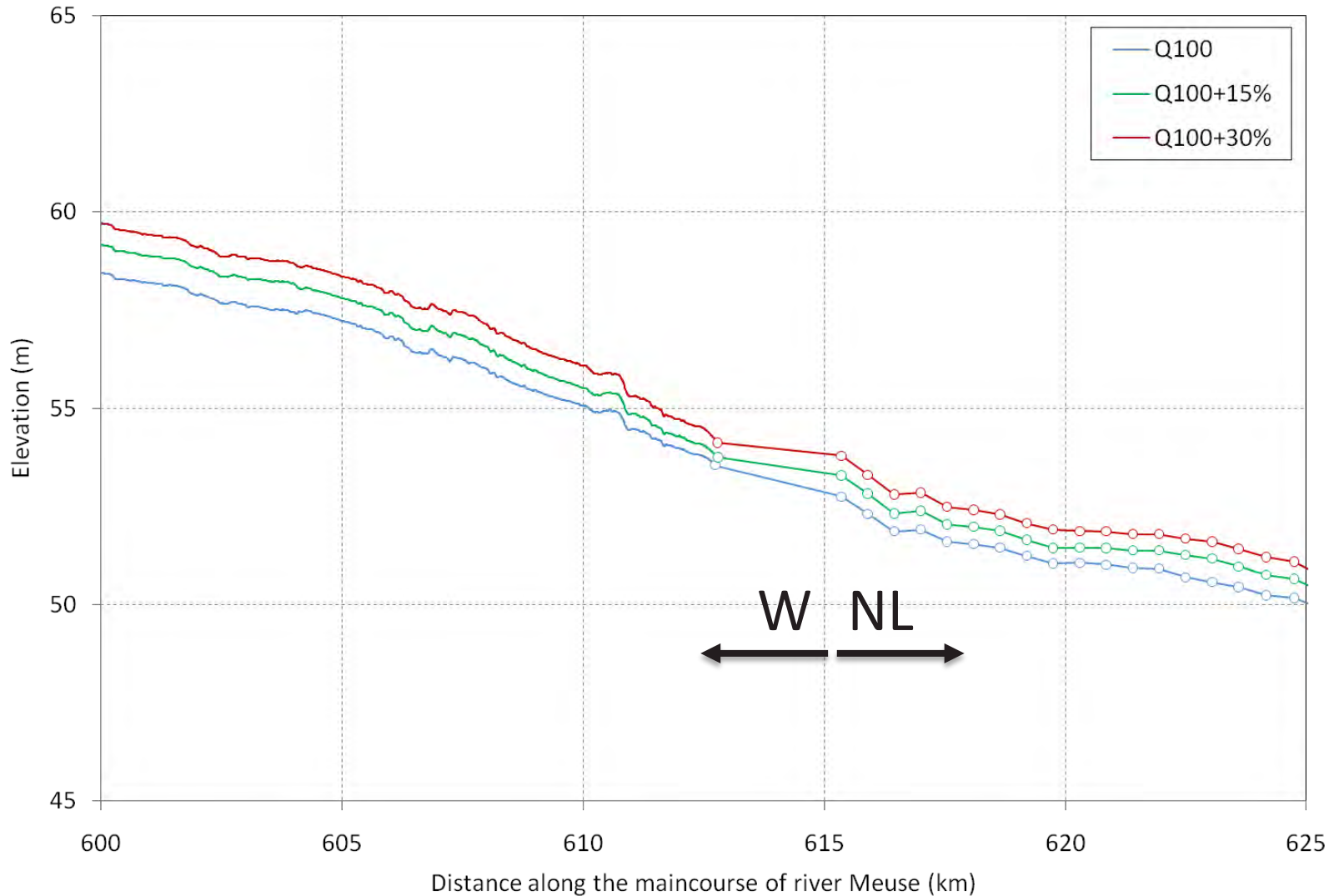
# Maximum water elevation (m)



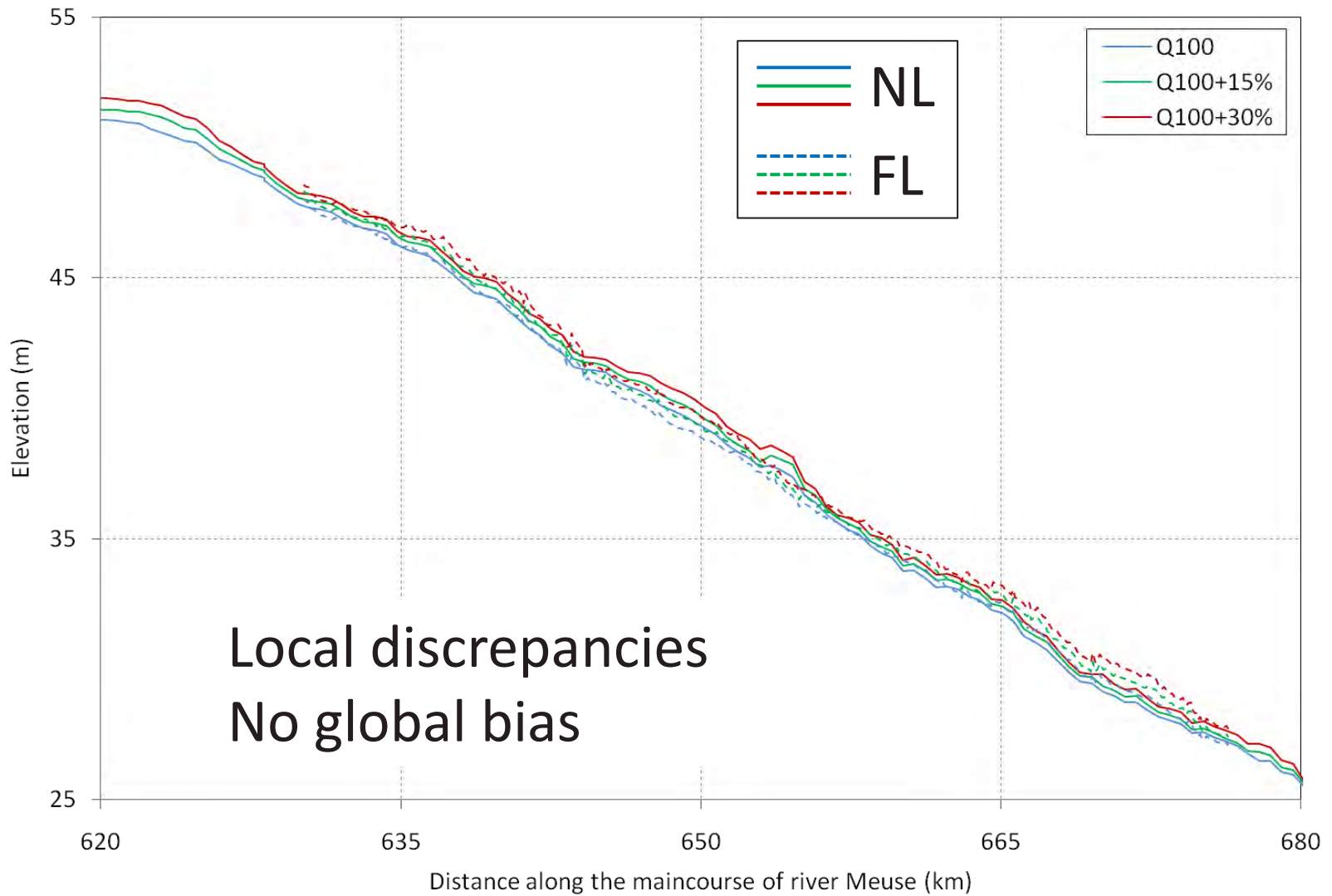
# Maximum water elevation (m) at the F-W border



# Maximum water elevation (m) at the W-NL border



# Maximum water elevation (m) along the FL-NL border

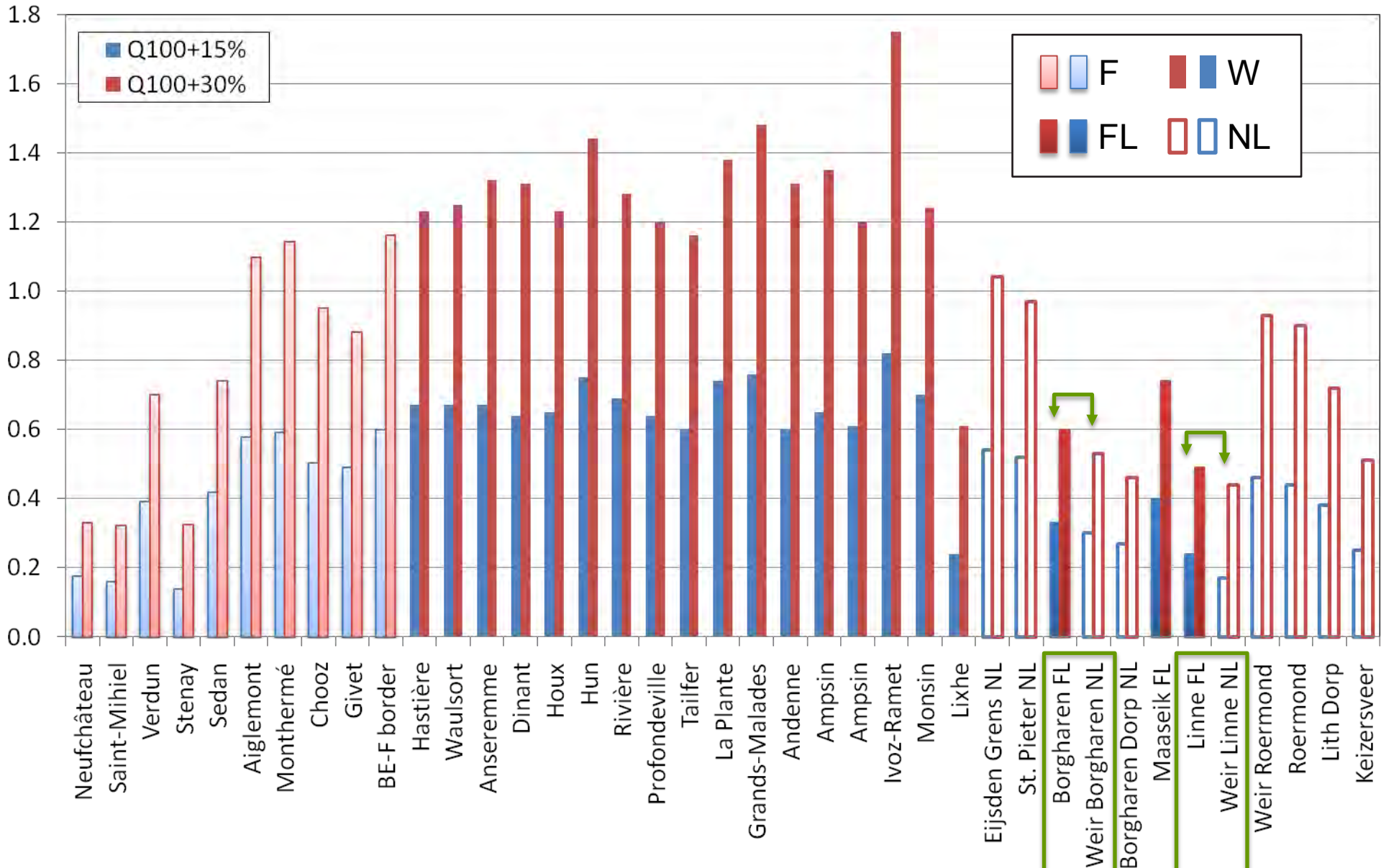


Local discrepancies  
No global bias

Despite the total difference in the hydrograph shape, there is no major bias; only little discrepancies locally. In some parts, the Dutch model is above the Flemish one, and sometimes it is the Flemish model above the Dutch one.



# Change in water depth at gauging stations or mobile weirs



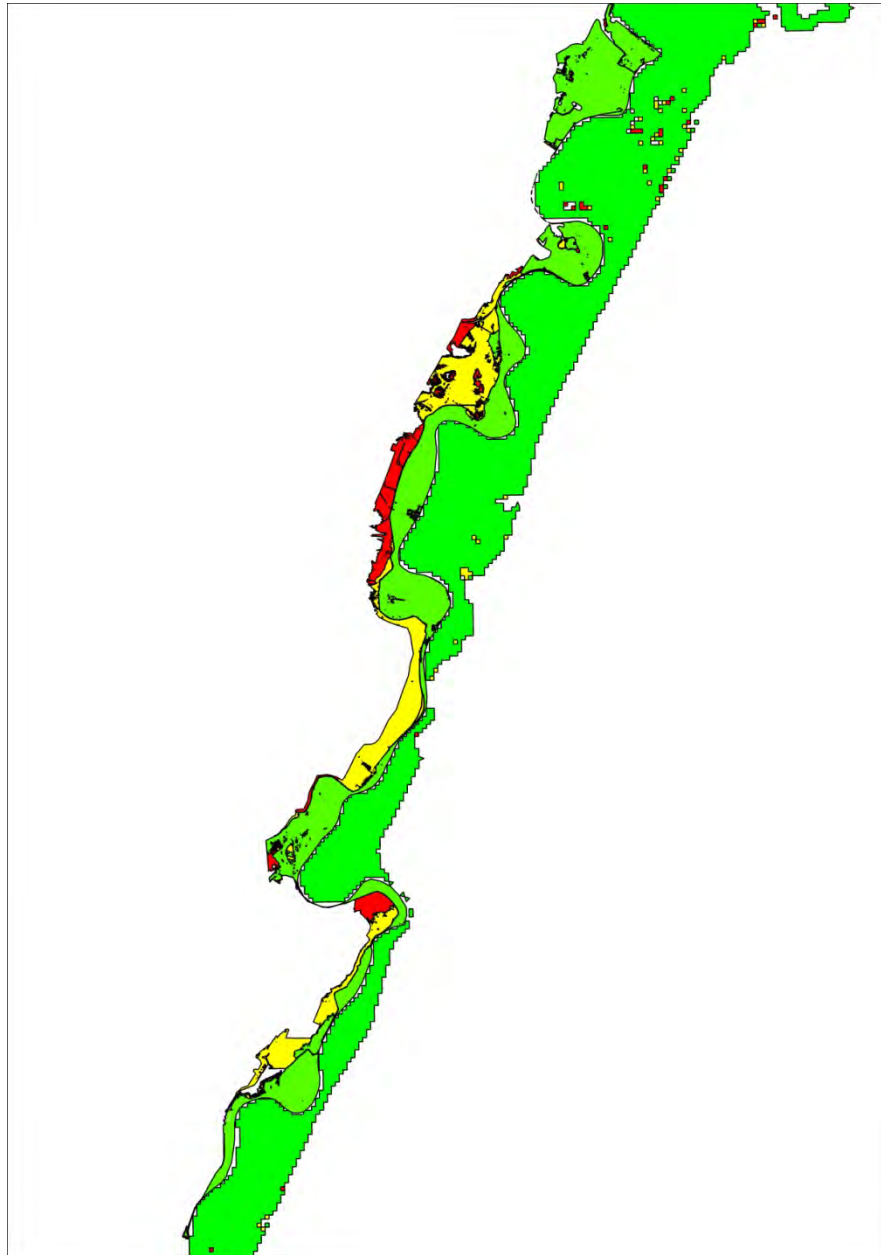
The bars are showing the difference between Q100 and Q100+15% (blue) or Q100+30% (red). The green boxes are identical points but provided by the Dutch or the Flemish model : in Borgharen and in Linne. You can see that they are quite consistent.

Then we can separate this graph into 3 parts.

In the upper part, upstream of Aiglemont, the increases are respectively +30cm and +50cm. You obtain almost the same figures (+30 cm and +70cm) in the lower part, downstream of Monsin.

In the central part, it is totally different : +60cm and +130cm. This separation does not match with the change in the models. The central part extend quite far in the French part where the unsteady model has been used. In the same way, the steady model extend downstream of Monsin. This suggest that you have a big difference in the sensitivity to the discharge increase.

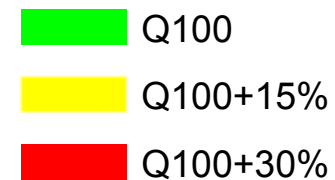
# Inundation extents along Lanaken - Kessenich



Significant increase  
on the left bank (FL)

No change on the  
right bank (NL)

## Effect of dikes



Let's take a look at the flood extent and the stored volume in the flood plain (not yet available for France).

This should be further discussed between the Partners. Dikes are present there that could explain this situation.

# Conclusions (1/2)

- Set up of a transnational modelling methodology having required max. 2 runs of each model to achieve consistency of results across the borders
- Hydraulic simulations run for two time horizons, corresponding to the wet scenario identified in Ac3
- Sensitivity of water elevations with respect to perturbations in discharge :
  - higher in the central part of the basin
  - lower in the upper and lower parts of the basin
- Mean changes in water depth in the ranges
  - 0.3 – 0.6 for 2021-2050
  - 0.5 – 1.3 m for 2071-2100

# Conclusions (2/2)

- Effect of damping and derivations on hydrographs between Borgharen and Roermond twice stronger for  $Q_{100} + 30\%$  than for  $Q_{100}$
- Reaches mostly contributing to the increase in flooded area as a result of climate change:
  - between Andenne and Monsin (W), especially Ivoz-Ramet - Monsin
  - Lanaken - Kessenich (FL/NL)

## Next steps:

- Delivering hydraulic modelling results (incl. GE) for risk analysis (Ac7) as well as other parts of the project (Ac8 ...)
- Detailed analysis of hotspots, including spatialization

S.Folkertsma: The results show that the city of Liege is prone to considerable floodings, doesn't that trigger you to start unsteady simulations ? The flood area is quite large and should have a significant effect on the damping.

B.Dewals: That's a very good question, we have made the verification. We have computed the volumes stored in the city of Liege and the overflow discharge. The results is that the volume can be filled by the overflow discharge in less than 8 hours which is by far shorter than the duration of the flood of river Meuse (peak discharge is long enough).

S.Folkertsma: You also said that the difference between Linne and Maaseik is caused by a bypass to the Oude Maas.

B.Dewals: That's according to B. Becker.

O.DeKeizer: You say a lot about damping but there are also canals. Did you take these into account ?

B.Dewals: They are counted in the hydraulic models but in the results we show only the discharge if the river Meuse itself.

J.DeBijl: That means the canals are used to discharge a part of the water from the Meuse

B.Dewals: Yes they do.