Adaptation of the Meuse to the Impacts of Climate Evolutions

Impact of climate change on inundation hazard along river Meuse

Reference partner: University of Liege - HACH

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Dr P. Archambeau, Ir L. Gouverneur & Prof. M. Pirotton
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
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)
I - Hydraulic modelling within AMICE

**Hazard modelling**
- FLOOD
  - e.g. water retention (incl. large reservoirs)
- INUNDATION
  - e.g. enhanced river conveyance (maintenance dredging, dikes ...)
  - e.g. ban on building in floodplains, reduced vulnerability of assets...

**Vulnerability modelling**
- Housing
- Trade, industry
- Infrastructure
  - Forest, crops ...

**DAMAGE**
I - Hydraulic modelling within AMICE

AC 3: Scenarios
- FLOOD
  - e.g. water retention (incl. large reservoirs)

AC 6: Hydraulics
- INUNDATION
  - e.g. enhanced river conveyance (maintenance dredging, dikes ...)

AC 7: Risk
- e.g. ban on building in floodplains, reduced vulnerability of assets ...

AC 8,9: Evaluation of measures

Hazard modelling
- Vulnerability modelling
  - Housing
  - Trade, industry
  - Infrastructure

Vulnerability modelling
- Forest, crops ...

DAMAGE
- Infra-structure
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
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

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

Map indicating locations such as Neufchâteau, Keysers Veer, SOBEK model, Mike11 model, WOLF2D model, and SOBEK model.
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)
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
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]
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

Bell shaped hydrograph

Regression of river stage measurement

Δ ∼ 2–3%
Transnational modelling methodology

for consistent transnational modelling and sound comparison of models outputs

Main requirements for the methodology...

Benefit from current practice in each country

Feasible within the Amice timing, given calculation time of each model

Ensure consistency at the borders

Future re-use of Amice results
Sequential vs. parallel runs of the models

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

- Downstream BC = water depth
- Upstream BC = discharge

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

No sense to run models sequentially
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.

Modelling from spring to mouth

<table>
<thead>
<tr>
<th>Full unsteady</th>
<th>Full steady</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous exchange of BC</td>
<td>Sequential runs from NL to F</td>
</tr>
<tr>
<td>Models should be linked and run simultaneously</td>
<td>Exchange of water depth BC from downstream to upstream</td>
</tr>
<tr>
<td>Difficulty to couple all the models</td>
<td>Assumptions on flood damping</td>
</tr>
<tr>
<td>Unnecessary in W</td>
<td>Not suitable in F, NL and FL</td>
</tr>
</tbody>
</table>

- Not in the scope of Amice
- Not in accordance with the current practice in W
- Such sequential runs not optimal/feasible in the timing of Amice
- Not in accordance with the current practice in F, NL and FL
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
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.

1\textsuperscript{st} runs in parallel based on boundary conditions prescribed
from extrapolated available measured data instead of transferred from one model to the next
High values of historical discharges available in the recorded data at the gauging stations (Chooz, Lixhe, Linne, Roermond)

→ Only limited extrapolation of the corresponding stage-discharge relationships will be needed

State-discharge relation at Lixhe from 2002 to 2004
Overall procedure

First step

1\textsuperscript{st} 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.
Handling boundary conditions

**Downstream**

**France**
- Run 1: Extrapolation of the gauging curve at Chooz $\rightarrow$ BC for F model
- Run 2 (optional): BC for F model is the result of W model

**The Netherlands**
- Run 1: Extrapolation of the Sobek-RE model $\rightarrow$ BC for NL model
- Run 2: not necessary

**Wallonia**
- Run 1: Extrapolation of the gauging curve at Lixhe $\rightarrow$ BC for W model
- Run 2 (optional): BC for W model is the result of NL, FL models

**Germany**
- Run 1: Extrapolation of the gauging curve at Roermond $\rightarrow$ BC for GE model
- Run 2 (optional): BC for GE model is the result of NL, FL models

**Flanders**
- Run 1: Extrapolation of the gauging curve at Linne $\rightarrow$ BC for FL model
- Run 2 (optional): BC for FL model is the result of NL model
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)

<table>
<thead>
<tr>
<th></th>
<th>Chooz - FR</th>
<th>Chooz - W</th>
<th>Lixhe - W</th>
<th>Lixhe - NL</th>
<th>Borgharen - FL - NL</th>
<th>Roermond - GE</th>
<th>Roermond - NL</th>
<th>Linne - FL - NL</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>Y</td>
<td>X</td>
<td>Y</td>
<td>X</td>
<td>Y</td>
<td>X</td>
<td>Y</td>
<td>X</td>
</tr>
<tr>
<td>Lambert 1 [m]</td>
<td>777786</td>
<td>277445</td>
<td>777771</td>
<td>277428</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lambert 72 [m]</td>
<td>182638</td>
<td>95515</td>
<td>182620</td>
<td>95500</td>
<td>243000</td>
<td>160930</td>
<td>242663</td>
<td>161676</td>
</tr>
<tr>
<td>Rijksdriehek [m]</td>
<td>2498735</td>
<td>5673585</td>
<td>2498735</td>
<td>5673585</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>German coord system?</td>
<td>2498735</td>
<td>5673585</td>
<td>2498735</td>
<td>5673585</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long/Lat [°]</td>
<td>4.826</td>
<td>50.170</td>
<td>4.825</td>
<td>50.170</td>
<td>5.687</td>
<td>50.751</td>
<td>5.682</td>
<td>50.758</td>
</tr>
</tbody>
</table>

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)
Comparison at borders (NL/W) after 1st 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
Comparison at borders (F/W)

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

- 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
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

M. de Wit 2008
Peak discharges (m³/s)
Peak discharges (m³/s)
Peak discharges (m³/s)

Distance along the main course of river Meuse (km)
Maximum water elevation (m)

- Linne, Roermond

SLOPE: $4 \times 10^{-4}$, $1 \times 10^{-4}$

Distance along the maincourse of river Meuse (km)

Elevation (m)
Hydrographs in the NL

- **Q100**
- **Q100 + 15%**
- **Q100 + 30%**

Damping + derivations: 15%
Damping + derivations: 23%
Damping + derivations: 29%!
Peak discharges (m³/s)

Distance along the main course of river Meuse (km)
Hydrographs used in NL vs. FL

![Graph showing hydrographs for NL and FL](image_url)
Maximum water elevation (m)
Maximum water elevation (m) at the F-W border

$\Delta h < 10\text{cm}$
Maximum water elevation (m)

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

Local discrepancies
No global bias
Change in water depth
at gauging stations or mobile weirs
Change in water depth at gauging stations or mobile weirs

- + 0.3 m
- + 0.5 m
- + 0.6 m
- + 1.3 m
- + 0.3 m
- + 0.7 m

Legend:
- Q100+15%
- Q100+30%

Sites:
- Neufchâteau
- Saint-Mihiel
- Verdun
- Stenay
- Sedan
- Aiglemont
- Montherme
- Choizy
- Givet
- BE-F border
- Hastière
- Waulsort
- Anseremme
- Dinant
- Houffalize
- Hun
- Rivière
- Profondeville
- Tailfer
- La Plante
- Grands-Malades
- Andenne
- Ampsin
- Amps
- Ivoz-Ramnet
- Monsin
- Libin
- Ejsden Grens NL
- St. Pieter NL
- Borgharen NL
- Borgharen Dorp NL
- Maas NL
- Linne FL
- Weir Roermond
- Lith Dorp
- Welserveen
Change in water depth averaged per reach

- **Q100+15-Q100**
  - + 0.6 m
  - + 1.2 m

- **Q100+30-Q100**
  - + 0.3 m
  - + 0.7 m
Mean changes in water depth

<table>
<thead>
<tr>
<th></th>
<th>2021-2050 Q100 + 15%</th>
<th>2071-2100 Q100 + 30%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper part</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Upstream of Sedan</em></td>
<td>+ 0.3 m</td>
<td>+ 0.5 m</td>
</tr>
<tr>
<td>Central part</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Sedan → Monsin</em></td>
<td>+ 0.6 m</td>
<td>+ 1.3 m</td>
</tr>
<tr>
<td>Lower part</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Downstream of Monsin</em></td>
<td>+ 0.3 m</td>
<td>+ 0.7 m</td>
</tr>
</tbody>
</table>
Change in flooded area / stored volume (W) expressed as relative contribution of each reach to the total increase for Q100 + 30%

Increase in flooded area

Increase in volume stored in floodplains
Inundation extents in Dinant vs. Liege

Dinant

Liege

Q100
Q100+15%
Q100+30%
Change in flooded area / stored volume (FL/NL) expressed as relative contribution of each reach to the total increase for Q100 + 30%

Increase in flooded area

Increase in volume stored in floodplains
Inundation extents along Lanaken - Kessenich

Significant increase on the left bank (FL)

No change on the right bank (NL)

Effect of dikes

- Green: Q100
- Yellow: Q100+15%
- Red: Q100+30%
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