Quantification of the impacts of future floods and low flows on the economy in the Meuse basin
AMICE Action 7

AMICE future climate projections

more frequent and severe floods

wet scenario too much water

effects on economy

flood risk analysis

1. Floods
2. Droughts and Low Flows

more frequent droughts and low flows

dry scenario too little water

drought and low flow damage assessment
Flood Risk

(DIRECTIVE 2007/60/EC)

„flood risk“ means the combination of the probability of a flood event and the potential adverse consequences for human health, the environment, cultural heritage and economic activity associated with a flood event.

Conventionally risk is expressed by the equation

\[ R(D) = P(D) \times C(D) \]

The AMICE flood risk analysis is restricted to economic flood risk.

1. Step: Quantification of economic flood damage
2. Step: Probabilities of flood events
Flood Damage

- Input parameters: Economic flood damage model

- Land use categories

- Inundation depth

- Damage functions

- Relative flood damage

- Category specific asset value in €/m²

- Economic flood damage in €
Flood Damage

- Common transnational harmonized flood damage approach applicable for the whole Meuse basin (AMICE Flood Damage Approach)

- Economic flood damage calculations for selected discharge values

<table>
<thead>
<tr>
<th>Discharge Value</th>
<th>Return Period [a]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1971-2000 (PS)</td>
</tr>
<tr>
<td>Q_{25}</td>
<td>25</td>
</tr>
<tr>
<td>Q_{50}</td>
<td>50</td>
</tr>
<tr>
<td>Q_{100}</td>
<td>100</td>
</tr>
<tr>
<td>Q_{100+15}</td>
<td>300</td>
</tr>
<tr>
<td>Q_{100+30}</td>
<td>1250</td>
</tr>
</tbody>
</table>

5 hydraulic simulations and economic flood damage calculations for the flood risk analysis
Generating risk curves for PS, FSI and FSII

Risk = Probability x Flood Damage

Risk curves:

- PS
- FSI
- FSII

The economic flood risk is the area under the risk curve in unit [€/a]

C

F

= economic flood damage [€]

F

= flood frequency [1/a]
Risk Results

- Uncertainties in the overall chain of flood risk calculation
- Changes in flood risk is presented on a percentage basis
- Risk maps for selected hot spots

Relative Flood Risk

\[ \Delta R_{FS,t} = R_{FS,t} - R_{PS} \] [%]

Flood Risk Increase

\[ RI_{FS,t} = \frac{\Delta R_{FS,t}}{R_{PS}} \] [%]

<table>
<thead>
<tr>
<th></th>
<th>Increase of flood risk [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FSI (2021-2050)</td>
</tr>
<tr>
<td>Total Meuse basin</td>
<td>148</td>
</tr>
</tbody>
</table>
AMICE Action 7

1. Floods
2. Droughts and Low Flows
Impacts of future droughts and low flows

**AMICE future dry scenario**

- Increase in Air- (Water) Temperature $\Delta T$
- Decrease in discharge $\Delta Q$
- Increase in atmospheric CO$_2$ concentration

**Drinking Water**

- Not quantifiable

**Energy**

- Quantitative Impact Assessment

**Agriculture**

**Navigation**
Energy sector

Energy production

Thermal power plants

Hydropower plants

AMICE future dry scenarios

ΔT [°C]
Δ Q [m³/s]

Δ Q [m³/s]

Reduction in energy production
Energy sector

- Economic damage for thermal and hydropower plants

- Reduction of energy production [%]
- Annual operation capacity [MWh/a]
- Stock exchange price [€/Mwh]

**AMICE Calculation**
- Data from power plant operator
- Mean value from EEX

**Economic damage [€/a]**

**Economic damage related to the present state [%]**

<table>
<thead>
<tr>
<th></th>
<th>FSI (2021-2050)</th>
<th>FSII (2071-2100)</th>
</tr>
</thead>
<tbody>
<tr>
<td>↓2 [%%]</td>
<td></td>
<td>↓7 [%%]</td>
</tr>
</tbody>
</table>
Agriculture

- Simulation: evolution of yields
  - for the main 3 crops (maize, wheat, barley)
  - main soil of the region
  - main slope of the region

- Model used: EPIC-Grid

Evolution of the 3 main crops in the Meuse basin
Agriculture

- Economic damage/benefit for the agricultural sector

<table>
<thead>
<tr>
<th>AMICE Calculation</th>
<th>Mean annual yield [t/ha]</th>
<th>crop price [€/t]</th>
<th>cropland [ha]</th>
<th>Economic damage [€/a]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value (EUROSTAT)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

↑11 [%] | ↑15 [%]

=> Actually benefit!
Navigation

- Navigability in a weir controlled river via locks

- Water is lost during the locking process

- Measures to compensate the water losses:
  - Reducing the number of locking cycles
  - Reducing the water loss during a lock cycle (storing water in reservoirs, water pumping, siphoning water in a multi chamber lock complex)


\[\textbf{Economic damage} \text{ caused by increased waiting times}\]
Assessment of economic damage (caused due to increased waiting times) based on SIVAK simulations (AVV, 2002)

⇒ Correlation between extra costs [€/d] and water savings [m³/s] to guarantee sufficient water levels in the locks

<table>
<thead>
<tr>
<th>AMICE Assumptions</th>
<th>SIVAK Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic damage related to the present state [%]</td>
<td></td>
</tr>
<tr>
<td>FSI (2021-2050)</td>
<td>FSII (2071-2100)</td>
</tr>
<tr>
<td>↓36 [%]</td>
<td>↓1500 [%]</td>
</tr>
</tbody>
</table>
Impact of economic sector

- Impact of the economic sector to the total economic damage in the whole Meuse basin
  \[ \Rightarrow \text{Economic Sector Impact Factor (ESIF)} \]

\[ ESIF = \frac{ED_{FSi,s}}{\sum ED_{FSII,s}} \]

### Impact of Economic Sector on Economic Damage

- **Energy**: 2021-2050
- **Agriculture**: 2071-2100
- **Navigation**: 2021-2050
Outlook

Floods

- Flood risk analysis has revealed a strong increase in economic flood risk for the future
- The procedure of harmonization of the regional damage approaches has enabled an extensive exchange of knowledge between the partners
- The cooperation between the partners has to be intensified to improve the transnational approach
- Implementation of intangible flood losses (People at risk; ecological risk, psychosocial risk) in the flood damage approach
- Implementation of approaches to consider the probability of failures of flood protection measures
Outlook

Drought and Low Flows

- Assessment of the impact of future climate conditions on 3 economic sectors (Energy, Agriculture and Navigation)
- Energy production and Navigation are negatively affected due to decreased future discharges
- Agriculture is positively affected by the CO$_2$ fertilizer effect and longer growing season

- Methodologies towards low flow damage calculation have to be improved (data availability, transnational exchange of knowledge)
- The conducted analysis is based on mean annual hydrological input values ($Q_{\text{mean}}$, $T_{\text{mean}}$)
- A more detailed approach requires an event specific consideration
Thanks for Attention!!
Flood damage

Flood damage classification

Direct
  - tangible
  - Property, Inventory, Yield

Indirect
  - tangible
  - Fatality, Casualties, Ecosystem

  - intangible
  - Business interruption, Evacuation

  - intangible
  - Psychosocial effects, Migration

The AMICE damage approach is only focused on direct tangible (economic) flood losses
Flood damage

- Land use data

**CORINE Land Cover:**

**Classification into 44 Land Use Categories**

**Cons:**
Coarse resolution

**Pros:**
Free available as 100m x 100m Raster

⇒ Full coverage of the Meuse basin with consistent damage categories
Flood damage

- Land use data

CORINE Land Cover:

⇒ Aggregated into 5 damage categories

- Settlement: 14%
- Industry: 1%
- Infrastructure: < 1%
- Agriculture: 57%
- Forest: 24%
Flood damage

- Adaptation of the regional damage functions to AMICE damage functions

HOWAS 21 database

Regional damage functions

Transparency

Interpretation

Derivation

AMICE damage functions

5,924 Recorded damage cases
Scientific project specific reading access

Risk results and decisions based on risk are not biased by the use of national damage functions and the transnational discrepancies between them
Flood damage

- Input parameter AMICE damage calculation

<table>
<thead>
<tr>
<th>Input parameter</th>
<th>“AMICE” Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land use data</td>
<td>CORINE</td>
</tr>
<tr>
<td>Damage categories</td>
<td>AMICE damage categories</td>
</tr>
<tr>
<td>Damage function</td>
<td>AMICE damage functions</td>
</tr>
<tr>
<td>Asset value</td>
<td>National asset values/adapted asset values (Price level of 2009)</td>
</tr>
</tbody>
</table>
Flood risk

- Risk Quantification:

\[
\text{Risk} = \text{Probability} \times \text{Flood damage}
\]

- Selected hydrological events within AMICE representing the present state
  \(Q_{25}, Q_{50}, Q_{100}, Q_{300}, Q_{1250}\)

- Essential is the representation of the whole sample space

“Risk” is the integral over all possible undesired events. Summarizing all discrete scenarios the flood damage contributions are weighted by the probability of occurrence!
Flood risk

- Flood risk representing the present state 1971-2000

⇒ Flood risk for the future time periods 2021-2050 und 2071-2100
Flood risk

- Flood risk representing the considered future time periods
- “Return period shifting” according the projected AP3 hydrological scenarios

⇒ Avoiding of further time consuming simulation runs of the hydraulic models in AP 6
Risk Results

- Impact of selected reaches to the total flood risk increase

Risk Increase Impact Factor (RIIF)

\[
RIIF = \frac{\Delta R_{FS,i,R}}{\Delta R_{FSII,B}} \times 100\%\]

with:

\[
\Delta R_{FSII,B} = R_{FSII,B} - R_{PS,B} \times \frac{\epsilon}{q}
\]

\(\Delta R_{FS,i,R}\) = Relative Flood Risk of reach R due to the future scenario i related to the present state [€/a]

\(\Delta R_{FSII,B}\) = Relative Flood Risk of the total Basin due to the future scenario II related to the present state [€/a]
Impacts of low flow on thermal power plants

- Impacts on surface water body

Water demand: l/kwh
Impacts of climate change
Decrease in river discharge
Increase in water temperature

Discharge of heated water:
Negative impacts on the environment (Directive 2006/44/EC)
EU freshwater protection directive:
Temperature thresholds
28°C cyprinide water
21°C salmonide water
Thermal power plants

- Thermal power plants located at the Meuse

<table>
<thead>
<tr>
<th>thermal power plant</th>
<th>installed capacity [MW]</th>
<th>annual operation capacity [TWh]</th>
<th>power plant type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chooz</td>
<td>2900</td>
<td>19.4</td>
<td>nuclear</td>
</tr>
<tr>
<td>Tihange</td>
<td>2985</td>
<td>23.7</td>
<td>nuclear</td>
</tr>
<tr>
<td>Clauscentrale</td>
<td>1915</td>
<td>8.8</td>
<td>gas</td>
</tr>
<tr>
<td>Buggenum</td>
<td>253</td>
<td>1.5</td>
<td>coal</td>
</tr>
<tr>
<td>Amercentrale</td>
<td>1245</td>
<td>7.0</td>
<td>coal</td>
</tr>
<tr>
<td>Dongercentrale</td>
<td>121</td>
<td>0.06</td>
<td>coal</td>
</tr>
</tbody>
</table>
Thermal power plants

- Thermal power plants: Conversion of heat into electric power
- Temperature gradients ensuring sufficient steam pressure in the turbine: Surface water as cooling medium

- Increase water temperature $\Delta T$ [°C]
- Decrease discharge $\Delta Q$ [m$^3$/s]
- Reduction in efficiency $\Delta \mu$
Thermal power plants

- Estimated Energy Production Reduction due to the future climate conditions [%]
Hydropower plants

- Estimated energy production reduction due to future climate in [%]

![Graph showing estimated energy production reduction due to future climate for different hydropower plants. The graph compares the production reduction between 2021-2050 and 2071-2100.]
Thermal power plants

- Reduction in efficiency according to Forester and Lillistam: Adapted to the power plants along the Meuse

<table>
<thead>
<tr>
<th>water temperature increase</th>
<th>0 K</th>
<th>1 K</th>
<th>2 K</th>
<th>3 K</th>
<th>4 K</th>
<th>5 K</th>
</tr>
</thead>
<tbody>
<tr>
<td>stream flow</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 0 %</td>
<td>0</td>
<td>1,1</td>
<td>2,0</td>
<td>3,5</td>
<td>5,5</td>
<td>8,0</td>
</tr>
<tr>
<td>- 10 %</td>
<td>0,5</td>
<td>1,2</td>
<td>2,1</td>
<td>3,5</td>
<td>5,5</td>
<td>8,1</td>
</tr>
<tr>
<td>- 20 %</td>
<td>0,6</td>
<td>1,2</td>
<td>2,2</td>
<td>3,6</td>
<td>5,6</td>
<td>8,1</td>
</tr>
<tr>
<td>- 30 %</td>
<td>0,9</td>
<td>1,5</td>
<td>1,5</td>
<td>3,9</td>
<td>5,9</td>
<td>8,4</td>
</tr>
<tr>
<td>- 50 %</td>
<td>4,1</td>
<td>4,7</td>
<td>4,7</td>
<td>6,8</td>
<td>8,7</td>
<td>11,0</td>
</tr>
</tbody>
</table>

Forester & Lilliestam (2010)
Hydropower plants

- Hydropower plants

16 Hydro power stations

7 with a quantifiable economic loss

9 remaining:

\[ Q_{\text{max,Turbine}} < Q_{\text{mean,Stream}} \]

**Capacity**

\[ P = \eta \times \rho \times Q \times g \times H_n \]

- \( \eta \) = efficiency factor [-]
- \( \rho \) = water density \( \frac{\text{kg}}{\text{m}^3} \)
- \( g \) = gravity \( \frac{\text{m}}{\text{s}^2} \)
- \( Q \) = discharge \( \frac{\text{m}^3}{\text{s}} \)
- \( H_n \) = net drop height [m]
Hydropower plants

\[ P = \eta \times \rho \times Q \times g \times H_n \]

\[ P = 8 \times Q \times H_n \]

Strobl & Zunic (2010)
Agricultural Sector

- Impacts of climate evolution on the agricultural sector

AMICE Climate Evolution

- Increase $T \ [^\circ C]$
- Increase Atmospheric $CO_2$ [ppm]
- Decrease in Rainfall [%]

Change in yield
Navigation

- Extra costs due to waiting times to different locking strategies
Navigation

- Extra costs due to waiting times to different locking strategies