Impact assessment of flood mitigation measures

~ some new developments ~

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How to select measures?

**Impacts:**

- economic cost/benefit analysis
- nature
- landscape
- ........

**Measures:**

- disaster management (evacuation, sand bags)
- spatial planning
Flood risk evaluation

In the Netherlands the Technical Committee on Flood Defences (TAW) argues that flood defence should be based on:

- criteria on number of deaths (personal risk and societal risk)
- cost benefit analysis

But is not official policy (yet)
Flood risk: probability of flooding, consequences of flooding

- S1: industrial area
- S2: commercial buildings
- S3: livestock
- S4: agricultural equipment

- P: pathways or routes

- Sea
- River
- Lake
Is there a flood protection problem in the Netherlands?

- No: ‘we have never been as safe as we are today’ (probability)

- Yes: ‘damage increase and safety standards are set up some 50 years ago, and population increases and economy growths’ (consequences)

According to report of Ministry of Environment (RIVM) there is a serious problem (although the standards are relatively high!)
Flood risk in the Netherlands: social risk

Graph showing the estimate of flood risk with different lines for 'Gemiddelde' and 'Spreiding'. The x-axis represents the number of victims, and the y-axis represents the probability (Kans). The graph indicates the external safety of the flood risk.
New developments

Risk = flooding probability * consequences
(yearly insurance premium, expected number of deaths, ....)

- often: flooding probability = exceedance probability of design water level (safety standard)
- often: no uncertainty in flood damage
- often: no assessment of economical safety standard
  (dynamic investment approach to assess risks)
Flooding probability (1)

- Failure mechanism: overflow /wave overtopping the dike
- The Design water level is used to assess the flooding probability
- In design of dike we have a free board (of 0.5 - 1 meter) for (among others wave runup)

- There is a strong relation between the exceedance probability and the flooding probability. It depends among others on: probability distribution discharge, HQ relation, uncertainty in water levels given the discharge, wind speed and wind direction.
Flooding probability (2)

Diagram showing:
- Wave runup
- Design water level
- Free board (min. 0.5 m)
- aanleghoogte
- Dike height
Flooding probability (3)

Waterstand als functie van de afvoer op km-raai 915 (Waal)

90%-onzekerheidsband
Flooding probability (4)

Example Tiel: Dike design based on Design water level (exceedance probability of \(1/1250\)) plus free board of 0.5 m

**Stochastic variable**

<table>
<thead>
<tr>
<th>Description</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discharge + wave runup according guidelines</td>
<td>1/1800</td>
</tr>
<tr>
<td>Discharge + wave runup all wind directions</td>
<td>1/2200</td>
</tr>
<tr>
<td>Discharge + wave runup all wind speeds</td>
<td>1/2500</td>
</tr>
<tr>
<td>Discharge + uncertainty water levels</td>
<td>1/1700</td>
</tr>
<tr>
<td>Discharge + wind direction + wind speed + uncertainty water levels</td>
<td>1/2600</td>
</tr>
<tr>
<td>Discharge + wind direction + wind speed + uncertainty water levels + shape discharge</td>
<td>1/1700</td>
</tr>
</tbody>
</table>

Results for other locations: range 1/1000 -- 1/8000.
Uncertainty flood damage (1)

- Based on results of R. Egorova (Delft University of Technology and HKV Consultants)
- The general formula:

\[ S = \sum_{i=1}^{m} S_i \sum_{j=1}^{n} \alpha_{ij} n_{ij} \]

where:

- \( \alpha_{ij} \) -- damage factor for category i in cell j, (damage function)
- \( 0 \leq \alpha_{ij} \leq 1 \)
- \( n_{ij} \) -- number of flooded units in category i in cell j
- \( S_i \) -- maximum damage per unit in category i (Netherlands Economic Institute)

n – number of grid cells
m – number of damage categories (equal to 51)
“Standard” method for Assessing Damage and Casualties as result of flooding (HIS-SSM software)
Uncertainty flood damage (2)

Main Terms to calculate damage:
- Flood scenario
- Damage category
- Damage: direct, indirect, business interruption
- Maximum damage
- Damage factor (damage function)

Sources of uncertainty:
- damage factor
- number of flooded units
- maximum damage per unit
- flood depth
- flow velocities
- rate of water rising
Dependence modeling

- **Spatial dependence**
  
  HIS-SSM cells structure

\[
S = \sum_{j=1}^{m} \sum_{i=1}^{n} \alpha_{ij} n_{ij} S_i = \sum_{i=1}^{n} S_i \sum_{j=1}^{m} \alpha_{ij} n_{ij}
\]

- **Complete dependence**
- **Independence**
- **Stratified water depths** (complete dependence within class, independence between classes)
Uncertainty maximum damage

Maximum damage per unit object

<table>
<thead>
<tr>
<th>Damage categories</th>
<th>Unit</th>
<th>Maximum damage amount (€)</th>
<th>Damage Function</th>
<th>Database</th>
<th>90% confidence bounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture direct</td>
<td>m²</td>
<td>1.50</td>
<td>1</td>
<td>CBS</td>
<td>0.7 - 7.1</td>
</tr>
<tr>
<td>Urban area</td>
<td>m²</td>
<td>48.6</td>
<td>1</td>
<td>CBS</td>
<td>32 - 63</td>
</tr>
</tbody>
</table>

- Mean
- 5th percentile
- 95th percentile

probability

distribution
Case study: dike-ring area 14 (Central-Holland)
Simulation (MATLAB)

- objects per cell → damage function → Beta samples
- water depth → inner sum samples → Flood damage samples
- maximum damage → Triangular samples
Results: 2m (NAP) water level

(a) - complete dependence
(b) - independence
(c) - stratified dependence
## Uncertainty flood damage: results

<table>
<thead>
<tr>
<th>depth</th>
<th>HIS (bln.)</th>
<th>model</th>
<th>mean</th>
<th>5%</th>
<th>95%</th>
<th>st.dev (bln.)</th>
<th>coef.var.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2m (NAP)</td>
<td>282.7</td>
<td>DEP</td>
<td>288.0</td>
<td>245.1</td>
<td>332.7</td>
<td>26.6</td>
<td>0.092</td>
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<tr>
<td></td>
<td></td>
<td>IND</td>
<td>286.5</td>
<td>260.7</td>
<td>313.2</td>
<td>16.3</td>
<td>0.057</td>
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<tr>
<td></td>
<td></td>
<td>STR</td>
<td>285.6</td>
<td>251.7</td>
<td>320.5</td>
<td>20.1</td>
<td>0.070</td>
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<tr>
<td>-2m (NAP)</td>
<td>56.9</td>
<td>DEP</td>
<td>60.8</td>
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<td>78.3</td>
<td>9.9</td>
<td>0.163</td>
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<tr>
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<td></td>
<td>IND</td>
<td>60.6</td>
<td>55.4</td>
<td>66.0</td>
<td>3.3</td>
<td>0.055</td>
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<tr>
<td></td>
<td></td>
<td>STR</td>
<td>60.8</td>
<td>51.9</td>
<td>71.3</td>
<td>5.9</td>
<td>0.097</td>
</tr>
</tbody>
</table>
Economic safety standard (1)

Minimising sum of Loss (R) and Investment (I)
Economic safety standard (2)

- Deterioration of watersystem (settlement, climate change)
  => Increase of flooding probability

- Economic growth and increase population
  => Increase of potential damage

- In combination: Expected loss increases
  - Change of conditions implies more than one decision on height of dikes
Economic safety standard (3)

• Interest rate \( (r > 0) \):
  postpone costs as much as possible, do not more than strictly necessary at once

• Fixed investment costs
  investment in safety in ‘jumps’

Result: Safety level is not constant
• High, directly after investment
• Gradually decreasing afterwards until just before new investment
New strategy: periodic investments

Proposed by Central Planning Office (CPB)
(mr. C. Eijgenraam)
Conclusions of Central planning Office:

- Constant exceedance probabilities are misleading as good safety standards
- Expected loss is correct criterion for safety standards
- Actual calculation is needed

In future shift needed towards: control of expected loss by flooding
Economic safety standard (5)

Total costs: very flat

Optimum safety level: 1/4800 (now: 1/1250)