Urban flood damage estimation

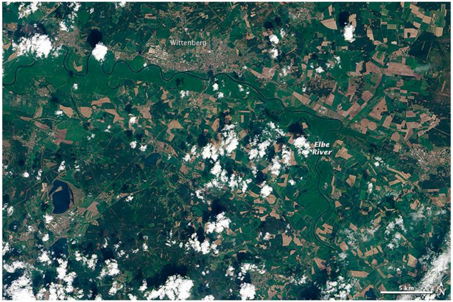
Matthieu Spekkers

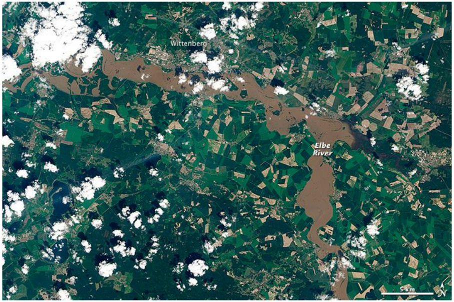
Delft University of Technology

September 17, 2013

Flood Central Europe 2013 - 2 billion Euros

Elbe floodplains





Source: www.gazeta.ru

Figure : Passau... 3 June 2013

Figure : Passau... 3 June 2013

Not the first time for the Elbe...

Figure : Elbe in 2002, Grimma, Germany (source: FLOODsite)

But it is not only about rivers overflowing...

Figure : Summer 2007 pluvial floods, Hull (UK), damage to 8600 houses and 1300 businesses (source: www2.hull.ac.uk). No natural way of drainage.

Pluvial flooding

Flooding that occurs as a result of rainfall-generated overland flow ponding on the urban surface because it overwhelms urban drainage systems and surface watercourses by its high intensity or is for some reason unable to enter urban drainage systems or surface watercourses (Ten Veldhuis, 2010).

An example closer to “home”

Figure : Autumn 1998 pluvial floods, the Netherlands, damage to 2470 houses, 1220 businesses and agriculture.

“Annual” flooding

Figure : Enschede, August 26, 2010 (Flickr: Ruud Greven)

Types of urban flooding (1/2)

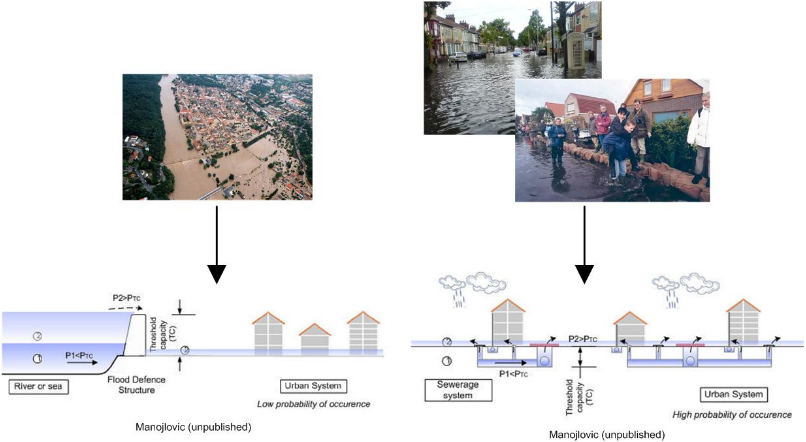


Figure : Flood sources: fluvial (left) or pluvial (right). Urban drainage systems are more relevant in the right cases.

What other flood sources/types do you know?

Types of urban flooding (2/2)

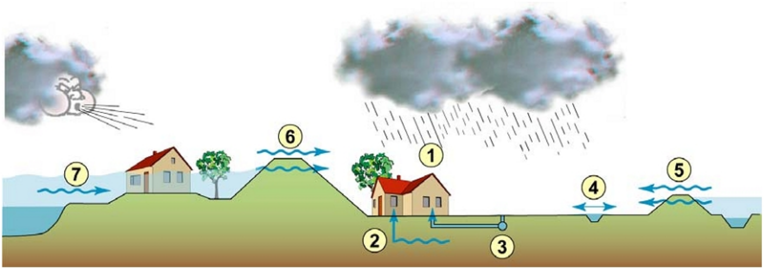


Figure : Flood types in the Netherlands (Kok, 2005)

Flood risk management

Kaplan and Garrick (1981):

- What can go wrong?
- How likely is this to happen?

} Probability

- If it does happen, what are the consequences?

} Consequences

Definition most commonly used

Risk = Probability x Consequences

- Current Dutch practice: maximum expected street flooding frequency of once per year or once per two years

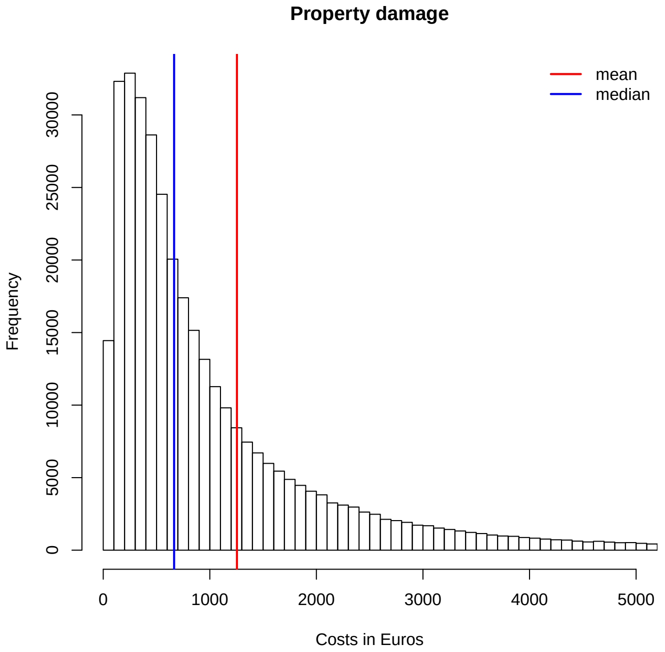
	Fluvial	Pluvial
What can go wrong?	Overtopping of a dike	Rainfall overwhelming a drainage system
How likely is it?	Very rare	Frequent
What are the consequences?	Extreme costs	Very local, small extents, few decimeters of water (flat areas), minor costs, hardly any casualties

There is around 10 centimeters of water in your ’average’ house. What will the costs for drying, cleaning and repairing your house?

A 500–5 000 €

B 5 000–10 000 €

C 10 000–100 000 €



Property damage
mean
median
Frequency
0
5000
10000
15000
20000
25000
30000
0
1000
2000
3000
4000
5000
Costs in Euros

What is the average rainfall-related damage related to residential buildings per capita per year?

Water-related damage in 2011*

	Population	Total damage	Related to rainfall
the Netherlands	16.7m	332m	136m
Denmark	5.5m	894m	800m
Sweden	9.1m	410m	n/a
Norway	4.7m	234m	n/a

*) figures are in Euros and related to residential buildings only; definition of water-related damage may vary between countries

Flood damage estimation

To estimate damage of a single element (e.g. building) or a spatially aggregated unit (e.g. neighbourhood)

Types of flood damages

Direct damage due to physical contact with water

Indirect damage induced by direct impacts, may occur outside the flooded area

Tangible can be assessed in monetary values

Intangible can not be valued

Types of flood damages

Direct	damage due to physical contact with water
Indirect	damage induced by direct impacts, may occur outside the flooded area
Tangible	can be assessed in monetary values
Intangible	can not be valued

Take a minute to think about an example for each quadrant.
Focus on damages relevant to pluvial flooding...

	Tangible	Intangible
Direct		
Indirect		

- Most flood damage models focus on direct/tangible

Take a minute to think about an example for each quadrant.
Focus on damages relevant to pluvial flooding...

	Tangible	Intangible
Direct		
Indirect		

- Most flood damage models focus on direct/tangible

Coffee break

How is direct tangible damage modelled traditionally?

- Gilbert White (1958) was one of the first to introduce ‘flood damage models’
- Principles are unchanged since then, but models have become much more detailed (thanks to computers!)

The four components of a “traditional” damage model

1. Flood characteristics (e.g. flood depth)
2. Elements at risk (e.g. land use, building classes)
3. Value elements at risk
4. Susceptibility of elements at risk (i.e. stage-damage curves)

The “traditional” method

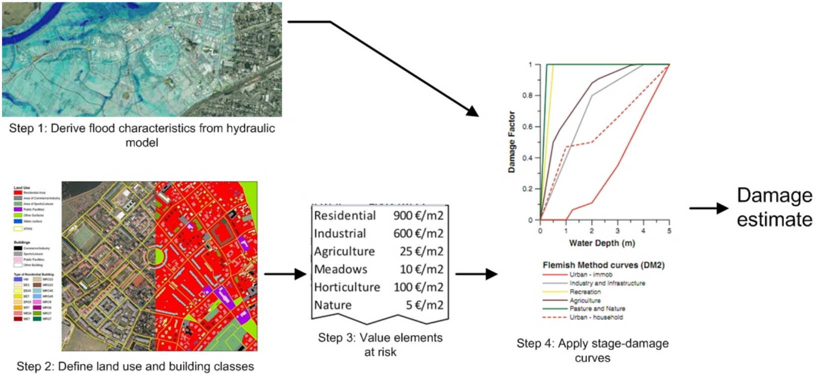


Figure : Sources: Neubert et al. (2012); De Moel and Aerts (2011)

Stage-damage curves

A stage-damage curve is a relationship between one or more flood characteristics and the (relative) flood damage of an element at risk, usually based on expert judgements

Input

- flood depth
- flood duration
- flow velocity
- flood depth x flow velocity

Output

- relative damage [0–100%]
- absolute damage [€]

Examples of stage-damage curves

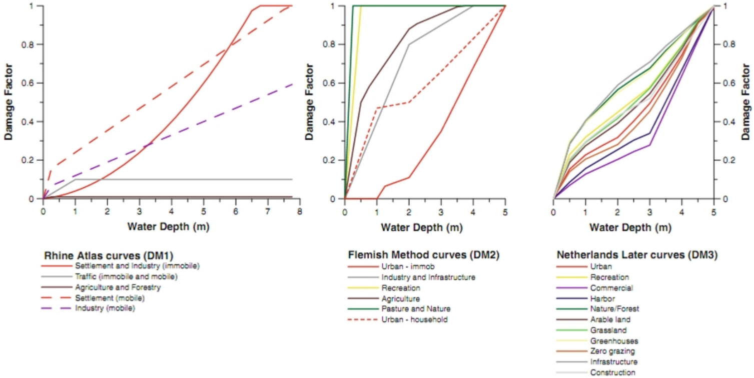


Figure : A wide variety of stage-damage curves exists, examples from De Moel and Aerts (2011)

Two types of uncertainties

1. Natural variability (aleatory)
   e.g. climate change, human behaviour
2. Incomplete knowledge (epistemic)
   e.g. model assumptions, generalisations

Epistemic uncertainties are the uncertainties we can reduce

Two types of uncertainties

1. Natural variability (aleatory)
   e.g. climate change, human behaviour
2. Incomplete knowledge (epistemic)
   e.g. model assumptions, generalisations

Epistemic uncertainties are the uncertainties we can reduce

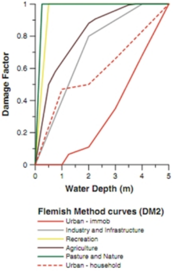
Can you come up with some examples of epistemic uncertainties (incomplete knowledge)?

Step 1: Derive flood characteristics from hydraulic model

Step 2: Define land use and building classes

Residential	900 €/m2
Industrial	600 €/m2
Agriculture	25 €/m2
Meadows	10 €/m2
Horticulture	100 €/m2
Nature	5 €/m2

Step 3: Value elements at risk



Step 4: Apply stage-damage curves

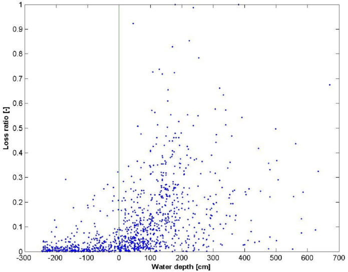
→ Damage estimate

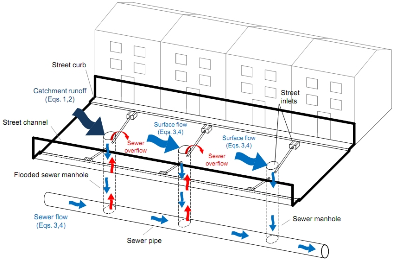
Epistemic uncertainties in damage calculations

1. Flood characteristics
   - Assumptions in numerical models
   - Erroneous or incomplete input and calibration data
2. Elements at risk
   - Limited number of land-use or building classes
   - Dated or low-resolution land-use data
3. Value elements at risk
4. Susceptibility elements at risk
   - Ignoring other flood impacts, such as flow velocity and flood duration
   - Aggregated stage-damage curves

Limits of the “traditional” damage models

- Poor 1-on-1 relationship between flood depth and damage
- There are many more factors than just ‘flood depth’ and ‘building class’
- For pluvial floods with flood depths between 0–50 cm, ‘flood depth’ is not meaningful
- For pluvial floods, we cannot reliably predict flood depths (yet)





Sources: Merz et al. (2013); Freni et al. (2010)

Collecting data to develop damage models

- Expert judgements (i.e. stage-damage curves)
- Computer-aided telephone interviews
- Insurance databases

Computer-aided telephone interviews

	#	Predictors	
hydrologic, hydraulic aspects	1	wst	Water depth
	2	d	Inundation duration
	3	v	Flow velocity indicator
	4	con	Contamination indicator
	5	rp	Return period
early warning and emergency measures	6	wt	Early warning lead time
	7	wq	Quality of warning
	8	ws	Indicator of flood warning source
	9	wi	Indicator of flood warning information
	10	wte	Lead time period elapsed without using it for emergency measures
	11	em	Emergency measures indicator
precaution, experience	12	pre	Precautionary measures indicator
	13	epre	Perception of efficiency of private precaution
	14	fe	Flood experience indicator
	15	kh	Knowledge of flood hazard
building characteristics	16	bt	Building type
	17	nfb	Number of flats in building
	18	fsb	Floor space of building
	19	bq	Building quality
	20	bv	Building value
socio-economic status	21	age	Age of the interviewed person
	22	hs	Household size, i.e. number of persons
	23	chi	Number of children ($<$ 14 yr) in household
	24	eld	Number of elderly persons ($>$ 65 yr) in household
	25	own	Ownership structure
	26	inc	Monthly net income in classes
	27	socp	Socioeconomic status according to Plapp (2003)
	28	socs	Socioeconomic status according to Schnell et al. (1999)

Multivariate statistics: tree-based model

- Splitting up data into smaller groups (leafs) that have more or less similar characteristics

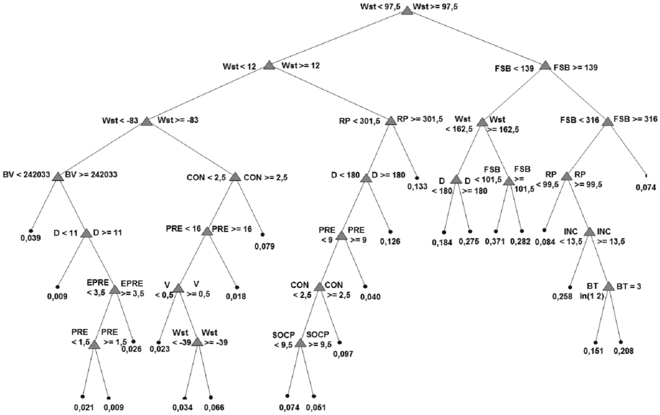
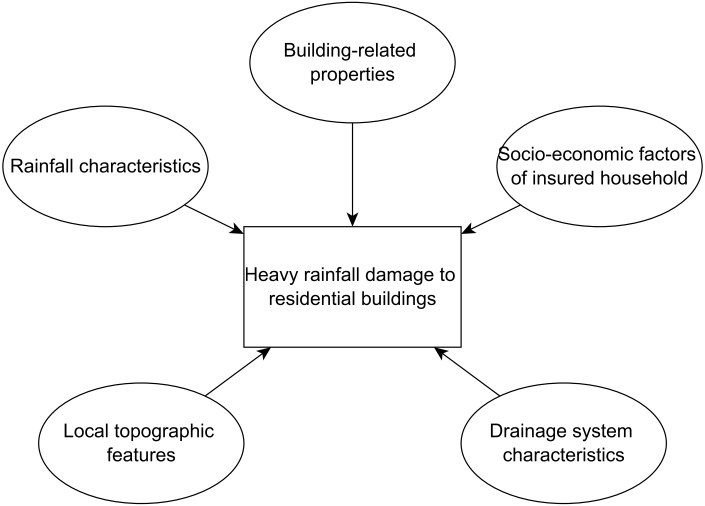


Fig. 3. Regression tree RT1 with 25 leaves for estimating building loss ratio (wst: water depth [cm]; fsb: floor space of building [m^2]; rp: return period [yr]; bv: building value [€]; con: contamination indicator [−]; pre: precautionary measures indicator [−]; inc: monthly net income [−]; epre: perception of efficiency of private precaution [−]; socp: socio-economic status [−]; bt: building type [−]). Terminal node values give the average loss ratio of all data values of the terminal node.

Figure : from Merz et al. (2013)

The many factors contributing to pluvial flood damage

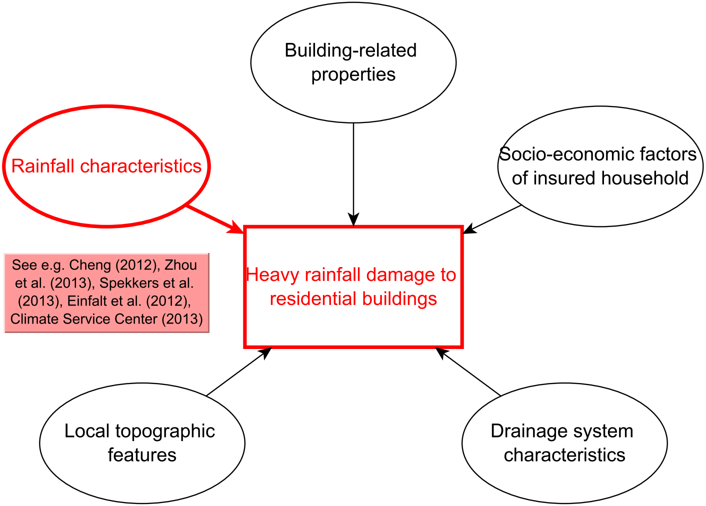



De hoge stoeprand met scherpe rand, in Dordrecht.


De 'dorpse' stoeprand uit de jaren '70


Sinds 2000: stoep en straat lopen in elkaar over

The many factors contributing to pluvial flood damage



1. Insurance database of Dutch Association of Insurers

- Insurance for private property and content
- Claims are related to heavy rainfall: sewer floods, roof leakages, etc.
- Data cover 30% of the insurance market, 1986–2011
- Spatially aggregated unit: neighbourhood level

2. KNMI C-band weather radar

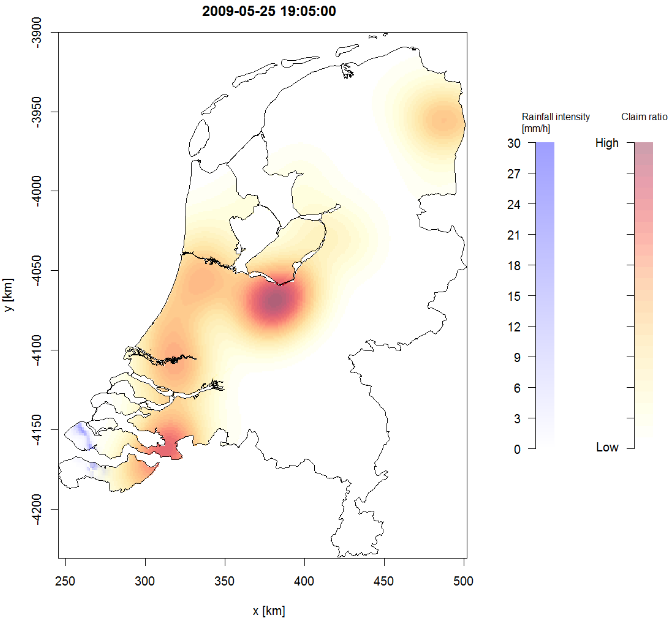
- 1998–2012
- Covering the entire land surface
- 1-km spatial resolution (2.5-km before 2009)
- One image every 5 minutes

1. Insurance database of Dutch Association of Insurers

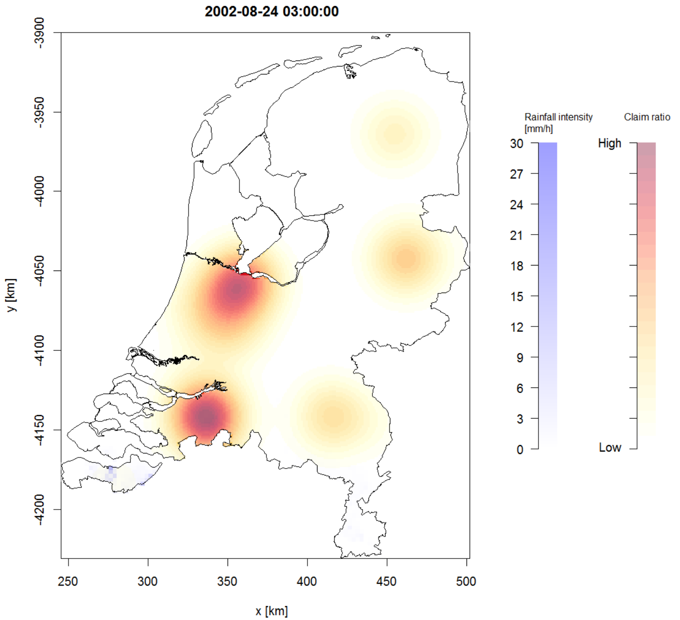
- Insurance for private property and content
- Claims are related to heavy rainfall: sewer floods, roof leakages, etc.
- Data cover 30% of the insurance market, 1986–2011
- Spatially aggregated unit: neighbourhood level

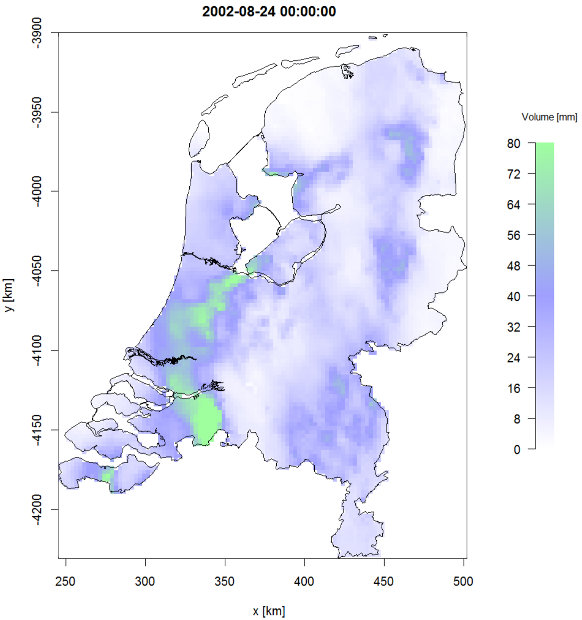
2. KNMI C-band weather radar

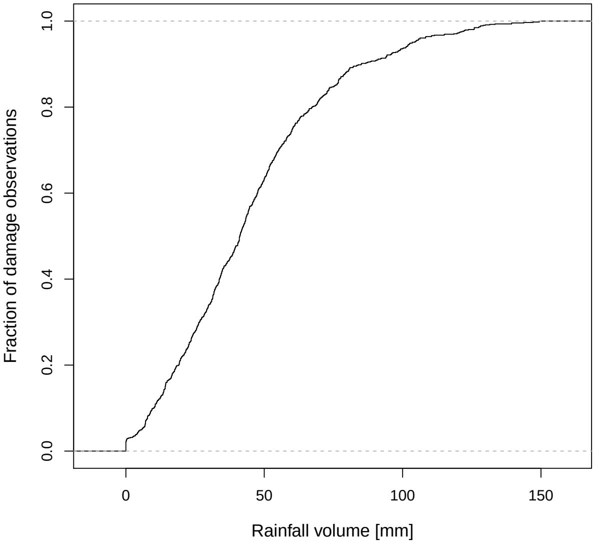
- 1998–2012
- Covering the entire land surface
- 1-km spatial resolution (2.5-km before 2009)
- One image every 5 minutes



2009-05-25 19:05:00
y [km]
-3900
-3950
-4000
-4050
-4100
-4150
-4200
250
300
350
400
450
500
x [km]
Rainfall intensity [mm/h]
30
27
24
21
18
15
12
9
6
3
0
Claim ratio
High
Low


2002-08-24 03:00:00
-3900
-3950
-4000
-4050
-4100
-4150
-4200
y [km]
250
300
350
400
450
500
x [km]
Rainfall intensity [mm/h]
30
27
24
21
18
15
12
9
6
3
0
Claim ratio
High
Low


2002-08-24 00:00:00
y [km]
-3900
-3950
-4000
-4050
-4100
-4150
-4200
x [km]
250
300
350
400
450
500
Volume [mm]
80
72
64
56
48
40
32
24
16
8
0



Fraction of damage observations
0.0
0.2
0.4
0.6
0.8
1.0
0
50
100
150
Rainfall volume [mm]

At radar pixel level

- Maximum intensity
- Mean intensity
- Volume
- Duration

At neighbourhood level

- Claim ratio
- Total damage
- Average damage

What is the best predictor for damage?

A Maximum intensity

B Mean intensity

C Volume

D Duration

Pearson correlations based on 150 days of data

	Claim ratio*	Total damage*	Average damage*
Maximum intensity	0.38	0.21	0.12
Mean intensity	0.25	0.17	-
Volume	0.26	0.16	-
Duration	0.06	-	-

*) damage variables were log-transformed

Summary of this lecture

1. Flood damage estimation is an important building block in the flood risk management framework
2. Traditional models for direct flood damage describe damage as a function of water depths and building class, but they are very simple and are subject to many epistemic uncertainties
3. Collecting data is important to develop new damage models that takes into the many factors influencing flood damage, e.g. through computer-aided telephone interviews or insurance databases

De Moel, H. and Aerts, J. C. J. H. (2011). Effect of uncertainty in land use, damage models and inundation depth on flood damage estimates. *Natural Hazards*, 58(1):407–425.

Freni, G., La Loggia, G., and Notaro, V. (2010). Uncertainty in urban flood damage assessment due to urban drainage modelling and depth-damage curve estimation. *Water Science and Technology*, 61(12):2979–2993.

Kok, M. (2005). Een waterverzekering in Nederland: mogelijk en wenselijk? Technical report.

Merz, B., Kreibich, H., and Lall, U. (2013). Multi-variate flood damage assessment: a tree-based data-mining approach. *Natural Hazards and Earth System Science*, 13(1):53–64.

Neubert, M., Naumann, T., and Hennersdorf, J. (2012). The GIS-based flood synthetic damage simulation model HOWAD.

Ten Veldhuis, J. A. E. (2010). *Quantitative risk analysis of urban flooding in lowland areas*. PhD thesis, Delft University of Technology.

The figures on slides 40-42 are preliminary results and may not be distributed, modified or reproduced without the permission of the author, M. H. Spekkers (M.H.Spekkers@tudelft.nl).