Including human behaviour in flood risk adaptation modelling

ISIMIP Workshop

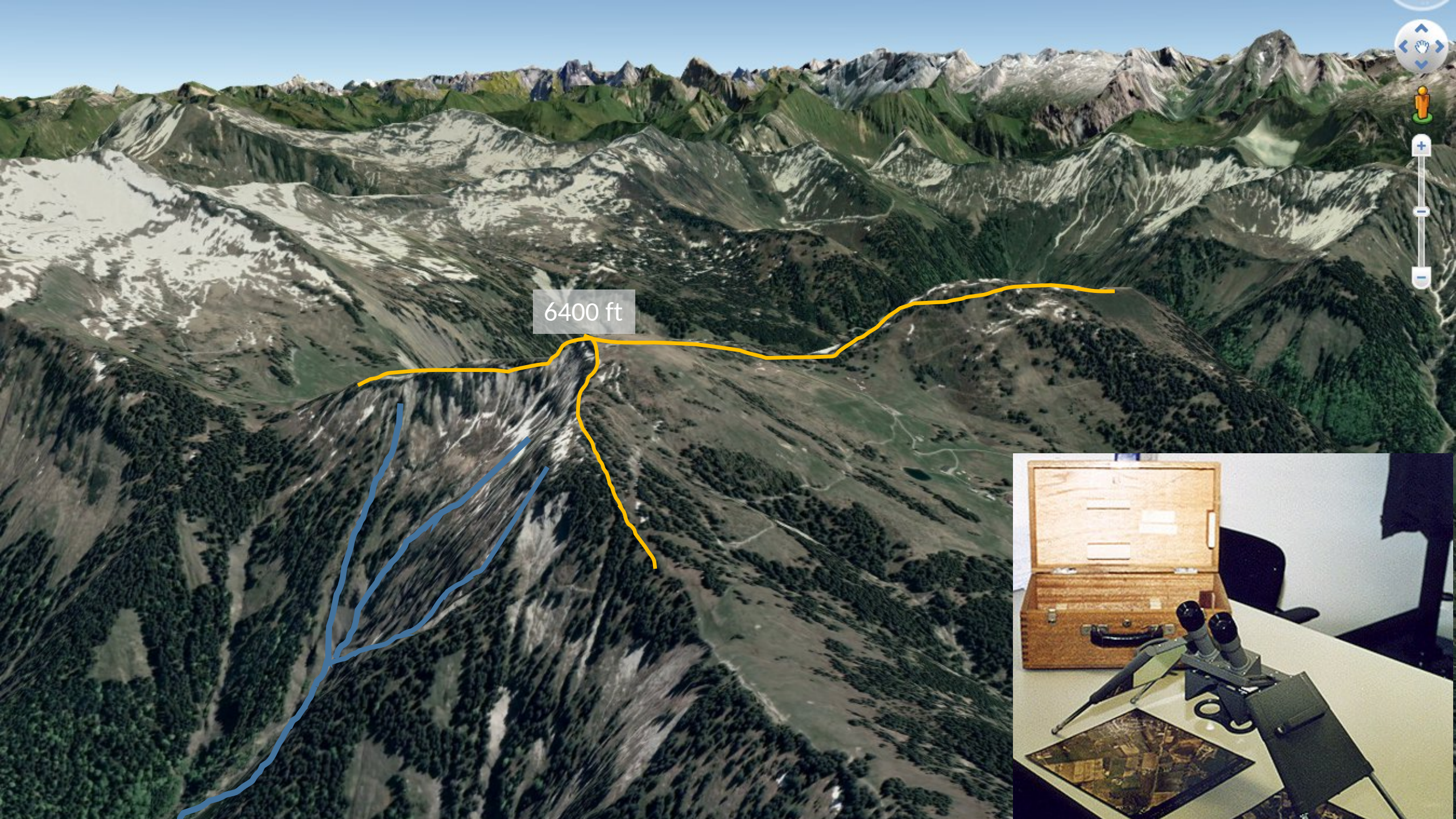
Potsdam, May 7th 2025

Dr. Jeroen Aerts

jeroen.aerts@vu.nl

IVM Institute for Environmental Studies

VU


6400 ft

Geomorphological hazard mapping

6400ft

Geomorphological hazard mapping?

IVM Institute for Environmental Studies VU

ELSEVIER

Journal of Hydrology 181 (1996) 305–321

Journal of Hydrology

Monitoring and modelling canopy water storage amounts in support of atmospheric deposition studies

Willem Bouten[a,*], Marcel G. Schaap[a], Jeroen Aerts[a], Aart W.M. Vermetten[b]

Research Paper

Accounting for Spatial Uncertainty in Optimization with Spatial Decision Support Systems

Jeroen C J H Aerts
Institute for Environmental Studies
Vrije Universiteit Amsterdam

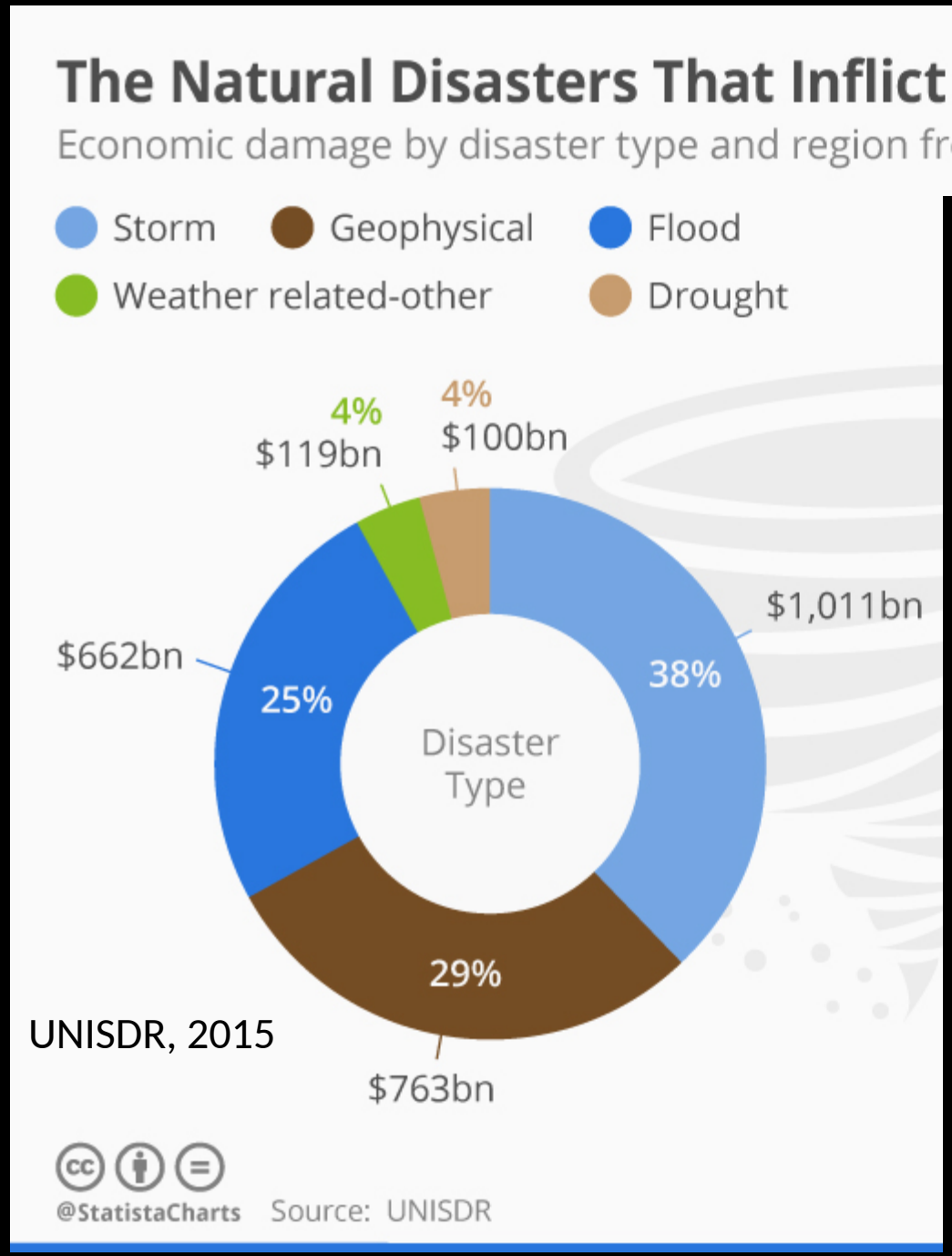
Michael F Goodchild
Department of Geography
University of California at Santa Barbara

Gerard B M Heuvelink
Institute for Biodiversity and Ecosystem Dynamics
Universiteit van Amsterdam

Natural disasters kill on average 60,000 people per year (~ 14% by floods)

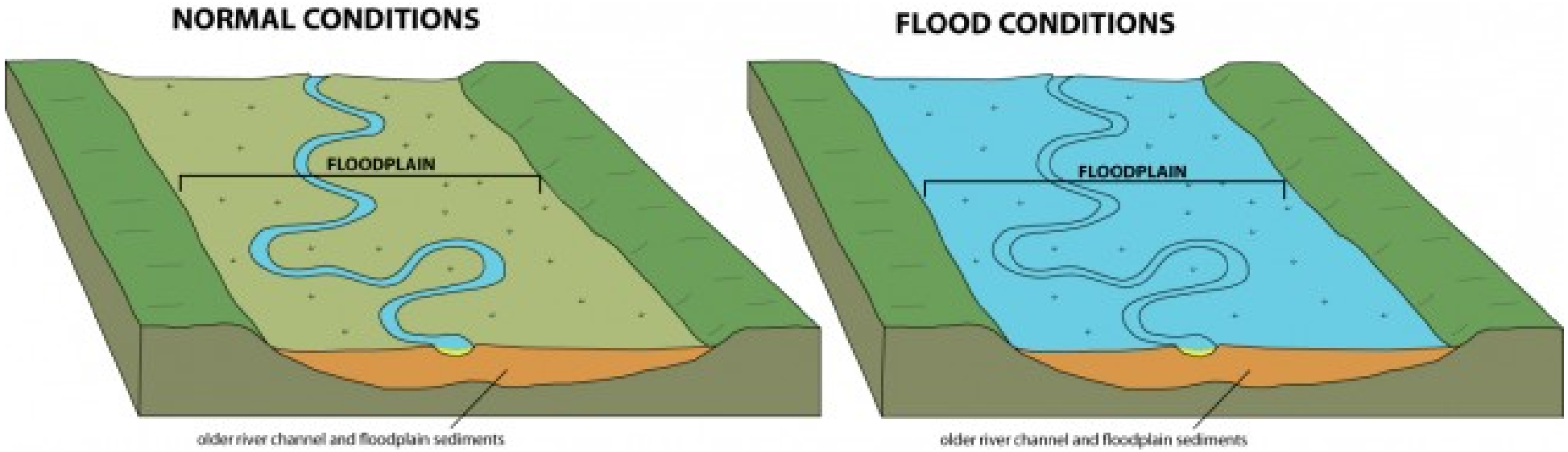
Source: ourworldindata.org / EM-DAT

IVM Institute for Environmental Studies VU


The Natural Disasters That Inflict The Most Economic Damage
Economic damage by disaster type and region from 1995 to 2015
Storm
Geophysical
Flood
Weather related-other
Drought
4%
$119bn
4%
$100bn
$1,011bn
38%
$662bn
25%
Disaster Type
29%
$763bn
@StatistaCharts
Source: UNISDR

UNISDR, 2015

Room for floods in floodplains is natural



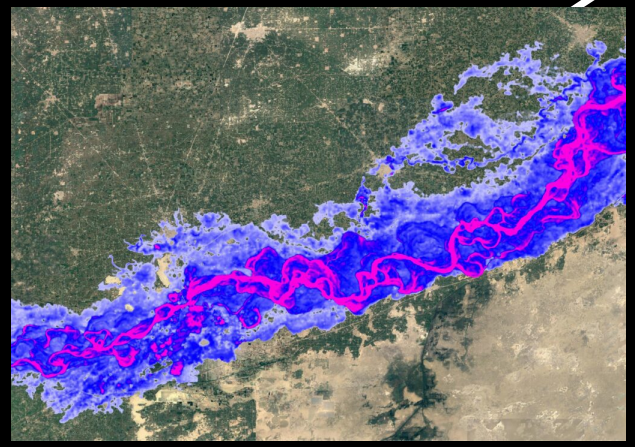
Floodplains are natural


HERSOL
Tucolada
INMO HÁBITAT
SERVICIOS INMOBILIARIOS
ROCKWOOL
ROCKWOOL
6185 DVR
2717 LFR
Sun Roller

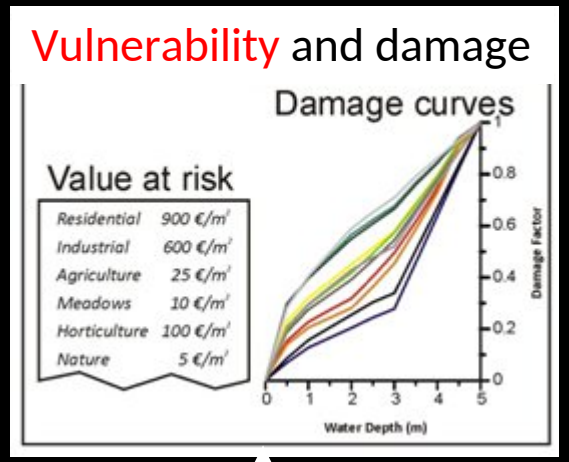
Flood risk modelling

Exposure: assets and people

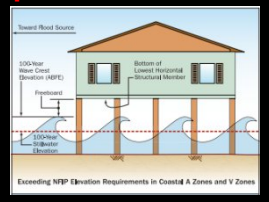
Flood hazard (Extent, depth)

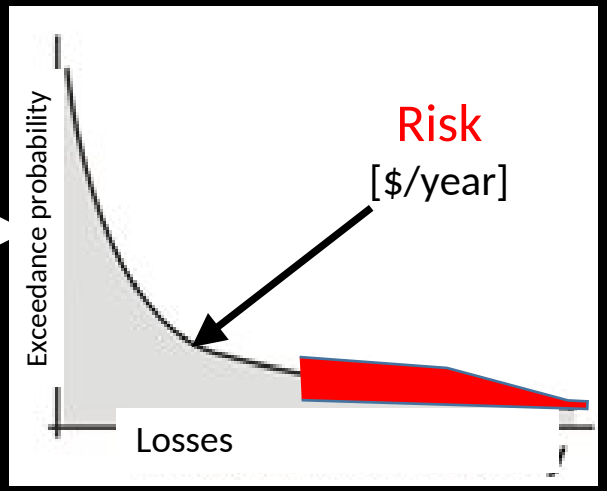


Vulnerability and damage



Adaptation measures





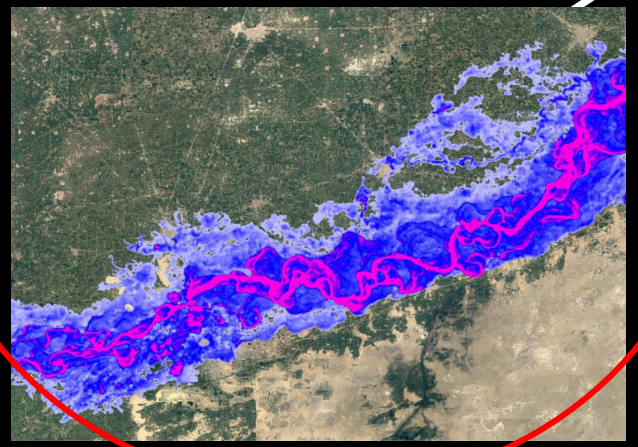
Kron, 2009; Water International

IVM Institute for Environmental Studies VU

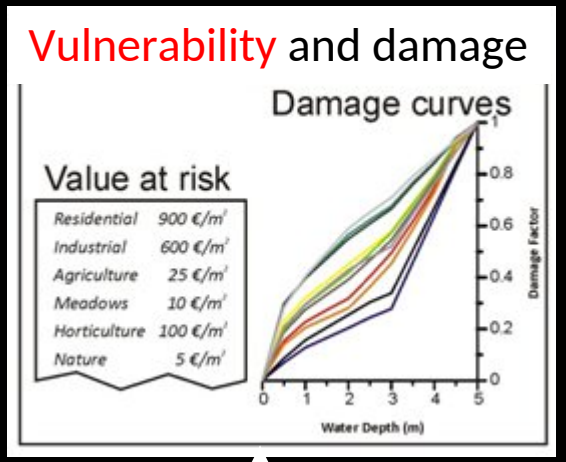
Flood risk modelling

Exposure: assets and people

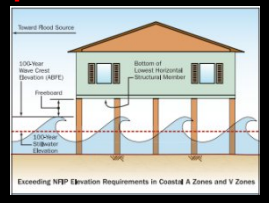
Flood hazard (Extent, depth)

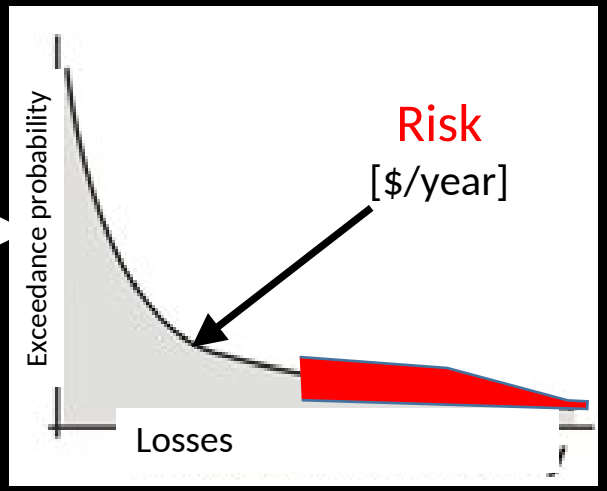


Vulnerability and damage



Adaptation measures





Kron, 2009; Water International

IVM Institute for Environmental Studies VU

DOCUMENT DE TRAVAIL juin 2003

Zone d'inondation des voies publiques en 1910

Zone d'inondation des caves en 1910

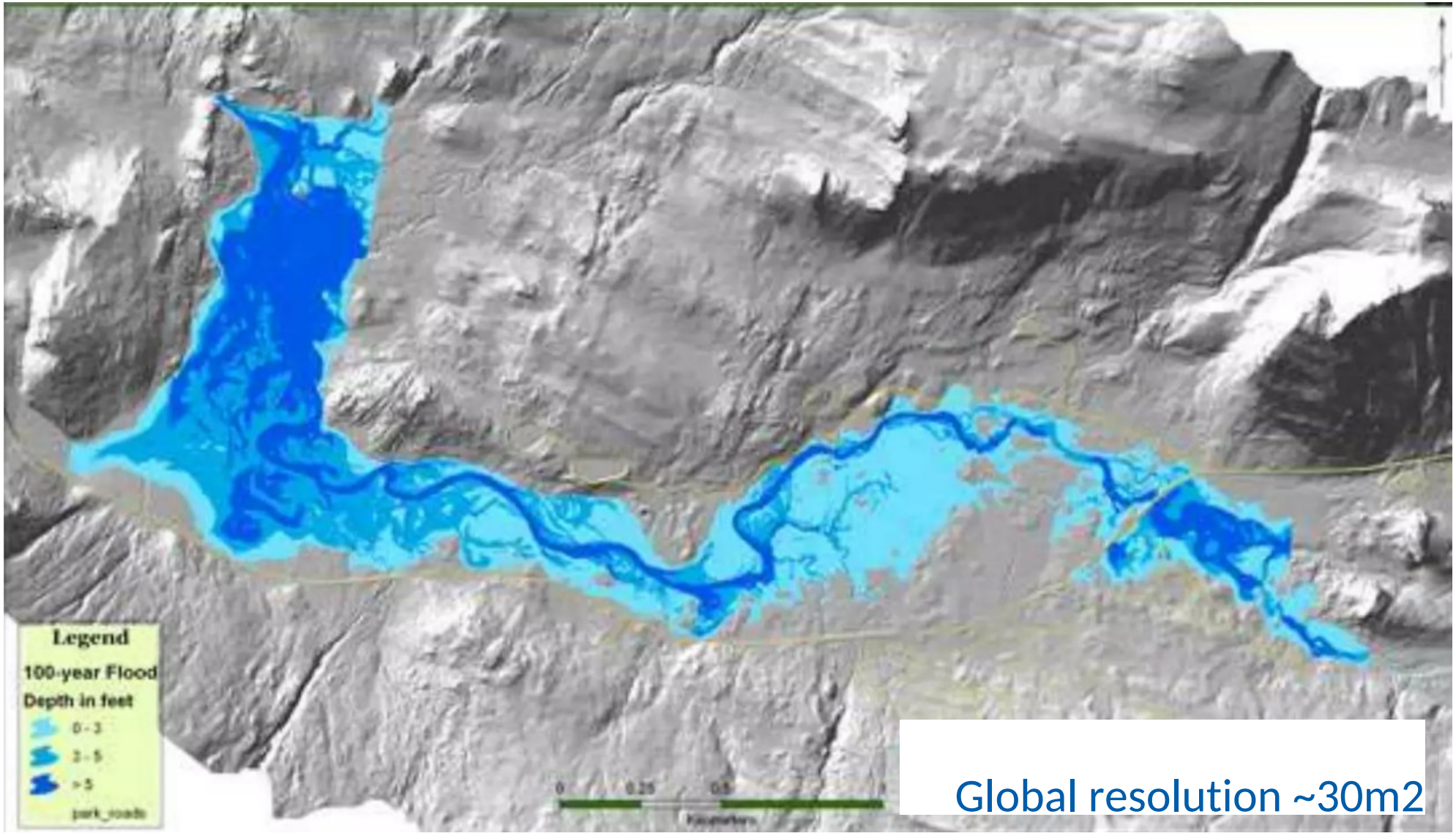
Enveloppe de la zone d'alimentation électrique fragilisée, dans l'hypothèse d'une crue type 1910

- absence de certains secours
- risques de coupures brèves ou dans certains cas de longue durée

EDF GDF SERVICES A PARIS

J. LEDOUX

Flood mapping and elevation

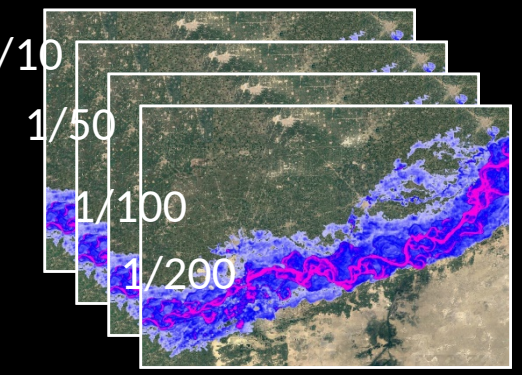


Global resolution ~30m2

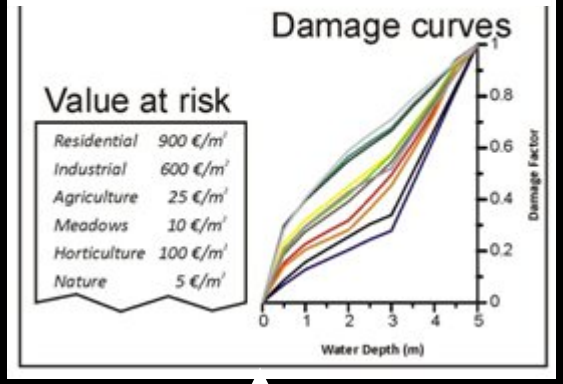
Flood risk modelling

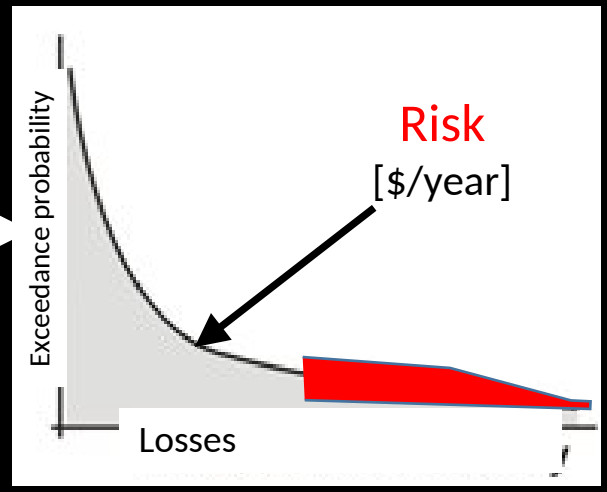
Exposure: assets and people

Flood hazard (Extent, depth)

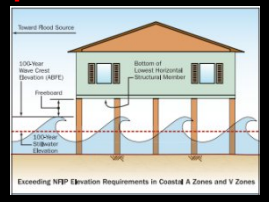


Vulnerability and damage





Adaptation measures

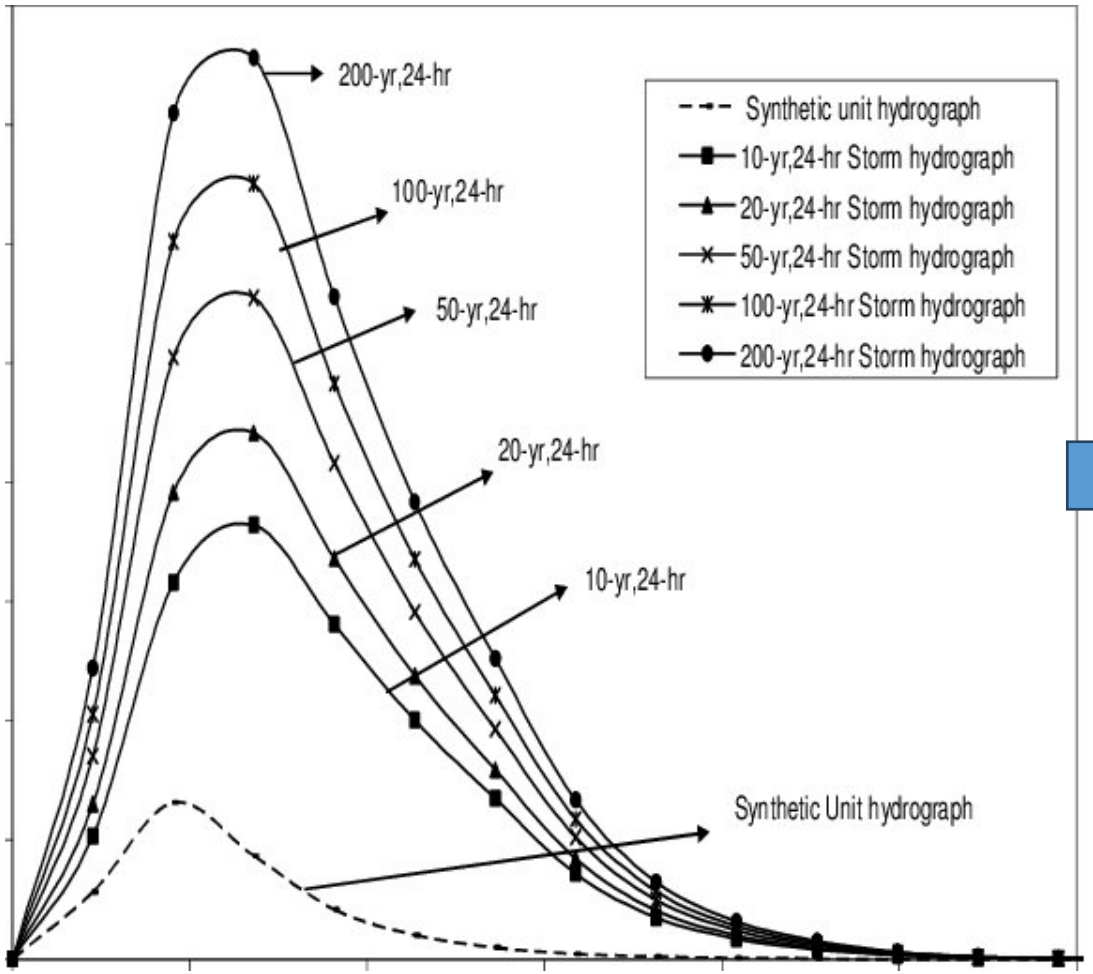


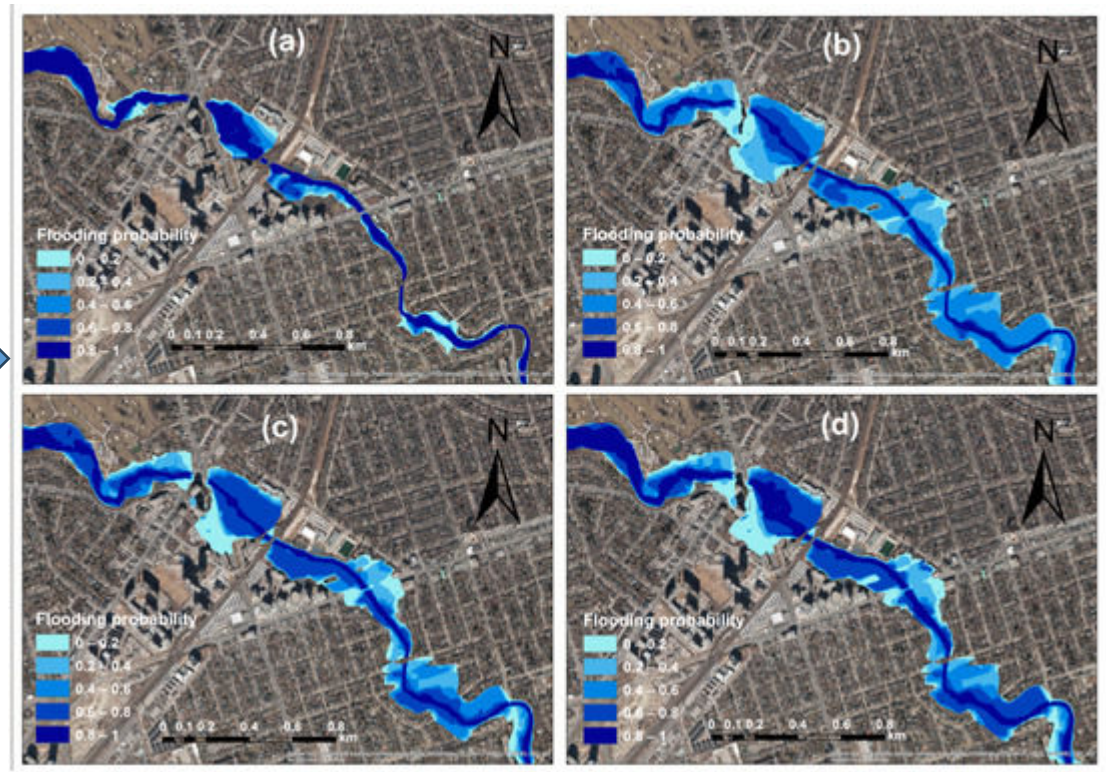
Kron, 2009; Water International

IVM Institute for Environmental Studies VU

Flood maps for different probabilities

Rainfall / discharge

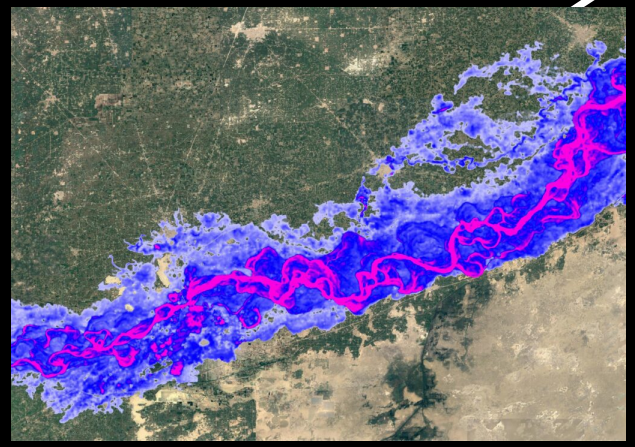




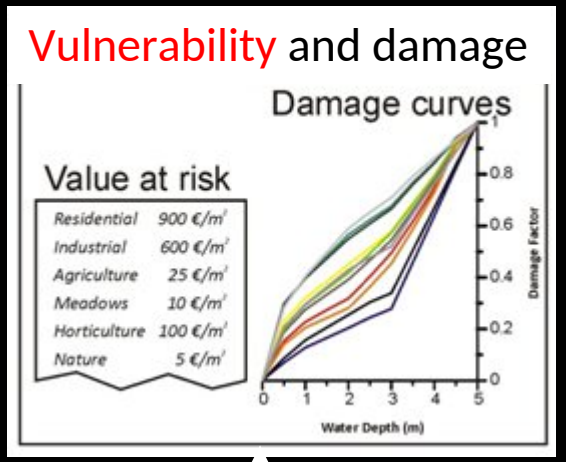
Flood risk modelling

Exposure: assets and people

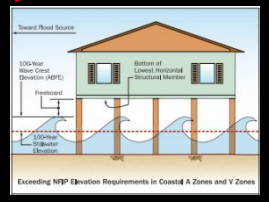
Flood hazard (Extent, depth)

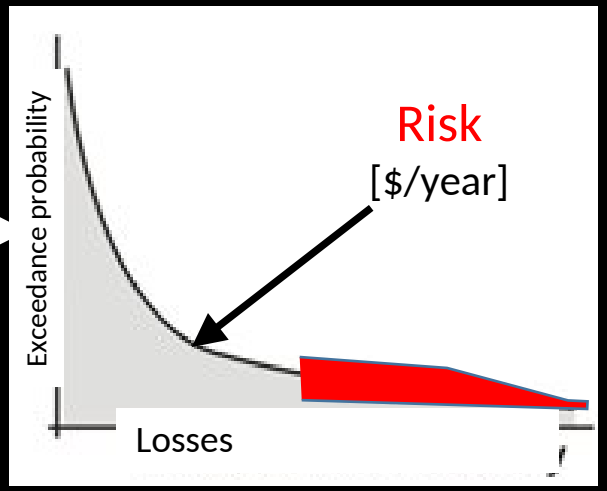


Vulnerability and damage



Adaptation measures





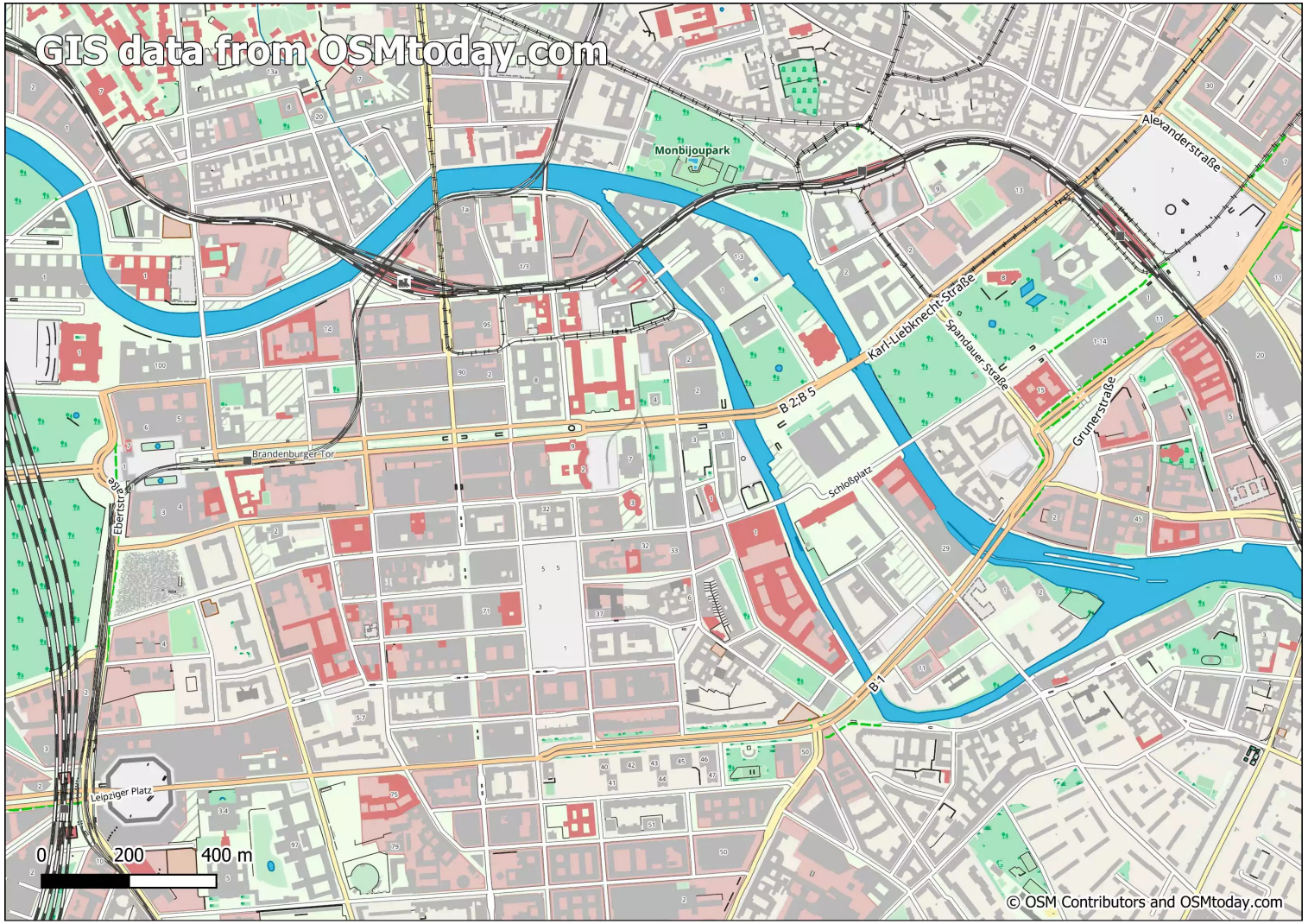
Kron, 2009; Water International

IVM Institute for Environmental Studies VU

Overlay Flood map with exposed assets and people

Ahrvalley, Germany 2021

Open Street Map (OSM)



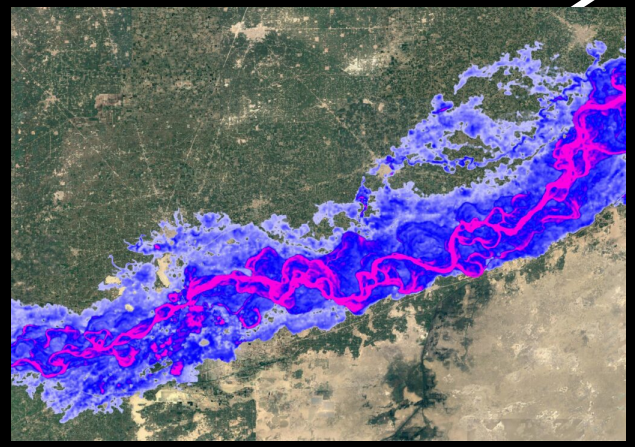
Classifying building footprints with AI

Source: Google-Microsoft open buildings dataset

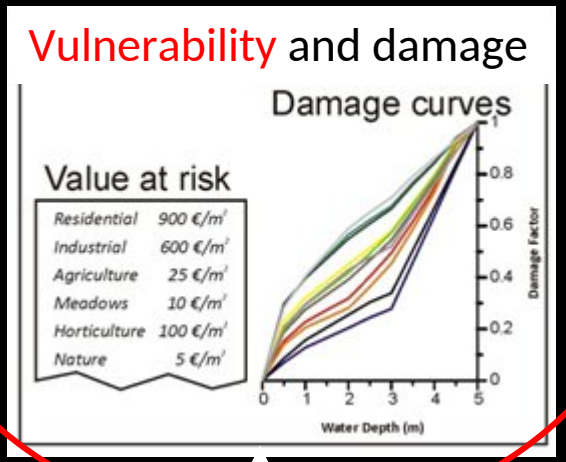
Flood risk modelling

Exposure: assets and people

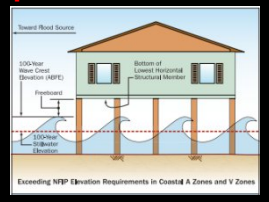
Flood hazard (Extent, depth)

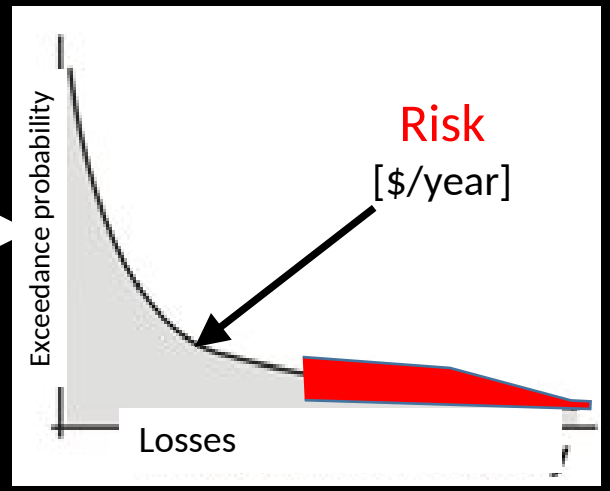


Vulnerability and damage



Adaptation measures

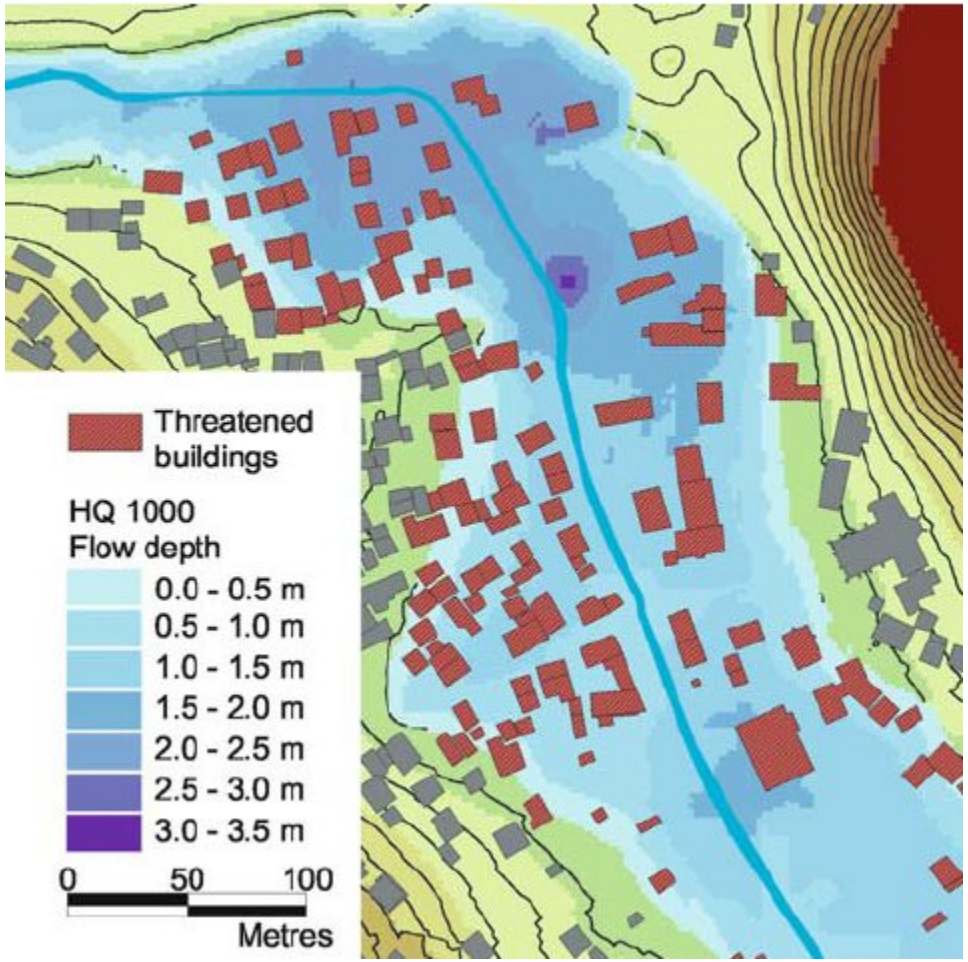




Kron, 2009; Water International

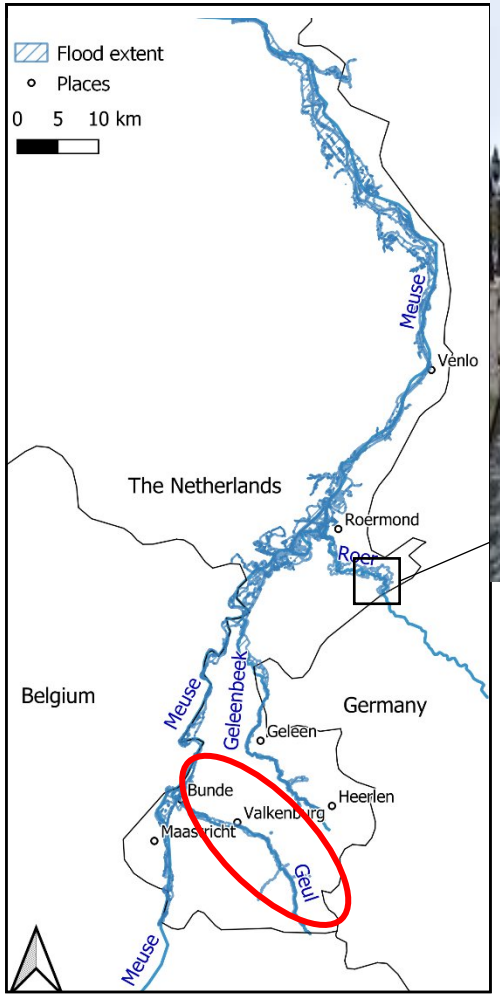
IVM Institute for Environmental Studies VU

Vulnerability: How much value at risk?



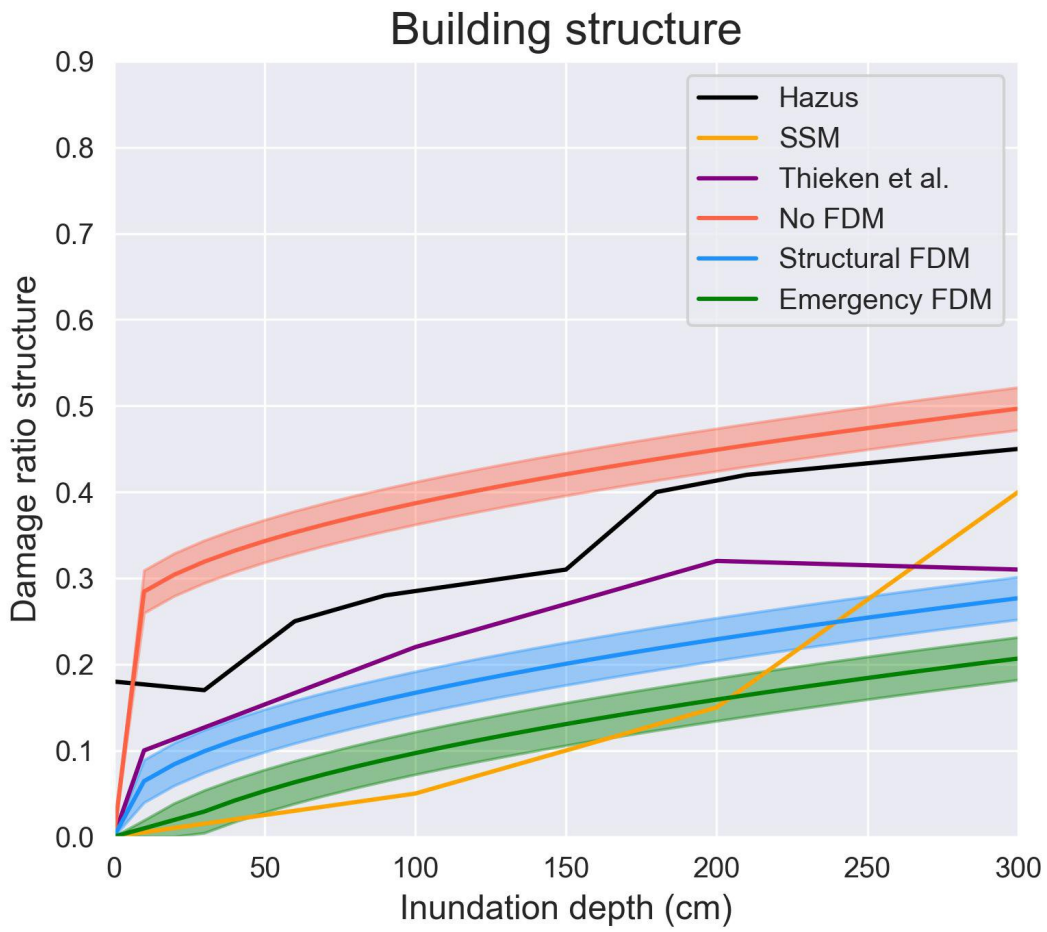
Survey

- N=1,509
- Median flood damage:
  - €25,000 to buildings
  - €17,000 to household contents



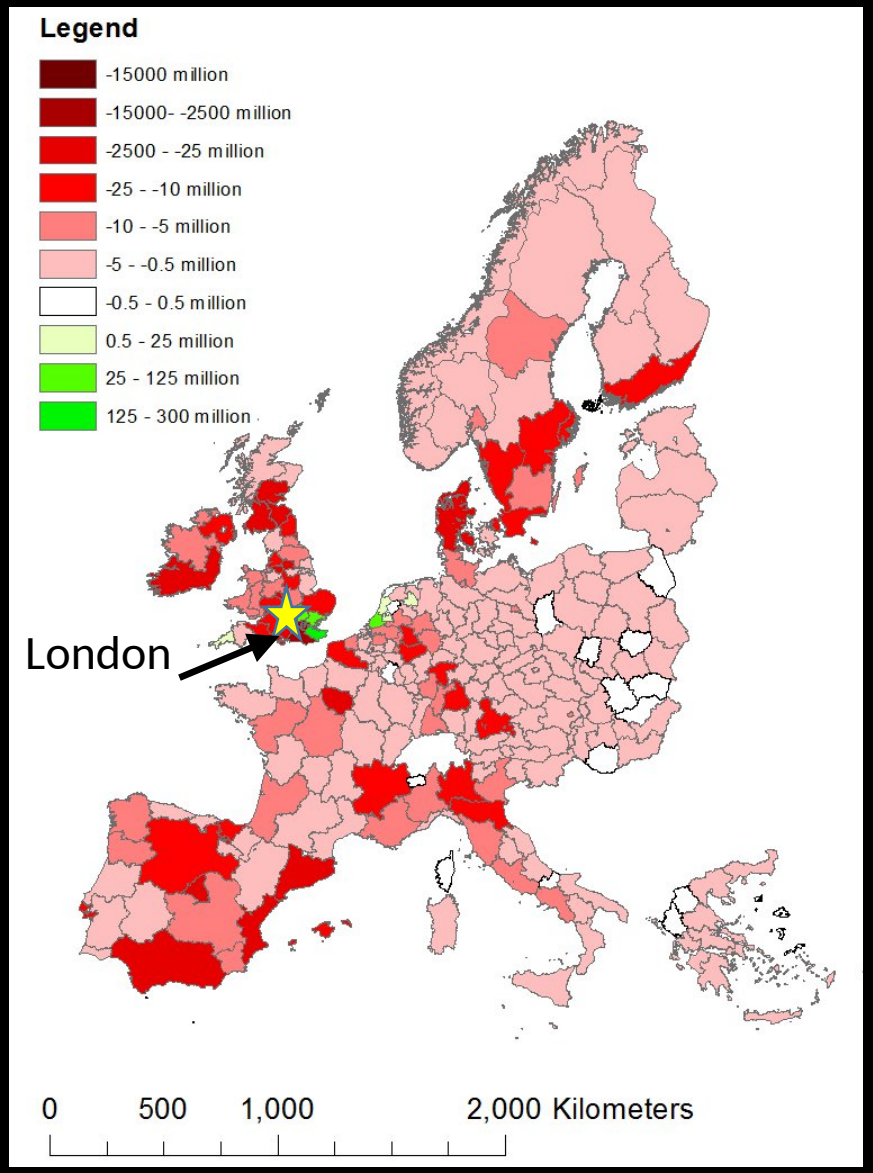
Flood depth per building

Vulnerability curves (depth Damage curves)



Endendijk et al., 2023; *WRR*

Indirect Economic damage from 1/100 flood in London



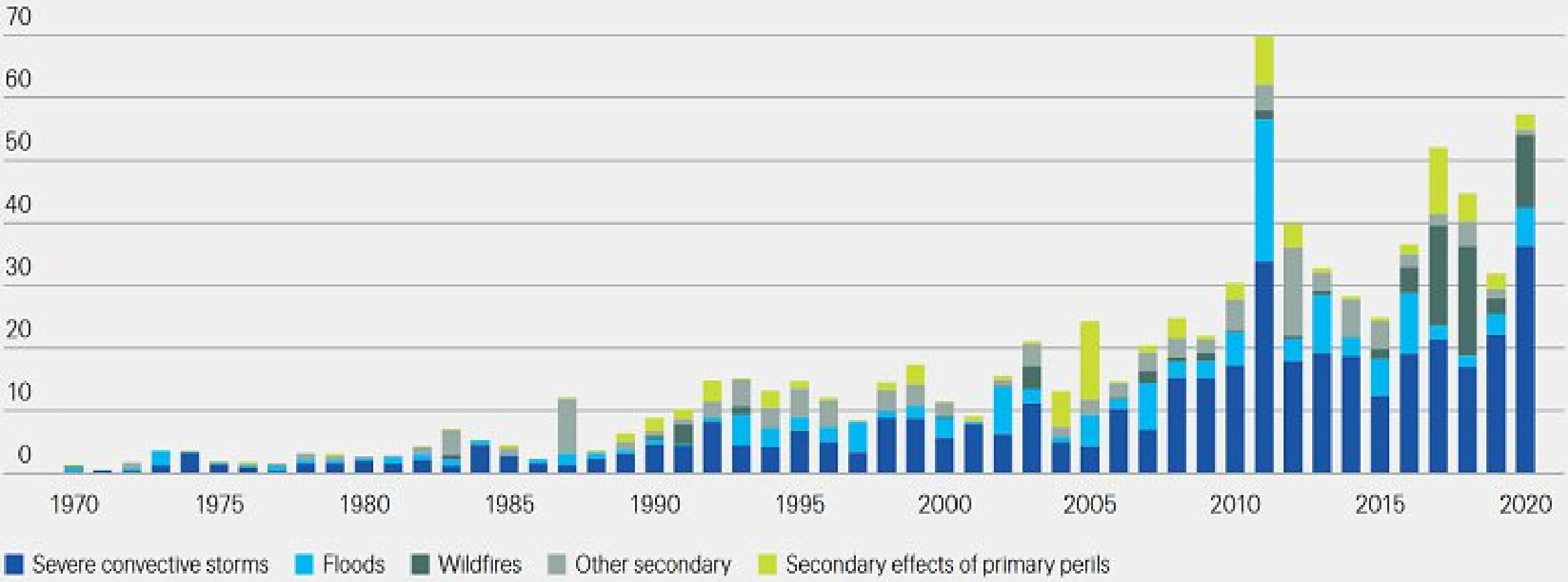
Using economic input – output model

Koks et al., 2019; ERL.

IVM Institute for Environmental Studies VU

Global insured losses from secondary perils since 1970, in USD billion (2020 prices)

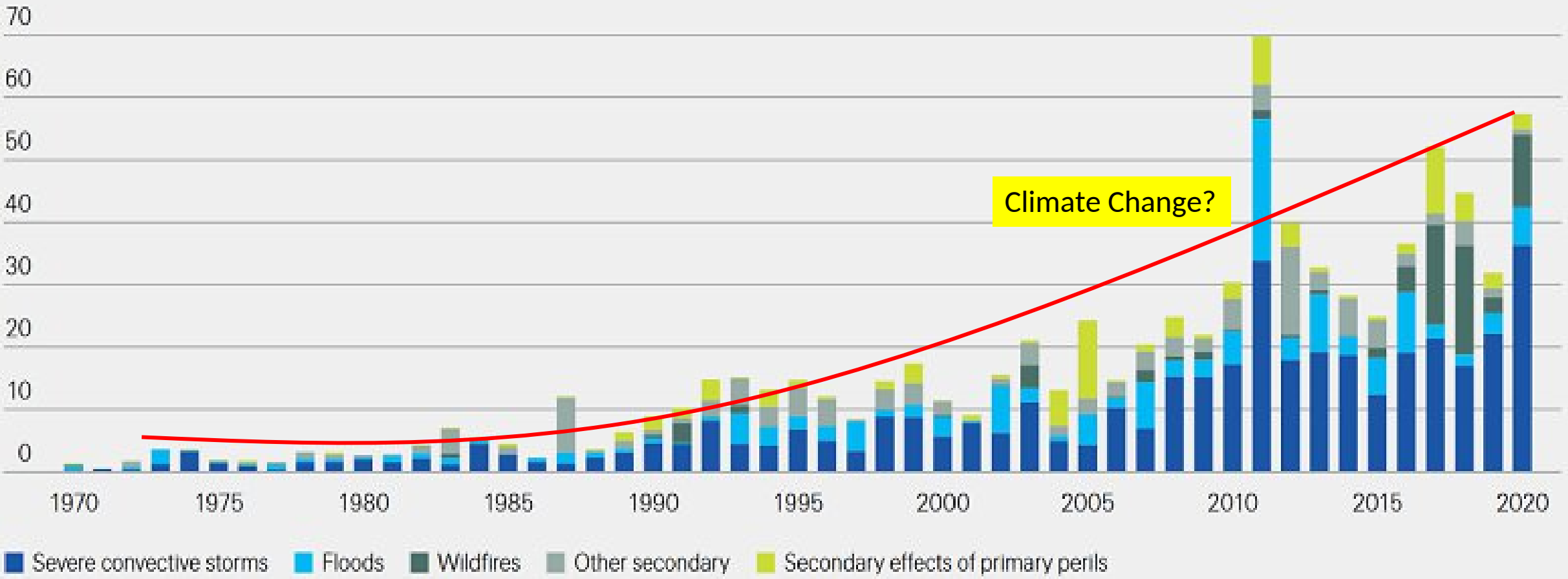
Insured losses from secondary perils have been growing steadily. Among them, losses from severe convective storms represent the biggest component. However, in recent years losses from wildfires have been growing fastest.



Source: Swiss Re Institute

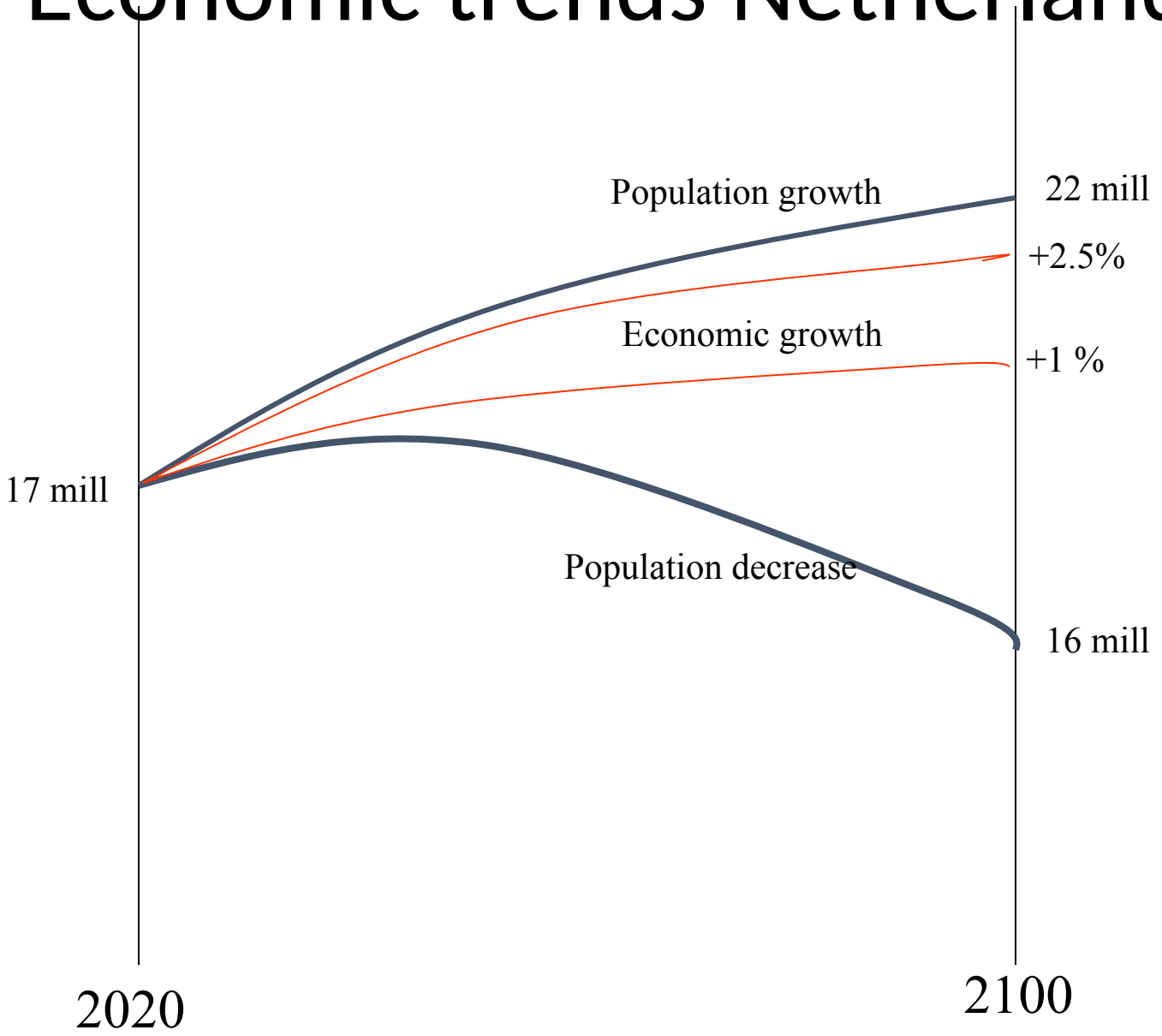
Global insured losses from secondary perils since 1970, in USD billion (2020 prices)

Insured losses from secondary perils have been growing steadily. Among them, losses from severe convective storms represent the biggest component. However, in recent years losses from wildfires have been growing fastest.

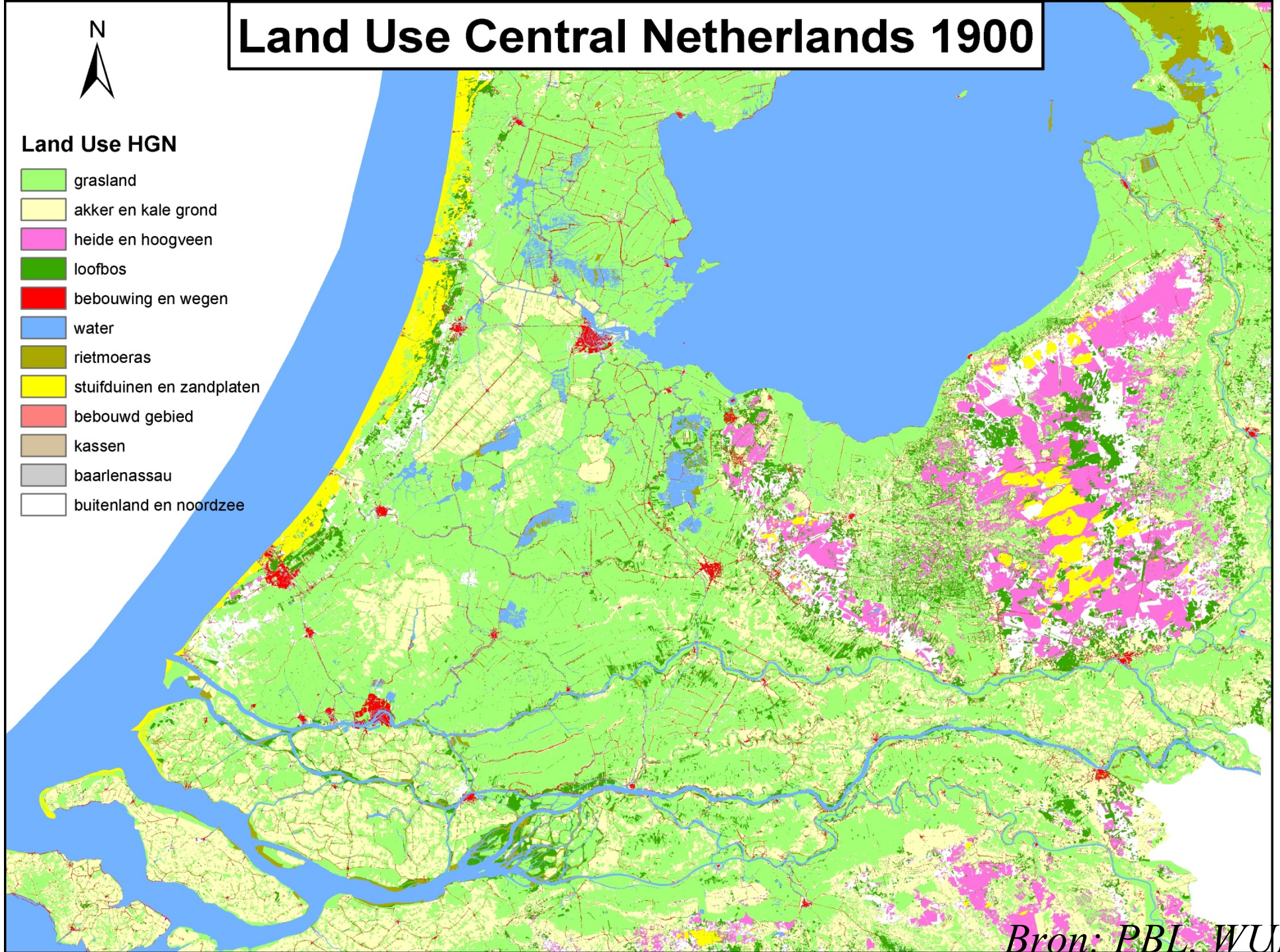


Source: Swiss Re Institute

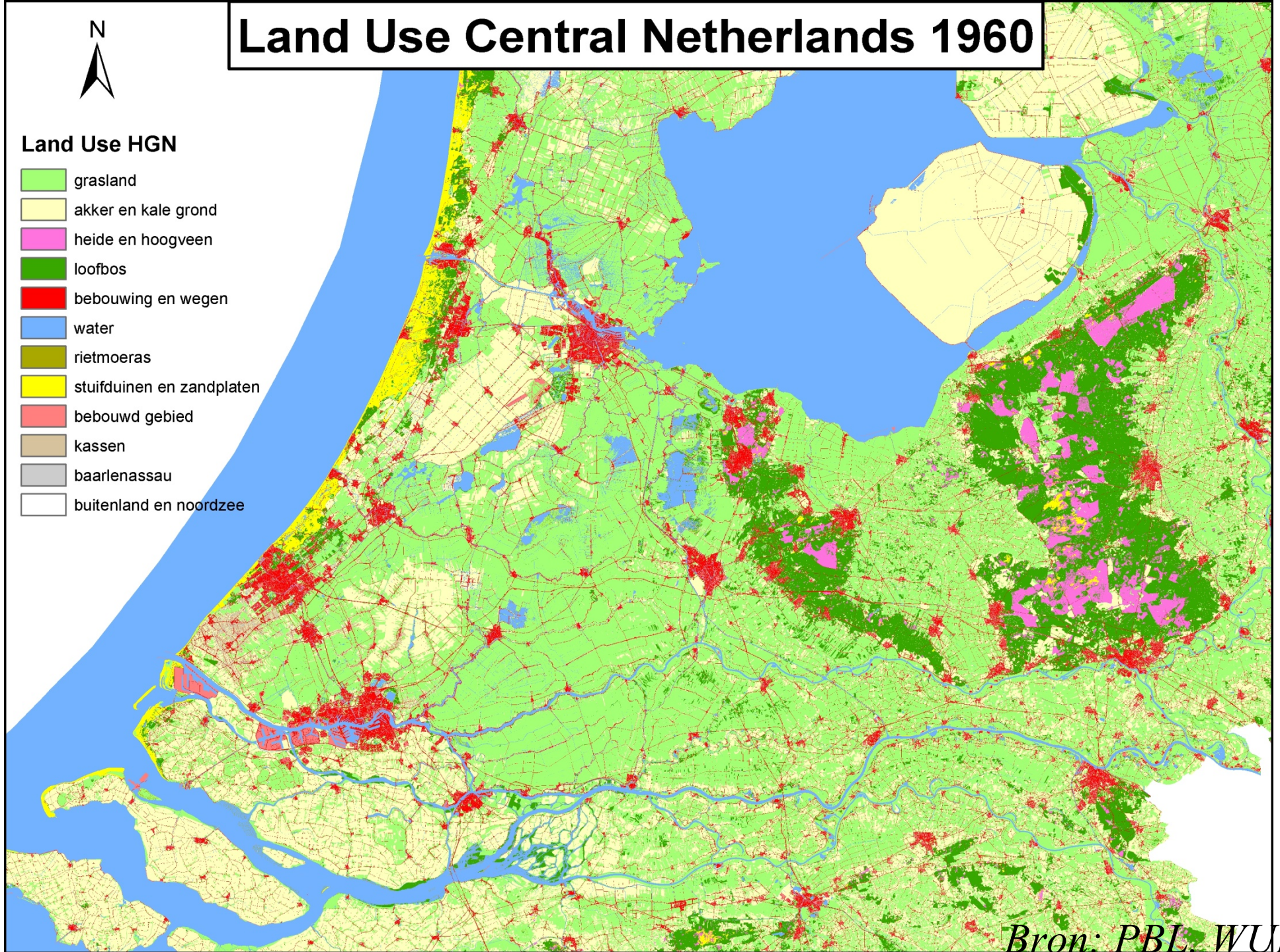
Socio- Economic trends Netherlands



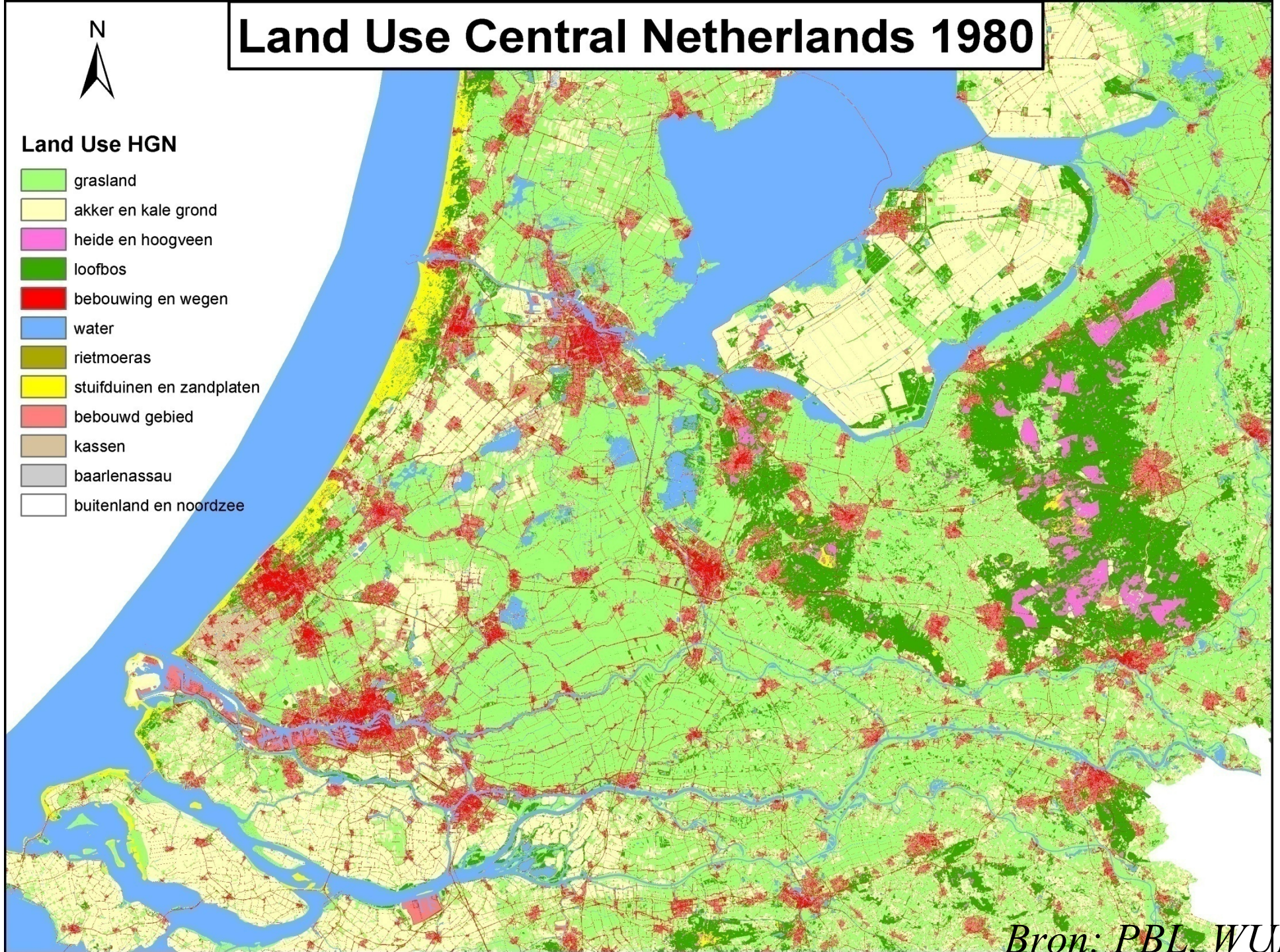
28


Land Use Central Netherlands 1900
N
Land Use HGN
grasland
akker en kale grond
heide en hoogveen
loofbos
bebouwing en wegen
water
rietmoeras
stuifduinen en zandplaten
bebouwd gebied
kassen
baarlenassau
buitenland en noordzee

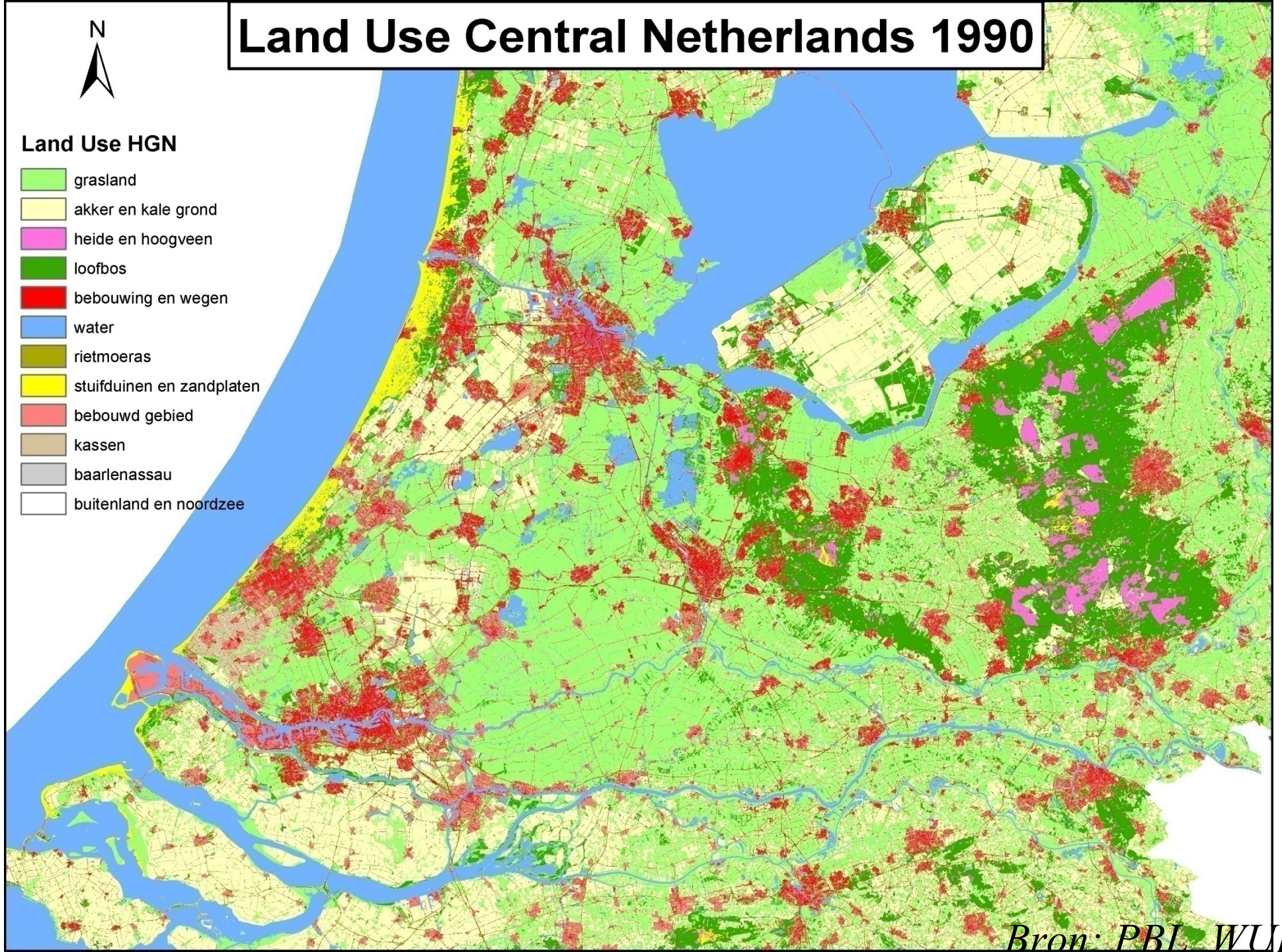
Bron: PBL, WUR


Land Use Central Netherlands 1960
N
Land Use HGN
grasland
akker en kale grond
heide en hoogveen
loofbos
bebouwing en wegen
water
rietmoeras
stuifduinen en zandplaten
bebouwd gebied
kassen
baarlenassau
buitenland en noordzee

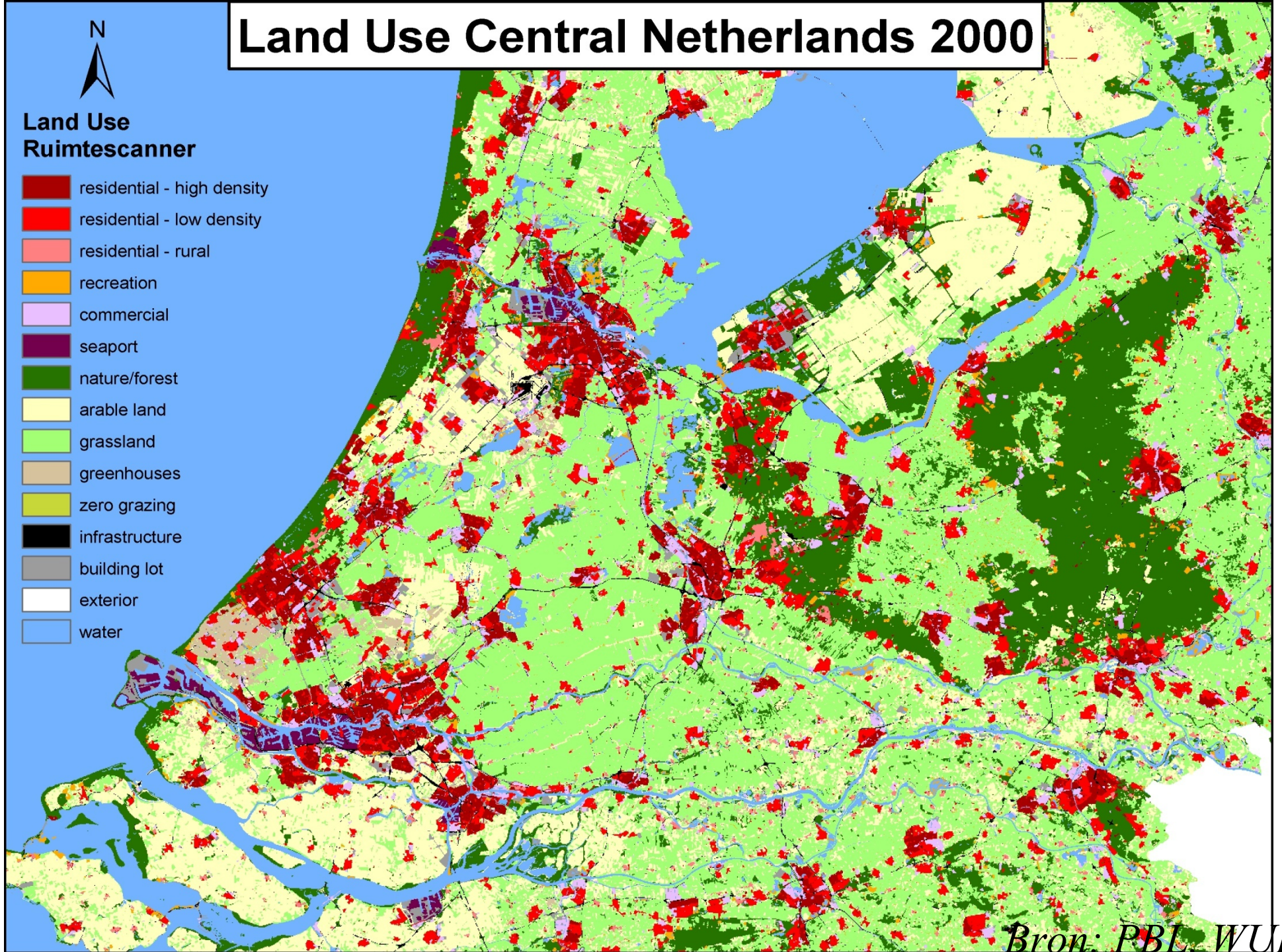
Bron: PBL, WUR


Land Use Central Netherlands 1980
N
Land Use HGN
grasland
akker en kale grond
heide en hoogveen
loofbos
bebouwing en wegen
water
rietmoeras
stuifduinen en zandplaten
bebouwd gebied
kassen
baarlenassau
buitenland en noordzee

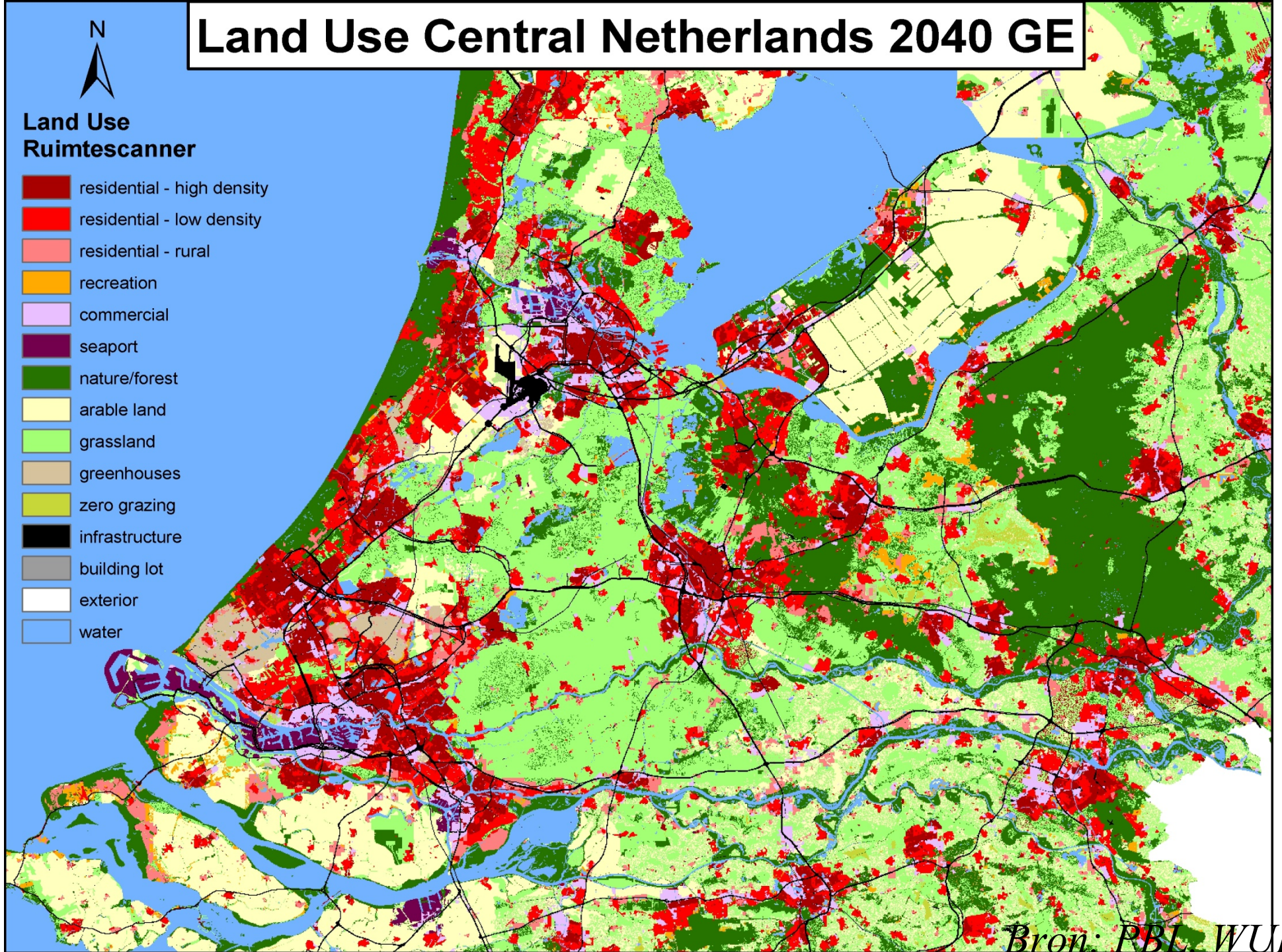
Bron: PBL, WUR


Land Use Central Netherlands 1990
N
Land Use HGN
grasland
akker en kale grond
heide en hoogveen
loofbos
bebouwing en wegen
water
rietmoeras
stuifduinen en zandplaten
bebouwd gebied
kassen
baarlenassau
buitenland en noordzee

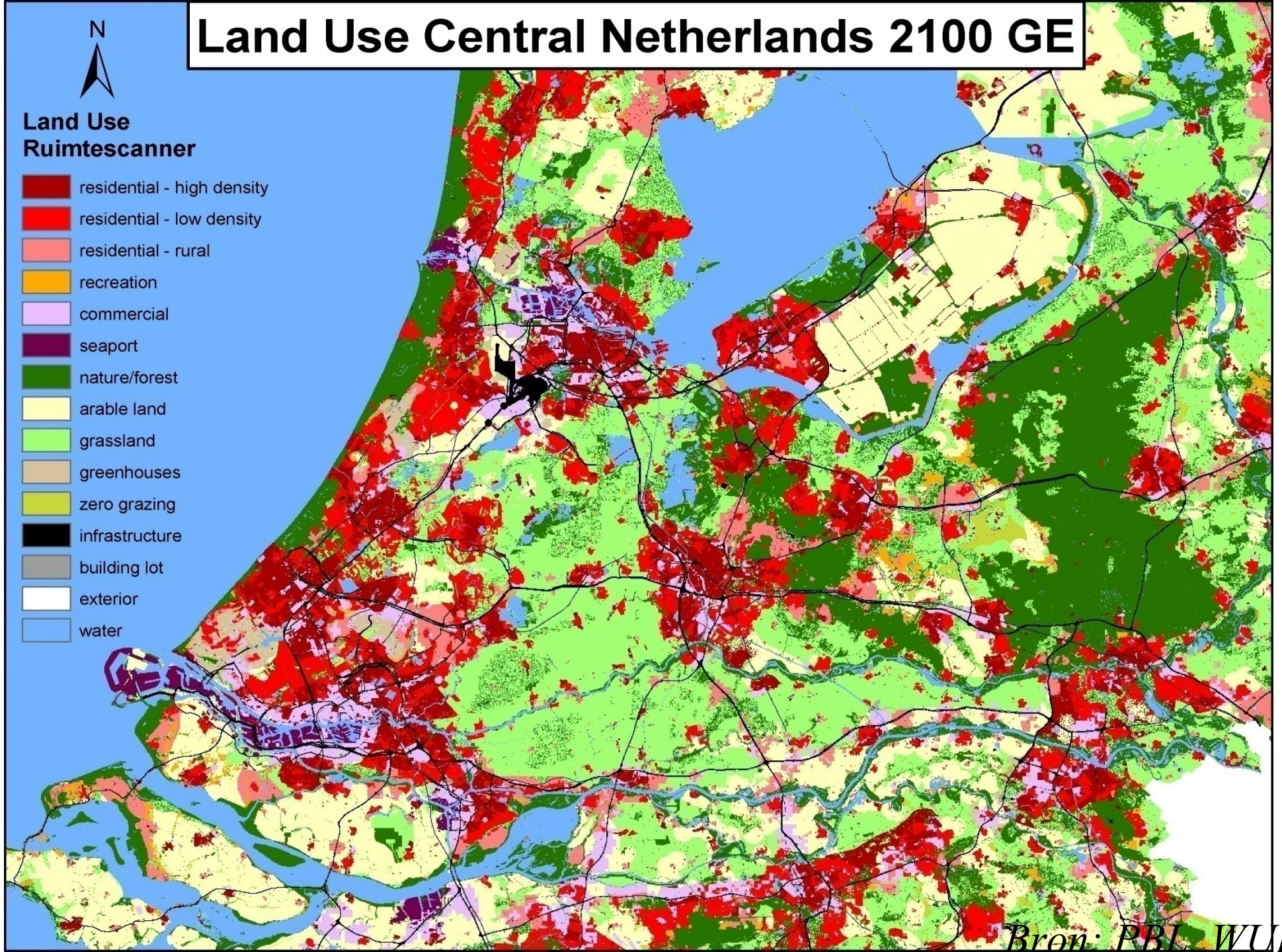
Bron: PBL, WUR


Land Use Central Netherlands 2000
N
Land Use
Ruimtescanner
residential - high density
residential - low density
residential - rural
recreation
commercial
seaport
nature/forest
arable land
grassland
greenhouses
zero grazing
infrastructure
building lot
exterior
water

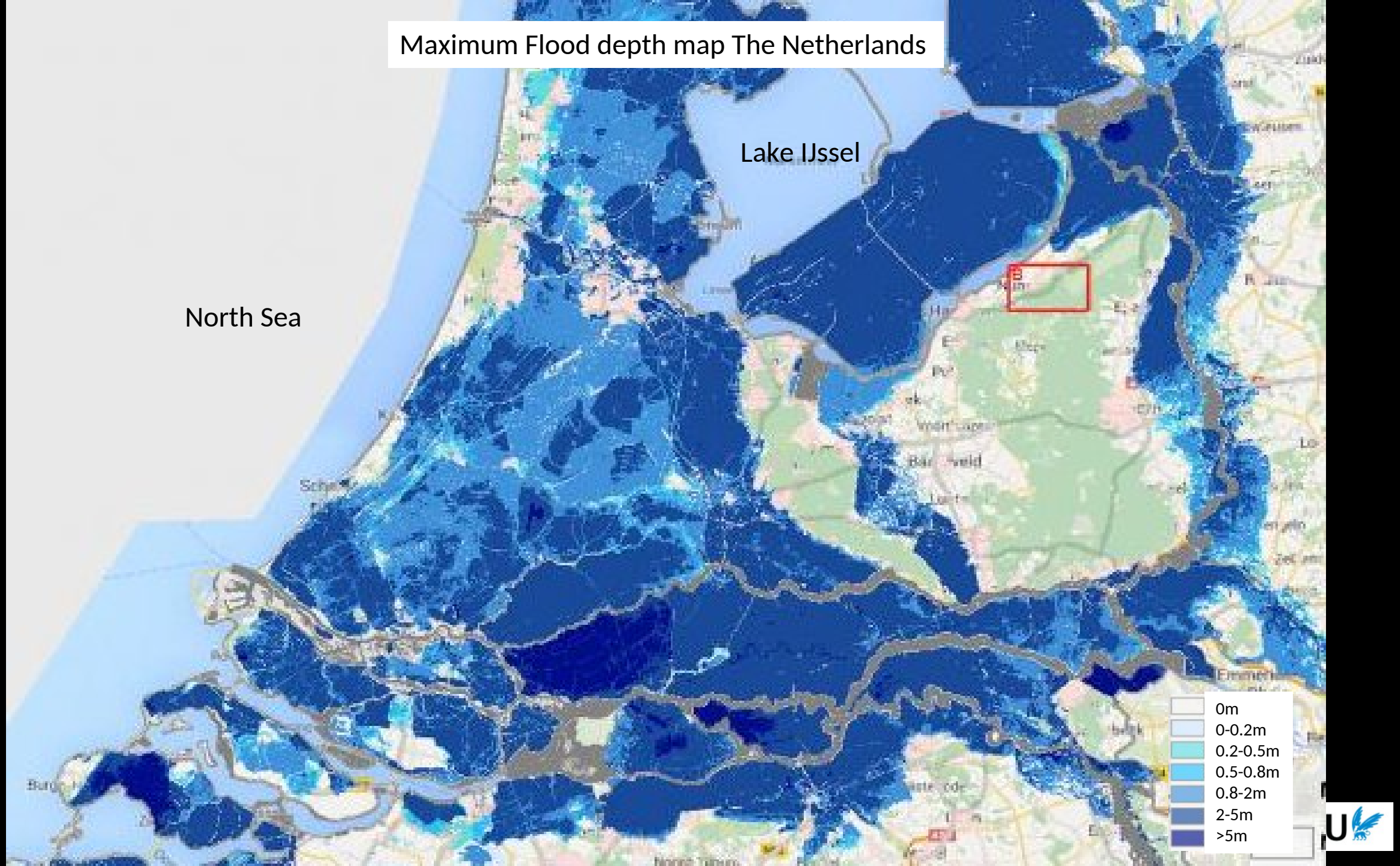
Bron: PBL, WUR


Land Use Central Netherlands 2040 GE
N
Land Use
Ruimtescanner
residential - high density
residential - low density
residential - rural
recreation
commercial
seaport
nature/forest
arable land
grassland
greenhouses
zero grazing
infrastructure
building lot
exterior
water

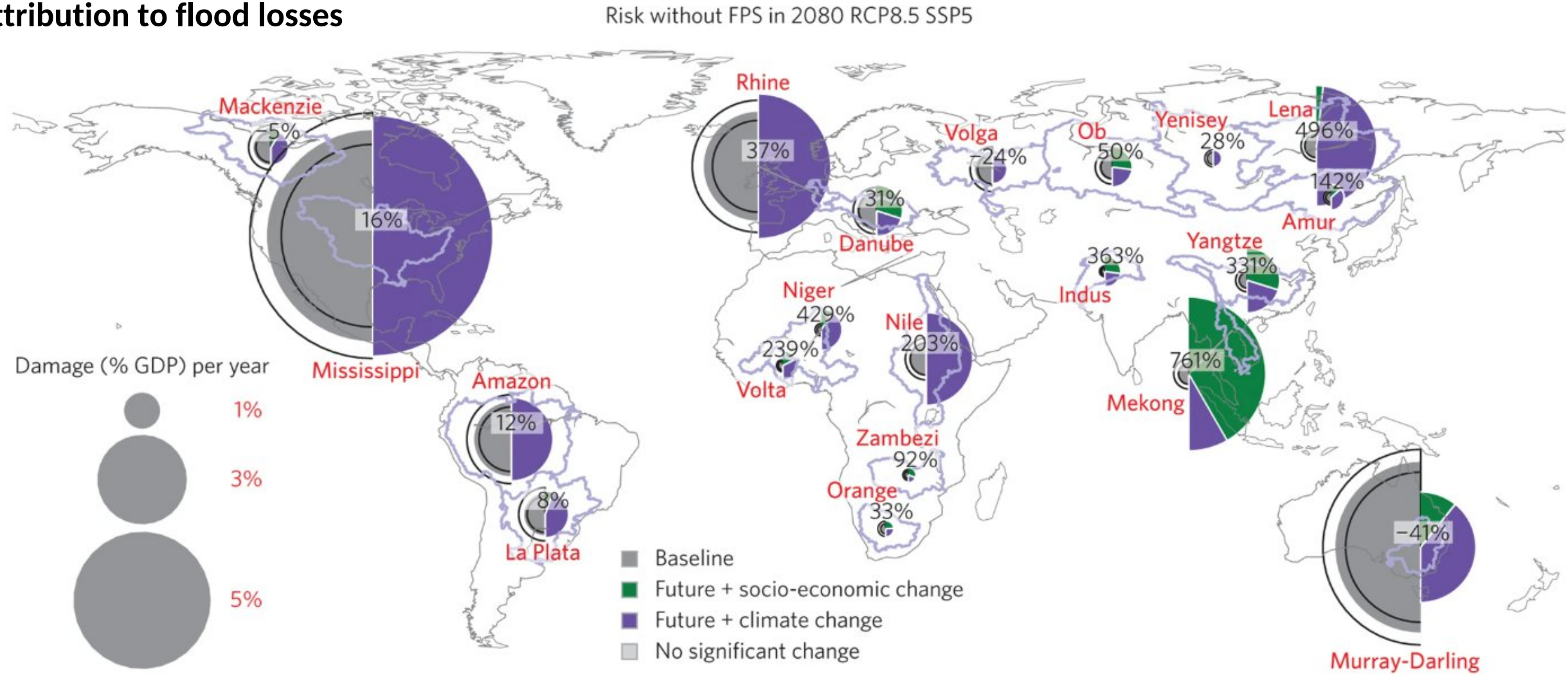
Bron: PBL, WUR


Land Use Central Netherlands 2100 GE
N
Land Use
Ruimtescanner
residential - high density
residential - low density
residential - rural
recreation
commercial
seaport
nature/forest
arable land
grassland
greenhouses
zero grazing
infrastructure
building lot
exterior
water

Bron: PBL, WUR


Maximum Flood depth map The Netherlands
Lake IJssel
North Sea
0m
0-0.2m
0.2-0.5m
0.5-0.8m
0.8-2m
2-5m
>5m

Attribution to flood losses

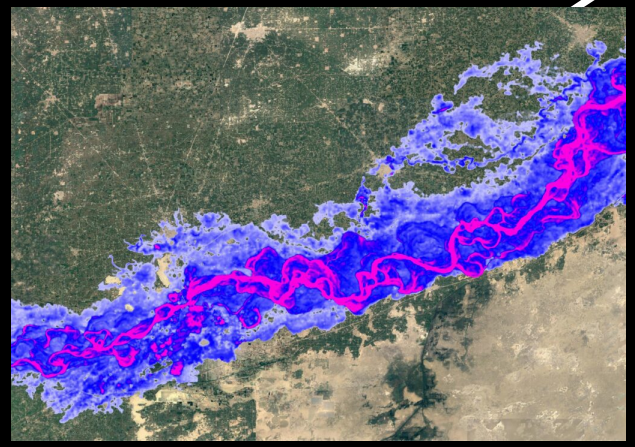


Winsemius et al., 2016 ; Nature CC

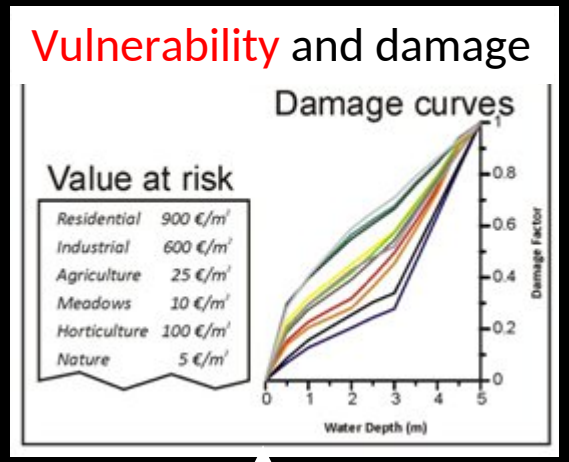
Flood risk modelling

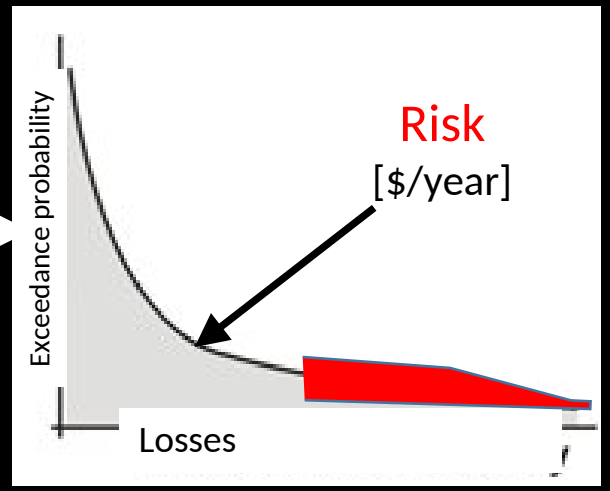
Exposure: assets and people

Flood hazard (Extent, depth)

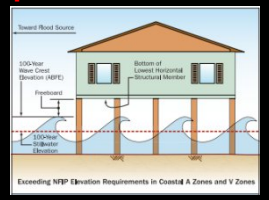


Vulnerability and damage





Adaptation measures



Kron, 2009; Water International

IVM Institute for Environmental Studies VU

Flood protection

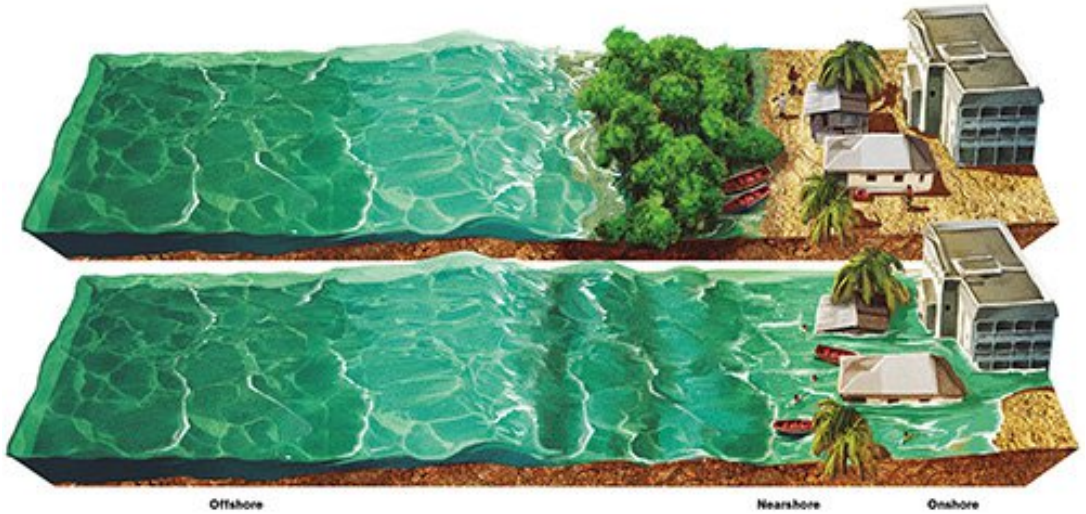
Maeslant surge-barrier (1997); Accessibility Rotterdam harbor

Inflatable barrier: Meuse river, Bayonne France

Nature based solutions: river widening

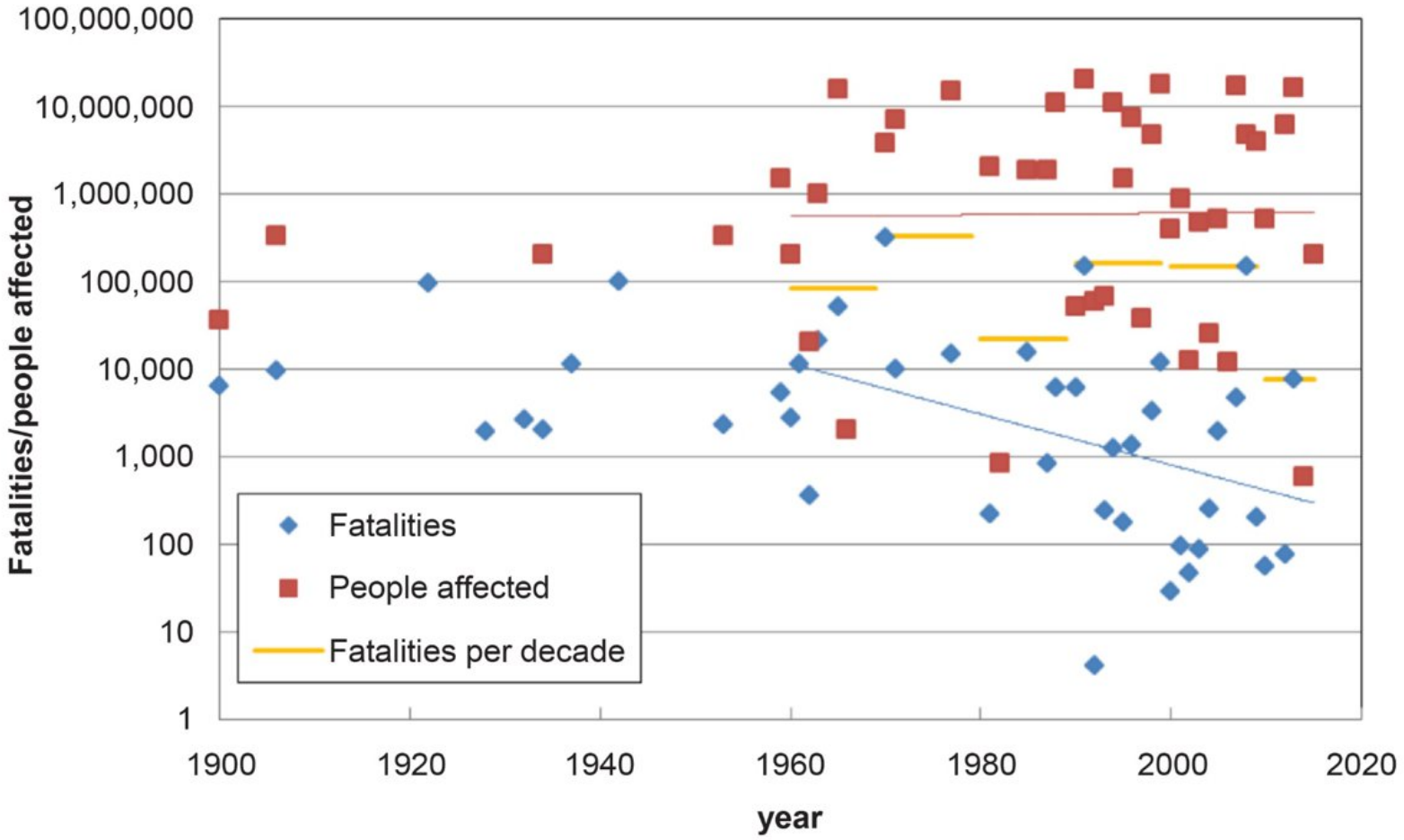

Nijmegen, Netherlands after river widening

Beach nourishment The Netherlands:
+/- 20 million m3 sand/ year



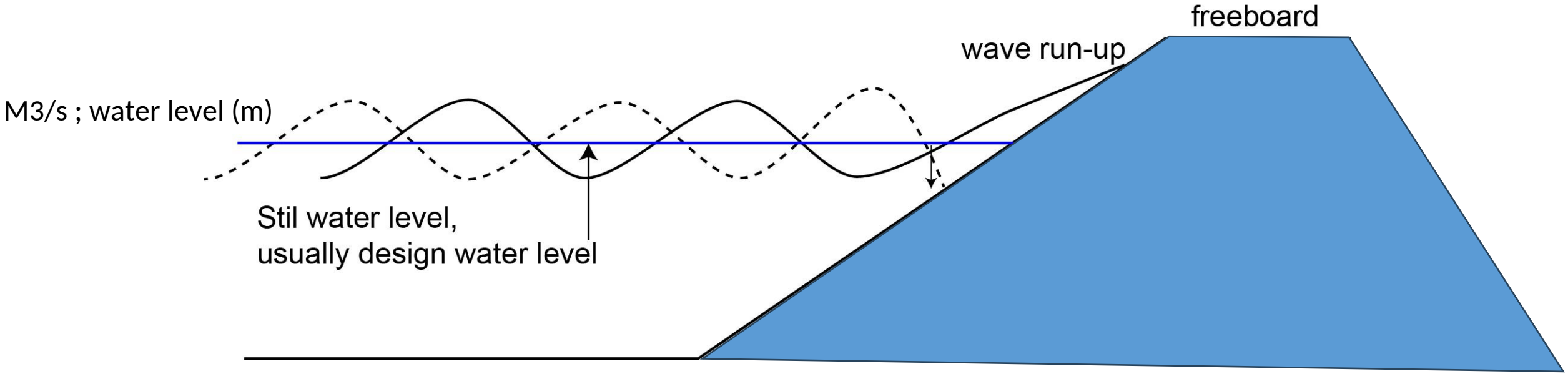
Mangrove restoration

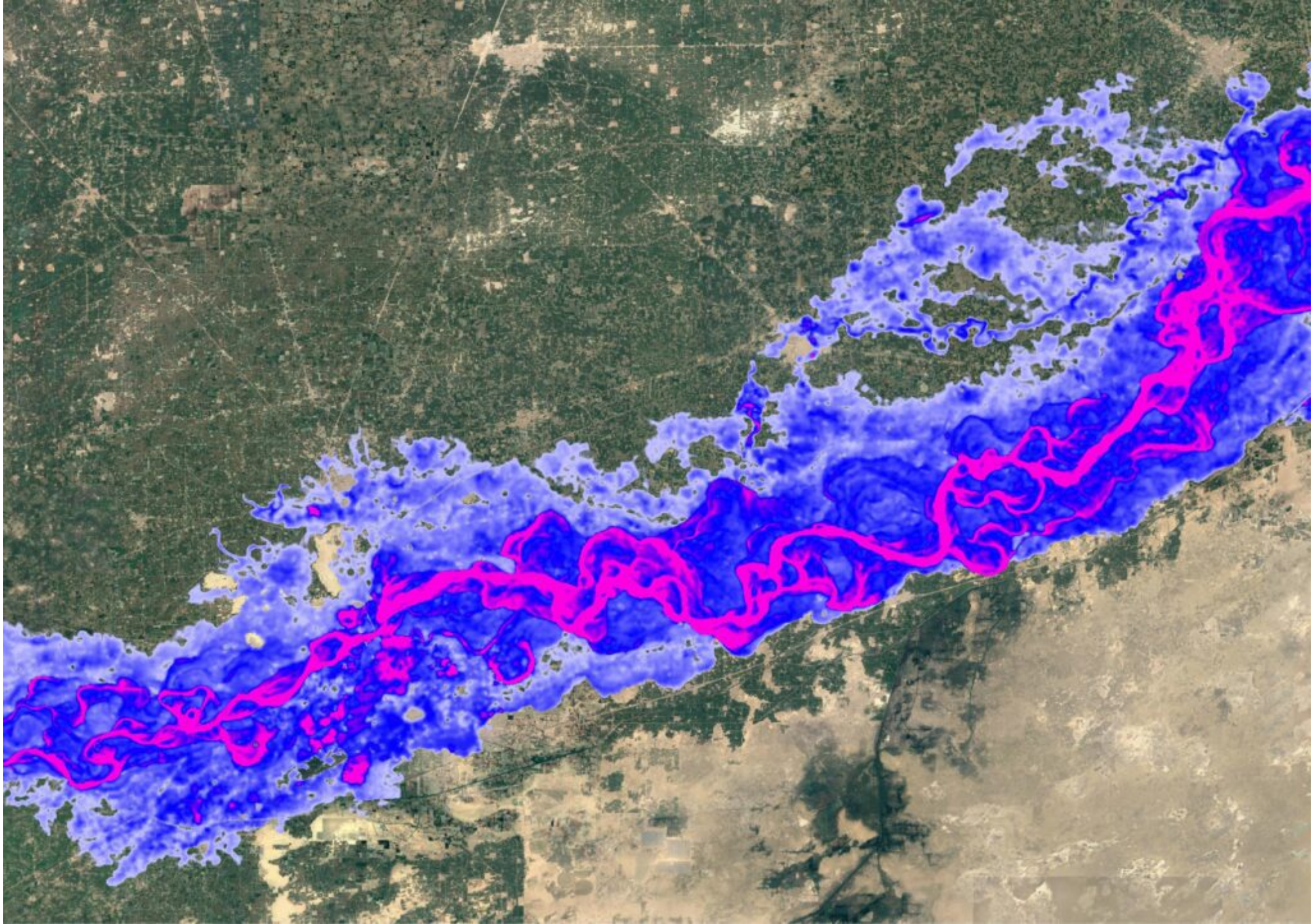
Effect of flood protection on flood fatalities

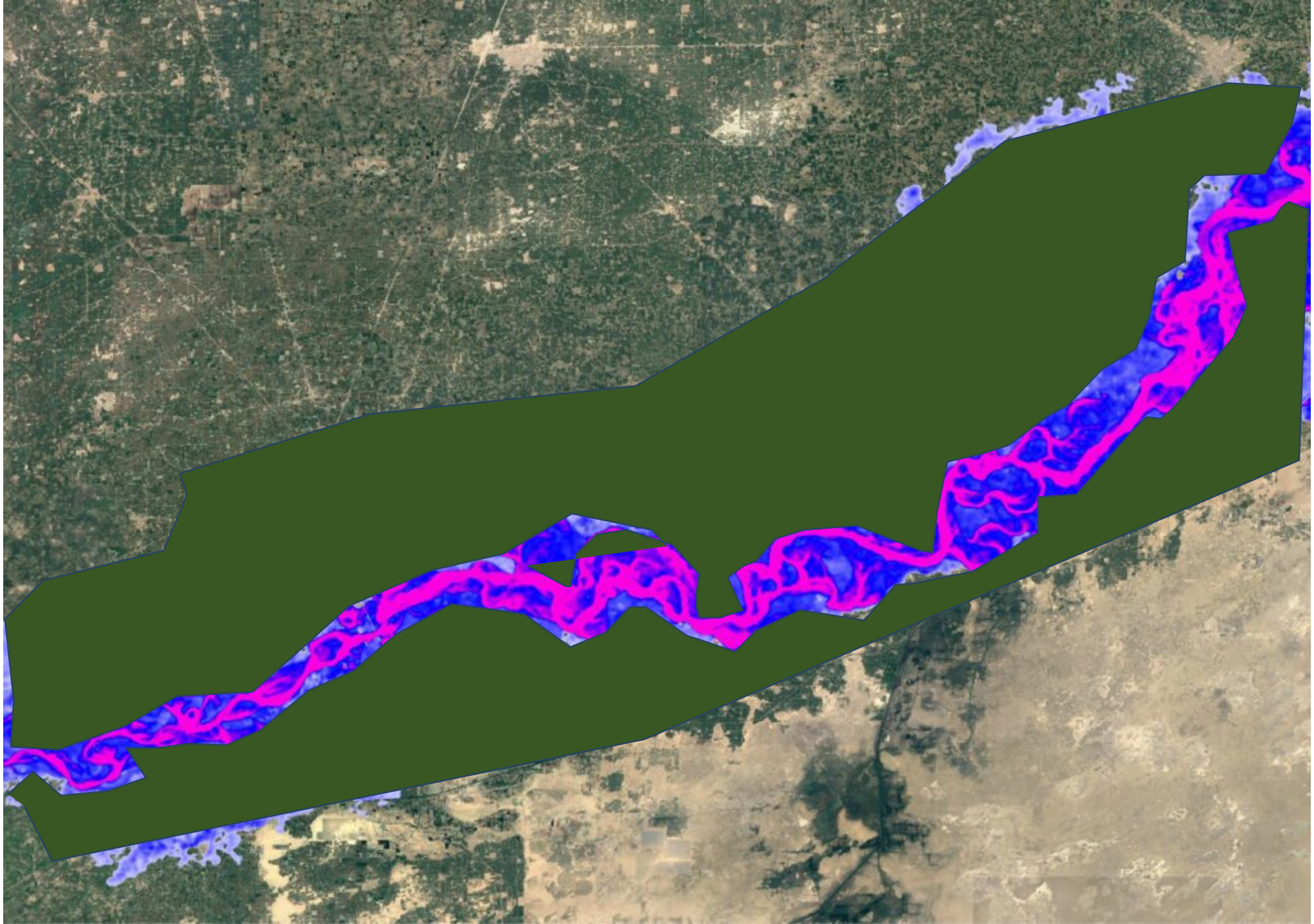


Bouwer and Jonkman 2019 *ERL*

Assume levee can withstand pre-defined water level



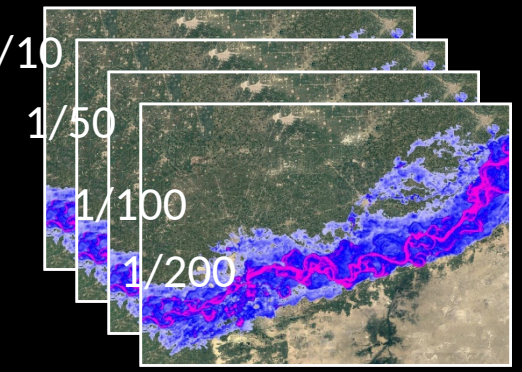




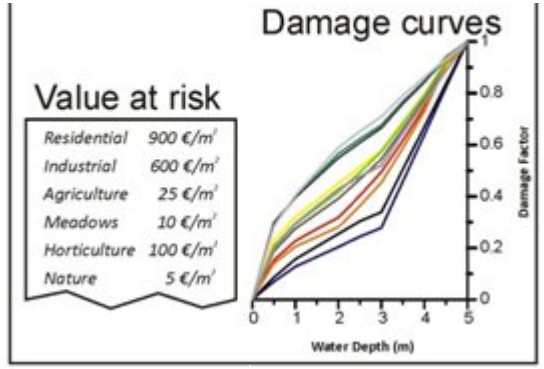
Assume 100yr protection level

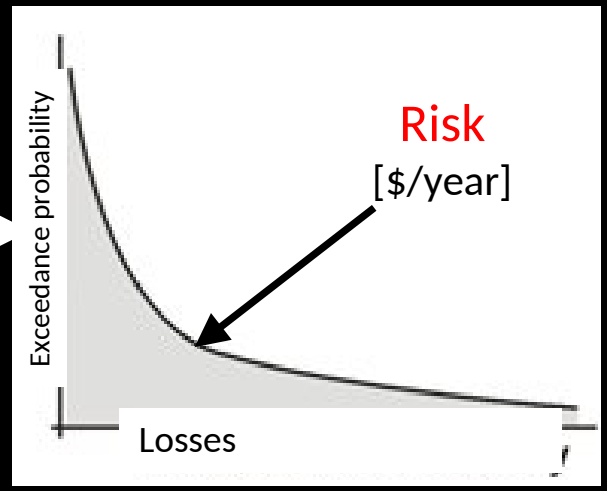
Exposure: assets and people

Flood hazard (Extent, depth)

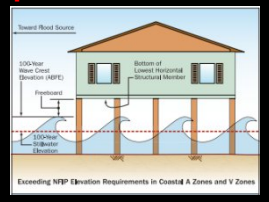


Vulnerability and damage





Adaptation measures



Kron, 2009; Water International

IVM Institute for Environmental Studies VU

Reduce exposure (e.g. zoning)

Exposed assets and people

Ahrvalley, Germany 2021

Overlay Flood map with exposed assets and people

Ahrvalley, Germany 2021

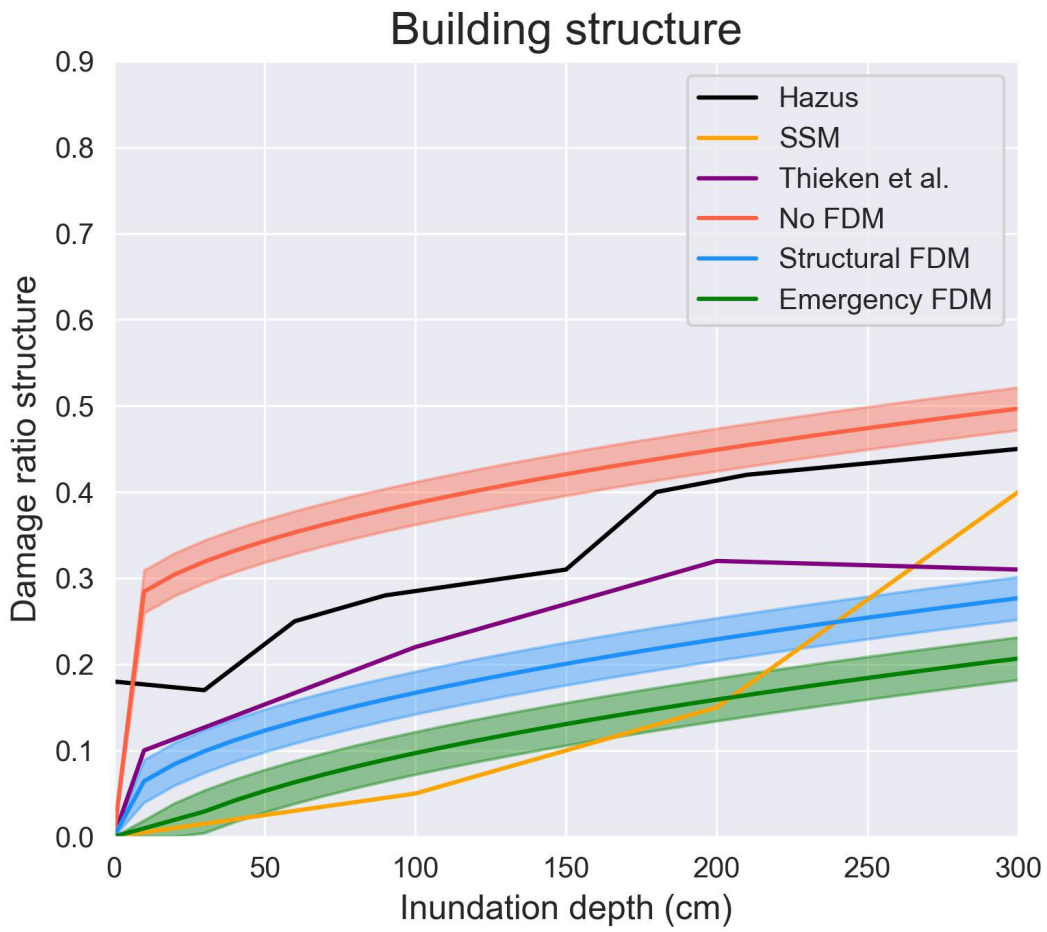
Reduce vulnerability
(e.g. flood proofing buildings)

Elevation

IVM Institute for Environmental Studies VU

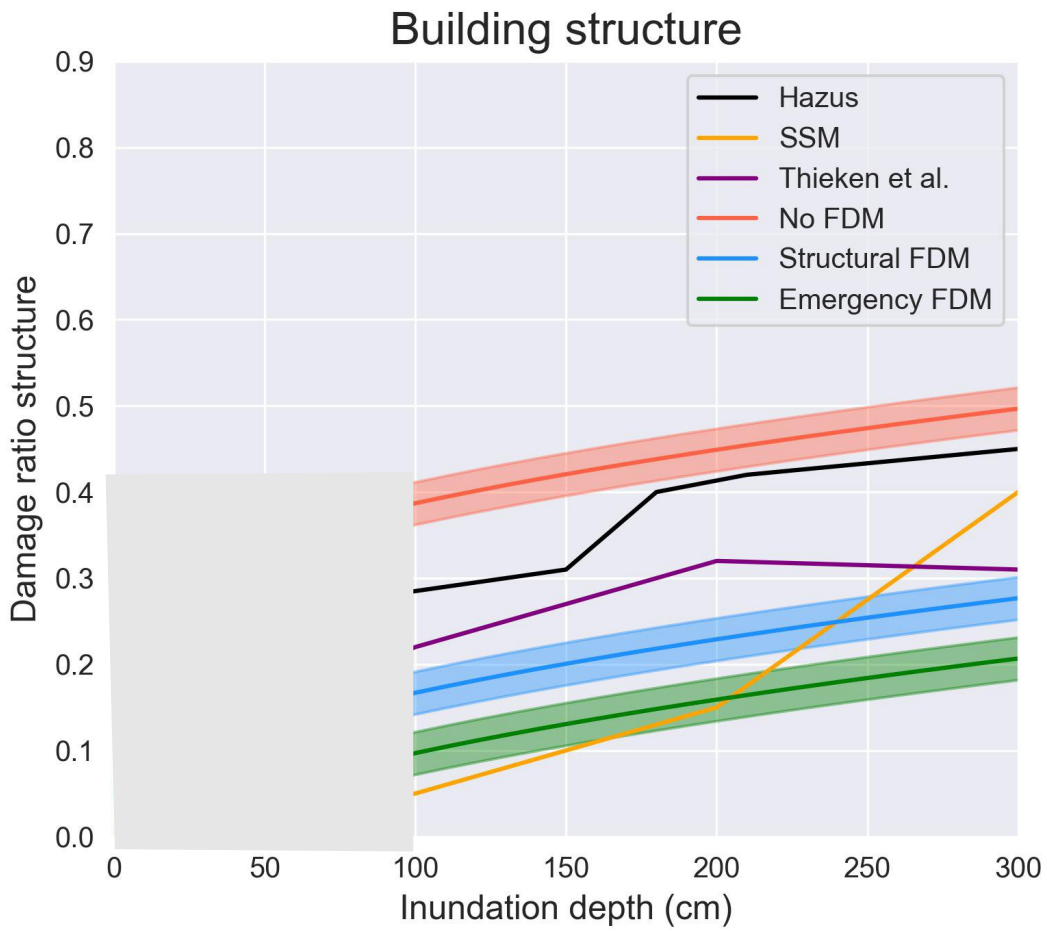

[QUICK DAM]
FLOODGATE

Vulnerability curves (depth Damage curves)



Endendijk et al., 2023; *WRR*

Vulnerability curves (depth Damage curves)

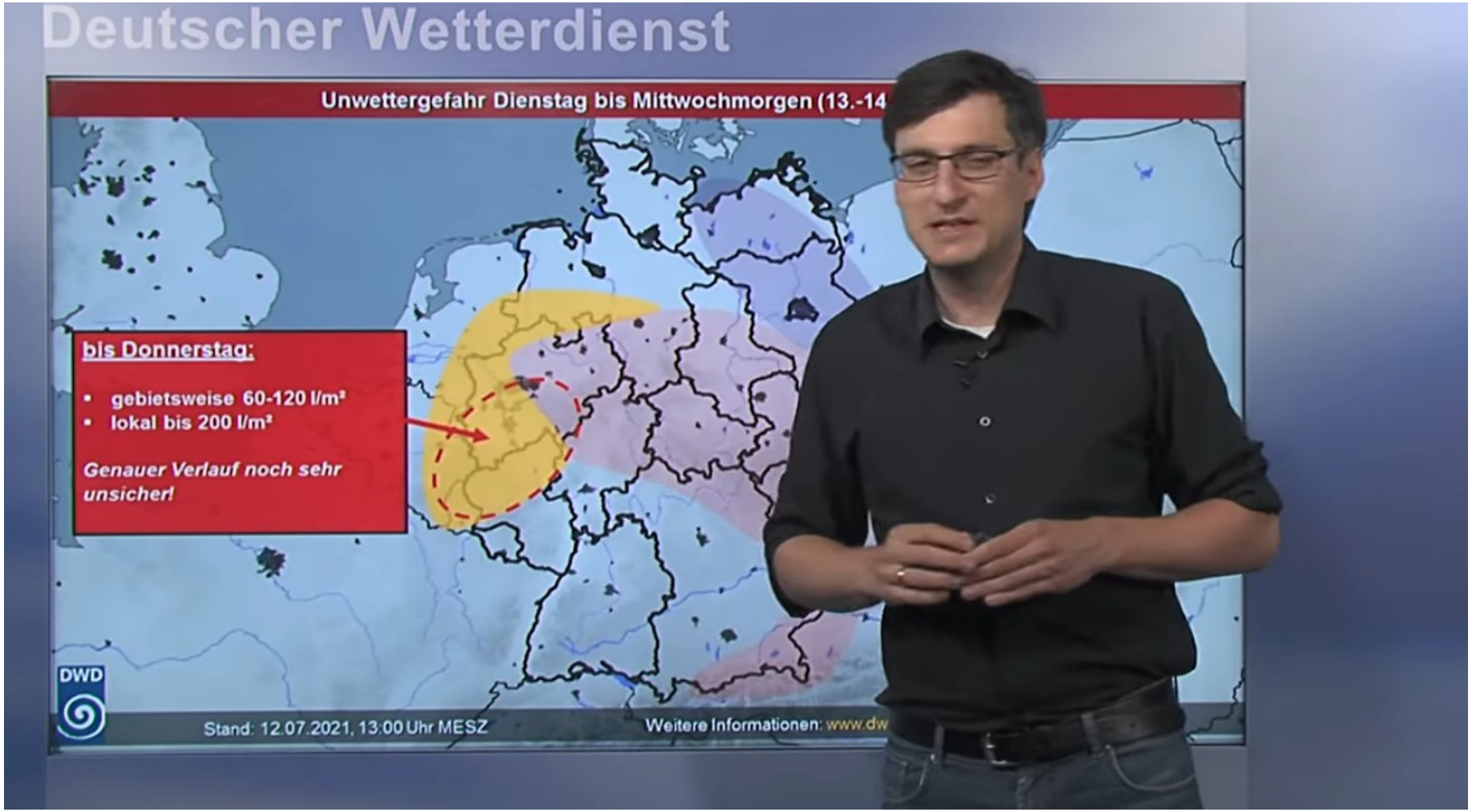


Endendijk et al., 2023; *WRR*


It seems rational to invest in protection
when benefits outweigh the costs


Is a rational view of flood management representative of the real world?

12- juli 2021


Deutscher Wetterdienst
Unwettergefahr Dienstag bis Mittwochmorgen (13.-14
bis Donnerstag:
gebietsweise 60-120 l/m²
lokal bis 200 l/m²
Genauer Verlauf noch sehr unsicher!
DWD
Stand: 12.07.2021, 13:00 Uhr MESZ
Weitere Informationen: www.dw

……from the people that were warned, 85% did not expect severe flooding (Thieken et al. 2023)

Local scale adaptation

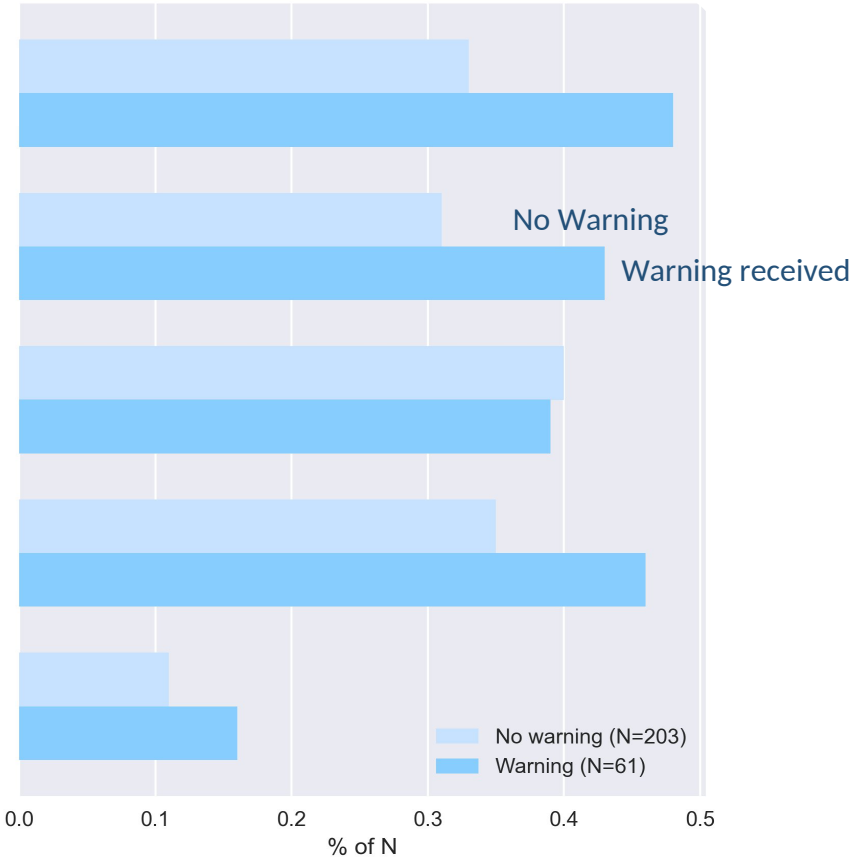
Move vehicle

Furniture second floor

Sand bags

Water Pump

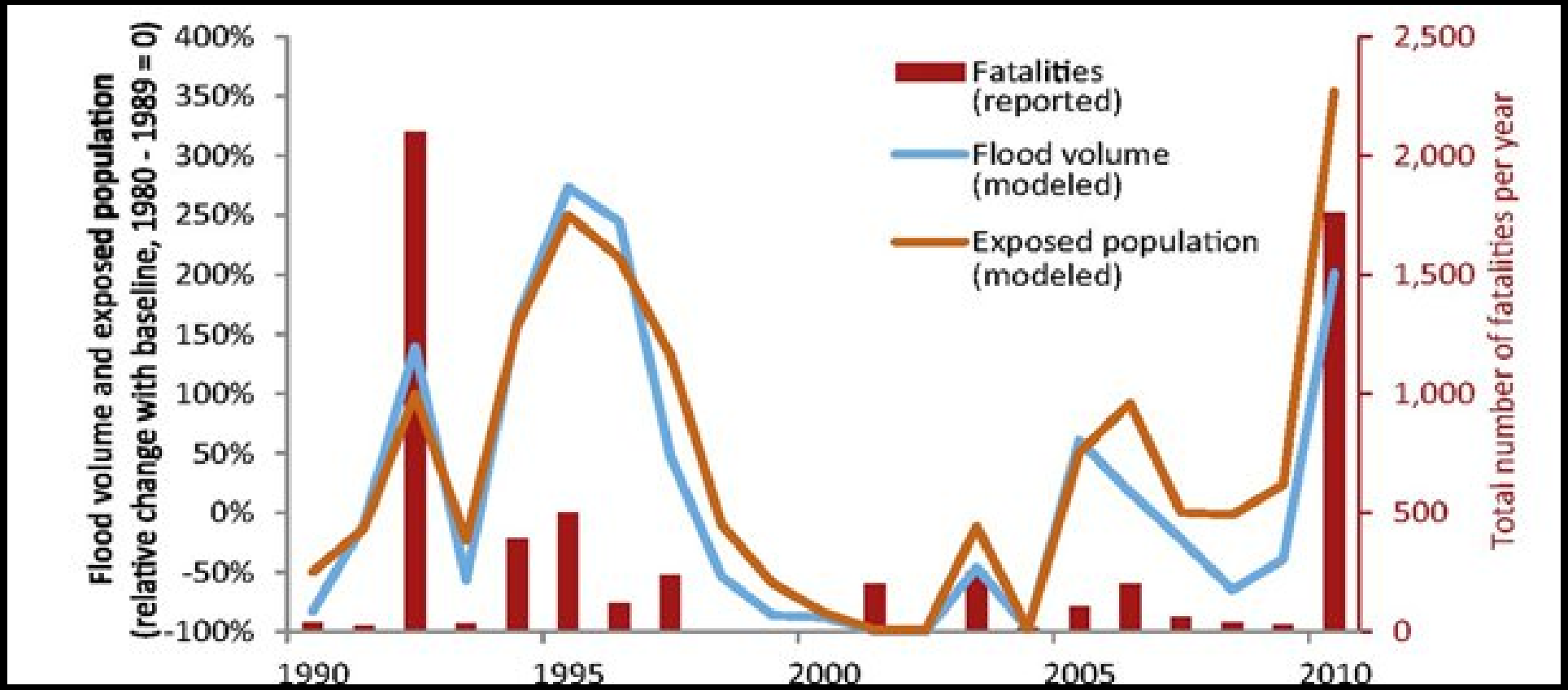
Flood barriers



Endendijk et al., 2023; WRR


Pakistan floods

Pakistan floods 1990-2010



Jongman et al. 2015, PNAS

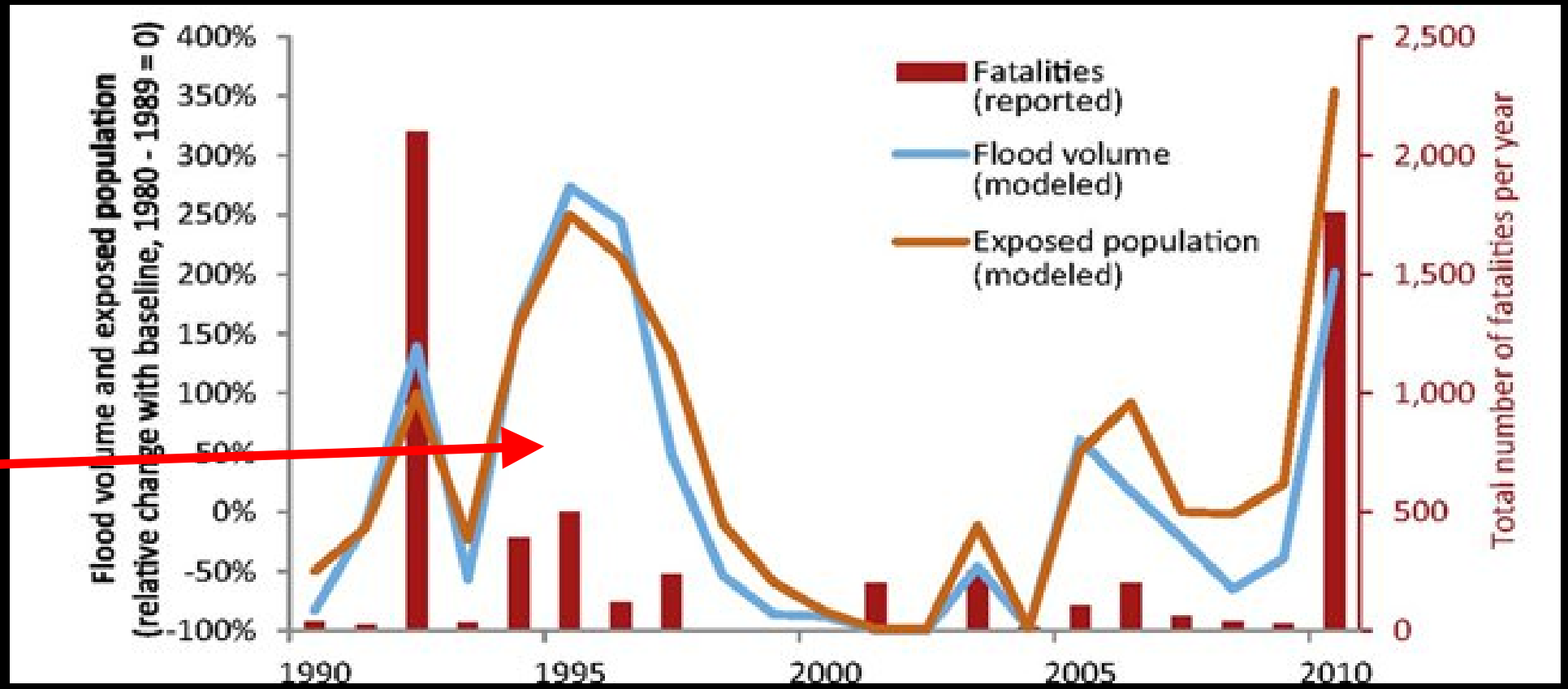
IVM Institute for Environmental Studies VU

Pakistan floods 1990-2010

People relocated?

Better measures?

Destructed houses were not rebuild?



Jongman et al. 2015, PNAS

IVM Institute for Environmental Studies VU

How do people react to extremes?

Which factors other than cost and benefits drive adaptive behavior?

Paradox: Adaptation effect

The University of Chicago

HUMAN ADJUSTMENT TO FLOODS

A GEOGRAPHICAL APPROACH TO THE FLOOD PROBLEM IN THE UNITED STATES

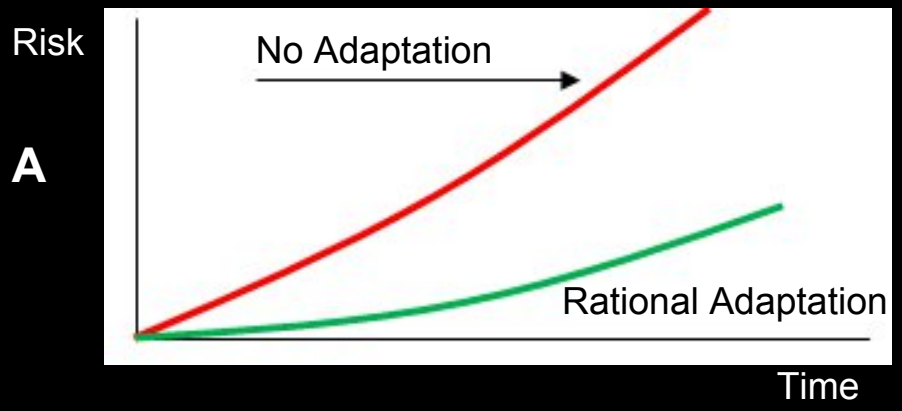
A DISSERTATION SUBMITTED TO THE FACULTY
OF THE DIVISION OF THE PHYSICAL SCIENCES
IN CANDIDACY FOR THE DEGREE OF DOCTOR
OF PHILOSOPHY

DEPARTMENT OF GEOGRAPHY
JUNE, 1942

Research Paper No. 29

By
GILBERT FOWLER WHITE

Adaptation effect



Without risk reduction
Rational behavior and risk reduction

Flood event

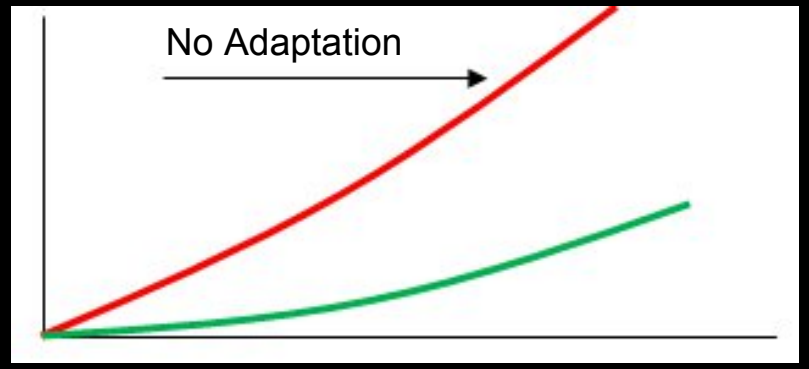
Aerts et al. 2018; Nature cc

IVM Institute for Environmental Studies VU

Adaptation effect

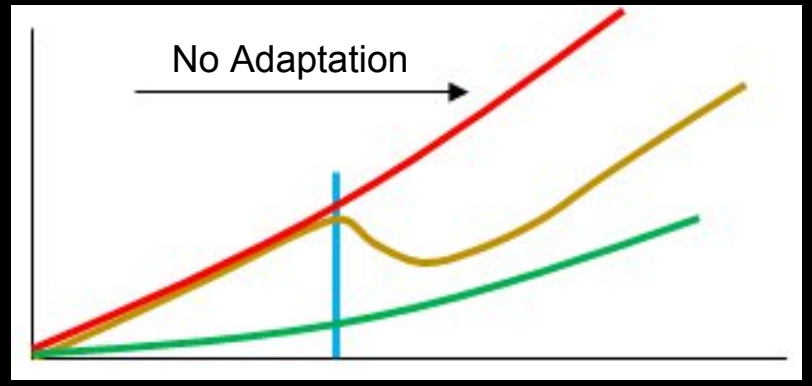
Risk

A



Risk

B



Without risk reduction

Rational behavior and risk reduction

Flood event

Aerts et al. 2018; Nature cc

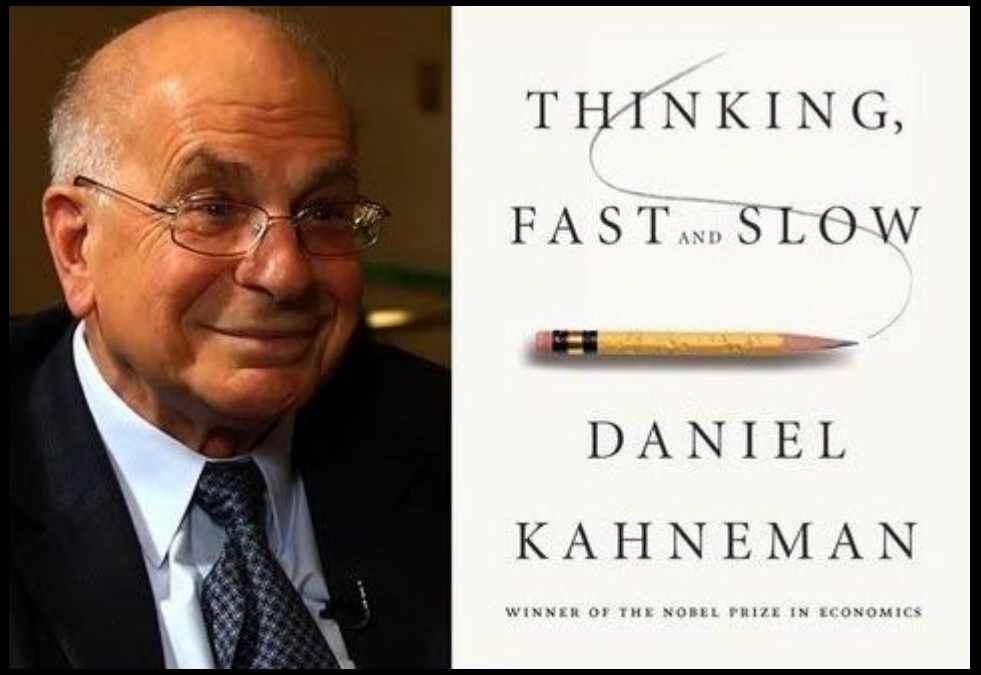
IVM Institute for Environmental Studies VU

Flood Risk perception

…….revealed that housing prices in the flooded area often decline with 6-15% after being flooded (Bin & Landry, 2013; Atreya et al., 2013).

However, households tend to ‘forget’ about their flood experience and flood risk perceptions erode over time (Atreya et al., 2013).

Empirical studies found that the price discount of 6-15% after flooding fades away within 5 to 6 years (Bin & Landry, 2013; Atreya et al., 2013; Beltrán et al., 2019; Mutlu et al., 2022).



Human Decision Making

System 1: fast, instinctive and emotional

System 2: slower, more deliberative, rational

Human thinking and decision making is biased

We think we take rational decisions (Type 2), but follow a heuristic or influenced by cognitive biases (Type 1)

- Aversion of large losses
- Overestimate impacts from low probability events
- Risk perception is driving our actions

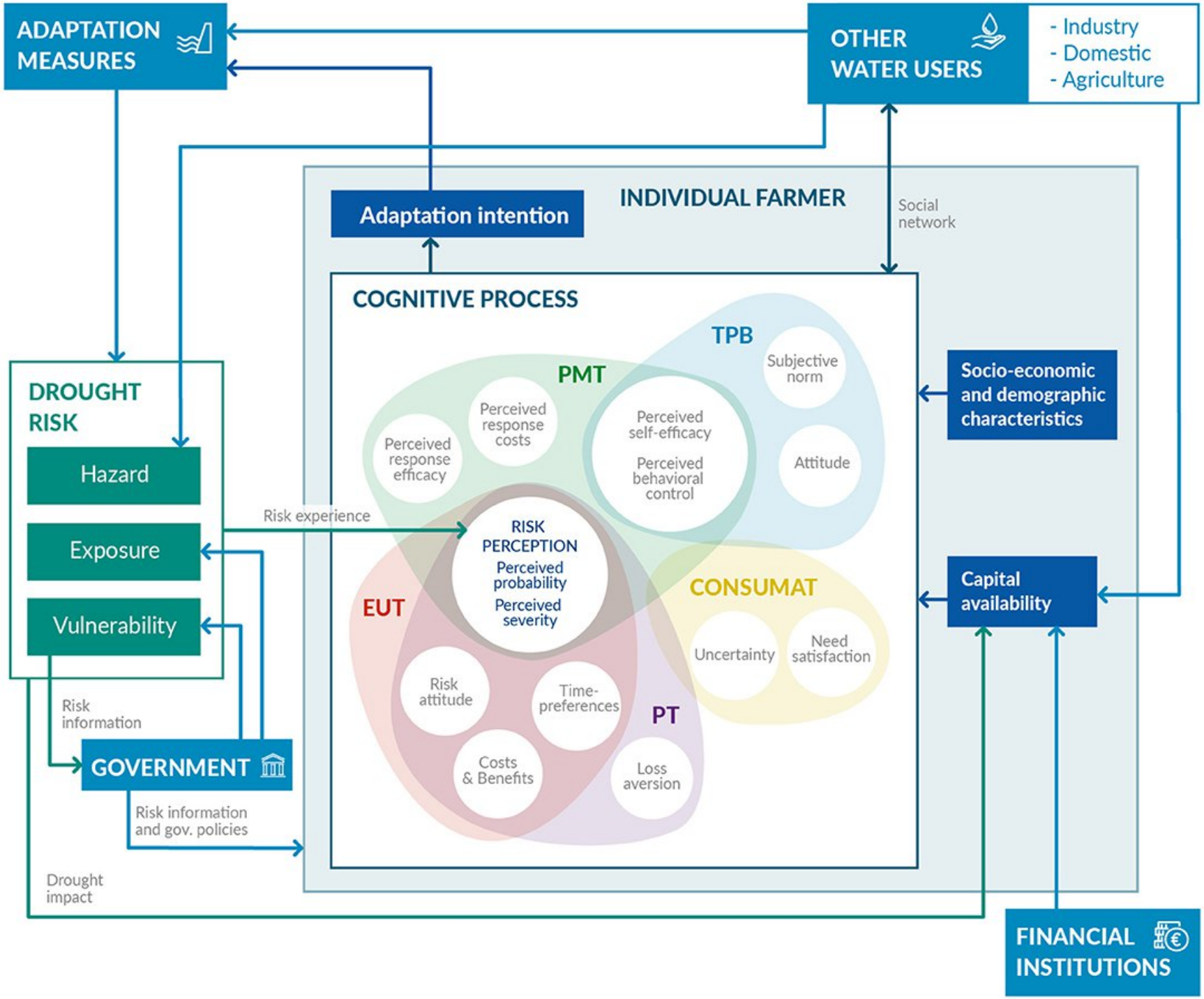
IVM Institute for Environmental Studies VU

Results survey flood risk perceptions NYC

- 62% indicated Hurricane Sandy increased their flood risk perception

- 59% of respondents think climate change will increase flood risk; 41% don't think it will

Botzen et al. 2015, JDM

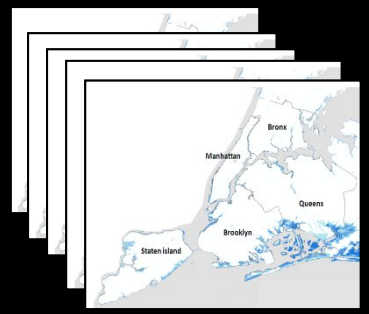


Schrieks et al., 2021;
Frontiers in Water

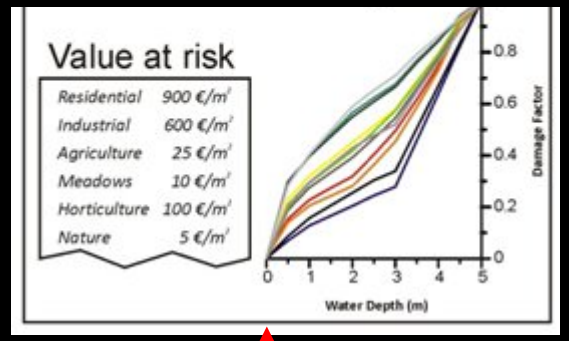
Flood risk modelling & adaptation decision making

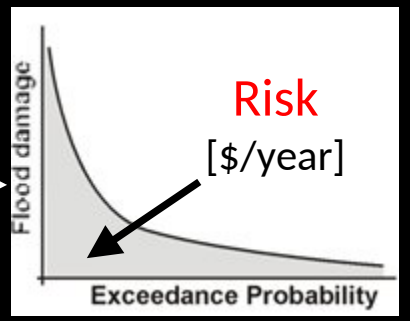
Exposure: assets and people

Flood hazard (Extent, depth)



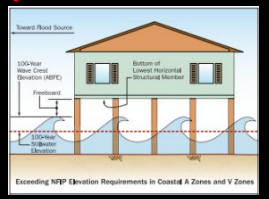
Vulnerability and damage



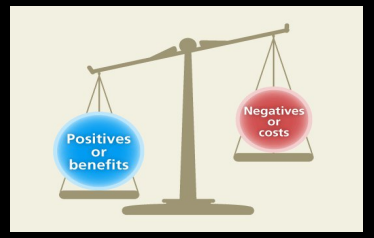


Behavioral & socio-economic factors

Adaptation measures



Cost – Benefit analysis



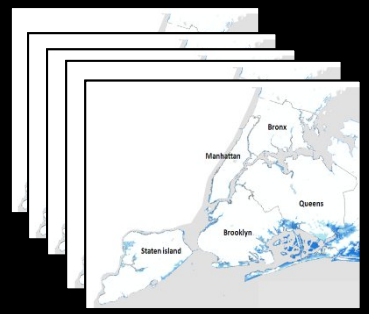
Haer et al., 2019; ERL

IVM Institute for Environmental Studies | VU

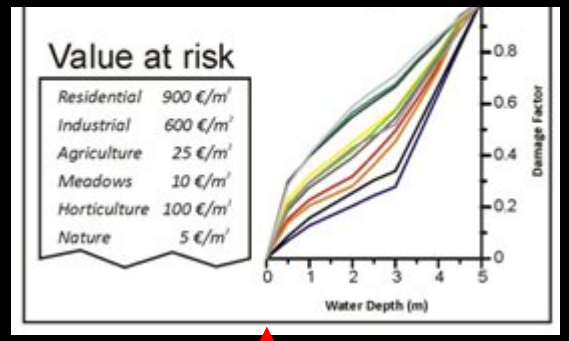
Flood risk modelling & adaptation decision making

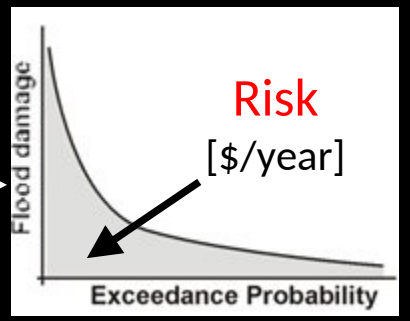
Exposure: assets and people

Flood hazard (Extent, depth)



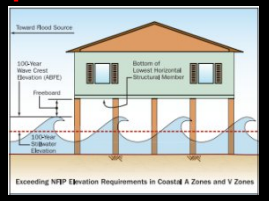
Vulnerability and damage



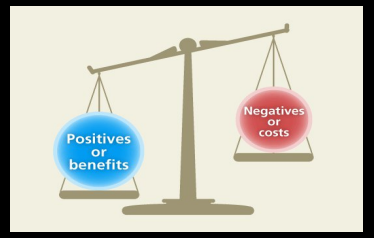


Agent – based model

Adaptation measures



Cost – Benefit analysis



Haer et al., 2019; ERL

IVM Institute for Environmental Studies | VU

Households execute the strategy that yields the highest subjective expected utility (SEU)

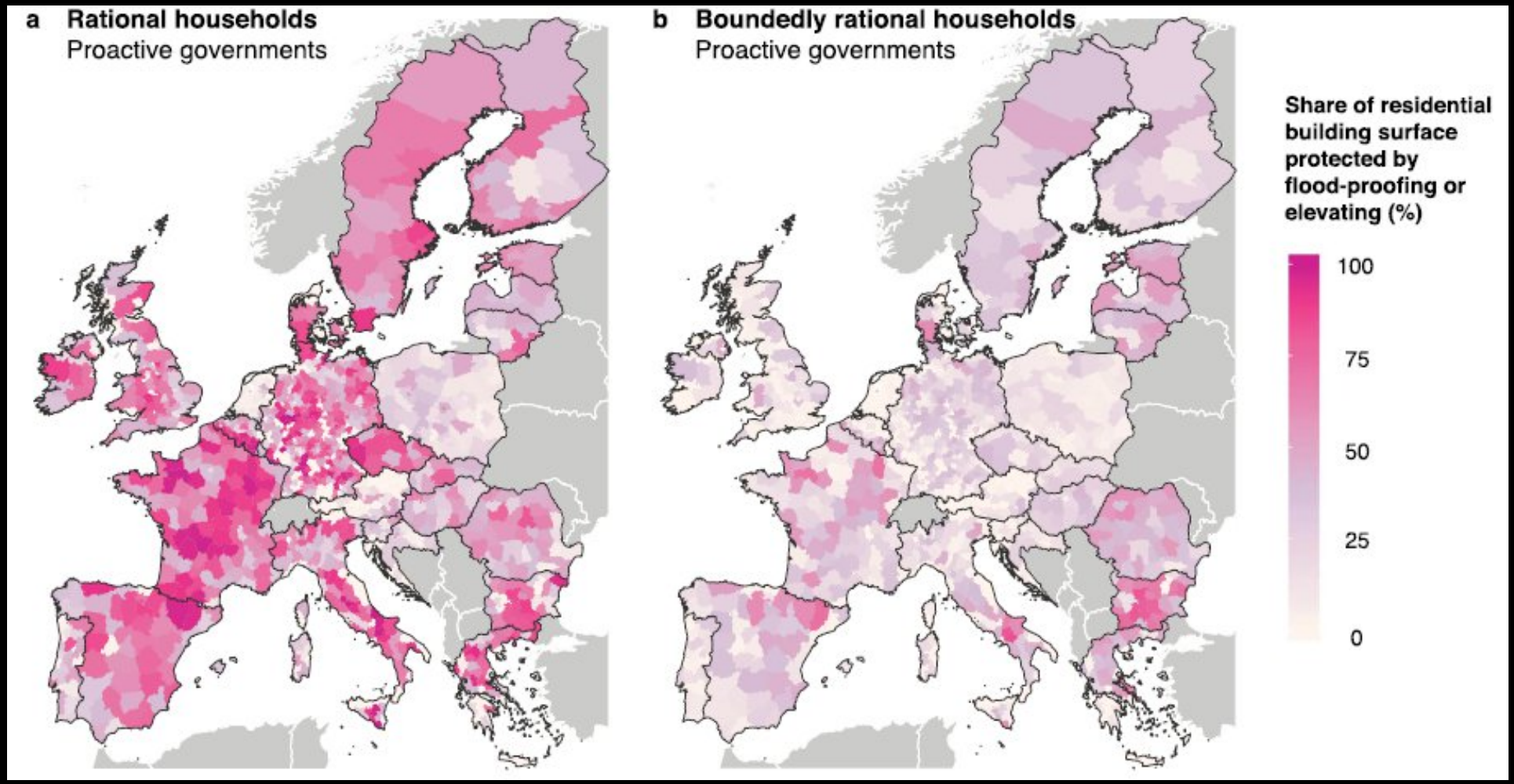
Risk perception
Flood experiences

$$SEU_{\text{No action}} = \int_{p_i}^{p_I} \beta_t * p_i * U \left(\sum_{t=0}^{T} \frac{W_x + Inc_x + A_x - D_{x,i}}{(1+r)^t} \right) dp$$

$$SEU_{\text{Adapt}} = \int_{p_i}^{p_I} \beta_t * p_i * U \left(\sum_{t=0}^{T} \frac{W_x + Inc_x + A_x - D_{x,i}^{adapt} - C_t^{adapt}}{(1+r)^t} \right) dp$$

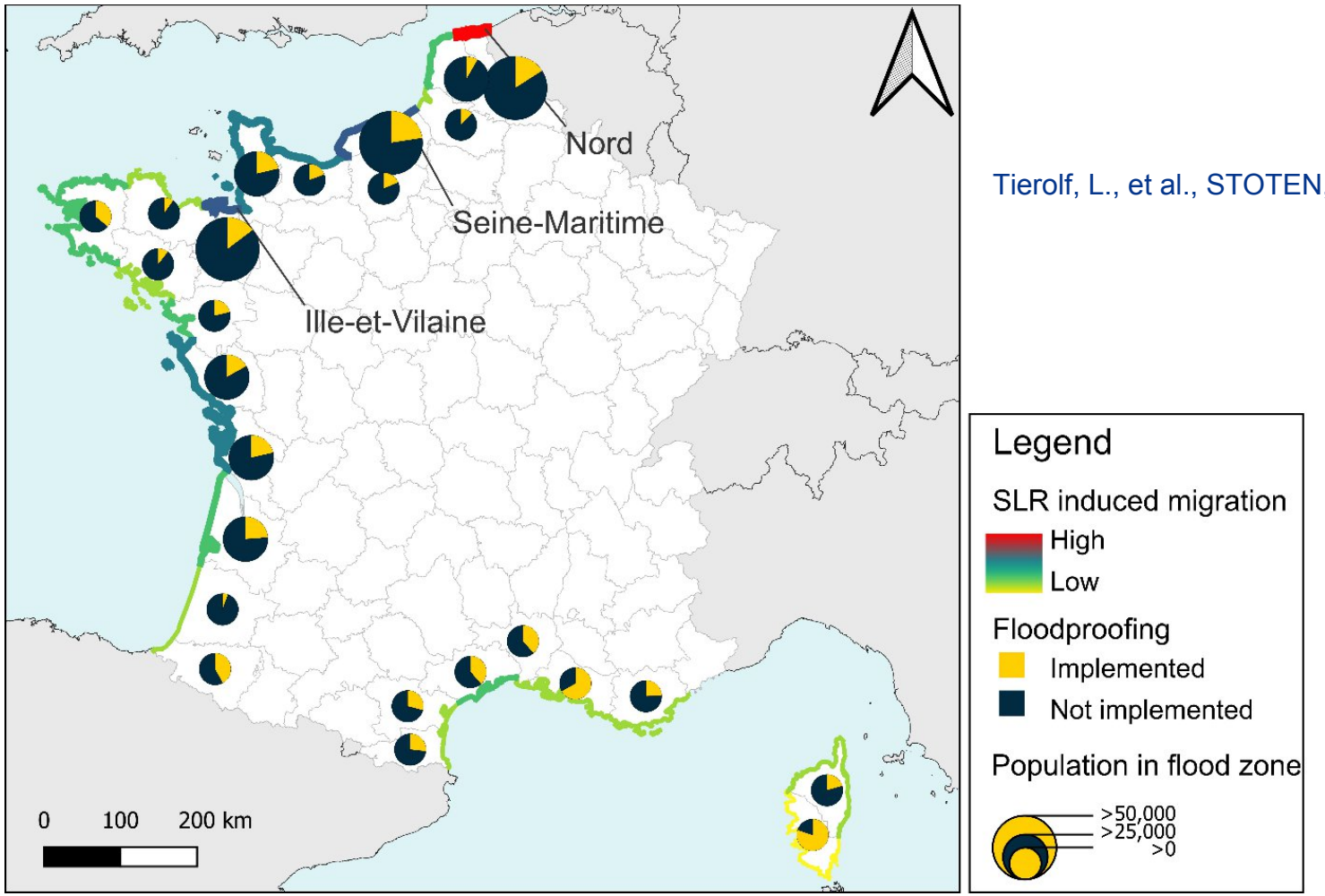
$$SEU_{\text{Migrate to y}} = U \left(\sum_{t=0}^{T} \frac{W_y + Inc_y + A_y - C_{y,t}^{migration}}{(1+r)^t} \right)$$

Share (%) of buildings flood-proofed by residents in 2080 [RCP8.5 / SSP5]



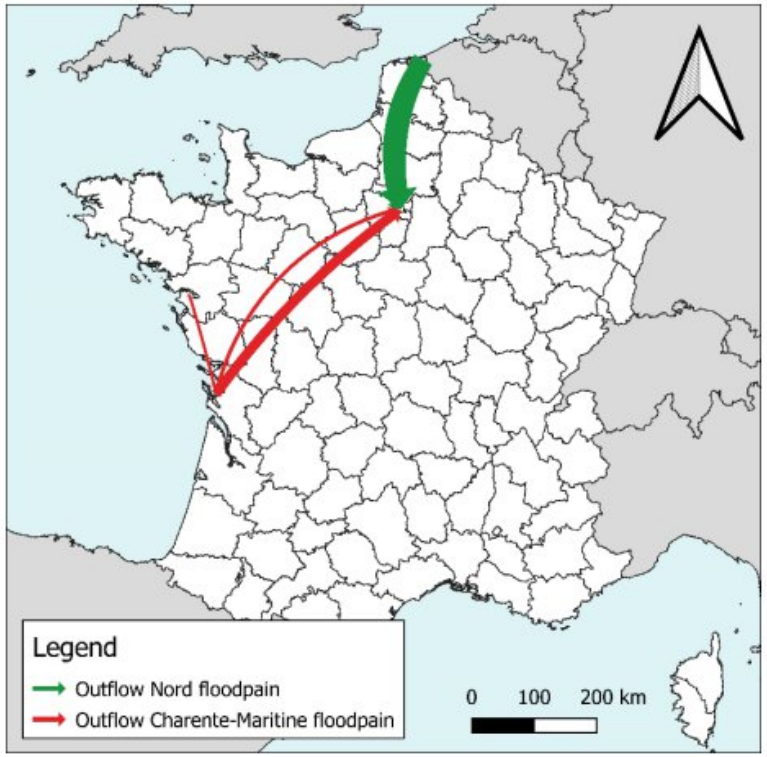
Haer et al., 2019; ERL

IVM Institute for Environmental Studies VU



Tierolf, L., et al., STOTEN, 2024

Gravity model for al regional migration flows



Tierolf, L., et al., Scientific Reports, 2023

Figure S4. Migration flows from the floodplains of Nord and Charente-Maritime based on the mean of 50 Monte Carlo model runs. The width of the arrow indicates the relative size of the migration flow. This figure was generated using QGIS 3.22.13 (QGIS Association: https://qgis.org/).

scientific data

Check for updates

OPEN

DATA DESCRIPTOR

A global dataset of 7 billion individuals with socio-economic characteristics

Marijn J. Ton[1]✉, Michiel W. Ingels[1], Jens A. de Bruijn[1,2], Hans de Moel[1], Lena Reimann[1], Wouter J. W. Botzen[1] & Jeroen C. J. H. Aerts[1,3]

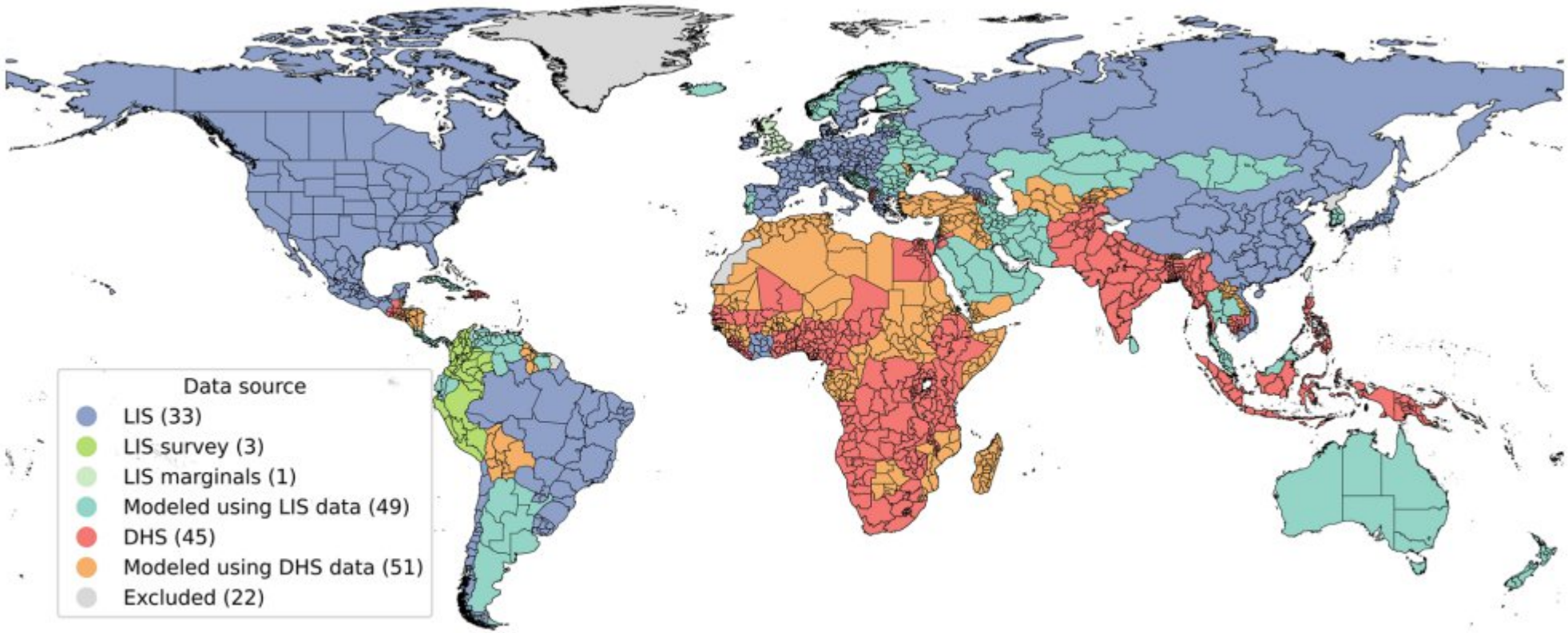
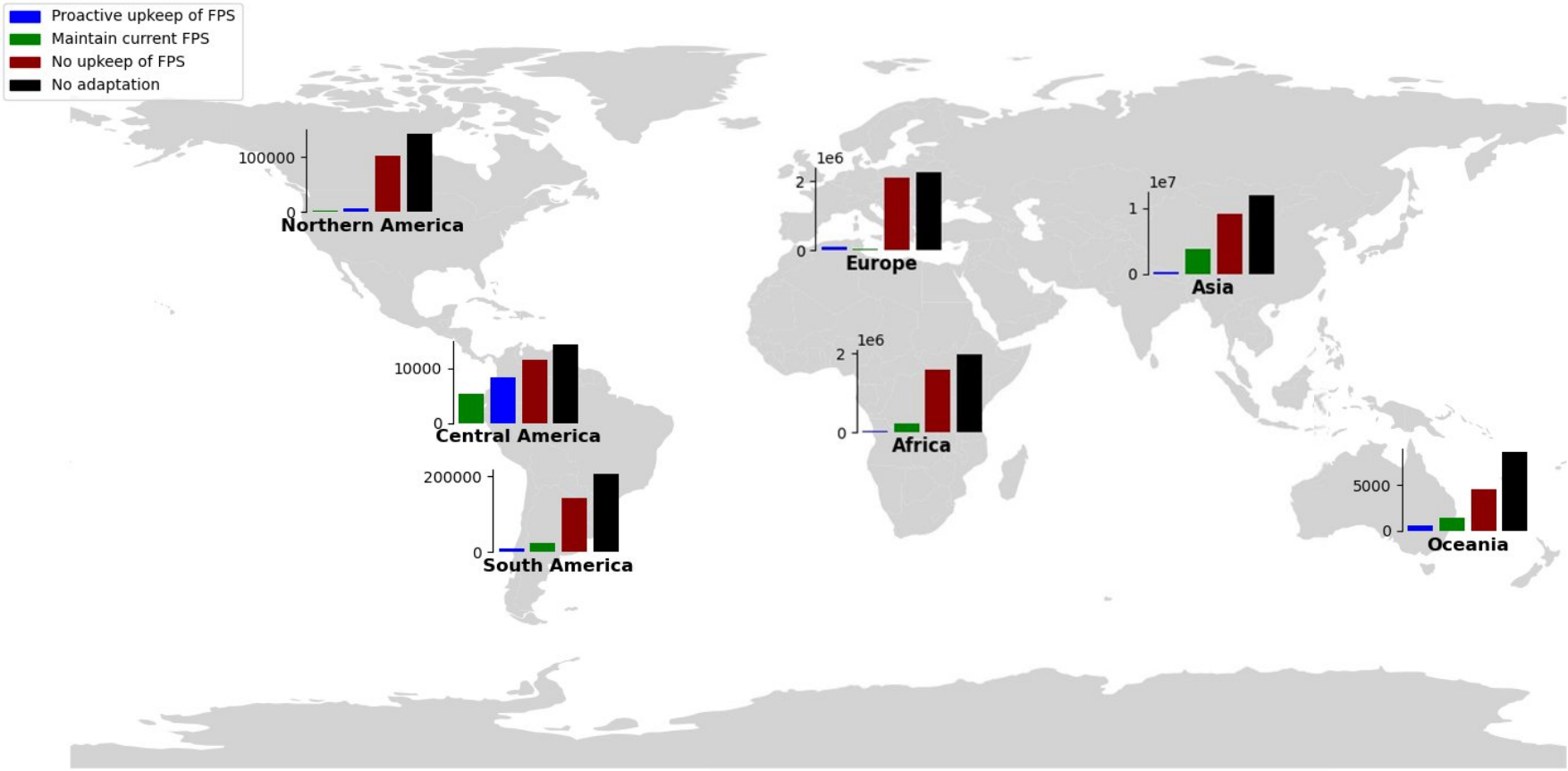


Fig. 1 Source of data for each country.

DYNAMO-M – Global migration



nature water

Perspective

https://doi.org/10.1038/s44221-024-00274-x

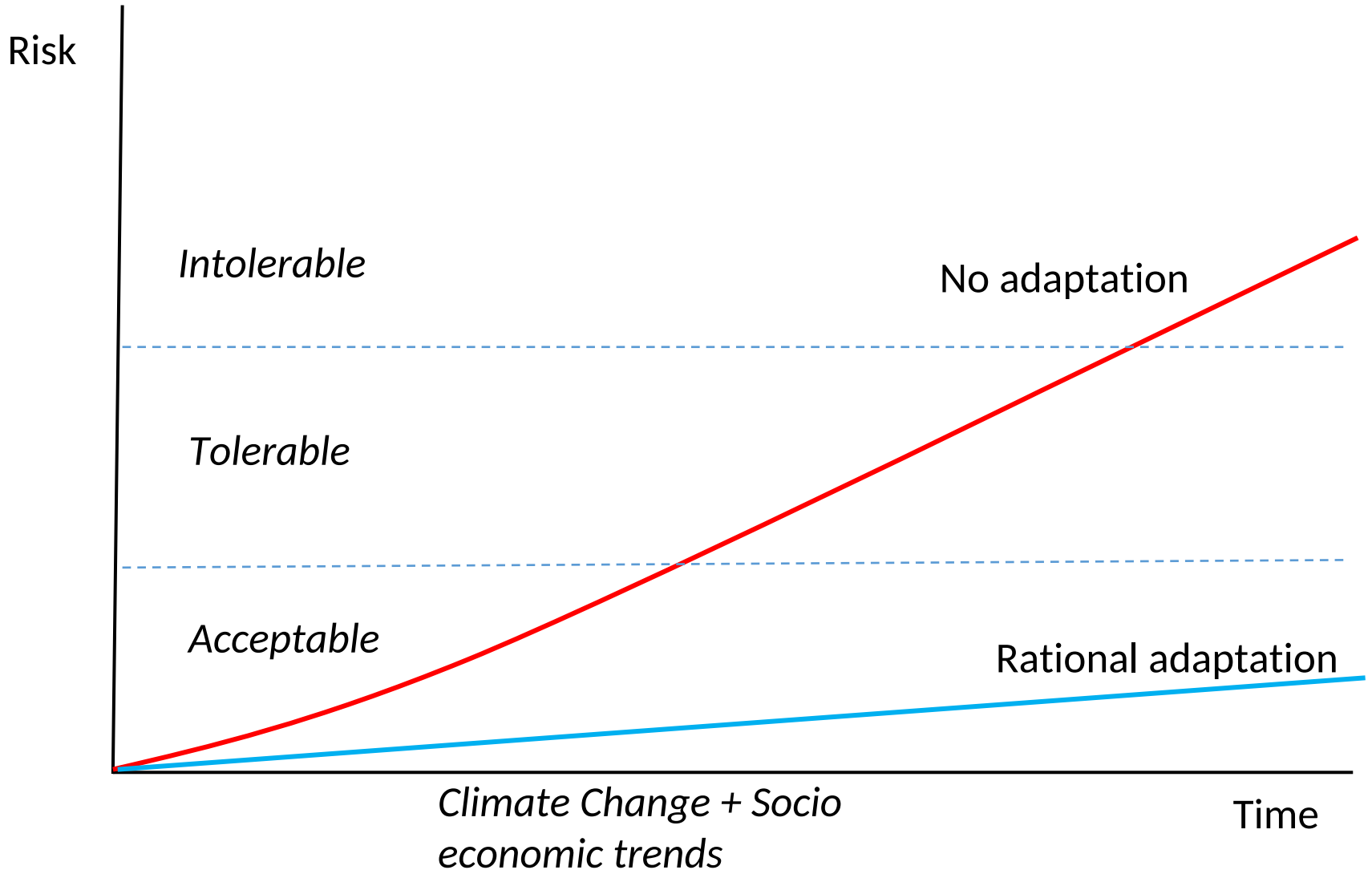
Exploring the limits and gaps of flood adaptation

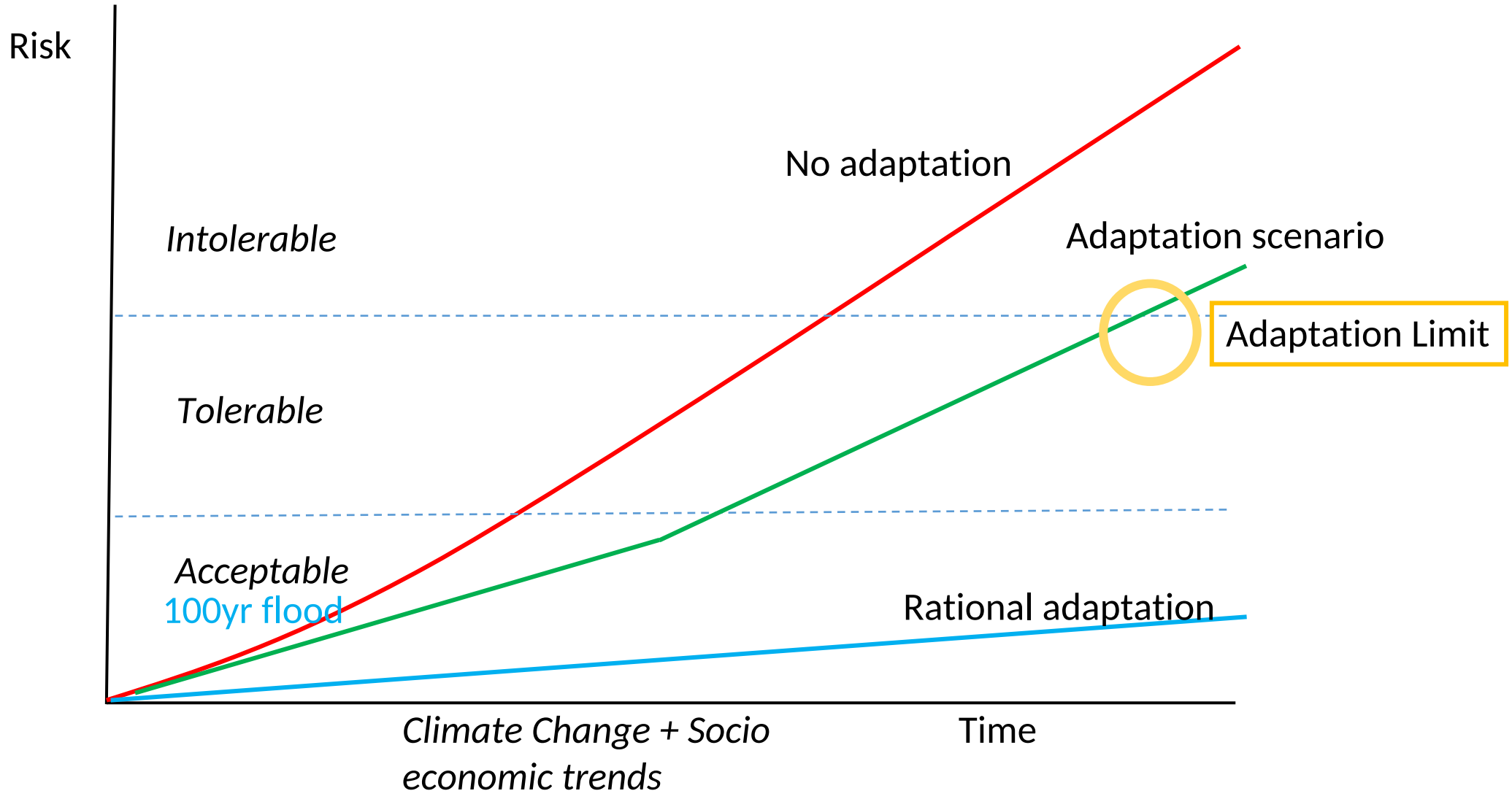
Received: 4 December 2023

Accepted: 10 June 2024

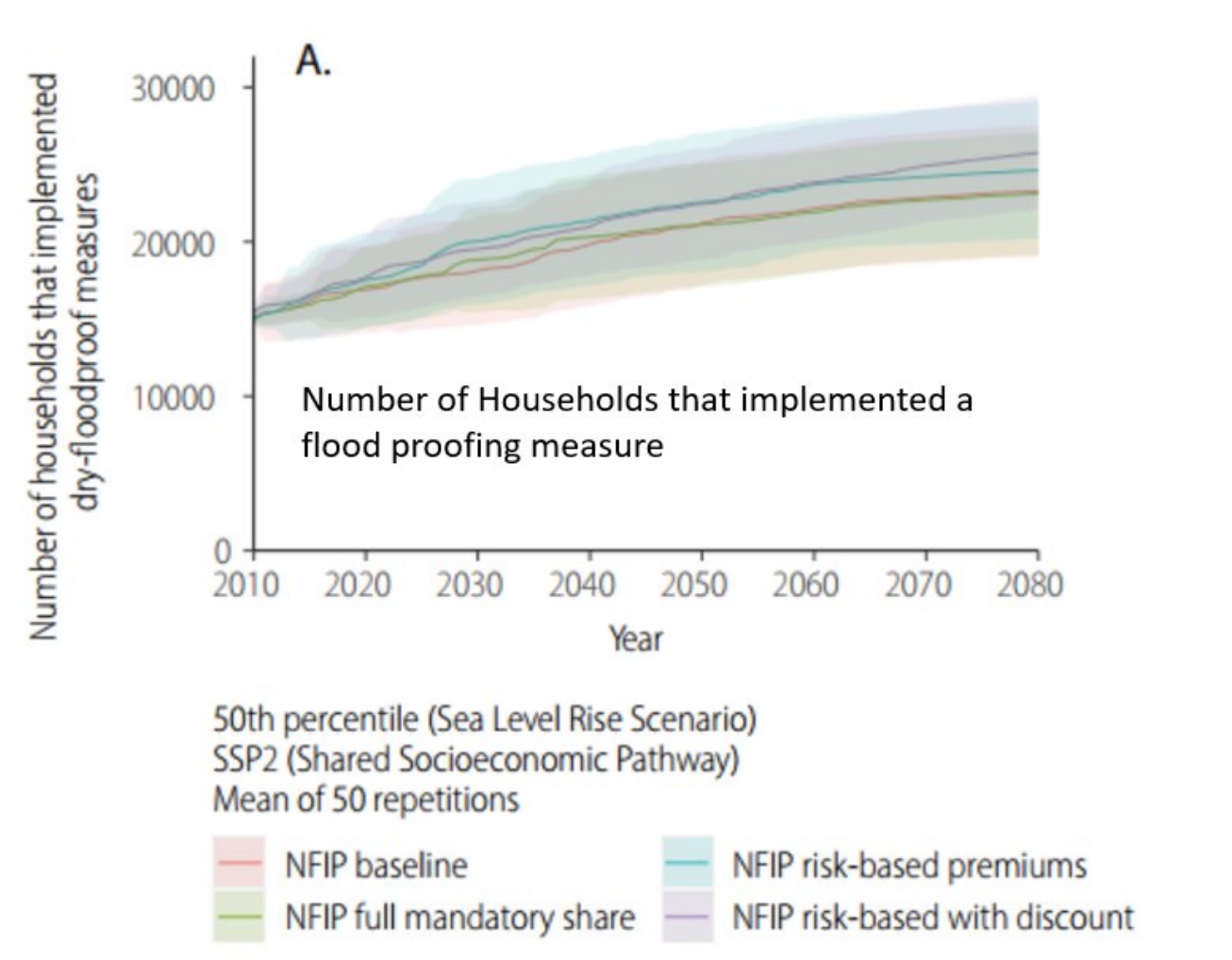
Published online: 16 July 2024

Jeroen C. J. H. Aerts[1,2] ✉, Paul D. Bates[3], W. J. Wouter Botzen[1], Jens de Bruijn[1,4], Jim W. Hall[5], Bart van den Hurk[1,2], Heidi Kreibich[6], Bruno Merz[6,7], Sanne Muis[1,2], Jaroslav Mysiak[8], Eric Tate[9] & Frans Berkhout[10]


Risk
Intolerable
Tolerable
Acceptable
No adaptation
Rational adaptation
Climate Change + Socio economic trends
Time

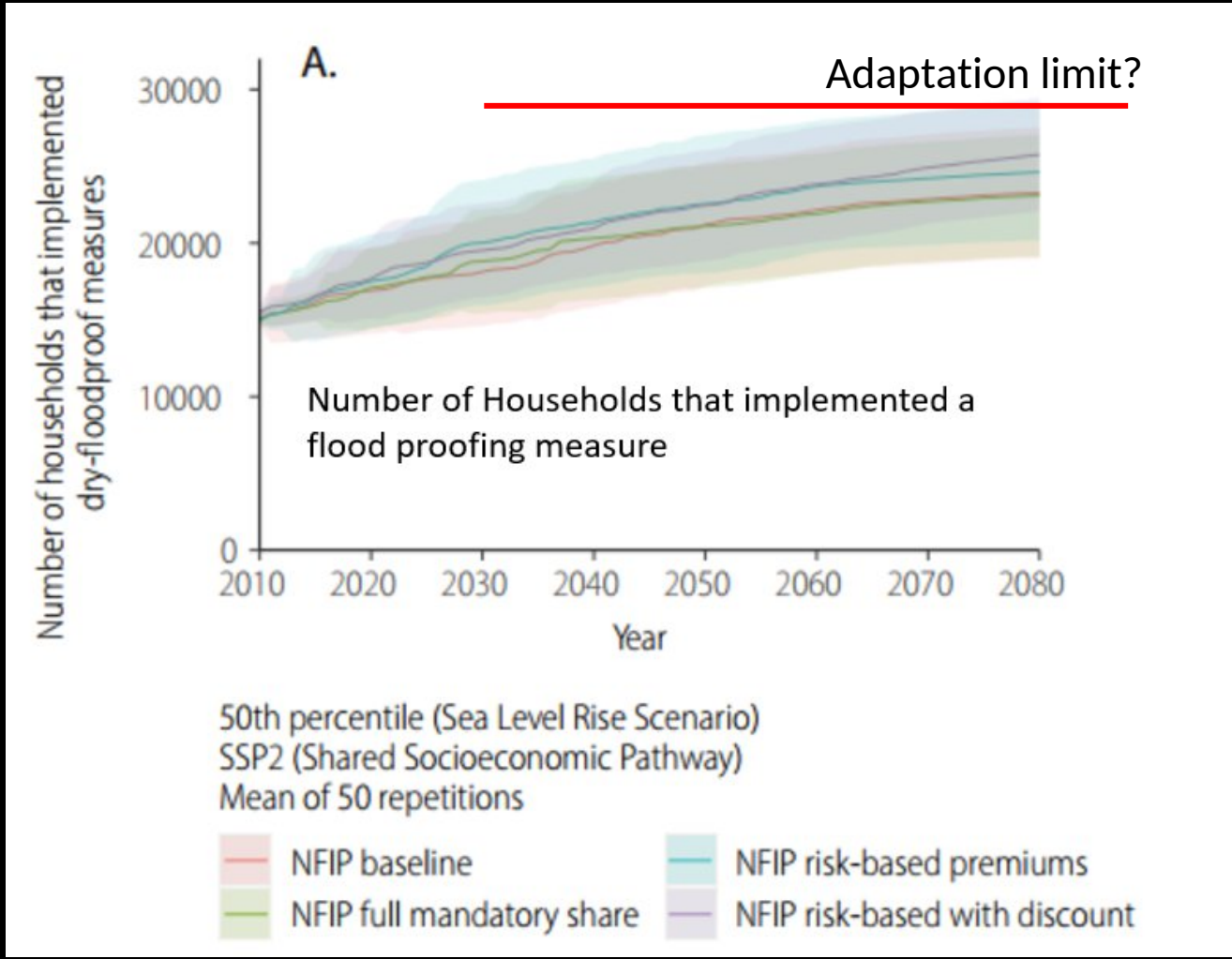

Risk
No adaptation
Intolerable
Adaptation scenario
Adaptation Limit
Tolerable
Acceptable
100yr flood
Rational adaptation
Climate Change + Socio economic trends
Time

#households in flood zone that implement flood measures



De Ruig et al., 2022, Risk Analysis

#households in flood zone that implement flood measures



De Ruig et al., 2022, Risk Analysis

Take aways

- Adaptation is a dynamic action that varies over time and space, influenced by drivers / constraints
- Having knowledge about adaptation drivers/constraints can improve adaptation policy and avoid adaptation limits
- Risk metrics can be used to quantify limits
- Research on how we perceive acceptable, tolerable or intolerable risk

Thank you for your attention!

jeroen.aerts@vu.nl

erc

IVM Institute for Environmental Studies

VU