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Methodological Framework for Climate Change Risks, Impacts and Adaptation

And how to deal with uncertainties

Margreet van Marle

Mike Woning

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Goal Regional Strategy

- Provide guidance on how to increase resilience of the road network in the Western Balkan
- Per country:
  - Provide an overview of potential natural hazards that impact each countries infrastructure
  - Identify which hazards are influenced by climate change
  - What is current climate variability
  - What is the future climate variability and how do these translate to changes in Natural Hazards
  - How is the road transportation is affected
- Ultimately to get guidance on how the engineering should be adapted to cope these events

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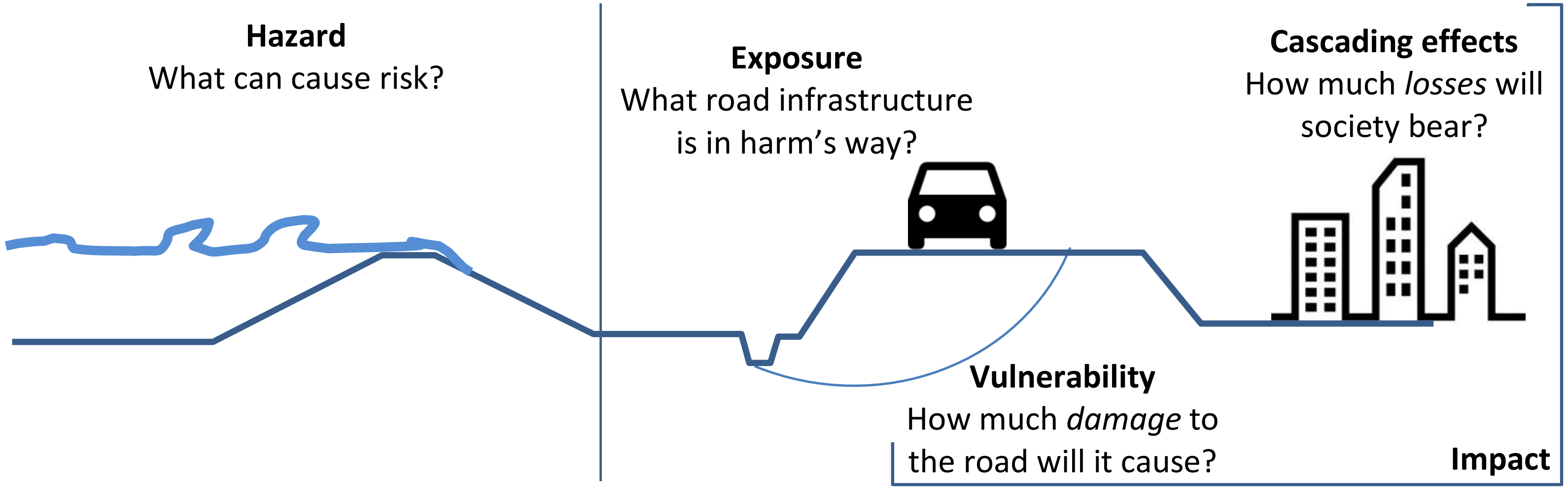
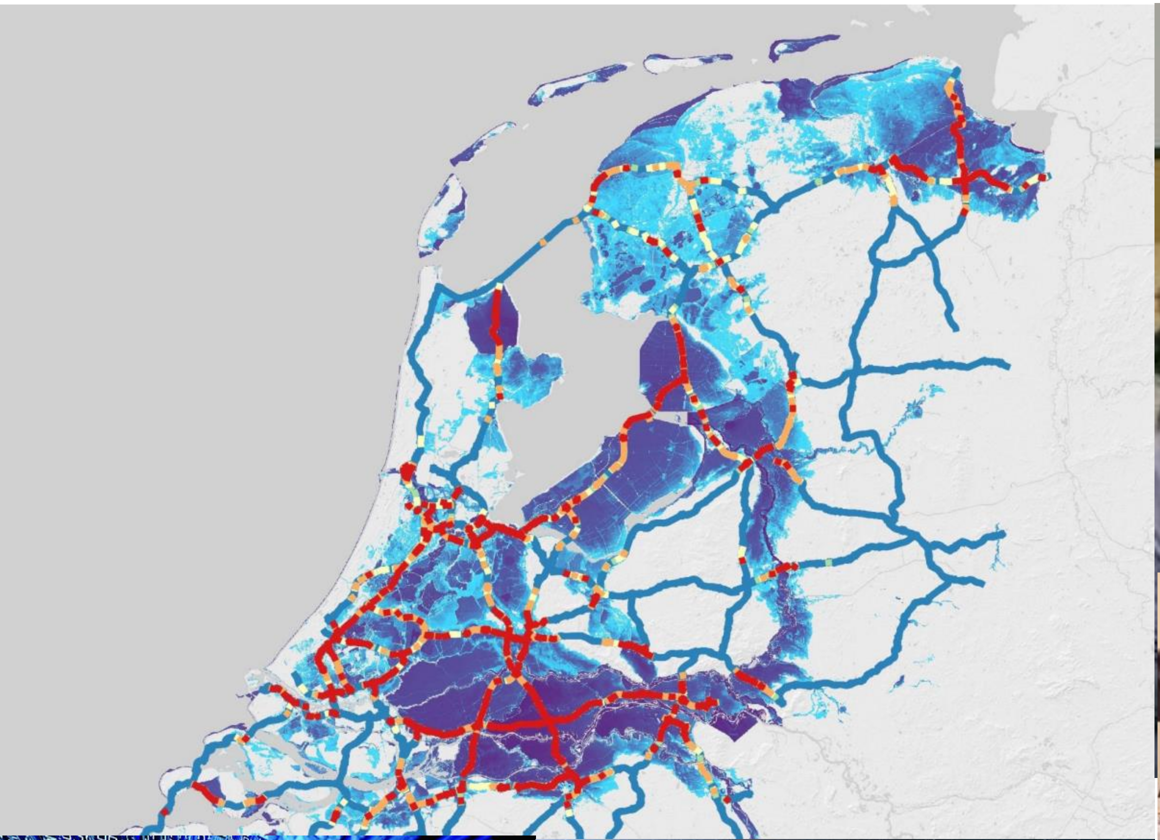
Natural Hazard Resilience Assessments
From Theory to Practice

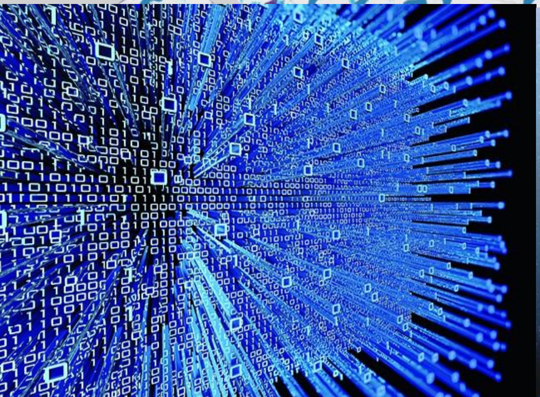
Risk Components
(UNISDR 2016)

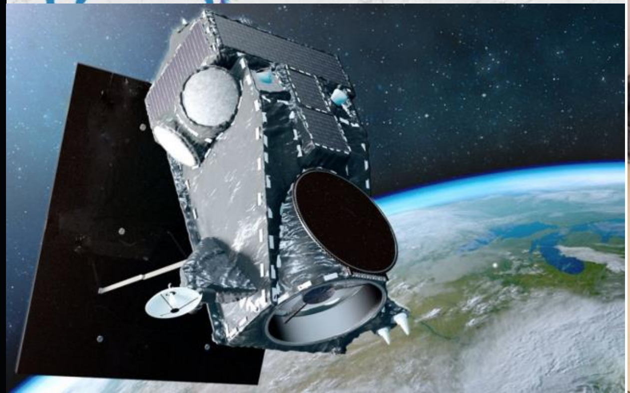


Hazard assessment → Exposure assessment → Vulnerability assessment → Impact assessment → Resilience evaluation → Action perspective

Quantitative and qualitative, desk and collaborative





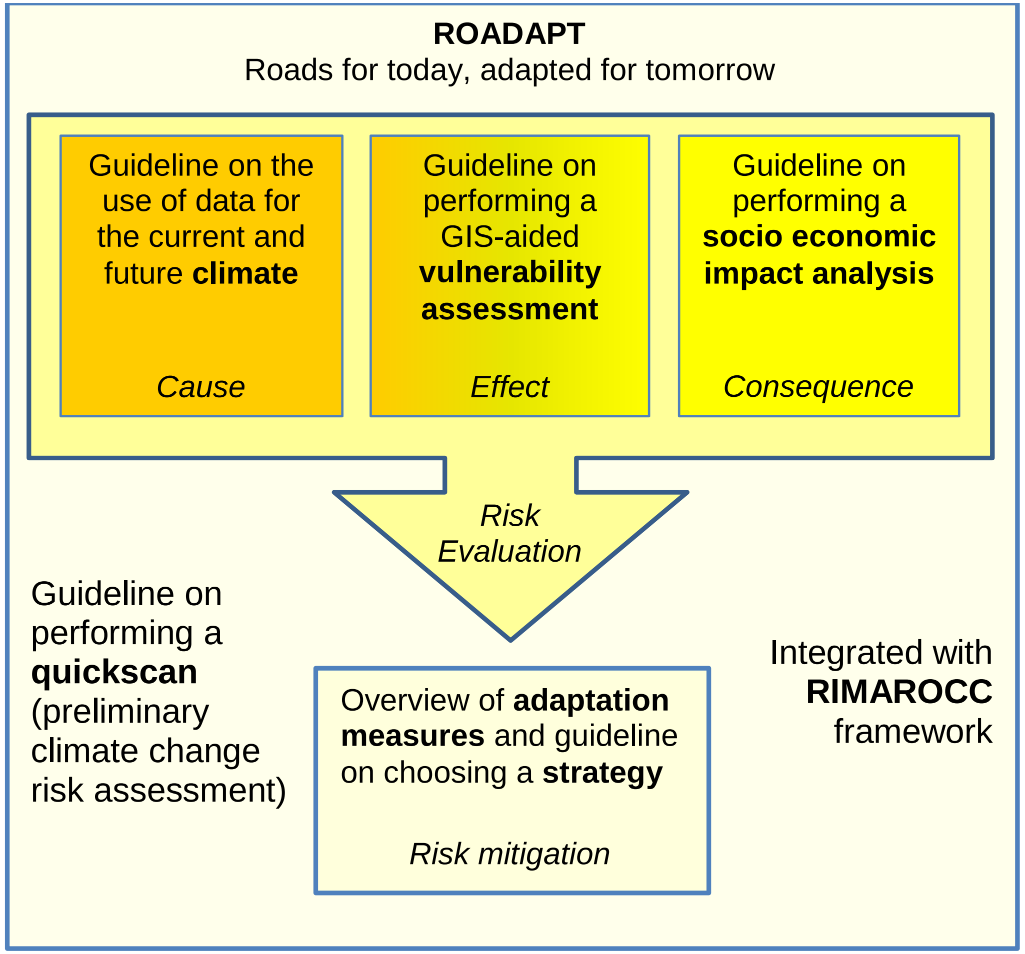


Qualitative approach: ROADAPT QuickScan approach

- QuickScan – what are the most important risks?

Only for the biggest risk

- Vulnerability assessment of the road
- Identification of measures
- Socio economic analyses
  - do benefits outweigh the costs?
- Climate change adaptation strategy



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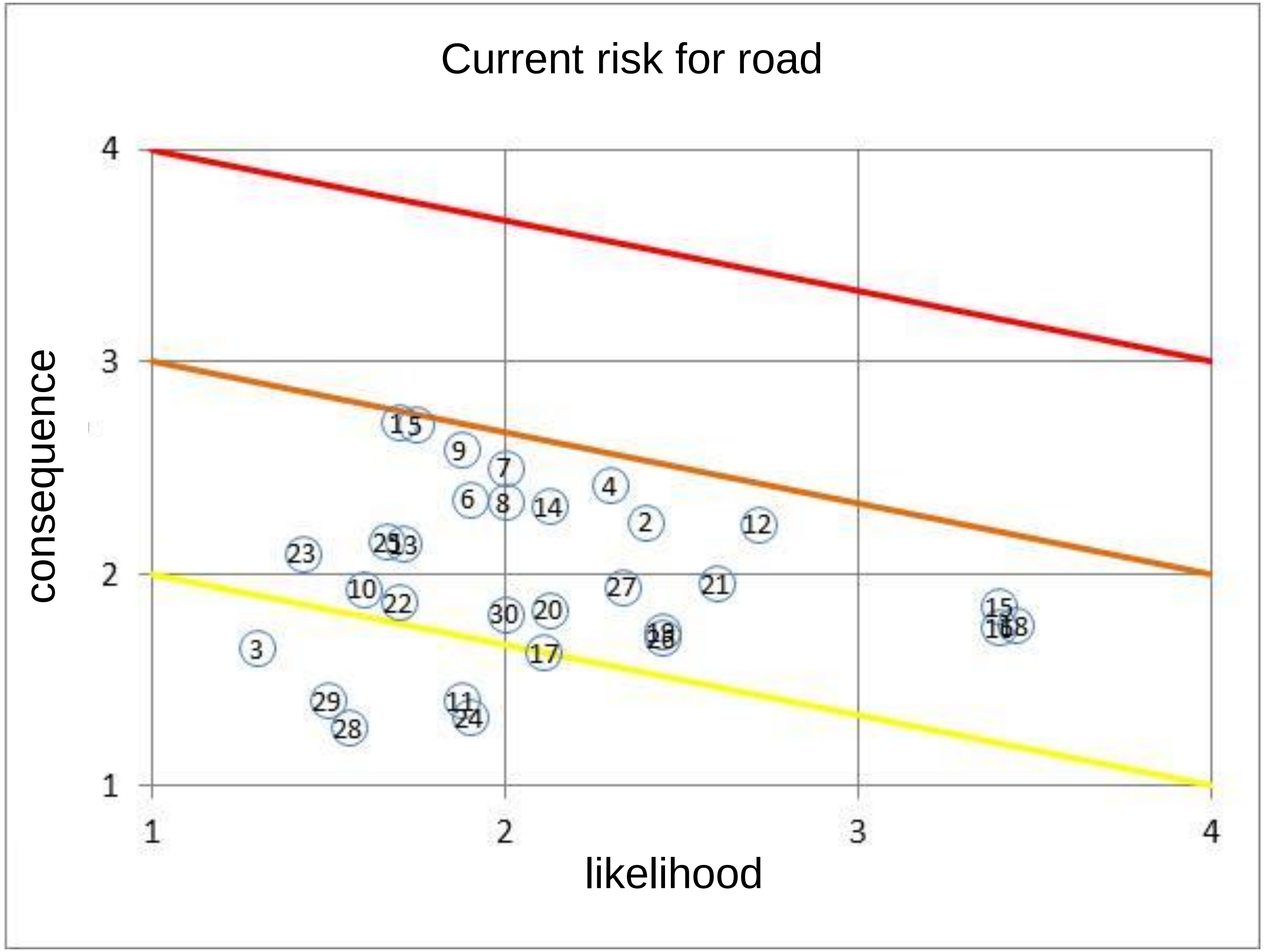
Quick Scan results



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Quantitative resilience assessments

- Hazard maps
- Vulnerability functions and damage calculation
- Resilience functions and losses evaluation
- Prioritizing hot spots

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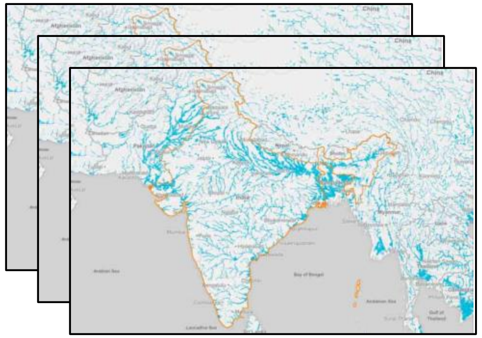
Overview of steps (RA2CE)



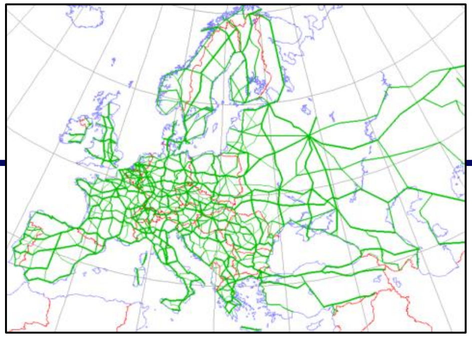
Hazard maps (pref. with return period)

Vulnerability curves
Replacement costs

1. Transportation network

Provided by user (shapefile)

Open Street Map (anywhere in the world)



2. Network Exposure

3. Direct damages ($$$)

6. Annual expected Damages and Losses

8. Adaptation measures/ Cost Benefit Ratios Measures

4. Network criticality (Redundancy)

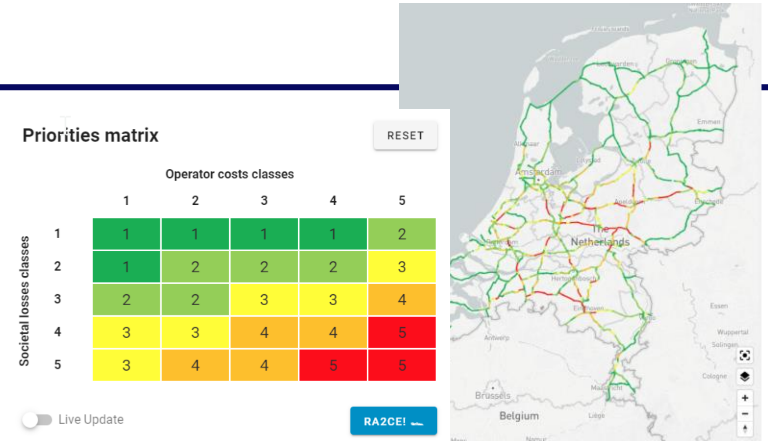
5. Societal costs ($$$)

7. Prioritization

Multi-link disruption

Single-link disruption

Traffic Data
Value of Time
Duration of failure
Social Inclusiveness



	1	2	3	4	5
1	1	1	1	1	2
2	1	2	2	2	3
3	2	2	3	3	4
4	3	3	4	4	5
5	3	4	4	5	5

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General outline regional strategy

- Introduction
- Climate change projections
- Road infrastructure vulnerability
- Resilience planning
- Risk assessment and management
- Roadmap for adaptation planning

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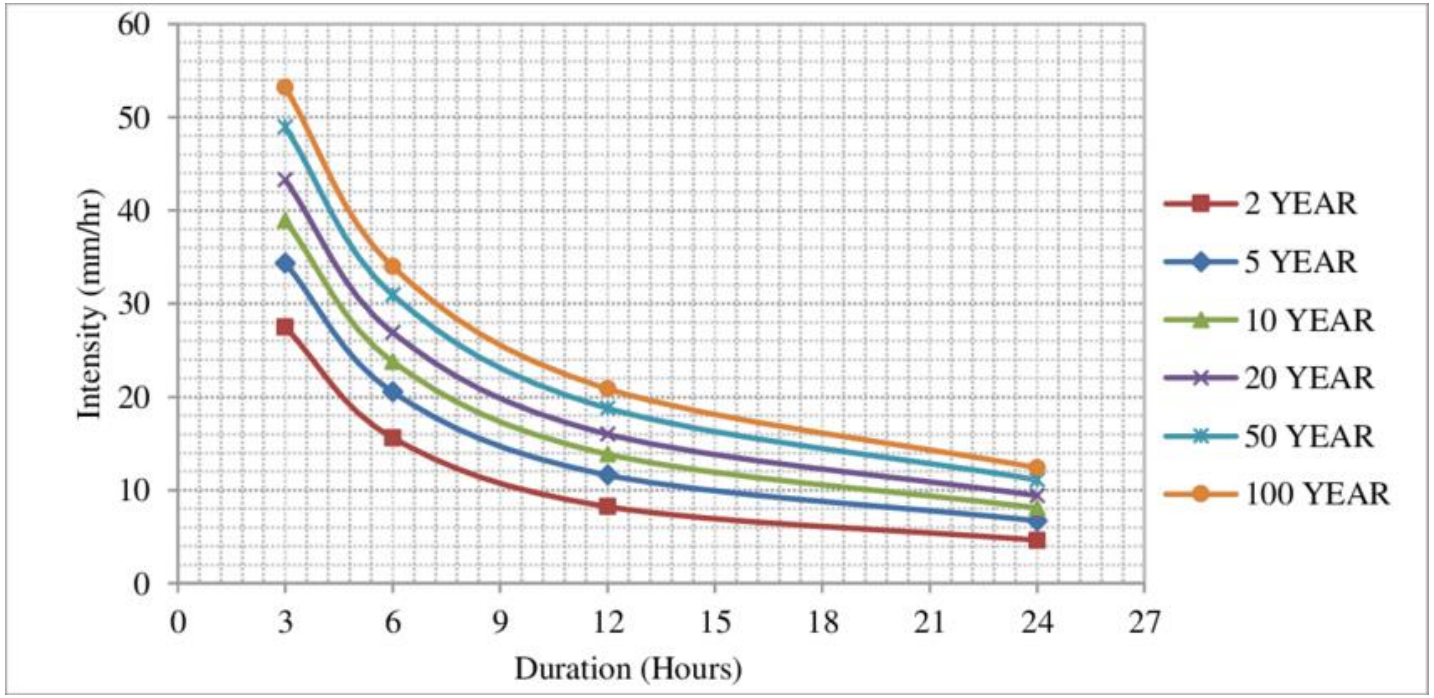
1. Introduction

- Overview of what natural hazards the region is prone to.
- Split per country with
  - an overview and description of the region.
  - The risk level of each country to natural hazards and what the road infrastructure is exposed to
  - The importance of the road infrastructure per country including the main transport corridors.
  - The key economic regions and where they are located in each country (e.g. fishery, (air)ports, tourism, agriculture, industry etc.)

2. Climate change projections in the region

- First describe the current climatic behaviour.
  - Seasonality (wet and dry months). Number of mm per year.
  - Potentially Intensity-Duration-Frequency curves
  - regional differences
  - variability in temperature throughout the year



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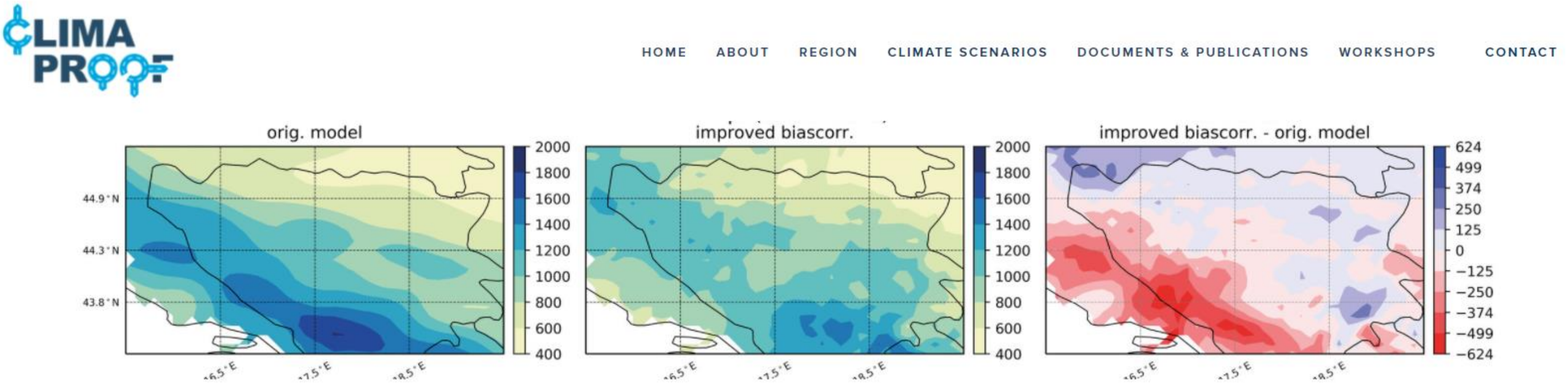
2. Climate Change projections in the region and per country

- Then describe the changes.
- Based on the bias-corrected climate scenarios (climaproof.net)
- Describe general trends in changes in precipitation and temperature
- Also describe the uncertainty in these results.



Effects of climate change on infrastructure design

- In general we know whether precipitation or temperature influences the engineering design.
  - For example: More intense rainfall may result in overloading of the hydraulic system (e.g. culverts)

Main climate variable	Effects on road infrastructure
Extreme rainfall events (showers with high intensity)	• Pluvial flooding on road surface • Flooding of road surface • Erosion of road embankments • Reduced visibility • Aquaplaning • Failure of embankments next to the road • Road embankment failure • Debris flow, Rock fall • Bridge scour • Overloading of the hydraulic systems crossing the road (e.g. culverts)

Effects of climate change on infrastructure design

- In general we know whether precipitation or temperature influences the engineering design.
  - For example: More intense rainfall may result in overloading of the hydraulic system (e.g. culverts)
- However, the reality is more complex. Often multiple causes may influence the failure of infrastructure.
- For example:

Erosion of road embankments and foundations	Overloading of hydraulic systems crossing the road	Extreme rainfall events (long periods of rain)	mm/day	several days - week	Culverts	Valley floors, low lying areas	week - months	hours
		Extreme rainfall events (heavy showers)	mm/h	minutes - hours				
		Thaw (for rapid ablation of snow)	˚C	days				
	Erosion of road embankments	Sea level (rise)	cm	day(s)	Earthworks, culverts (higher vulnerability where culverts cross the road), road embankment materials	Valley floors, low lying areas	week - months	minutes - days
		Extreme wind speed, wind direction (-> storm surge)	m/second	hours-days				
		Extreme rainfall events (heavy showers)	mm/h	minutes - hours				
		Extreme rainfall events (long periods of rain)	mm/day	several days - week				
	Bridge scour	Sea level (rise)	cm	day(s)	Bridges	Rivers, canals, low lying areas	months	hours - days
		Extreme wind speed, wind direction (-> storm surge)	m/second	hours-days				
		Extreme rainfall events (heavy showers)	mm/h	minutes - hours				
		Extreme rainfall events (long periods of rain)	mm/day	several days - week				

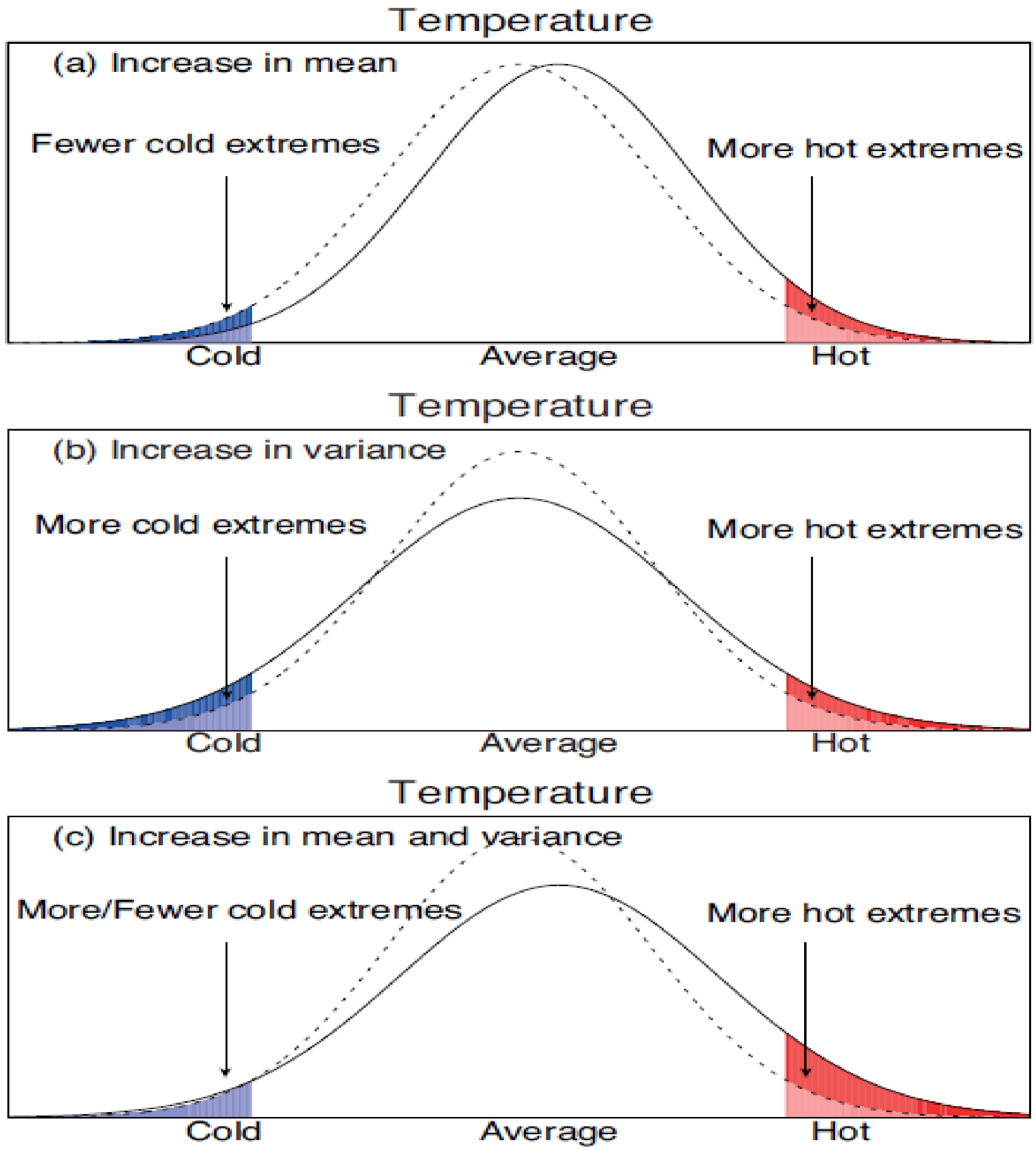
How to use climate change data in engineering

- Also climate change data often is not available at the level that is needed for engineering purposes
- Climate models are global models which identify mostly general changes in precipitation and not necessarily the details of extreme events at a local scale (e.g. at bridge level)
- Internationally hardly any guidelines exist on how to use climate change data in engineering.

- For operation and maintance:
  - We can rely on experience gained during past events

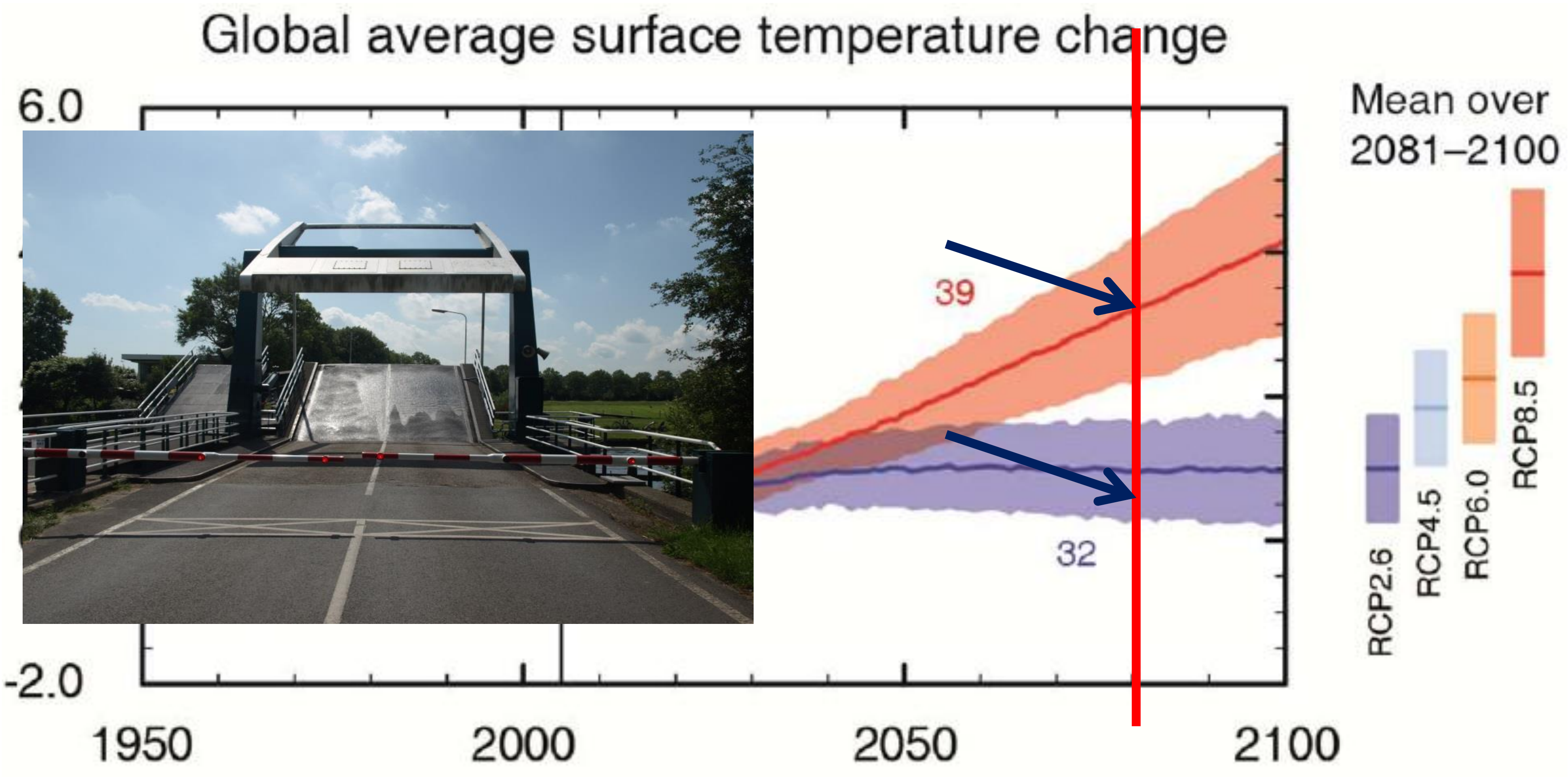
- For design and construction:
  - We need to rely on experiences from the past, but also need to know what will happen in the future.

What is climate change?



Change in the statistics
- Averages
- Extremes
- Or both

Use of climate models



Different types of uncertainties!

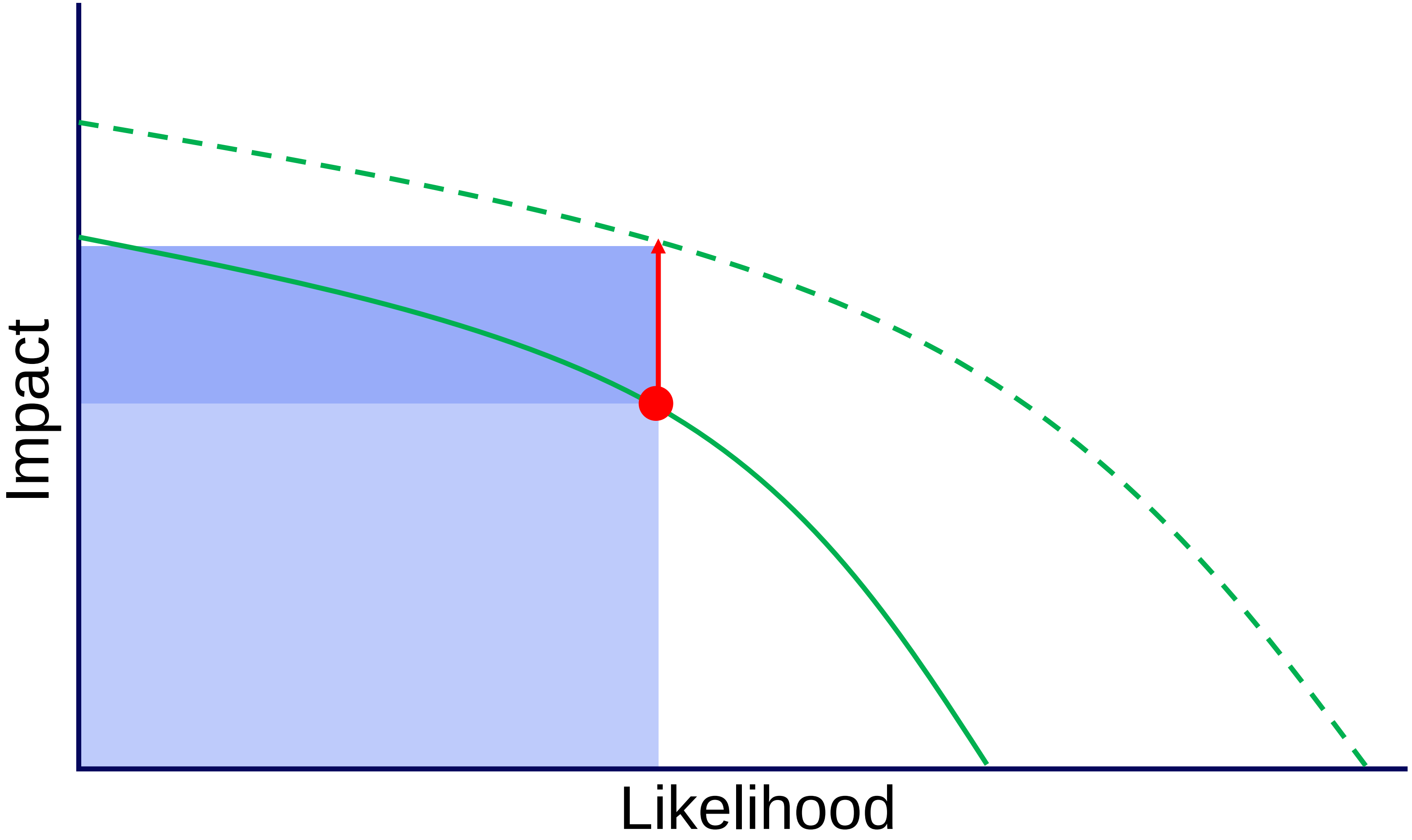
Do not trust in the results of only one climate projection

How to include climate change in resilience assessment

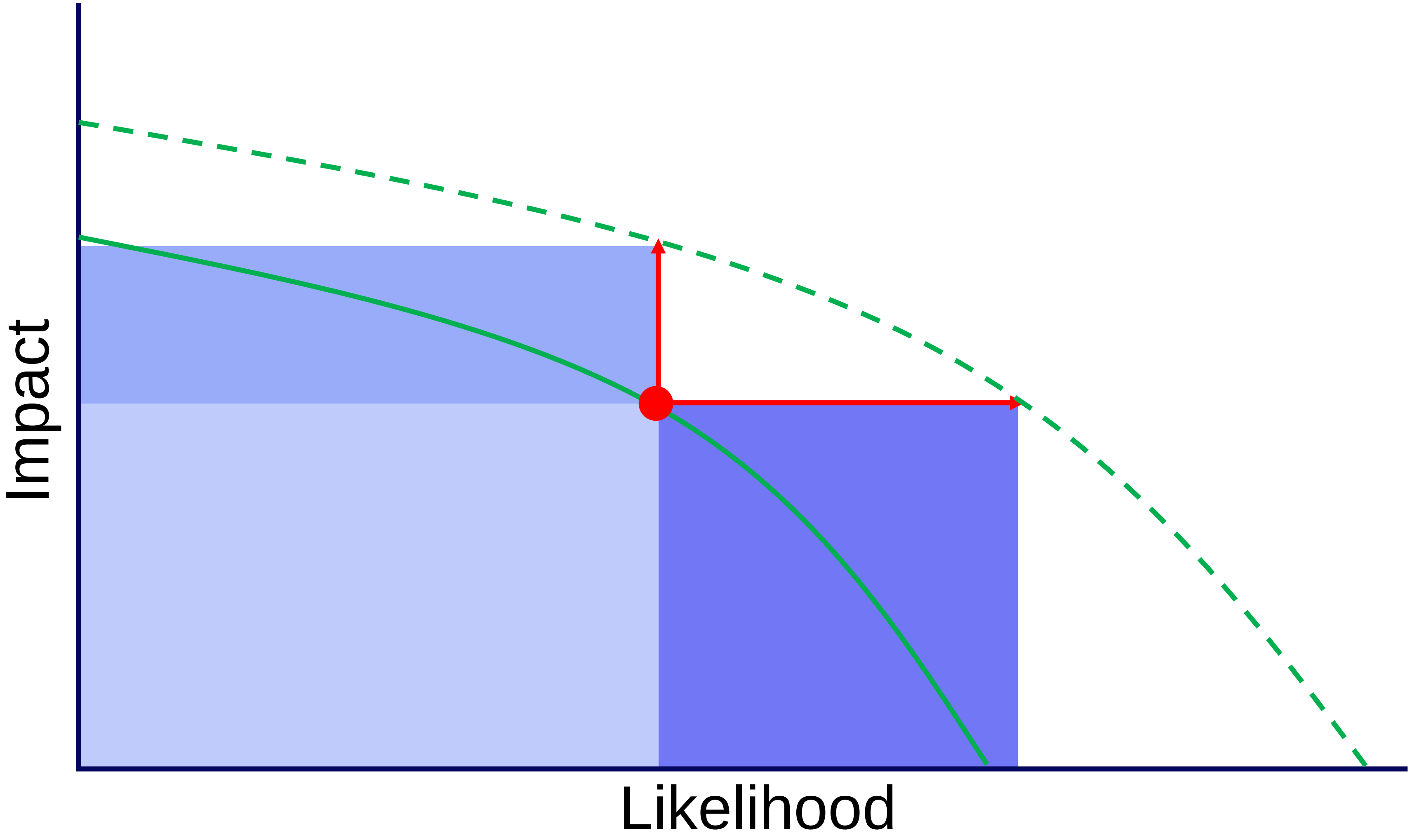
- Change hazard maps
  - Provides the best results
  - Time consuming
  - Data often unavailable

- Change likelihood / return period
  - And keep impact the same
  - Keep the available hazard maps and change the return period

Considering climate change



Considering climate change



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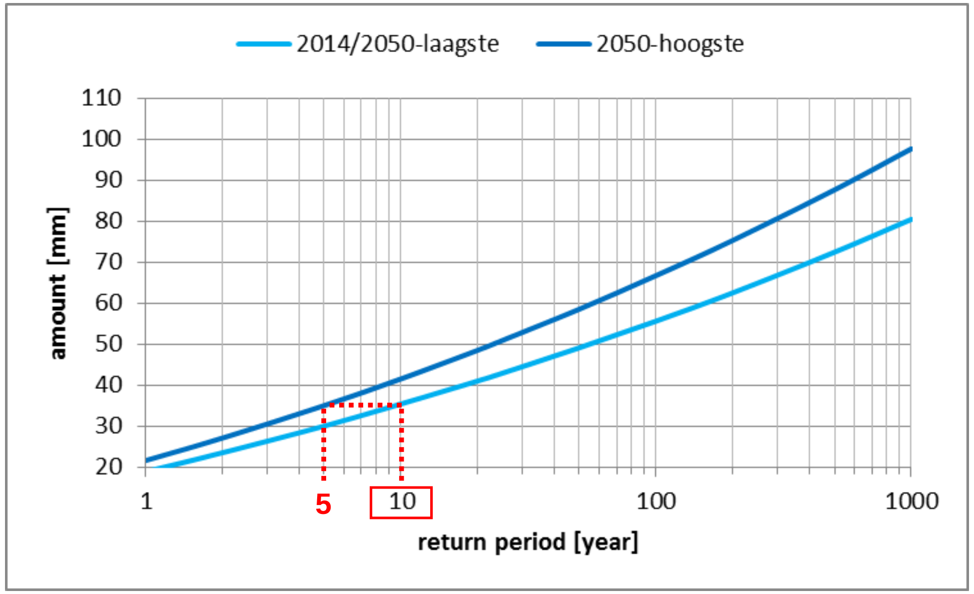
KNMI Statistics – 2 hour shower

Select proper precipitation regime

hoeveelheden		2014	2050												
		GL			GH			WL			WH				
	2014/2050-lower	low	centr	upp	low	centr	upp	low	centr	upp	low	centr	upp	2050-lower	2050-upper
0,5	15	15	15	15	14	15	15	15	16	16	14	15	16	14	16
1	19	19	20	20	19	19	20	19	20	22	18	20	21	18	22
2	24	24	24	25	23	24	25	24	26	27	23	25	27	23	27
5	30	30	31	32	30	31	32	30	33	35	30	32	35	30	35
10	36	35	37	38	35	36	38	35	39	42	35	38	42	35	42
20	41	41	43	44	40	42	45	41	45	48	41	45	49	40	49
25	43	43	45	46	42	44	47	43	47	51	43	47	51	42	51
50	49	49	51	53	48	51	53	49	54	58	49	54	59	48	59
100	56	56	58	60	54	57	61	56	61	66	55	61	67	54	67
200	63	62	65	68	61	65	68	62	69	74	62	69	75	61	75
500	73	72	76	79	71	75	79	72	79	86	72	80	88	71	88
1000	81	80	84	87	78	83	88	80	88	96	80	89	98	78	98



probability of extreme weather:

- Current 1:10 years
- Future 1:5 years

‘probability’ increases by factor: 2

3. Road infrastructure vulnerability

- We need to understand what part of the road is affected by each hazard.
- Therefore is needed per country:
  - Overview of natural hazard
  - How each hazard is affected by potential climate variables
  - Historic records of road damages due to climate related hazards.
  - This includes: Time, and location, the hazard intensity, assets involved, asset characteristics, duration of the disruption, what the economic losses were and potentially the number of people affected.

Natural Hazard	**Relation to climate change indicators**	**Present in country**	**Expected change in climate indicators (Chapter 2)**
Hydro-meteorological			
Pluvial Flooding	Precipitation		
Fluvial Flooding	Precipitation		
Landslides (precipitation-induced)	Precipitation		
Coastal Flooding – storm surges and sea level rise	Sea Level Rise (global temperature)		
Heat waves	Temperature		
Wildfires	Temperature, Precipitation		
Water scarcity	Temperature, Precipitation		
Heavy snow fall	Temperature, Precipitation, (wind – snow drifts)		
Geophysical			
Landslides (seismic-induces)	-		
Earth quakes	-		
Tsunami	-		
Volcano	-		

Table 3.1 overview of potential natural hazards and how climate indicators could influence these.

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4. Resilience planning in Road Infrastructure Development

Documents & Publications

PRESENTATIONS

TRAINING MATERIALS

PUBLICATIONS

RECORDS

MINUTES OF MEETINGS

INTRODUCTION FOCUS REPORT

Download here

FOCUS REPORT ALBANIA

Download here

POLICY GUIDELINES ALBANIA

Download here

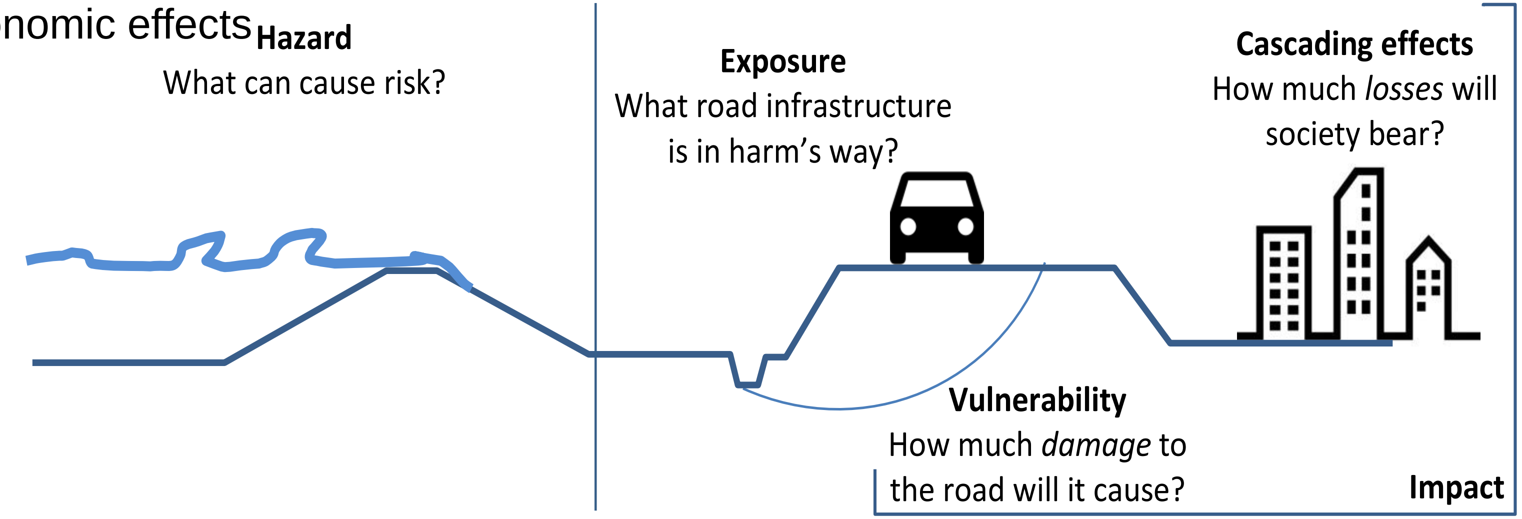
FOCUS REPORT BOSNIA HERZEGOVINA

Download here

POLICY GUIDELINES BOSNIA AND HERZEGOVINA

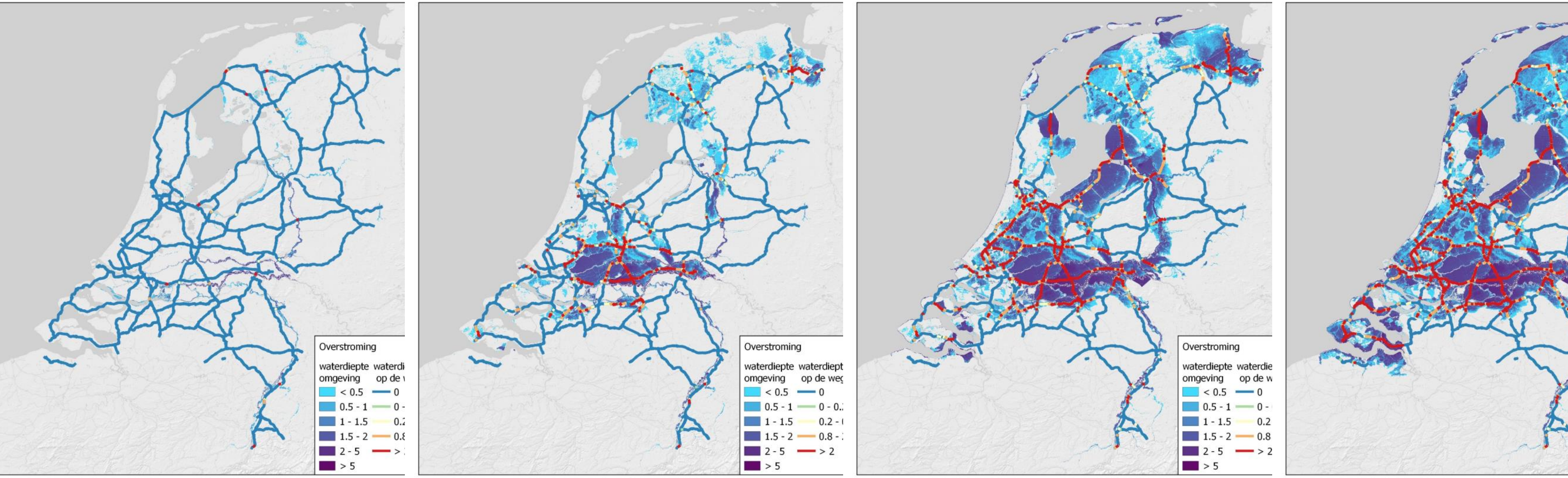
5. Risk assessment and management

- All previous chapters are needed to be able to perform a resilience assessment.
- Gather information on
  - Hazard
  - Exposure -> road network, assets, type of pavement, type of road and where to gather this information
  - How to determine the vulnerability functions
  - Data to determine the socio-economic effects



Hazard maps

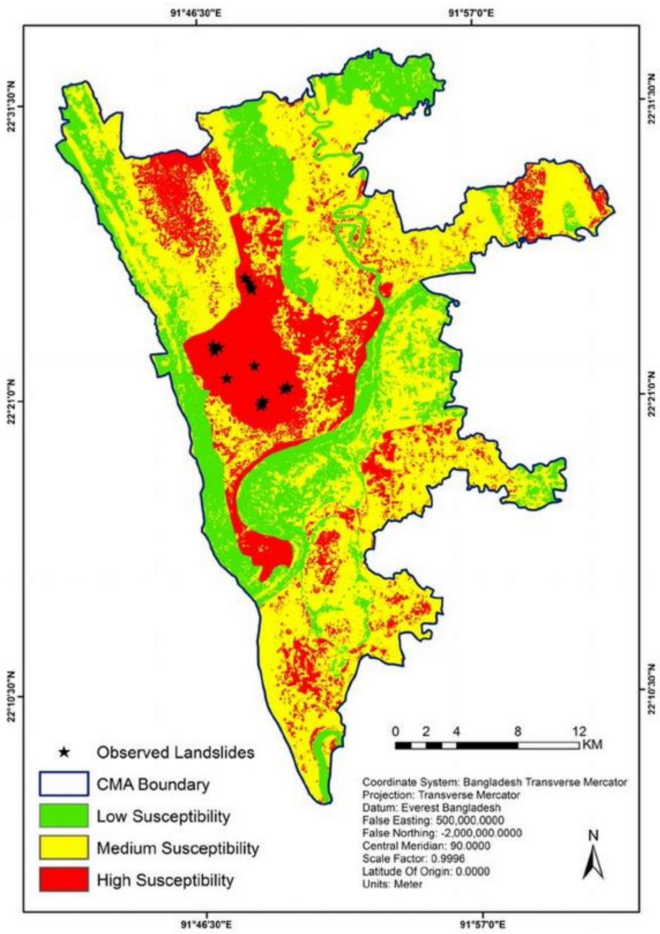
- Normally input from:
  - Meteorological institute (direct impacts like temperature)
  - Relevant authority (e.g. for making hydrological assessment to generate flood maps)
- Ideally hazard maps for different return periods (example Netherlands: 30 – 300 – 3000 - > 10000)



Hazard maps

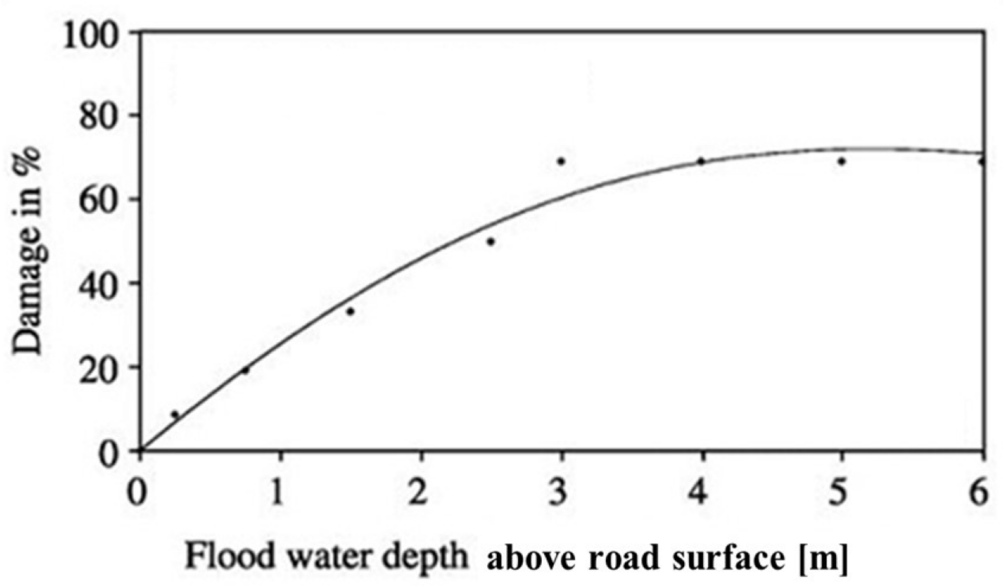
- Normally input from:
  - Meteorological institute (direct impacts like temperature)
  - Relevant authority (e.g. for making hydrological assessment to generate flood maps)
- Ideally hazard maps for different return periods
- Determine exposure, vulnerability and losses for all return periods
- Calculate the yearly to be expected damages and losses

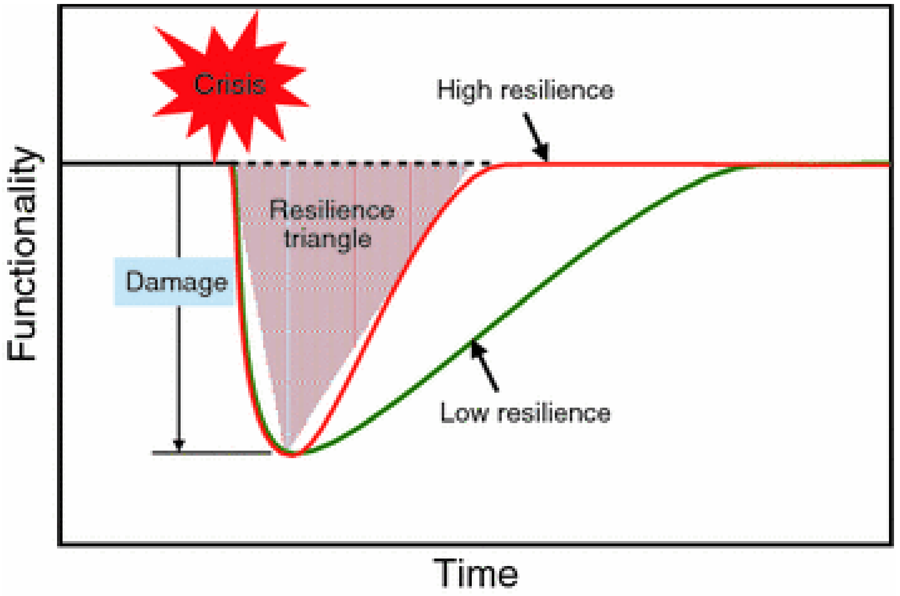
- Sometimes no hazard maps are present
  - Often the case for landslides: susceptibility maps



Quantitative Vulnerability and Resilience assessments

Vulnerability = percentage of construction costs for a hazard intensity





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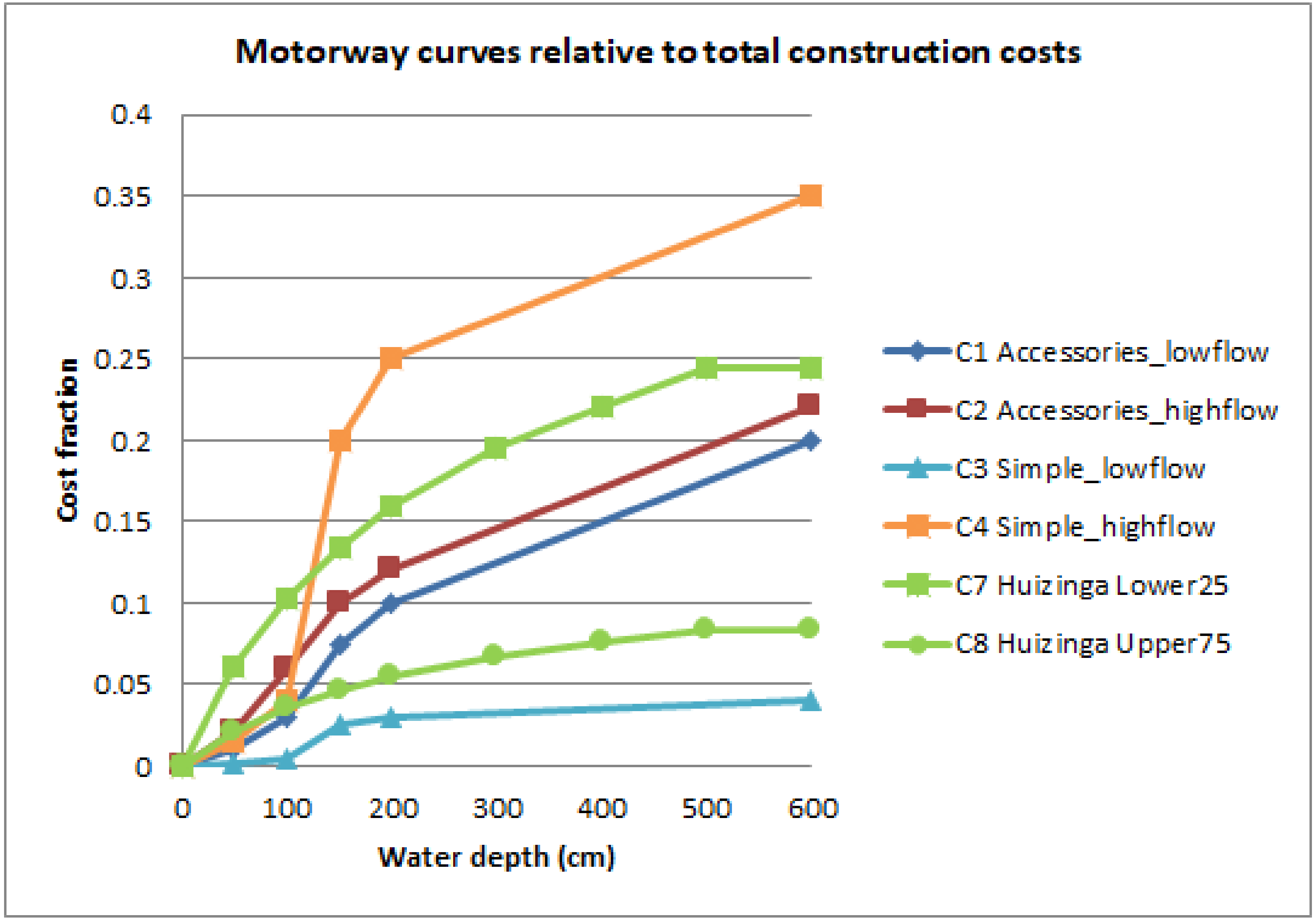
Vulnerability functions

Table 1. Road construction costs and maximum damage per road type, differentiated between low flow (low-flow velocities) and high flow (high-flow velocities). The values present the average for the former EU-28, in millions of euros (year 2015) per kilometre.

Road type	Lanes (–)	Construction cost range (millions of euros per kilometre)	Max damage (low flow) (–)	Max damage (high flow) (–)	Max damage (low flow) (millions of euros per kilometre)	Max damage (high flow) (millions of euros per kilometre)	Huizinga max damage[a, d] (millions of euros per kilometre)	Applicable damage curves[d]
			Relative to construction costs		Absolute values			
Motorway	2 × 2	3.5–35	20 % (ac)[b] 4 % (si)[b]	22 % (ac)[b] 35 % (si)[b]	3.9–7.0 (ac)[c] 0.1–0.8 (si)[c]	4.2–7.7 (ac)[c] 1.2–6.7 (si)[c]	0.90	C1, C2 C3, C4
Trunk	2 × 2	2.5–7.5	20 % (ac)[b] 4 % (si)[b]	22 % (ac)[b] 35 % (si)[b]	1.0-1.5 (ac)[c] 0.10–0.20 (si)[c]	1.1-1.7 (ac)[c] 0.88–1.75 (si)[c]	0.60	C1, C2 C3, C4
Primary	2 × 1	1.0–3.0	5 %	35 %	0.050–0.150	0.350–1.050	0.25	C5, C6
Secondary	2 × 1	0.50–1.5	5 %	35 %	0.025–0.075	0.175–0.525	0.225	C5, C6
Tertiary	2 × 1	0.20–0.60	5 %	35 %	0.010–0.030	0.070–0.210	0.175	C5, C6
Other	1	0.10–0.30	5 %	35 %	0.005–0.015	0.035–0.105	0.075	C5, C6

[a] Huizinga max damage costs (euros per kilometre) are obtained by multiplying the costs per square metre with typical road widths per road type (Table S4).
[b] "ac" refers to a sophisticated road with accessories such as street lighting and electronic signalling; "si" refers to a simple road without accessories.
[c] For accessories roads: 50 %–100 % of the construction cost range; for simple roads: 0 %–50 % of the construction cost range.
[d] Huizinga max damage is to be combined with the Huizinga damage function, not C1–C6.

Vulnerability functions



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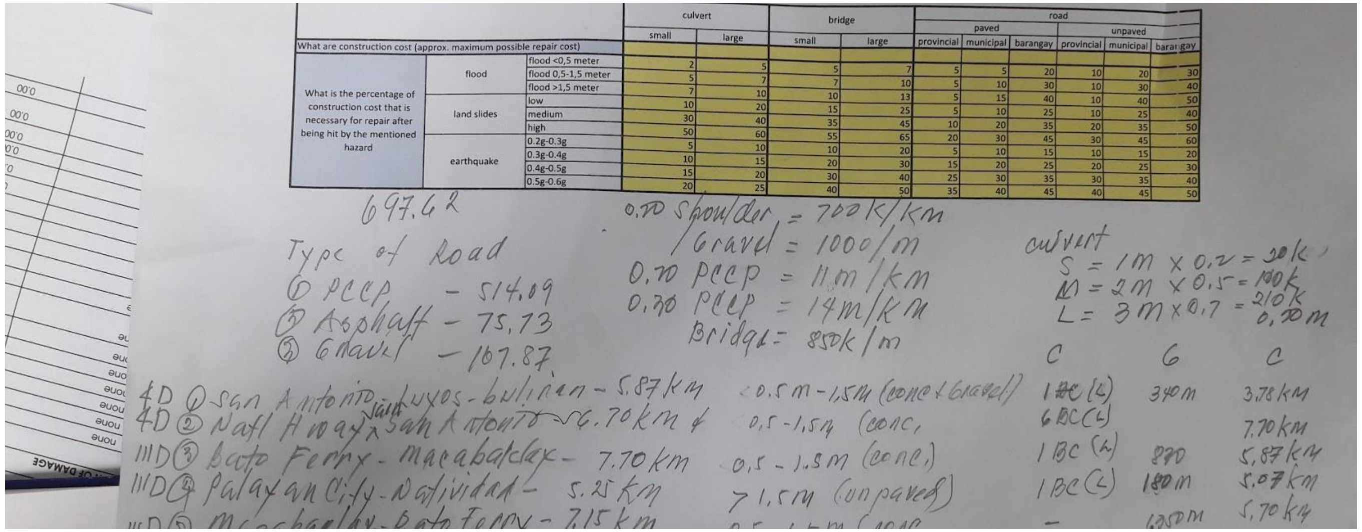
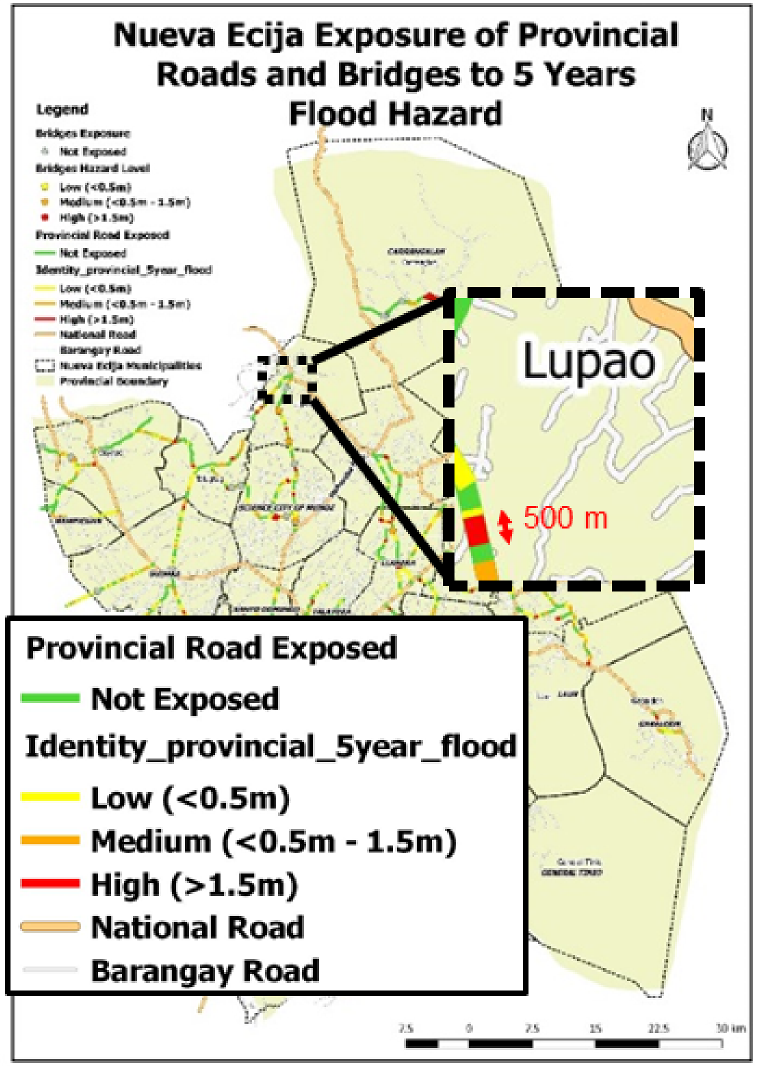
Vulnerability functions



			culvert		bridge		road					
							paved			unpaved		
			small	large	small	large	provincial	municipal	barangay	provincial	municipal	barangay
What are construction cost (approx. maximum possible repair cost)												
What is the percentage of construction cost that is necessary for repair after being hit by the mentioned hazard	flood	flood <0,5 meter	2	5	5	7	5	5	20	10	20	30
		flood 0,5-1,5 meter	5	7	7	10	5	10	30	10	30	40
		flood >1,5 meter	7	10	10	13	5	15	40	10	40	50
	land slides	low	10	20	15	25	5	10	25	10	25	40
		medium	30	40	35	45	10	20	35	20	35	50
		high	50	60	55	65	20	30	45	30	45	60
	earthquake	0.2g-0.3g	5	10	10	20	5	10	15	10	15	20
		0.3g-0.4g	10	15	20	30	15	20	25	20	25	30
		0.4g-0.5g	15	20	30	40	25	30	35	30	35	40
		0.5g-0.6g	20	25	40	50	35	40	45	40	45	50

Repair costs as a percentage of construction costs, per hazard, per asset type		Culverts		Bridges		Provincial road	
		Small	Large	Small	Large	Paved	Unpaved
		(PHP/unit)	(PHP/unit)	(PHP/m)	(PHP/m)	(PHP/m)	(PHP/m)
Flood hazard	<0.5	49%	7%	2%	2%	122%	283%
	0.5m-1.5m	44%	10%	2%	5%	122%	280%
	>1.5m	66%	13%	5%	12%	122%	278%
Earthquake hazard	0.2g-0.3g	10%	15%	8%	16%	15%	4%
	0.3g-0.4g	15%	20%	16%	24%	25%	6%
	0.4g-0.5g	20%	25%	24%	32%	35%	8%
	0.5g-0.6g	25%	30%	32%	40%	45%	10%

Damage calculation

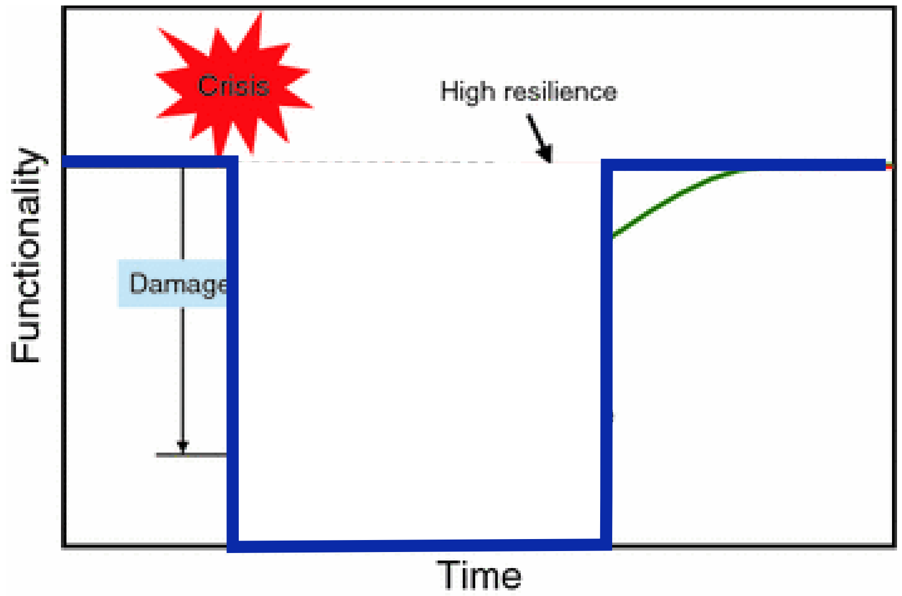


From Vulnerability Table:

- Cost of Provincial Paved Road: **14,000 pesos/m**
- Vulnerability for flood depth > 1.5m = **122%**

Damage (for stretch)
14,000 pesos/m * 122% * 500m =
8,540,000

Resilience functions



Estimated duration			Culverts		Bridges		Provincial road	
			Small	Large	Small	Large	Paved	Unpaved
Flood hazard	<0.5	< 2 hours	X		X			X
		2 hours – day		X		X		
		day – week						
		> week					X	
	0.5m-1.5m	< 2 hours						
		2 hours – day	X					
		day – week						X
		> week		X	X	X	X	
	>1.5m	< 2 hours						
		2 hours – day	X					
		day – week			X			
		> week		X		X	X	X

Use of resilience functions → criticality assessment

What defines criticality?

It is a measure of how essential to society each link in the network is

- Opportunities in future developments
- Potential losses
- Strategic function (evacuation, national corridor, international connection)
- New developments on incorporating inclusiveness

Destination

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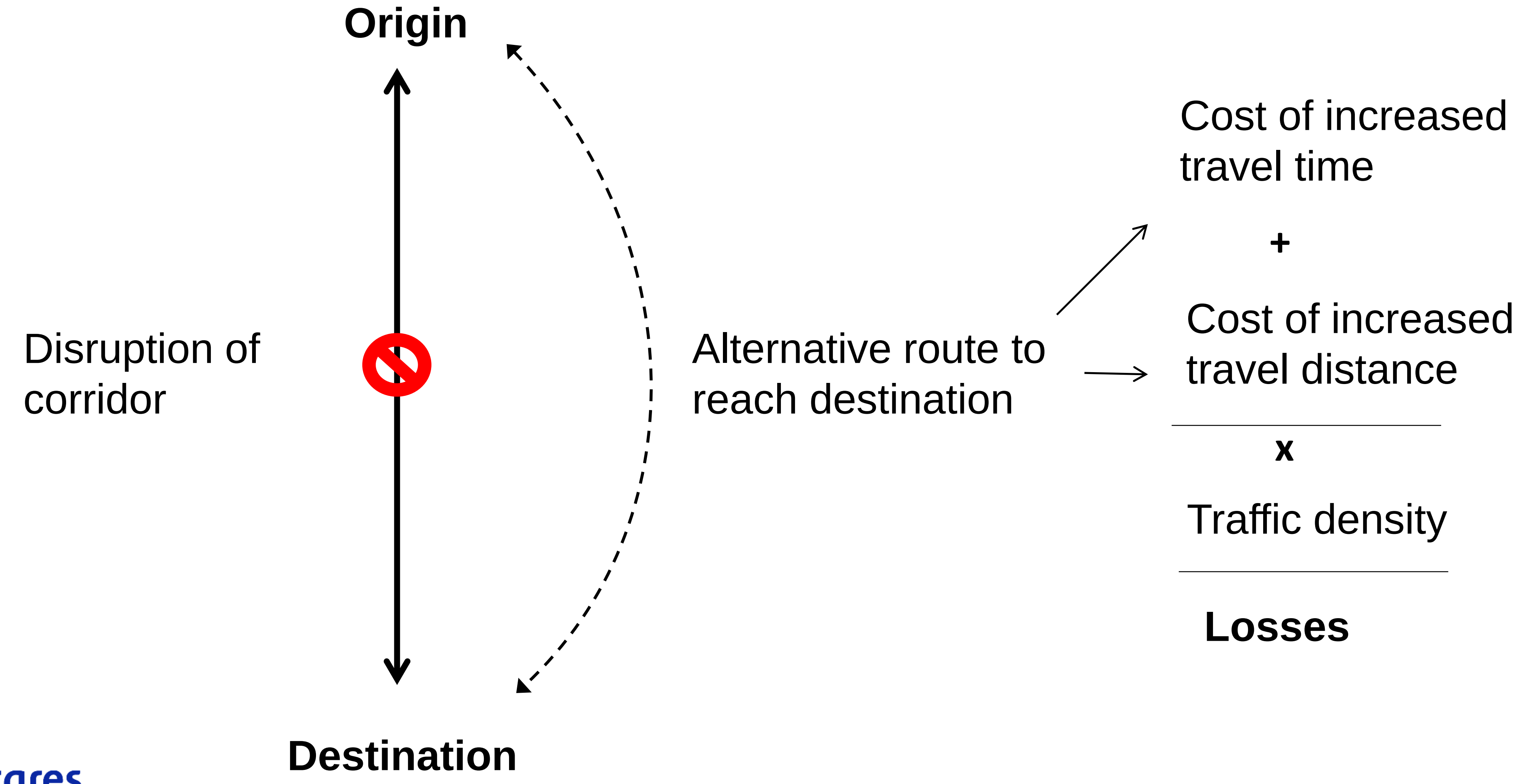
Use of resilience functions → criticality assessment



6. Roadmap for adaptation planning

- The roadmap is needed to identify with the stakeholders involved in the institutional framework what would be the ambitions level for users, operators, governments
- Also propose an action plan on what would be a desired ambition.
  - For example, should the road always be available. What is the maximum amount of people that potentially is affected? What are we willing to invest yearly in damages to the road due to natural hazards.
- This is used when identifying adaptation measures to improve resilience of the network.
- Based on ROADAPT identify a longlist of potential solutions to take, including green solutions. Take into account what the characteristics should be to evaluate these measures
  - For example, the lifetime of a meausre, the costs involved, the effectiveness, implementation time.
- Finally this should be translated to policy and regulations.

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