# How can climate change impact our bridges and what can we do about it?

**AMRO NASR – CIR DAGEN 2023, 31 JAN, 2023**
**Division of Structural Engineeirng, Lund University**

# Outline

- Background
- Overview of PhD project
- Risk identification
- Risk analysis
- Risk evaluation and treatment
- Conclusions

Flooding of a bridge during the 1997 Red River of the North flood, Minnesota, U.S.A.

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# Background: aim and motivation

- Infrastructure elements are traditionally designed to accommodate the historical climate conditions.

- However, significant changes to the climate are taking place at unprecedented rates.

Unseating of bridge deck during Hurricane Katrina, 2005

**Overarching aim: improve the current state of knowledge related to the identification, analysis, and adaptation of infrastructure to climate change risks.**

the safety and performance of infrastructure elements.

- Understanding these impacts is of paramount importance, especially for long-lived infrastructure elements (e.g., bridges, seawalls, and tunnels).

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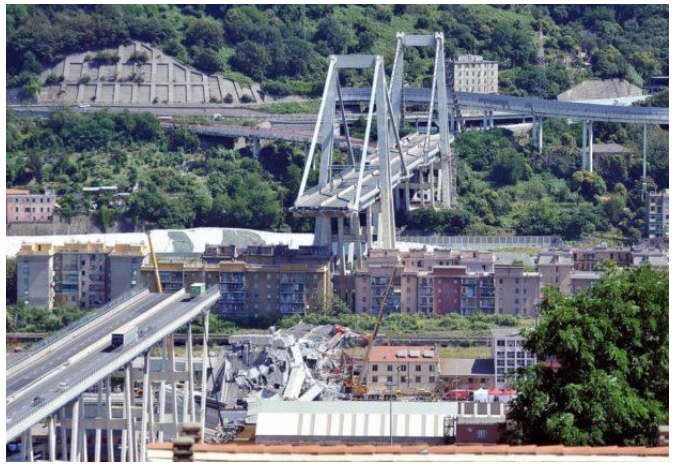
# Background: aim and motivation



Collapse of the Morandi bridge in 2018

Collapse of the Miami towers in 2021

Why study climate change effects on infrastructure?

Updating standards and design codes takes time! (15-20 years)

e.g.
-Superpave program (15 years)
-Limit state design (20 years)
-Partial safety factors design (15 years)

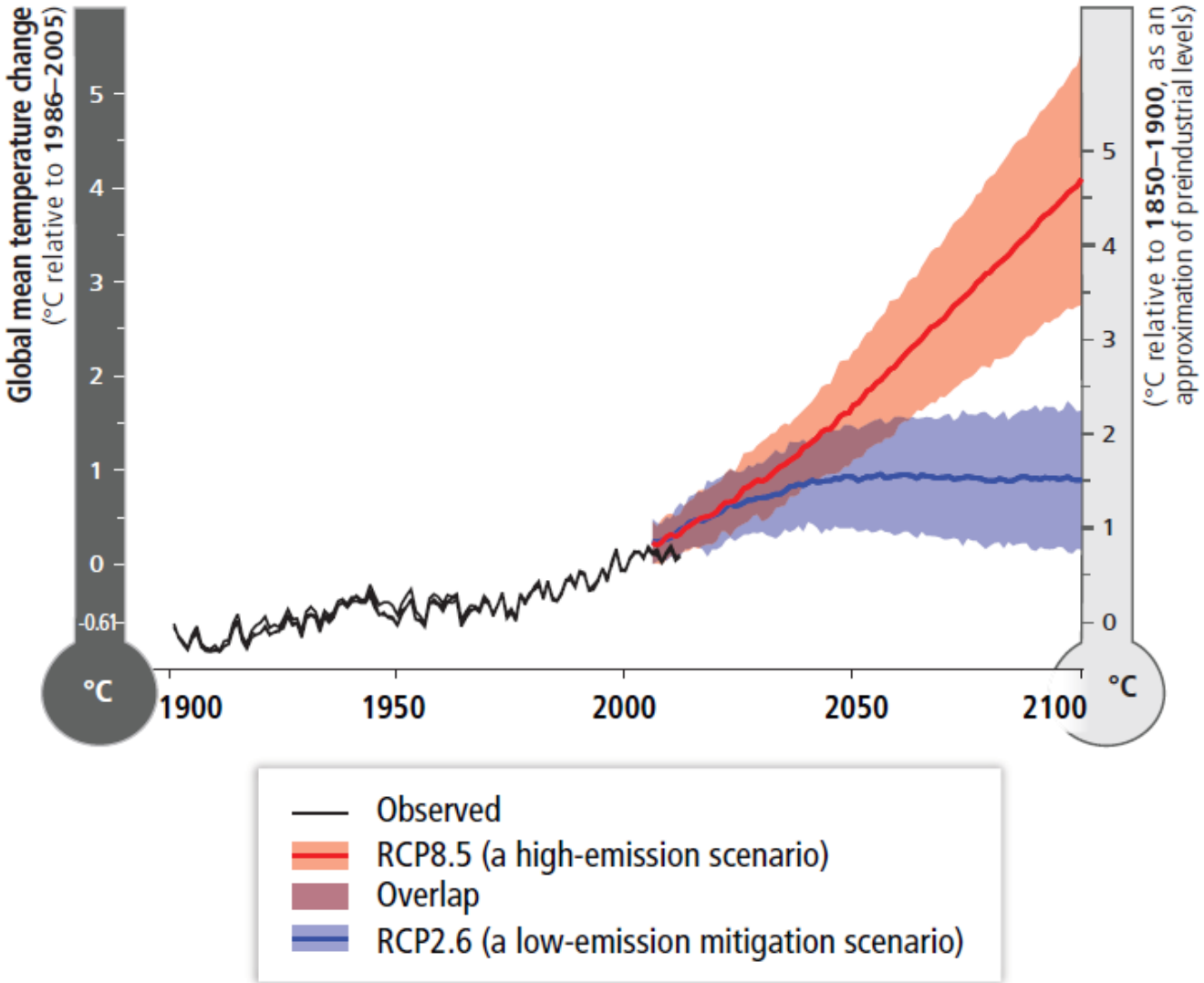
The impacts can be substantial!

e.g.
- Corrosion (Annual global costs estimated to exceed trillion USDs, loss of life, societal losses)

Major protection projects often have a long lead time! (30-40 years)

e.g.
Storm surge barriers in:
-Venice, Italy (37 years)
-Rotterdam, Netherlands (36 years)

# Background: climate change




- It is unequivocal that changes to the climate system are taking place.
- The Intergovernmental Panel on Climate Change (IPCC) fifth and sixth assessment reports of IPCC refer to four different RCP scenarios.
- RCP8.5, RCP6.0, RCP4.5 and RCP2.6

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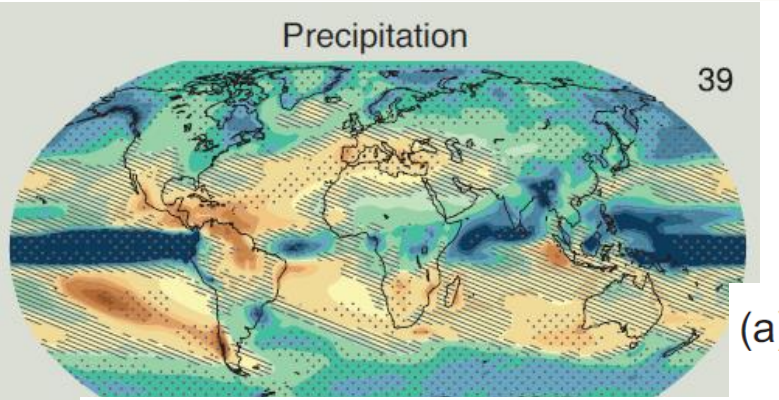
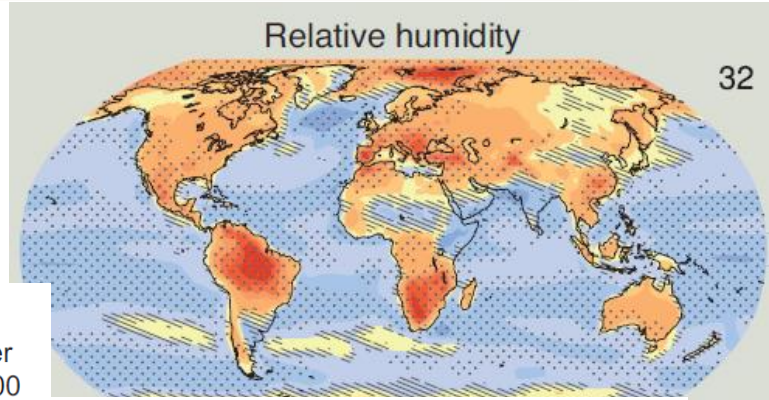
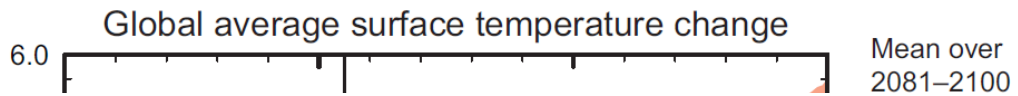
# Background: climate change



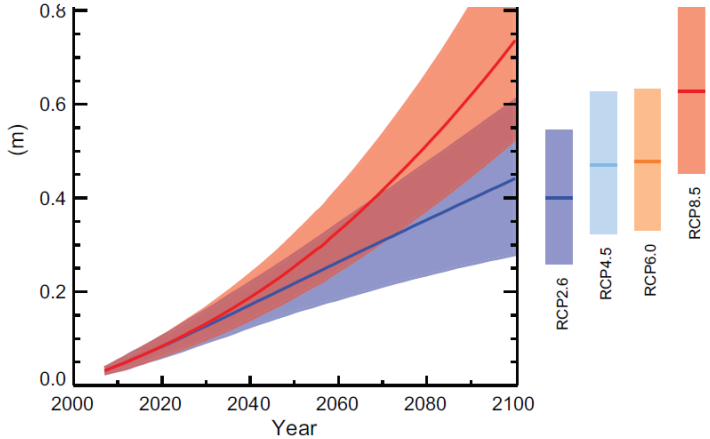



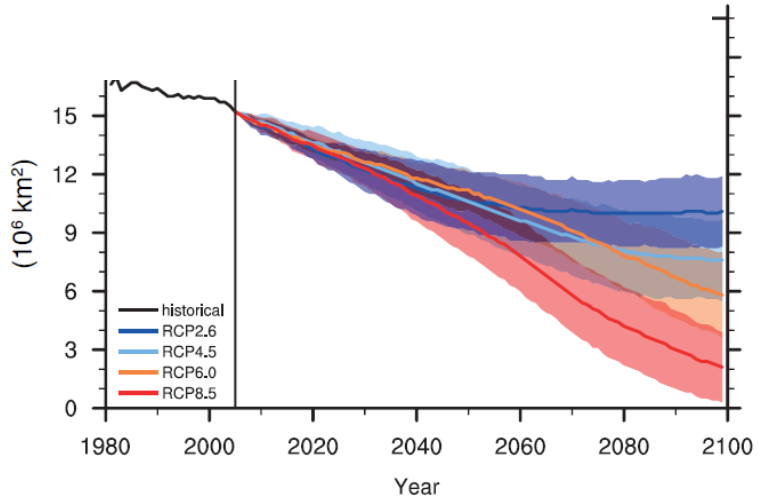




(1) What are the risks imposed on infrastructure by these (and other) changes?

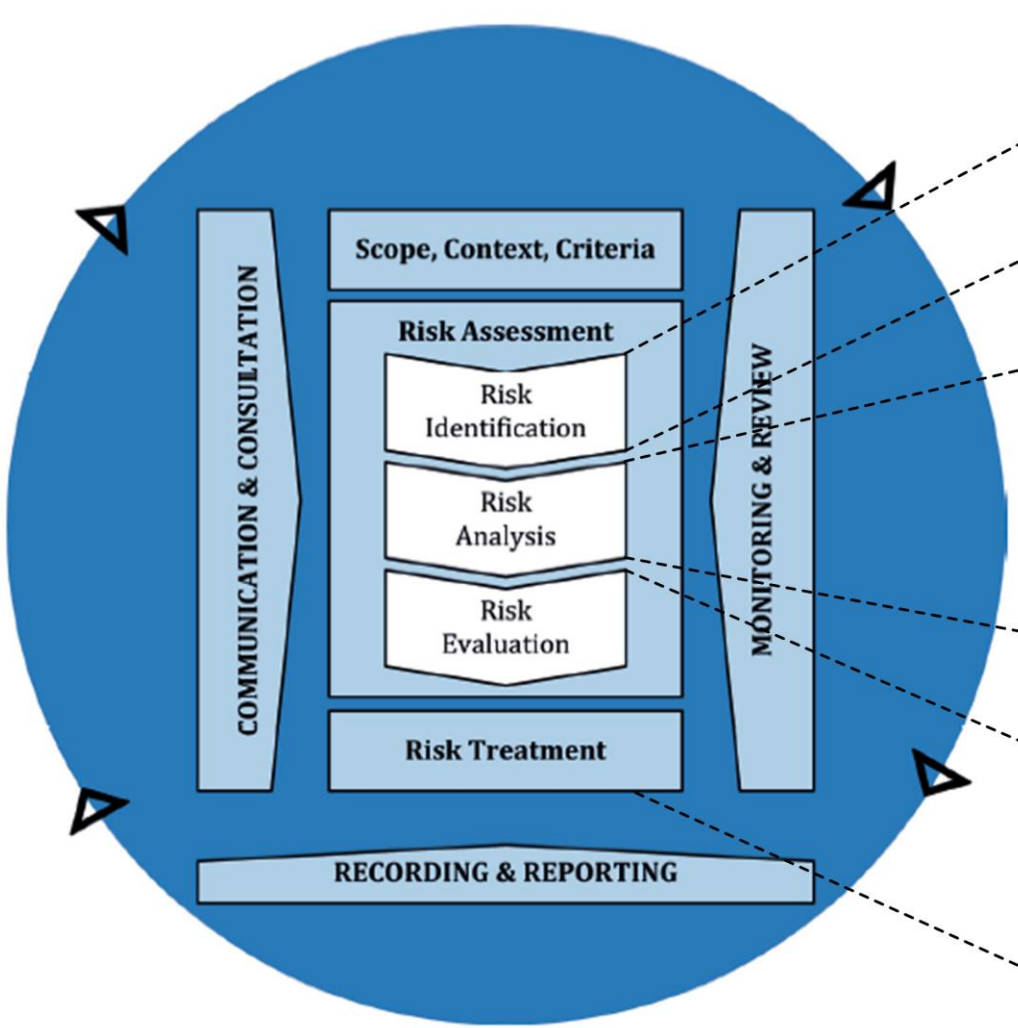
(2) How can these risks be analyzed?

(3) What can we do in response to these risks?



# Overview of PhD project




Risk Management Process (ISO 31000, 2018)

| | Paper |
|---|---|
| **Stage 1: Risk identification** | |
| (Q1) What are the potential impacts of climate change? | I |
| **Stage 2: Risk analysis** | |
| (Q2) Which of the identified impacts should be prioritized? | II |
| (Q3) How can the impact of climate change on selected risks be quantified? | III-VI |
| (Q4) What are the main drivers of uncertainty in assessing climate change risks? | V |
| **Stage 3: Risk evaluation and treatment** | |
| (Q5) What are the possible climate change adaptation techniques? | VII |
| (Q6) How can the potential impacts of climate change be considered in design? | VIII |

# Risk identification: What are the potential impacts of climate change?

"*Finding (risk) scenarios is part science and a large part art*" (Kaplan, 1997)

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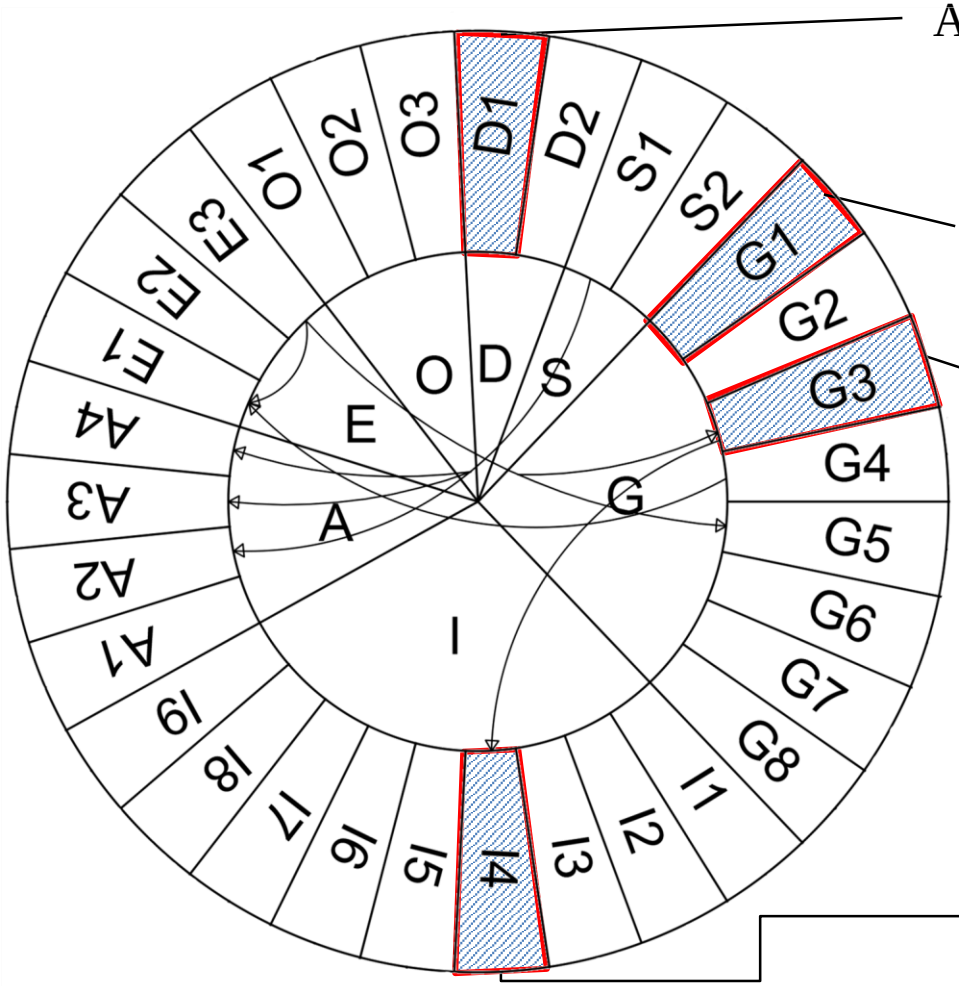
In total 31 potential climate change risks were identified and grouped into seven groups:

D- Durability risks
S- Serviceability risks
G- Geotechnical risks
I- Increased demand risks
A- Accidental loads risks
E- Extreme natural hazards risks
O- Operational risks




Accelerated **degradation of materials**

Higher **scour** rates

Higher risk of **landslides**

Additional **demand on deformation capacity**

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# Examples of identified risks

Higher temperatures→ Higher demand on deformation capacity



DuSable Bridge, Chicago

Joint closure during a heatwave in July 2018

# Examples of identified risks

Higher rainfall intensity → Higher risk of rockfalls, slope failures, and landslides

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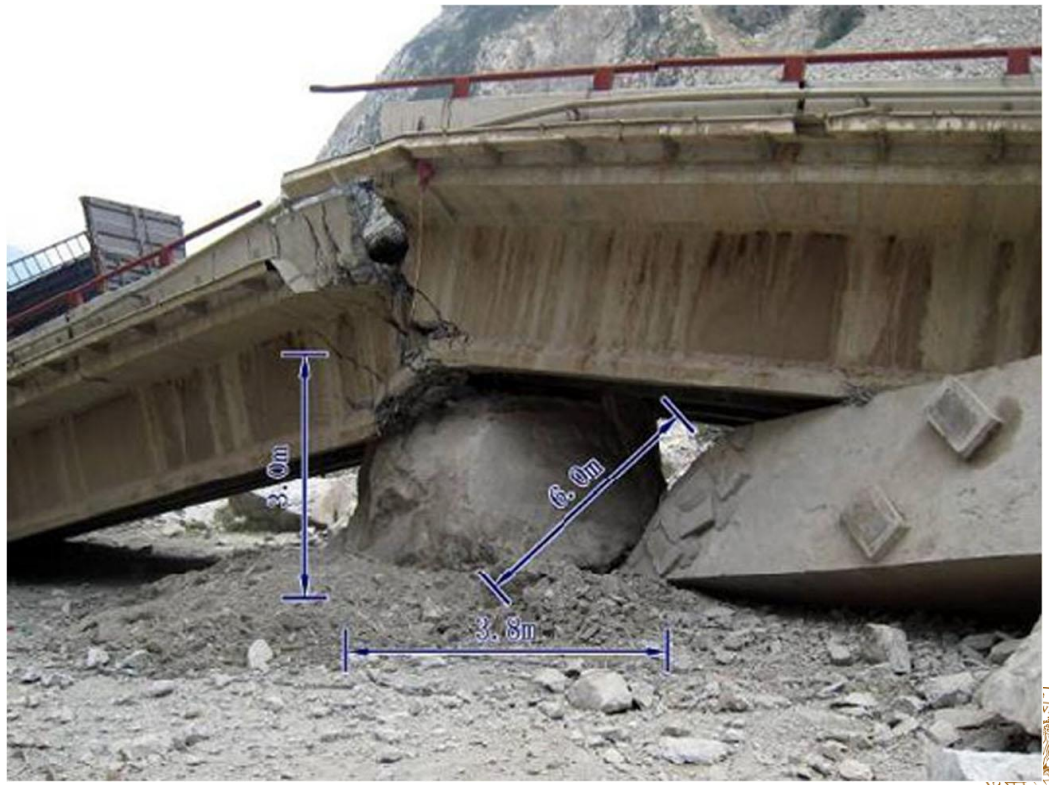


Chediguan Bridge, China was destroyed by a rockfall in May 2008 → Rebuilt in May 2009 → Again destroyed by another rockfall in July 2009

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# Examples of identified risks

Higher rainfall intensity and melting permafrost → Increased river discharge→Higher scour risk

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Failure of Sava bridge, Zagreb due to scour

The collapse of the I-90 Schoharie Creek Bridge, New York due to scour

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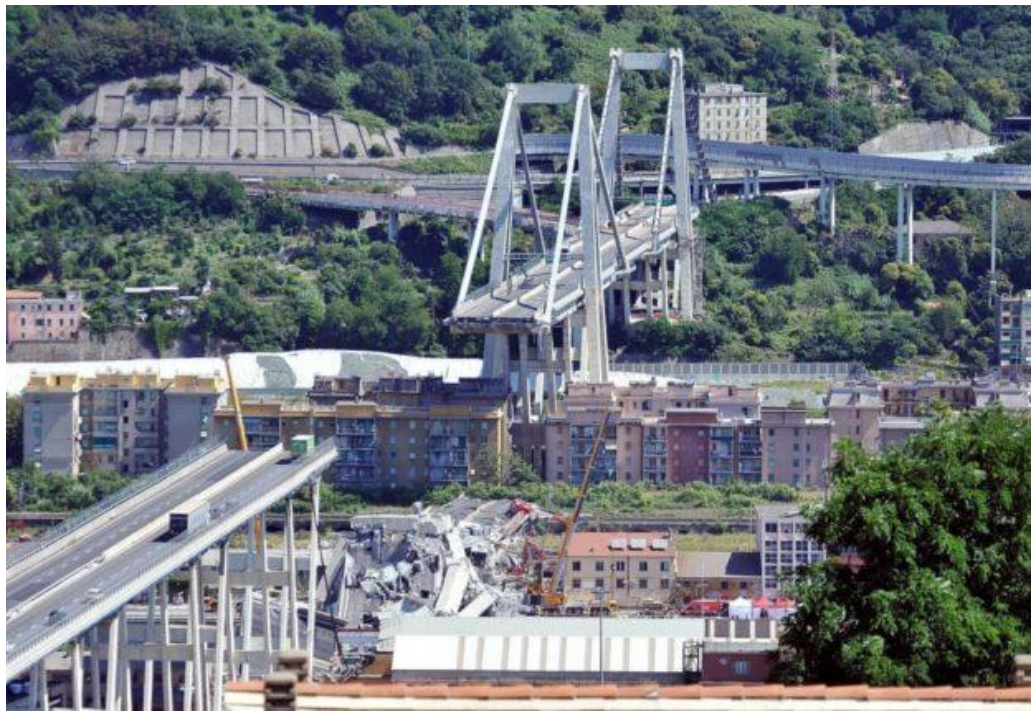
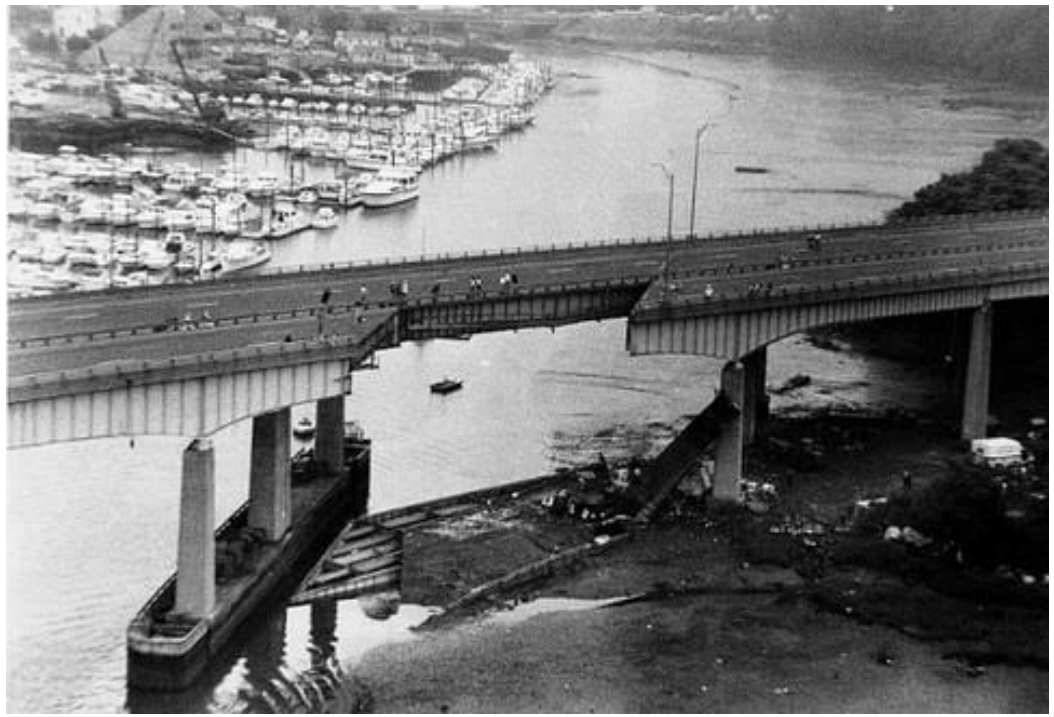
# Examples of identified risks

Changes in temperature, relative humidity, and rainfall→ Accelerated deterioration





Collapse of the Morandi bridge, Italy in 2018



Collapse of the Mianus River Bridge, USA in 1983.

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# Risk analysis: Which of the identified impacts should be prioritized?

- The large number of identified risks highlights the need for a decision support framework for prioritizing these risks.

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$$R = \underbrace{P(H) \cdot P(E|H) \cdot P(D|E \cap H)} \cdot C(D)$$

*Hazard* (H): potential change of a climate parameter (e.g., rainfall increase)
*Impact* (E|H): potential adverse impact due to hazard (e.g., increased scour)
*Vulnerability* (D|E∩H): potential damage resulting from impact
*Consequences* (C): potential consequences from damage (human, economic, etc.)

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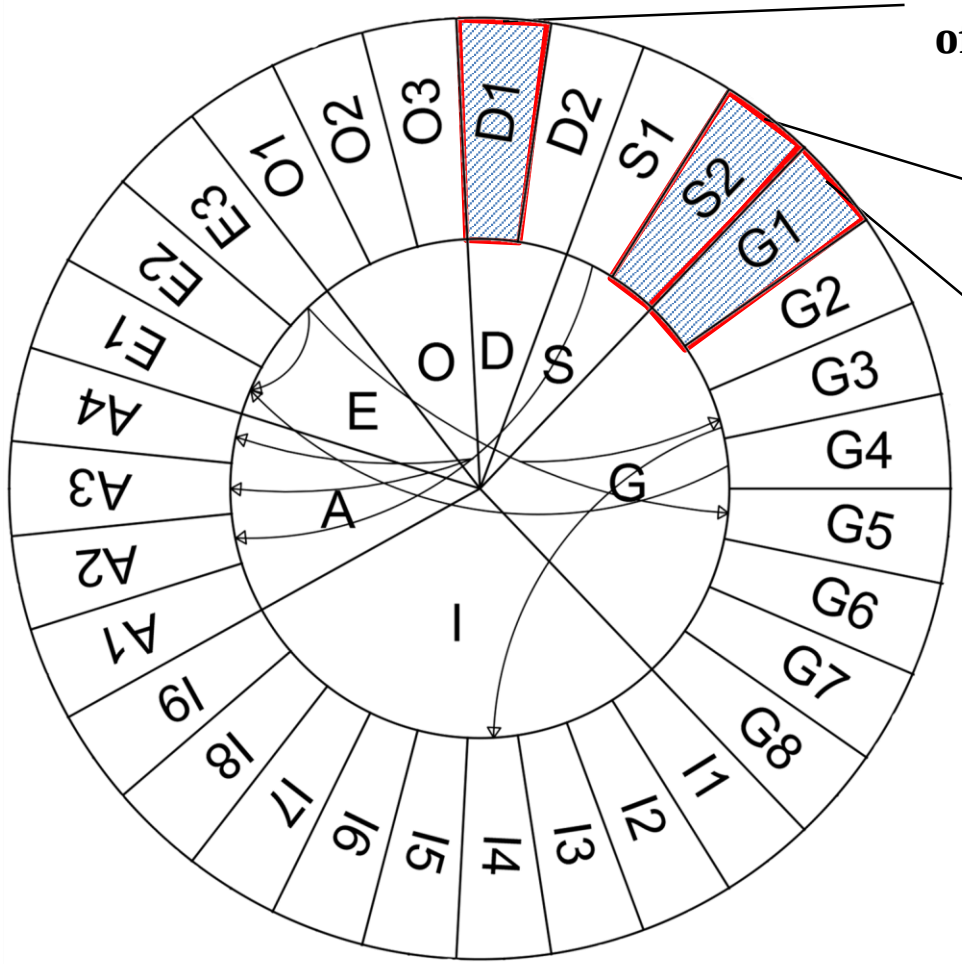
# Risk analysis: How can the impact of climate change on selected risks be quantified?

- Detailed analyses were carried out of the effect of climate change on:

- Chloride-induced corrosion of RC
- Fungal decay of timber in contact with ground
- Bridge scour
- Concrete creep

- Illustrative examples were used to demonstrate these impacts.




Accelerated **degradation of materials**

Increased **long-term deformations**

Higher **scour** rates

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# 1) Impact of climate change on chloride-induced corrosion

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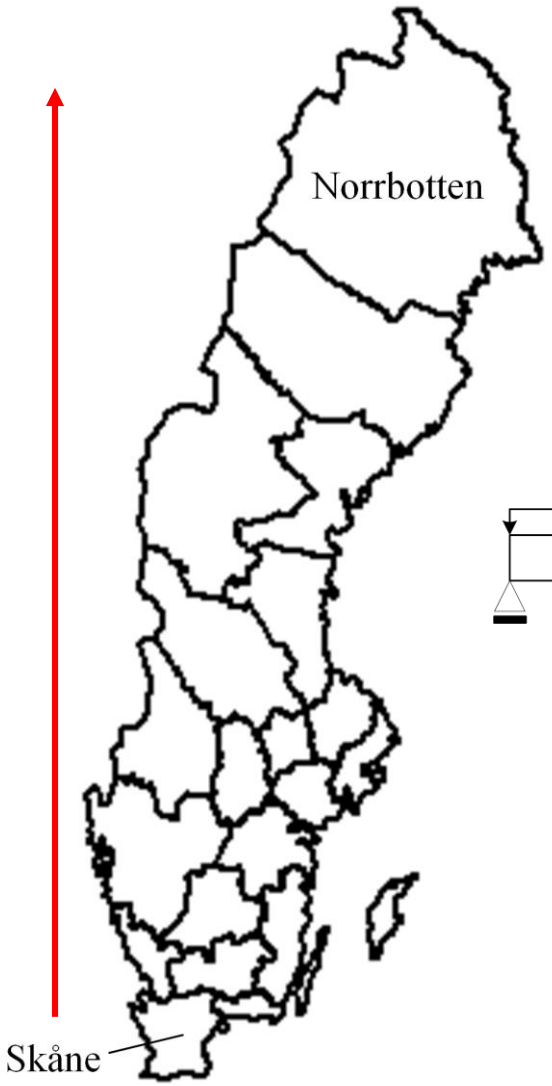
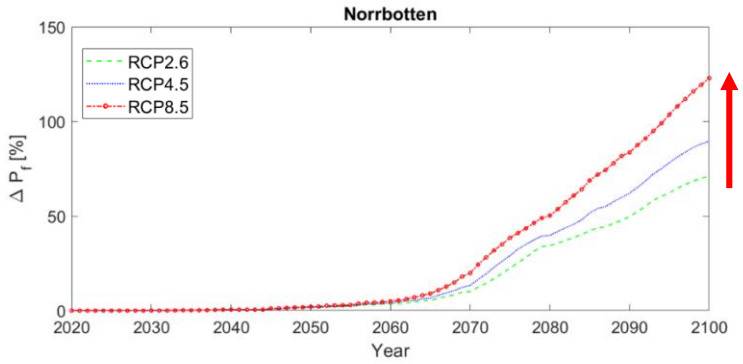
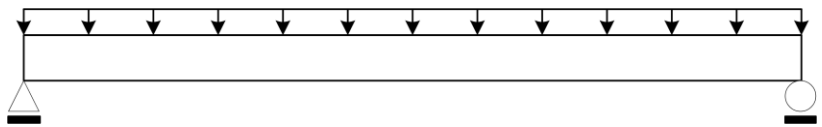
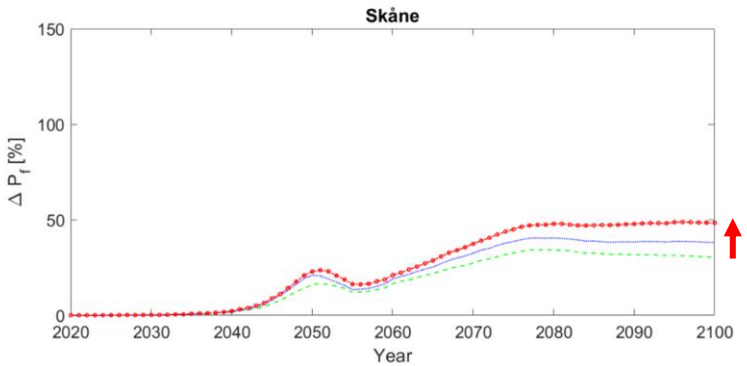
Increasing impact from south to north






Higher impact for higher GHG emissions

- Affected by temperature and relative humidity.
- The effect of climate change on corrosion initiation, crack initiation, severe cracking, and failure are assessed.
- Monte Carlo simulation is used.

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# 2) Impact of climate change on decay of timber elements in ground contact

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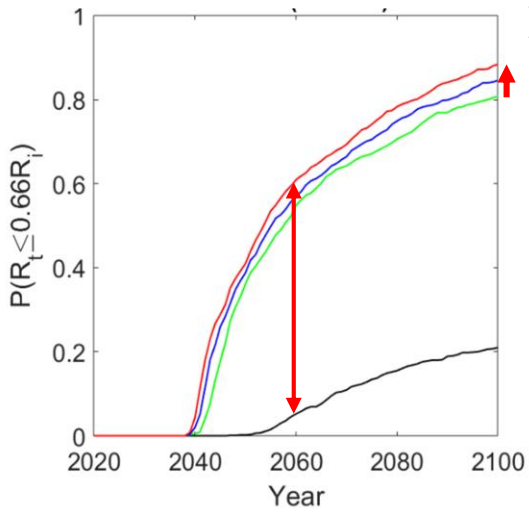
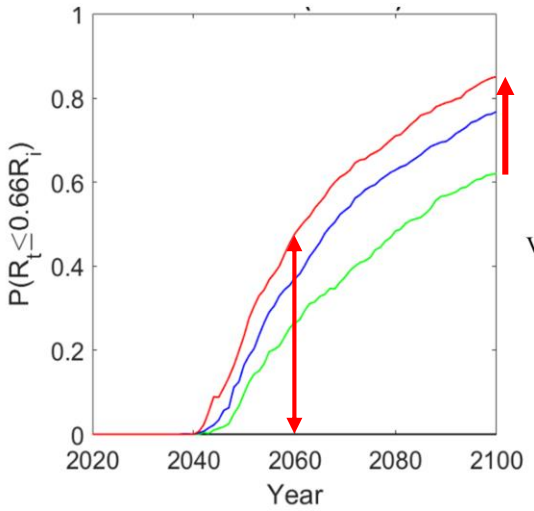
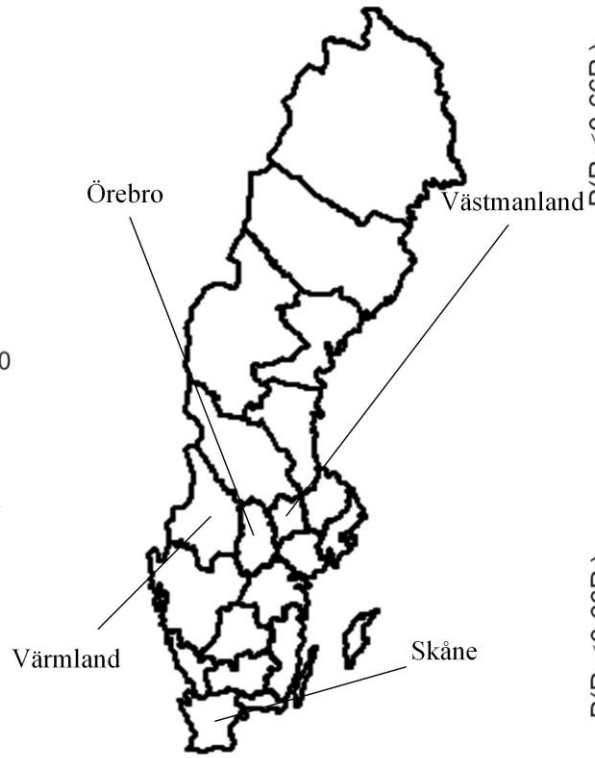
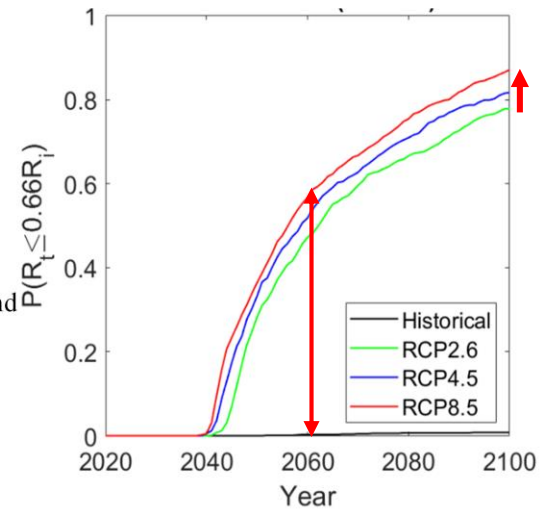


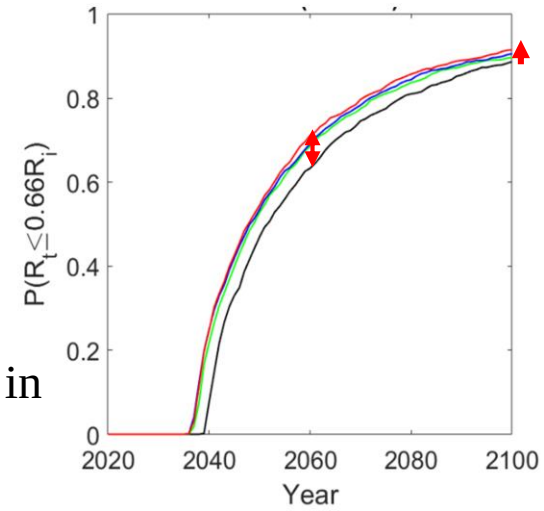

Higher impact for higher GHG emissions



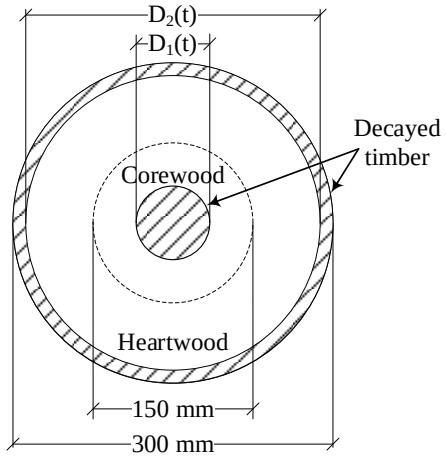




Highest impact for counties in mid-Sweden




- Affected by temperature and rainfall.
- The effect on the decay rate of wood and the long-term resistance of timber elements in ground contact are assessed.
- Monte Carlo simulation is used.

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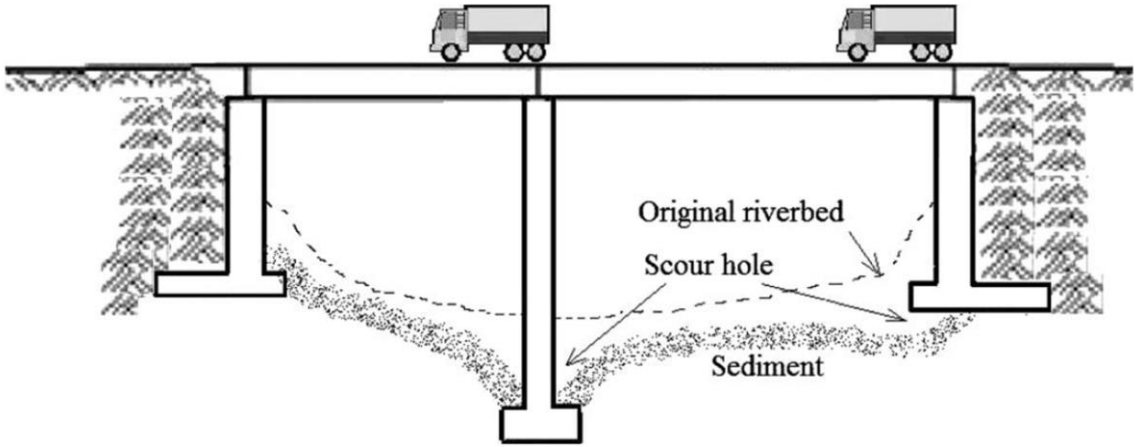
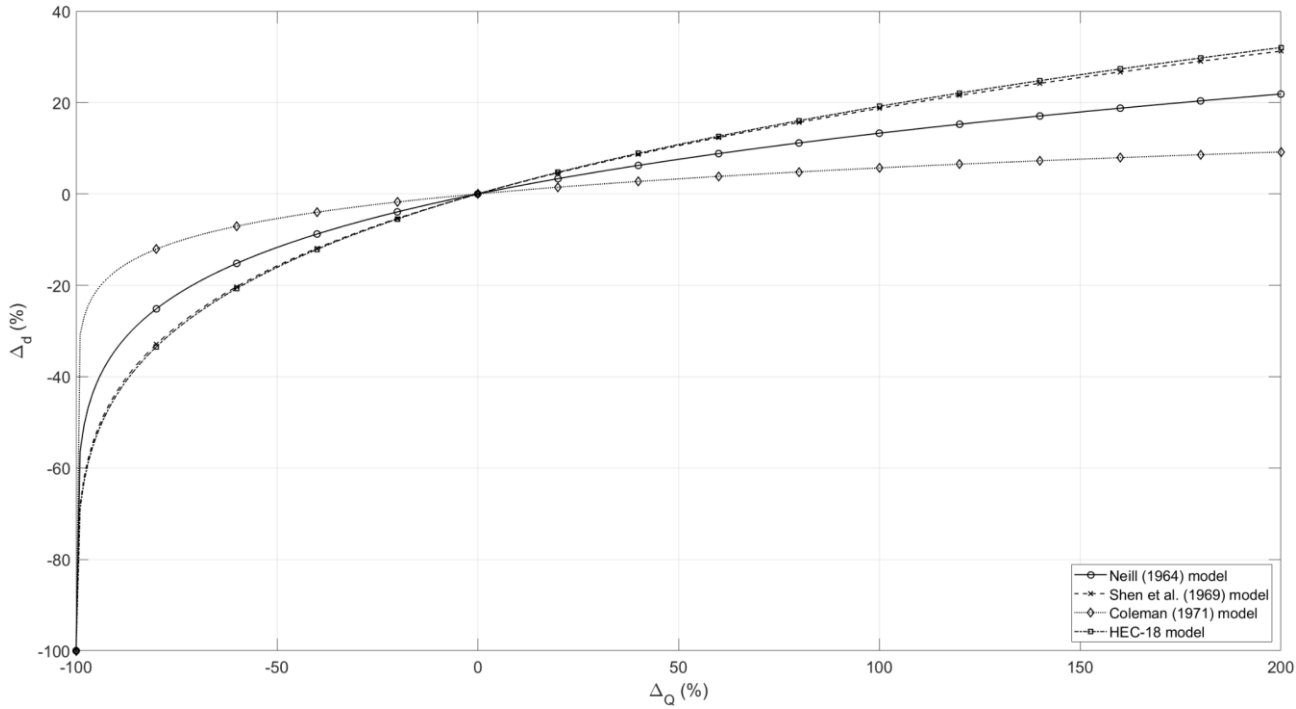
# Risk analysis: How can the impact of climate change on selected risks be quantified?

3) Impact of climate change on bridge-pier scour:




- Scour is affected by the discharge which is affected by rainfall intensity.
- Four different scour models are used to predict the change in scour depth.
- The most affected catchment areas are identified.



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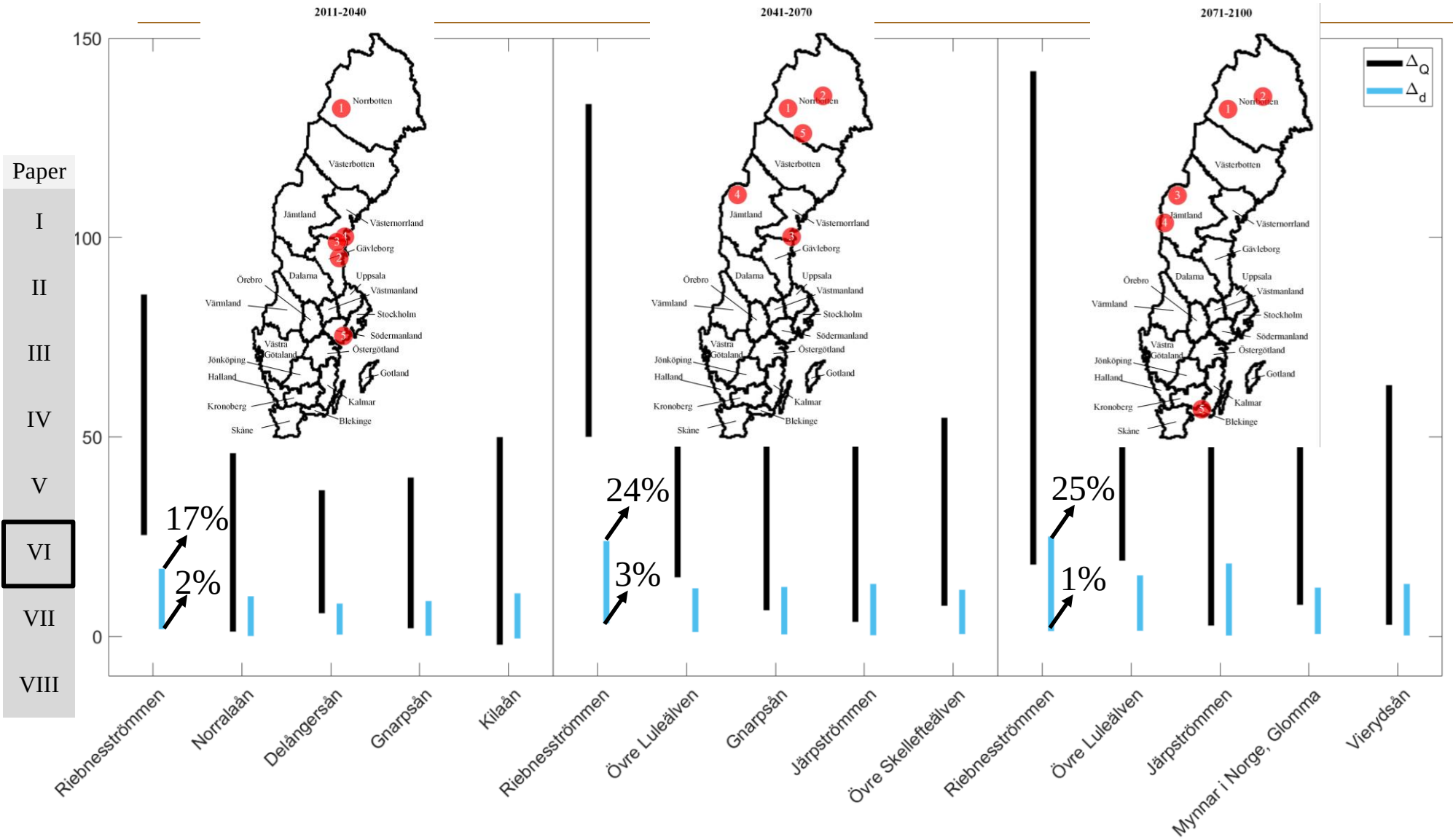
# Risk analysis: How can the impact of climate change on selected risks be quantified?

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- Other catchments show a decrease in scour depth instead (up to 13% decrease).
- The impact is not necessarily higher for scenarios with higher GHG emissions.

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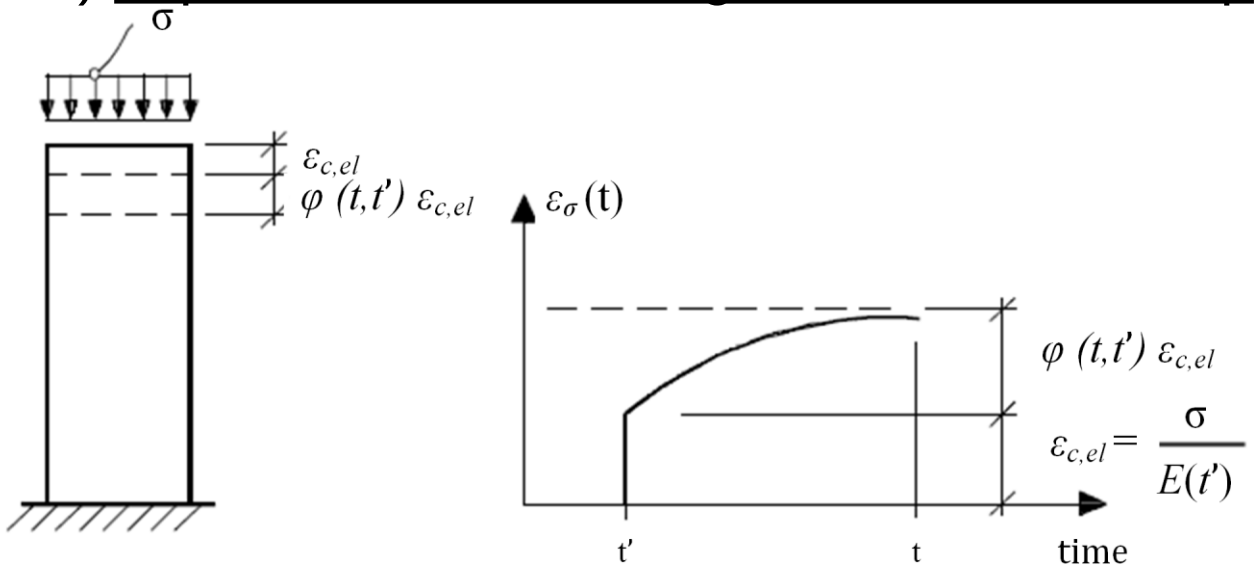
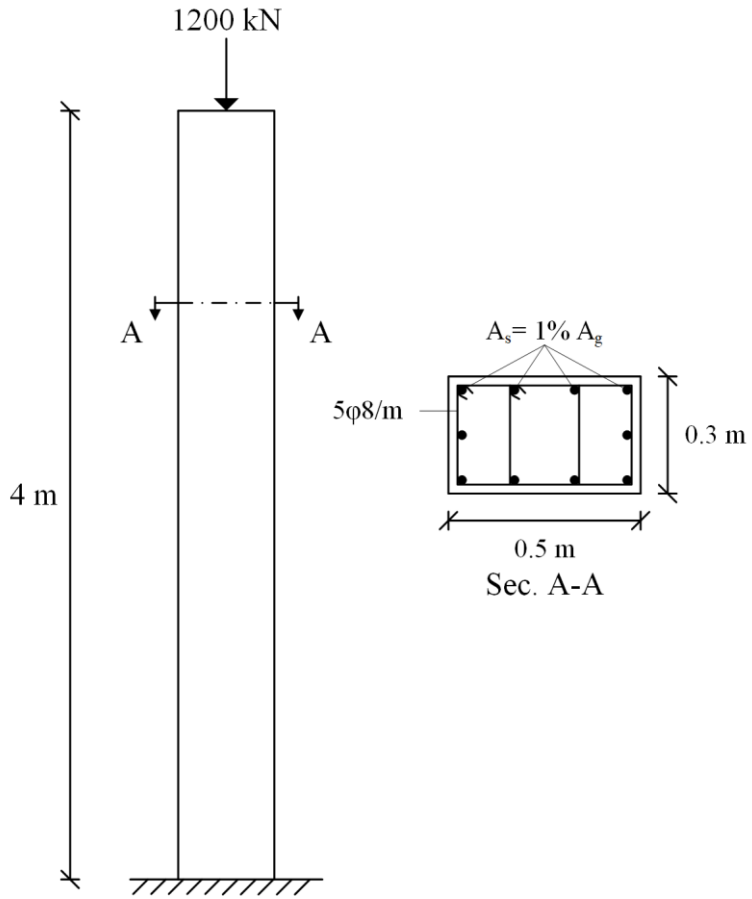
# Risk analysis: What are the main drivers of uncertainty in assessing climate change risks?

4) Impact of climate change on concrete creep:




- Temperature and relative humidity affect concrete creep.
- The impact of climate change on the end-of-century creep coefficient is assessed using five different models.
- Monte Carlo simulation is used.



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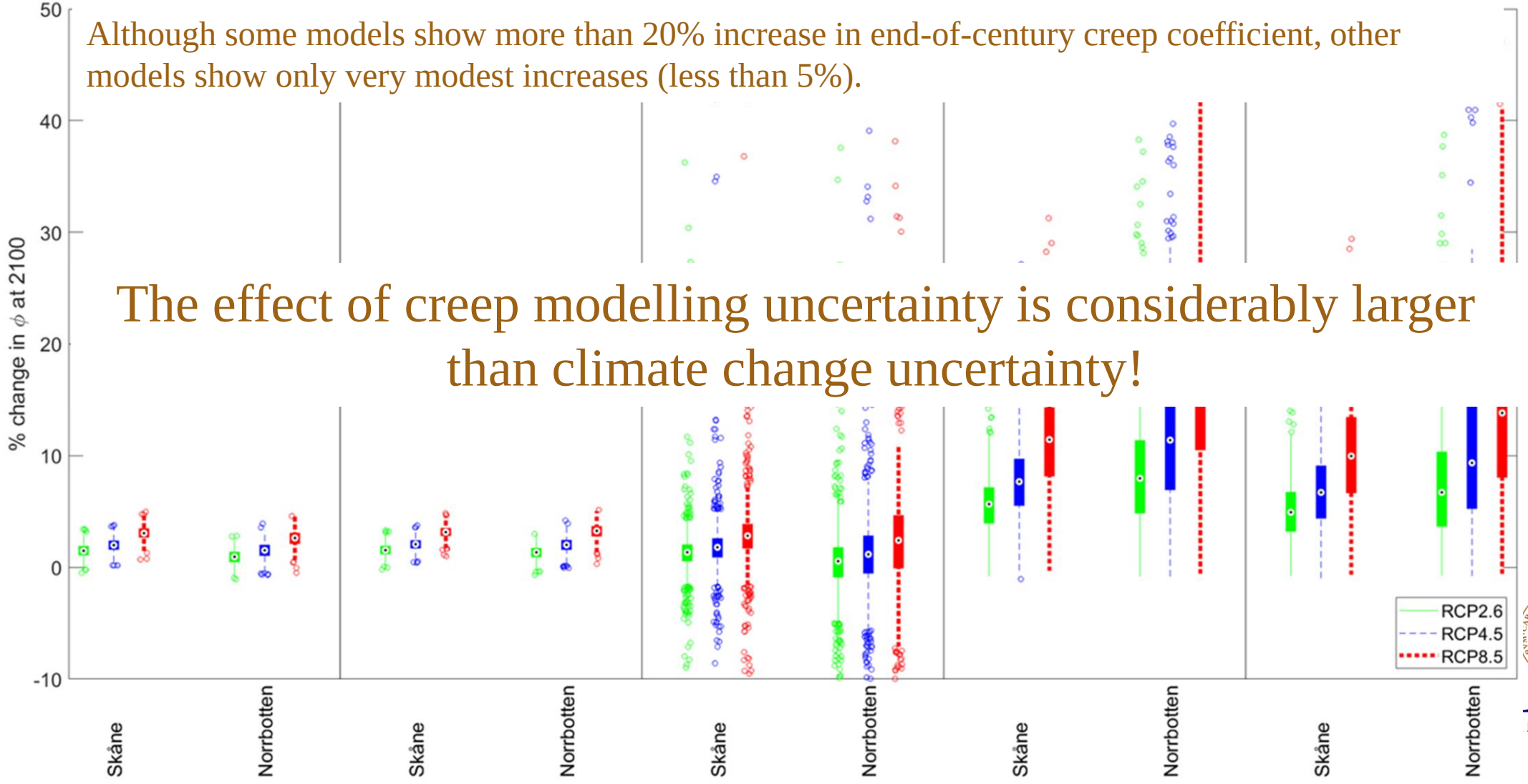
# Risk analysis: What are the main drivers of uncertainty in assessing climate change risks?

Although some models show more than 20% increase in end-of-century creep coefficient, other models show only very modest increases (less than 5%).




The effect of creep modelling uncertainty is considerably larger than climate change uncertainty!

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# What are the possible climate change adaptation techniques in response to these risks?

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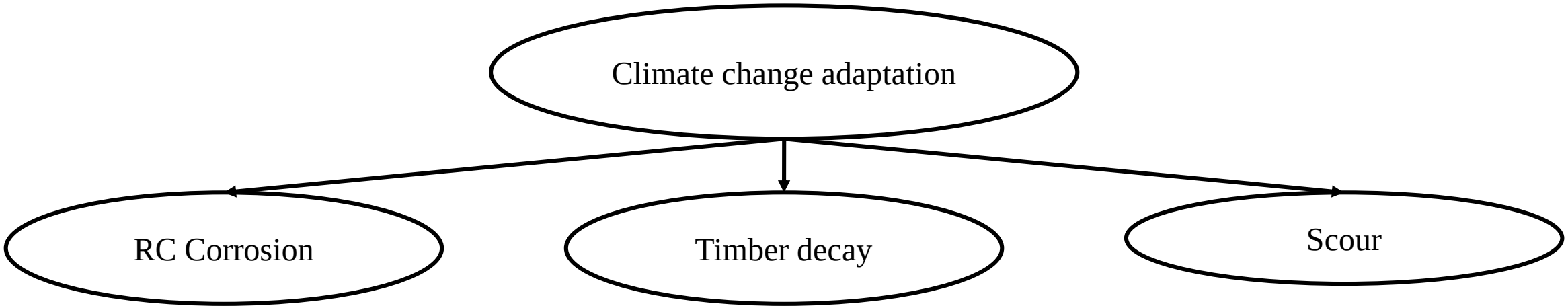


-Increase in concrete cover thickness

-Improve quality of concrete

-Electrochemical chloride extraction

⋮

-Preservative treatment

-Use of modified wood

-Protection by design

⋮

-Bed armoring (e.g., use of Riprap protection for foundations)

-Flow altering countermeasures

⋮

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# How to consider climate change impacts in infrastructure design?

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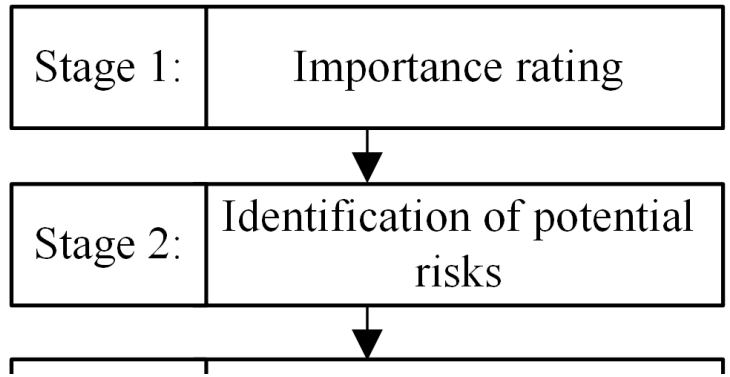
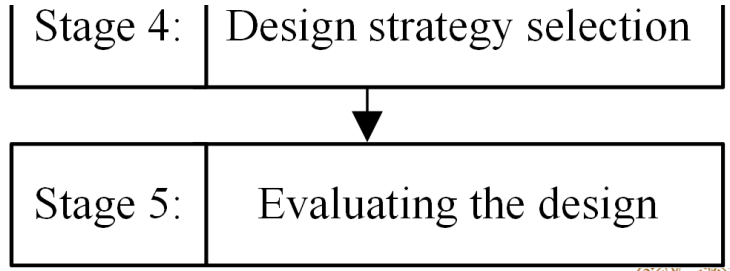
**Build to repair:**

Designing the infrastructure without specific consideration of climate change. (low importance assets; negligible risks)




Several challenges that hinder the consideration of climate change in infrastructure design are identified!

RCP2.6 or RCP4.5) while allowing for the structure to be adapted (i.e., upgraded). (continuous monitoring program is needed).




**Build for a "pessimistic scenario":**

Designing the infrastructure to withstand a relatively high GHG emissions scenario (e.g., RCP6.0 or RCP8.5). (high importance assets; severe risks; unobservable risks)

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# Conclusions

- Many potential climate change risks on infrastructure are foreseeable.
- Some impacts are higher for higher GHG emissions while other impacts do not follow this pattern.
- For some climate change impacts, the effect of other uncertainty sources may be considerably more important than climate change uncertainty.
- Several possible adaptation techniques in response to the identified risks are available.
- A conceptual framework for considering climate change in design is proposed (several challenges need to be addressed however!).
- Further research?

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