LUND UNIVERSITY

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

AMRO NASR, IVAR BJÖRNSSON – CIR DAGEN 2020, 28 JAN, 2020

Climate change

Business

Climate crisis fills top five places of World Economic Forum's risks report

For first time, environment is at top of list of issues worrying world's elite

Larry Elliott
Wed 15 Jan 2020
1.45 GMT

2544

▲ The damage caused by extreme weather events such as the Australian bushfires is at the top of the WEF's risks report. Photograph: Sam Mooy/Getty

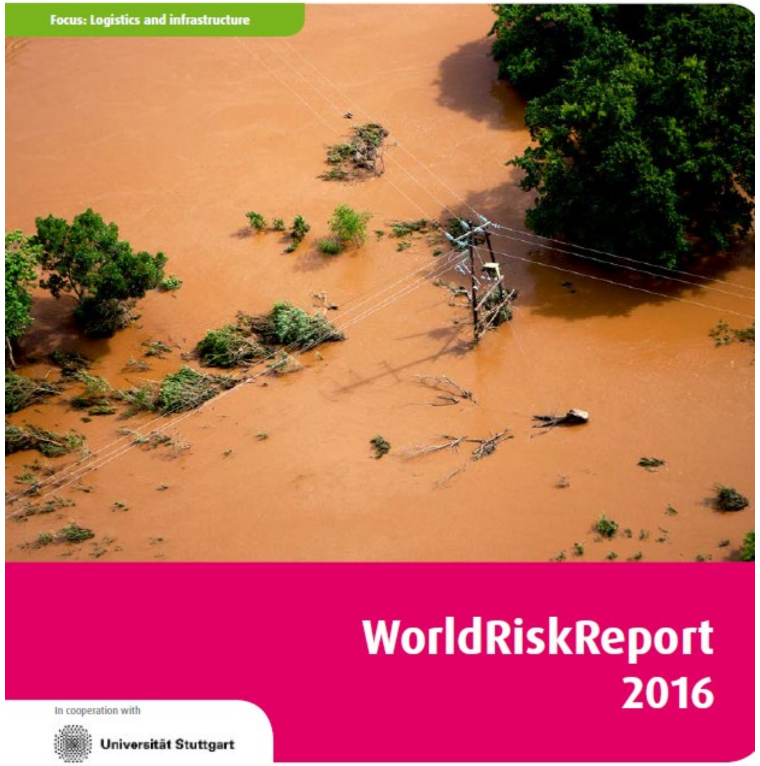
A year of extreme weather events and mounting evidence of global heating have catapulted the climate emergency to the top of the list of issues worrying the world's elite.

The World Economic Forum's annual risks report found that, for the first time in its 15-year history, the environment filled the top five places in the list of concerns likely to have a major impact over the next decade.

- Issue discussed for decades (global warming)
- Today, effects are felt by many around the world – rhetoric & societal interest has intensified
  - Although deep uncertainties still persist
- Critical to assess and evaluate potential impacts both in terms of mitigation as well as adaptation
- Society is the main stakeholder
  - Risk-informed approach desirable

LUND UNIVERSITY

Adapting to impacts for infrastructure



- Well-functioning & resilient infrastructure critical, especially in times of crises and natural disaster
- Relevant questions:
  - Which climate change risks are relevant?
  - Adaptation (& design) strategies?

PhD Project (2017-2022): Climate change impact on safety and performance of bridges

Main project aims:

1. Identify, assess and prioritize potential climate-change related risks to bridge
2. In-depth assessments of selected critical risks
3. Develop viable adaptation & mitigation strategies (incl. possible improvements to existing design & maintenance standards)
4. Case studies of new and/or existing bridges implementing previous finding

- Candidate: Amro Nasr
- Main Supervision @ LTH with support from SMHI, RISE & Skanska
- First three years funded by Trafikverket, BBT (2 227 000 SEK) & InfraSweden 2030, Vinnova (1 730 100 SEK)

LUND UNIVERSITY

Overview of PhD project phases

Progress so far:
Completed
Ongoing

WP1: Risk identification and ranking
- What are the additional risks introduced by climate change to our bridge stock?
- Which of these risks are more critical and require closer investigation?

WP2: Quantitative assessment of critical risks
- Is it possible to quantify these critical risks?
- How will they affect the overall safety of bridges?

WP3: Review of existing practices and development of adaptation strategies
- What are the possible adaptation techniques in response to the identified impacts?
- How can the cost efficiency of these adaptation techniques be assessed?
- Can an adaptation framework be developed?

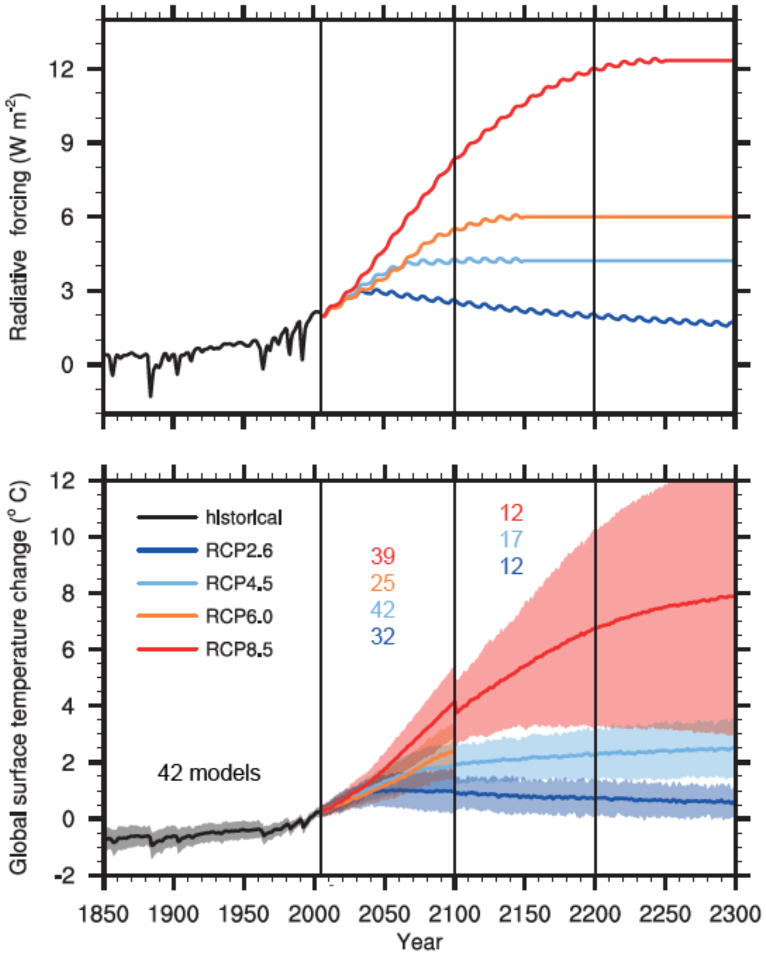
WP4: Demonstration
- Can the applicability of the developed techniques be demonstrated in case studies?

LUND UNIVERSITY

What we will present from the project today

- Very brief background about climate change projections
- Overview of primary results for:
  - Risk identification (incl. examples)
  - Prioritization framework for climate change related risks
  - Possible adaptation techniques
- Dissemination of results
- Future (& ongoing) work

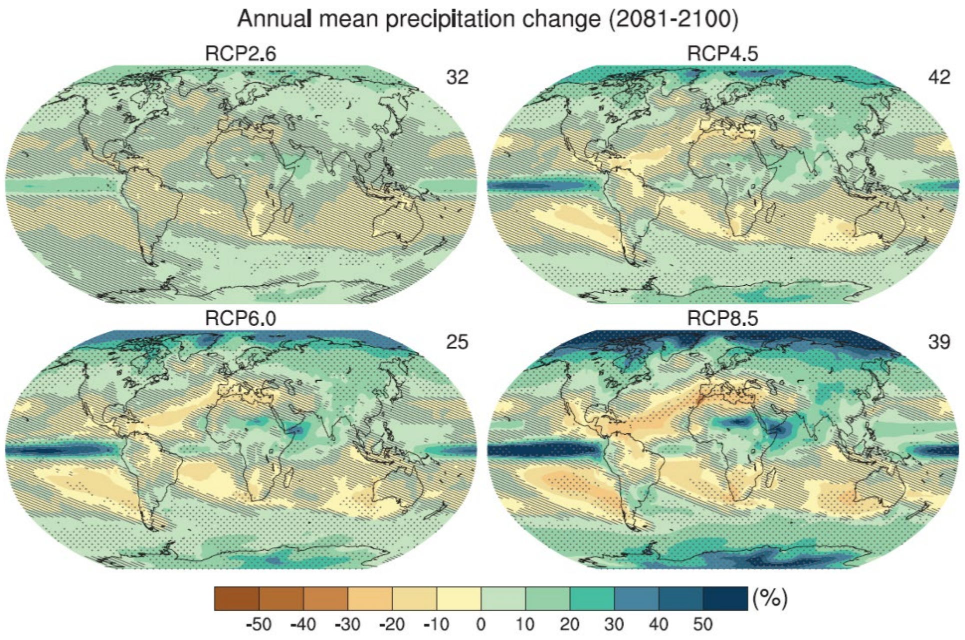
Emission scenarios and the projected climate changes

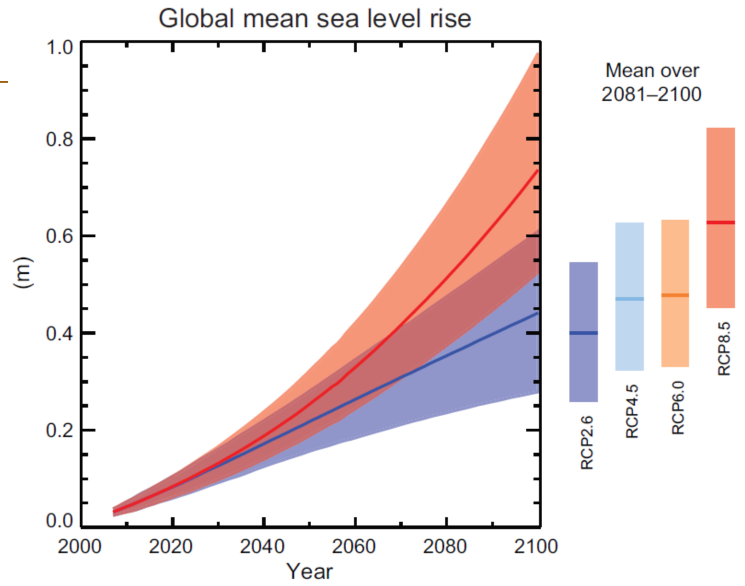


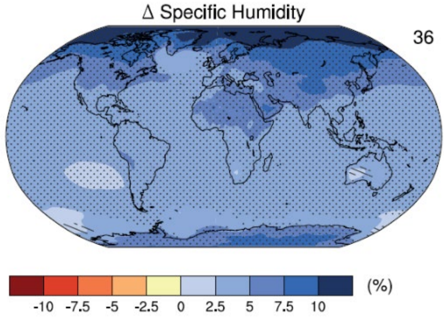
- The Intergovernmental Panel on Climate Change (IPCC) fifth assessment report (AR5) refers to 4 different emissions scenarios.

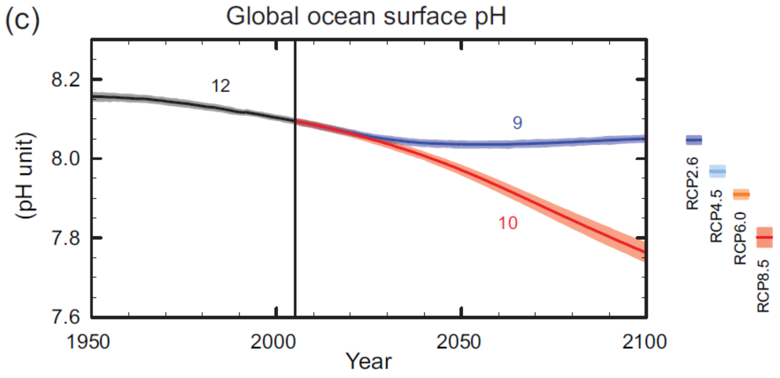
- RCP8.5, RCP 6.0, RCP4.5 and RCP 2.6.
  - RCP 2.6: A greenhouse gas (GHG) emissions scenario in which stringent mitigation measures would be taken to limit GHG emissions
  - RCP 8.5: A scenario of comparatively high greenhouse gas emissions.

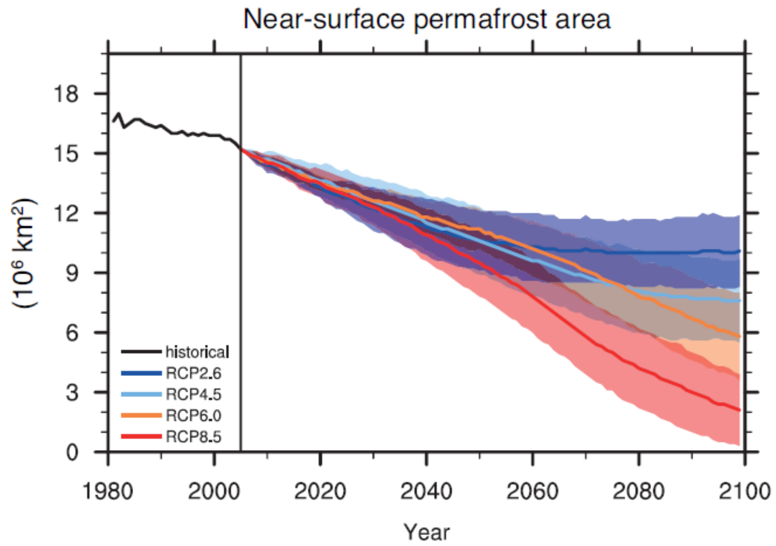
Emission scenarios and the projected climate changes





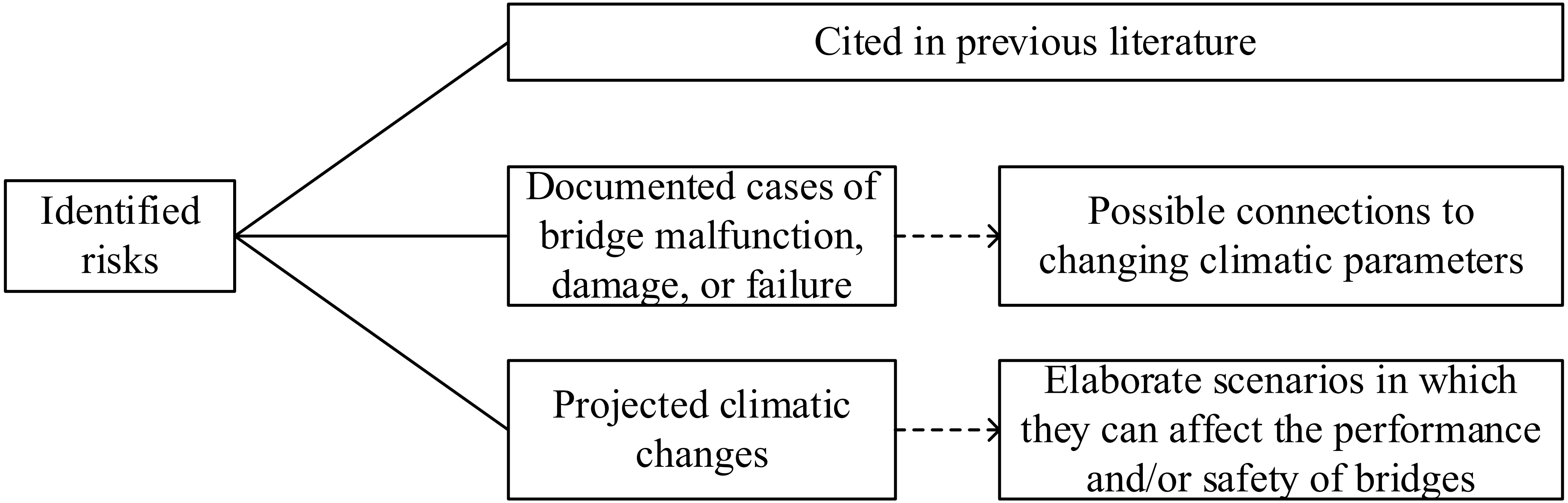






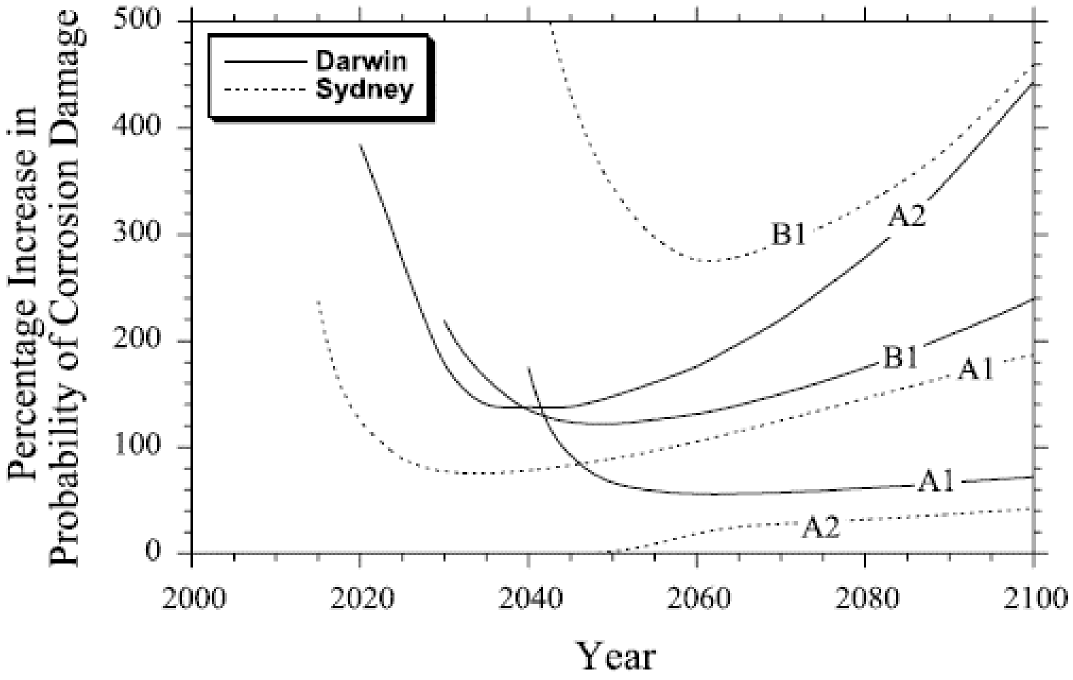
LUND UNIVERSITY

Risk identification - approach



Some examples will follow…

Risk D1



Percentage increase in probability of carbonation-induced corrosion damage.

Risk D1:

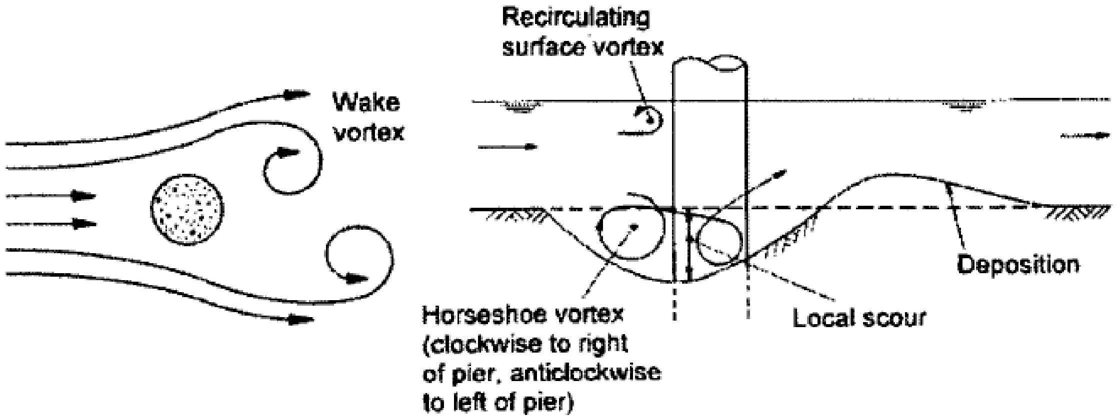
Accelerated degradation of superstructure

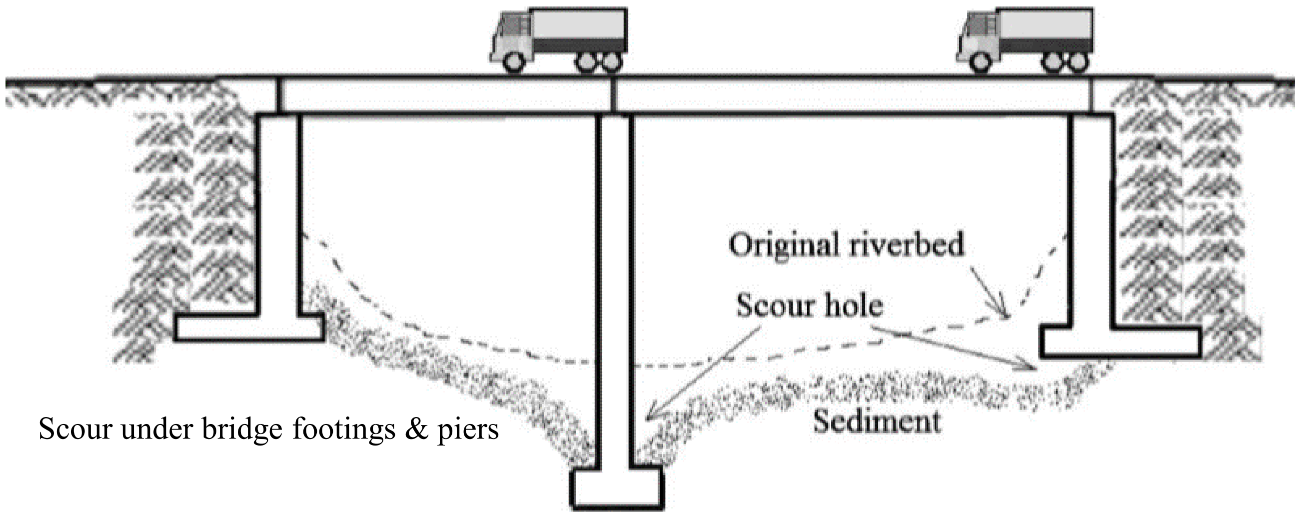
How can climate change affect this risk?

- Higher temperatures.
- Higher precipitation intensity and frequency.
- Higher carbon concentrations in atmosphere.
- Increase in solar radiation.
- Changes in relative humidity.

Figure Source: Stewart et al. (2011). Climate change impact and risks of concrete infrastructure deterioration. J. Eng. Str. 33

Risk G1





Scour under bridge footings & piers

Risk G1:

Higher scour rates.

How can climate change affect this risk?

- S.L.R.
- Increase in surface runoff.
- Melt of permafrost.

Figure sources: Deng, L., & Cai, C.S. 2010. Bridge scour: Prediction, modeling, monitoring, and countermeasures-review. Pract. Period. Struct. Des. Constr., 15(2): 125-134.
May R.W.P, Ackers, J.C. & Kirby, A.M. (2002). *Manual on scour at bridges and other hydraulic structures*. CIRIA C551, London.

LUND UNIVERSITY

Risk E1

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

Risk E1:

Increase in floods' intensity/frequency and permanent inundation due to Sea level rise

How can climate change affect this risk?

- Increased precipitation intensity
- Sea level rise

Figure source: U.S. Geological Survey

Risk I4

Additional demand on deformation capacity

Risk I4:

Higher demand on deformation capacity

How can climate change affect this risk?

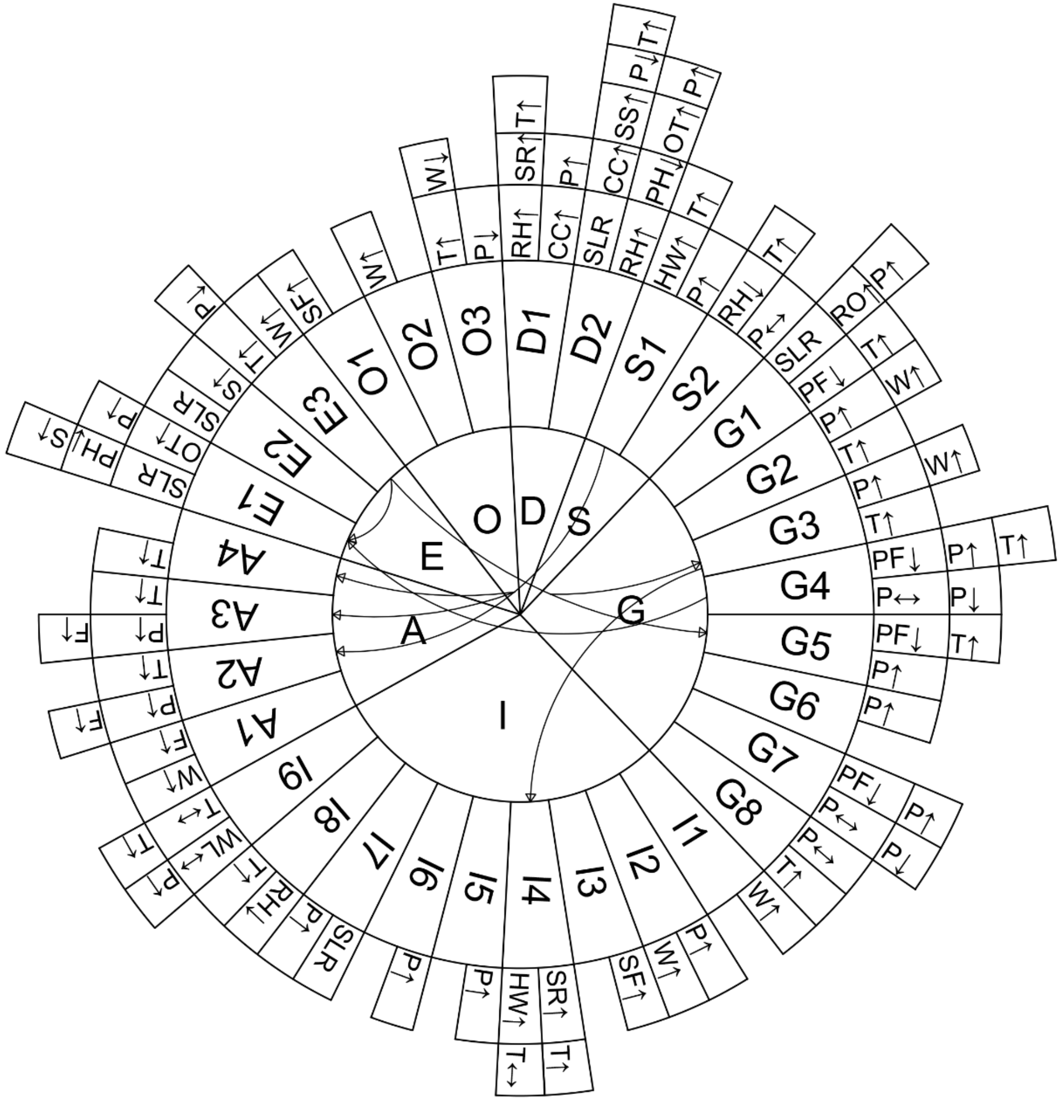
- Higher temperatures.

Risk I4

Joint closure of DuSable Bridge, Chicago, USA during a heatwave in July 2018

Bridge couldn't be opened for navigation and had to be hosed down by fire fighters

Identified risks



- 31 potential climate change risks were identified (7 categories)
- Bridges were the main focus
  - Many risks can be extended to other infrastructure elements

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

A risk-based prioritization method for the impacts of climate change on bridges

The large number of identified risks provokes two questions:

1. For a certain bridge of interest, which climate-change impacts should be prioritized? (referred to as level-I ranking)

2. Taking into account the potential impacts of climate change, which bridges should be prioritized from an ensemble of important bridges? (referred to as level-II ranking)

LUND UNIVERSITY

A risk-based prioritization method for the impacts of climate change on bridges

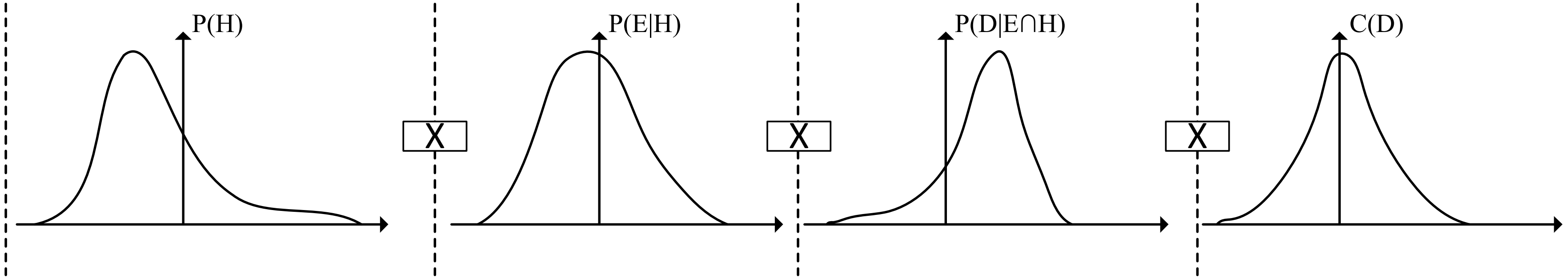
- Proposed prioritization framework based on following definition of risk

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

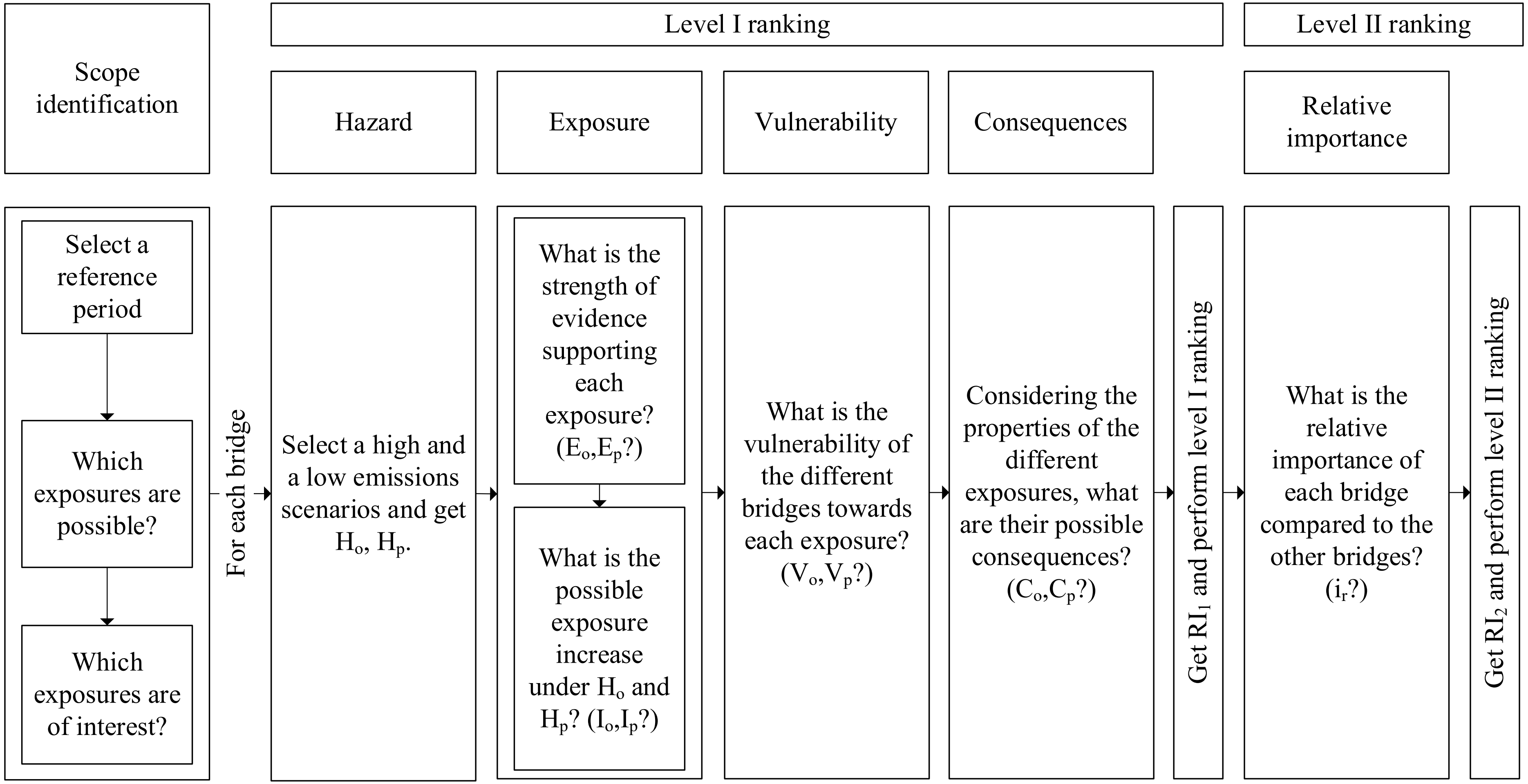
Hazard (H): potential change of climate parameter (e.g. temp)
Exposure (E): potential adverse impact to bridge due to change in given hazard (e.g. increased temp)
Vulnerability (D): potential damage resulting from a given exposure
Consequence (C): potential consequences (e.g. human, economic, environmental) from damage

- Given adequate information, uncertainties may be incorporated directly:

Risk = Hazard X Exposure X Vulnerability X Consequences



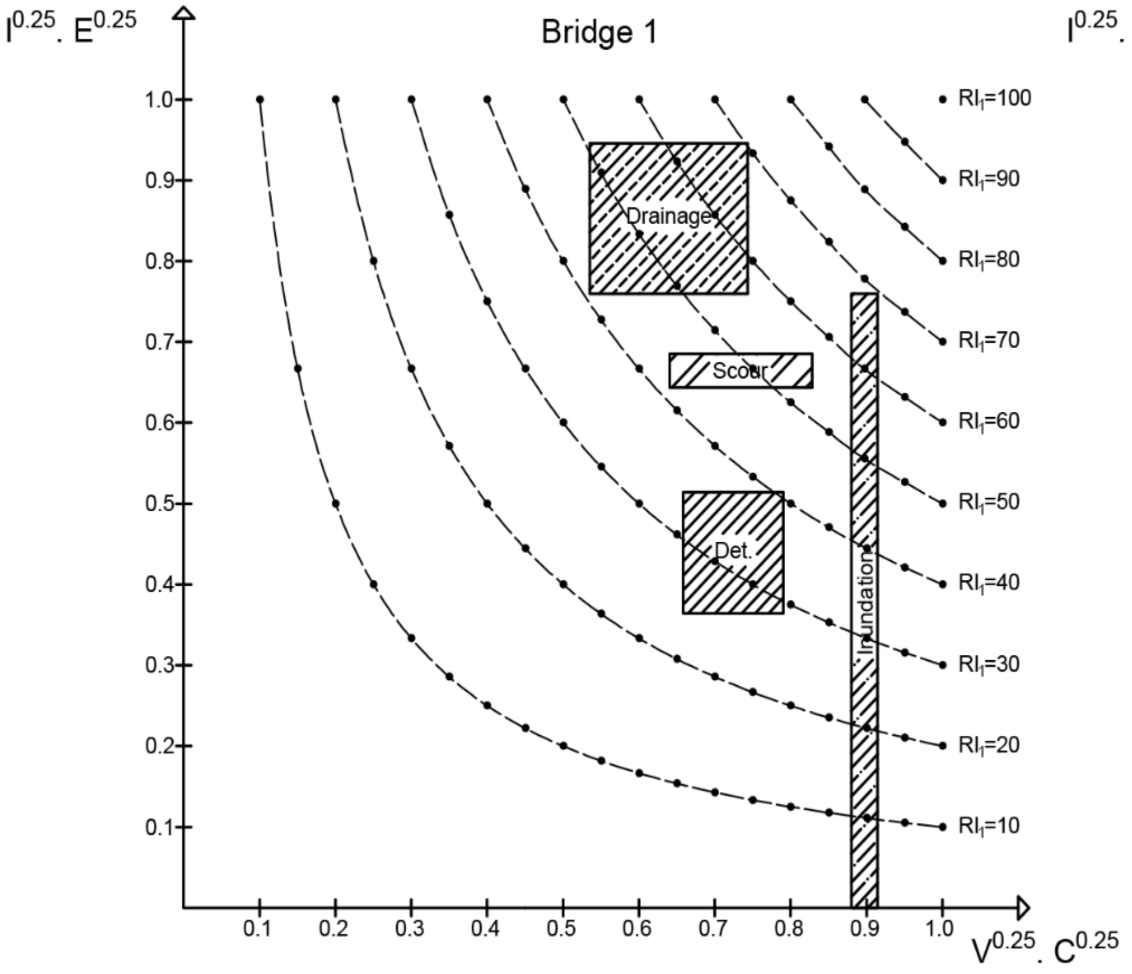
A risk-based prioritization method for the impacts of climate change on bridges



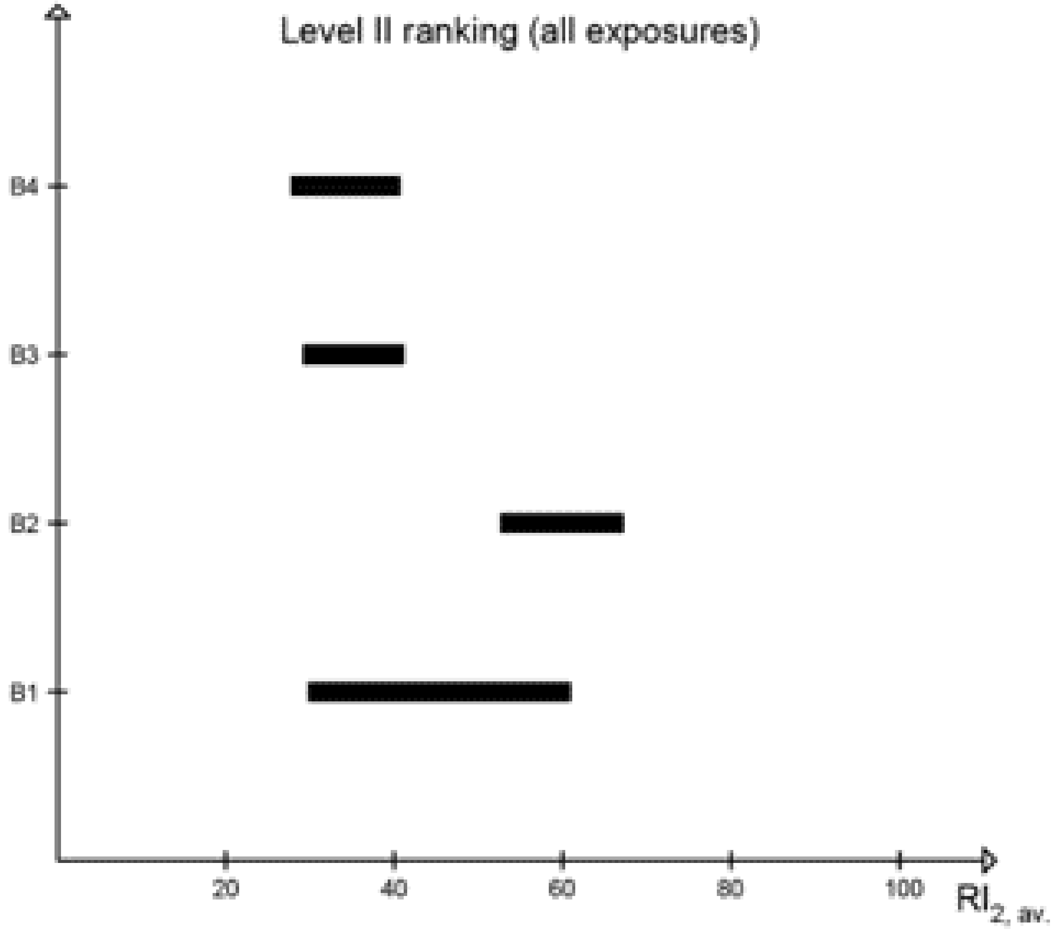
LUND UNIVERSITY

Presentation of ranking results - illustrative

Level-1 Ranking



Level-2 Ranking



Possible adaptation techniques

- In addition to identifying the potential climate change risks, a review of the possible adaptation techniques in response to these risks was conducted.

$R =$	$P(H)\ \cdot$	$P(E\vert H)\ \cdot$	$P(D\vert E\cap H)\ \cdot$	$C(D)$
cription	Hazard: The probability of a climatic hazard (e.g. increased storm activity)	Exposure: The probability of an adverse impact on the bridge as a result of the hazard (e.g. increased storm surge heights)	Vulnerability: The probability of a damage resulting from the increased hazard and exposure	Consequences: The cons of such a damage
sible risk agement asures	Reduction of GHG emissions (by e.g., introducing more strict regulations, reducing VMT through land use and urban planning strategies, etc.)	Regional adaptation measures, e.g.: • Storm surge barriers • Improved land use planning (e.g. relocation)	Local adaptation measures, e.g.: • Increase bridge elevation • Insert holes in the bridge superstructure • Improve span continuity • Use tie-down, restrainers, or anchorage bars	Adaptation measures for cascading effects: • Increase robustnes • Increase network r • Improved emergen and disaster prepar • Improved understa interdependencies

Possible adaptation techniques

Table 1. Potential climate change risks and their possible adaptations.

Potential impact	Adaptation
Accelerated degradation of material	Cathodic protection (Stewart et al., 2012; Vicroads, 2015); Increase in concrete cover thickness, improve quality of concrete (strength grade), protective surface coatings and barriers, use of stainless steel, galvanized reinforcement, corrosion inhibitors, electrochemical chloride extraction (Stewart et al., 2012); Protection by design, preservative treatment and the use of modified wood for timber bridges (Mahnert & Hundhausen, 2017); More frequent inspection and maintenance
Heat-induced damage to pavements and rails	Use of polymer modified binders (Vicroads, 2015); Development of new heat resistant paving materials (FHWA, 2009; NRC, 2008); More frequent maintenance(ATSE, 2008; FHWA, 2009; FHWA, 2013; Lindgren et al., 2009); Use of concrete railroad ties instead of wood ties (Delgado & Aktas, 2016); More expansion joints in pavements and rails (Meyer & Weigel, 2011); Introducing speed restrictions (Mehrotra et al., 2011).
Increased long-term deformations	Improved monitoring and inspection of bridges (Mahnert & Hundhausen, 2017)
Increased scour rate	Use of riprap (FHWA, 2009; Mondoro et al., 2018; Nemry & Demirel, 2012; NRC, 2008); Partially grouted riprap, concrete block systems, gabion mattresses, grout-filled mattresses; Upstream walls and obstructions, collars, etc. (Mondoro et al., 2018; NRC, 2008); Use of sacrificial embankments (Brand, Dewoolkar, & Rizzo, 2017); Increased use of sonars to monitor streambed flow and bridge scour (FHWA, 2009; NRC, 2008); For further scour protection measures see e.g., Arneson, Zevenbergen, Lagasse, and Clopper (2012); and Chen and Duan (2014)
Side-slope failure and Landslides	Adequate slope stabilization measures, river bank protection works (FHWA, 2009; NRC, 2008; Regmi & Hanaoka, 2011); Relocation, modification of slope geometry, drainage, retaining structures, internal slope reinforcement (see, e.g., Chen & Duan, 2014, p. 337)
Foundation settlement	Relocate facilities to more stable ground (Meyer & Weigel, 2011); Incorporate increased ground subsidence in the design of infrastructure (Meyer & Weigel, 2011); Remove permafrost before construction, crushed rock cooling systems, insulation/ground refrigeration systems (CCSP, 2008; Mehrotra et al., 2011; Meyer & Weigel, 2011); Use of different types of passive refrigeration schemes, e.g., thermosiphons, rock galleries, and “cold culverts”, to prevent settlement due to permafrost melt(NRC, 2008); Replacement of ice-rich soils with gravel (Bastedo, 2007)
Rockfalls	Energy dissipating protective structures for bridge piers (He, Yan, Deng, & Liu, 2018); Attenuator fence system and combined wire mesh and cable net drapery, soil berm to provide protection for piers (Graham, Turner & Axtell, 2016); Embankments and ditches, rockfall protection galleries (cushion layer, structural elevation), flexible protection systems (Volkwein et al., 2011).
Snow avalanches	Relocation, early warning systems, flow deflection (e.g., earthfill deflectors) and deceleration methods, structural protection measures (e.g. avalanche sheds), artificial release by explosives, afforestation (Decaulne, 2007; Ganju & Dimiri, 2004; Höller, 2007; Rheinberger, Bründl, & Rhyner, 2009)
Debris flows	Terrain alteration, soil bioengineering, debris flow breakers, debris flow deflectors, etc. (see, e.g., Huebl & Fiebiger, 2005)
Liquefaction	Stone columns (Adalier, Elgamal, Meneses, & Baez, 2003; Adalier & Elgamal, 2004); Gravel and rubber drainage columns (Bahadori, Farzalizadeh, Barghi, & Hasheminezhad, 2018); Chemical grouting, passive site remediation techniques (Gallagher, 2000); Ground improvement methods (grouting), Vibro systems, buttresses and surcharge fills, containment and reinforcement, drains, underpinning with mini-piles, deep dynamic compaction and deep blasting (Cooke & Mitchell, 1999)

LUND UNIVERSITY

Dissemination of results

- Results published & presented at international conferences (IABSE, ICASP, IALCCE), in international journals. Report in Swedish also published.
- Communication & discussion of research/results with reference group and other key persons
- Research presented at Nordic Conference on Climate Change Adaptation, Norrköping, 2018

LUND UNIVERSITY

Dissemination of results – some output so far…

Report in Swedish (available free online)

- Nasr, A: Ivanov, OL; Björnsson, I; Honfi, D; Johansson, J; Kjellström, E (2019) Klimatförändringars inverkan på broars säkerhet och prestanda – En översyn av potentiella effekter och anpassningsåtgärder. Rapport TVBK-3072, Konstruktionsteknik, Lunds Tekniska Högskola.

Journal papers

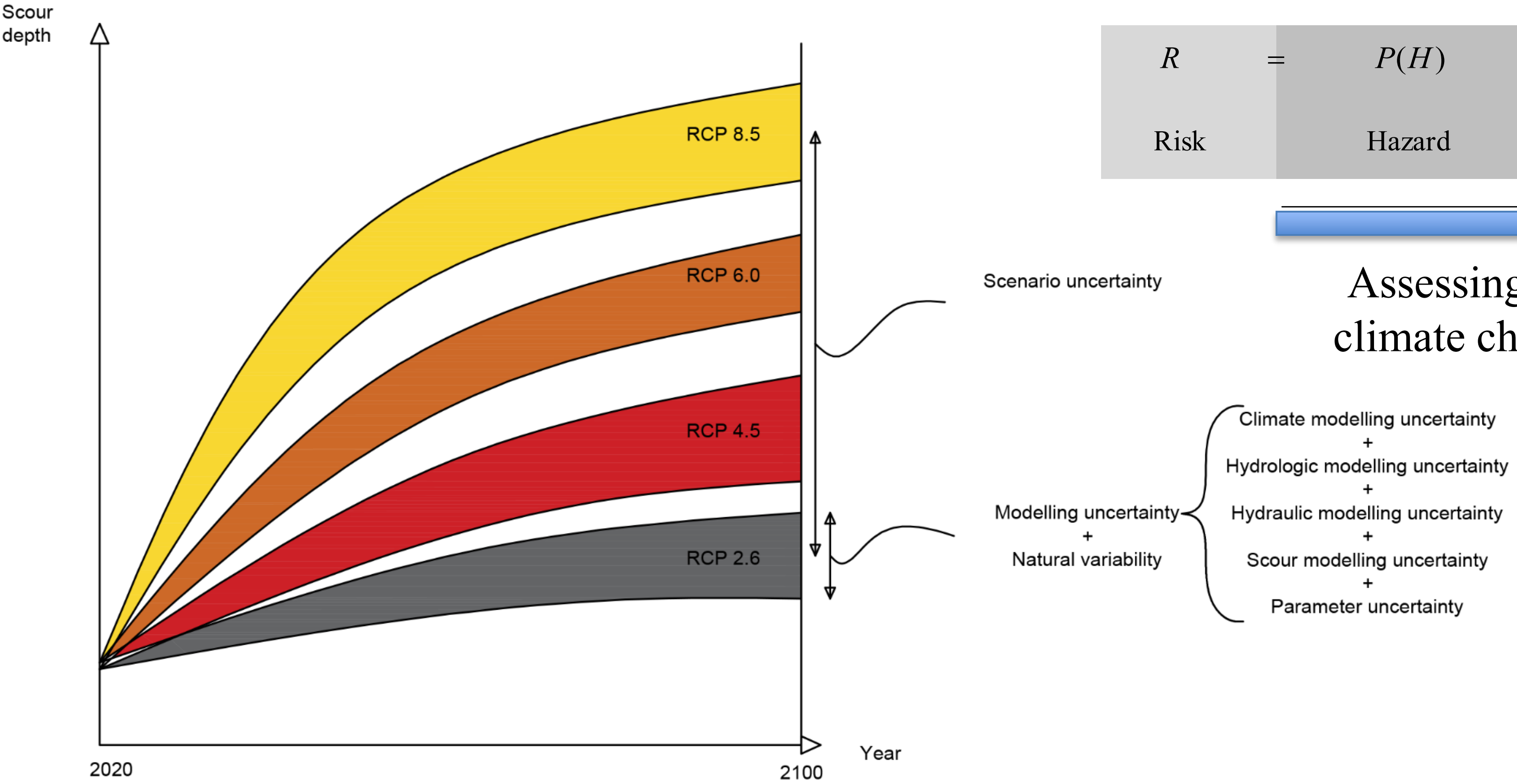
- Nasr, A., Björnsson, I., Ivanov, O. L., Johansson, J., Honfi, D., & Kjellström, E. (2019). A review of the potential impacts of climate change on the safety and performance of bridges. *Sustainable and Resilient Infrastructure*. doi: 10.1080/23789689.2019.1593003
- Nasr, A., Kjellström, E., Björnsson, I., Honfi, D, Ivanov, O. L., & Johansson, J. (2019). Bridges in a changing climate: A study of the potential impacts of climate change on bridges & their possible adaptations. *Structure and Infrastructure Engineering*. doi: 10.1080/15732479.2019.1670215
- Nasr, A., Björnsson, I., Honfi, D., Ivanov, O. L., & Johansson, J. (Submitted manuscript). Risk-based prioritization method for considering the effects of climate change on bridges. Journal of Infrastructure Systems

LUND UNIVERSITY

Future and ongoing research

- Future research will include:

1- A quantitative assessment of the effect of climate change on bridge scour.



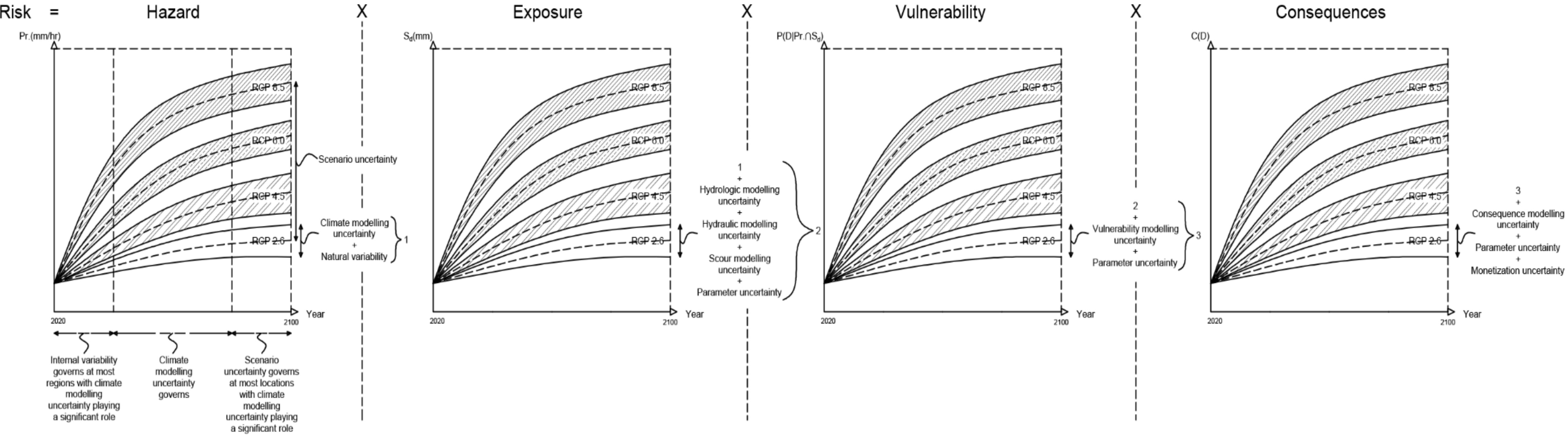
R	$=$	$P(H)$	$\cdot$	$P(E\|H)$	$\cdot$	$P(D\|E \cap H)$	$\cdot$	$C(D)$
Risk		Hazard		Exposure		Vulnerability		Conse

Assessing the effect of climate change on scour

Scour Vulnerability analysis

Future and ongoing research

2- Developing a practical framework for the rational consideration of climate change uncertainty in the design and assessment of infrastructure (with a focus on bridges)



LUND
UNIVERSITY