New Zealand Lifelines Committee

2014 National Lifelines Forum
5, 6 November 2014
Wellington

Towards more Resilient Infrastructure Systems: Methods and Tools

Dr Sonia Giovinazzi *(University of Canterbury)*

Dr Deirdre Hart *(University of Canterbury)*

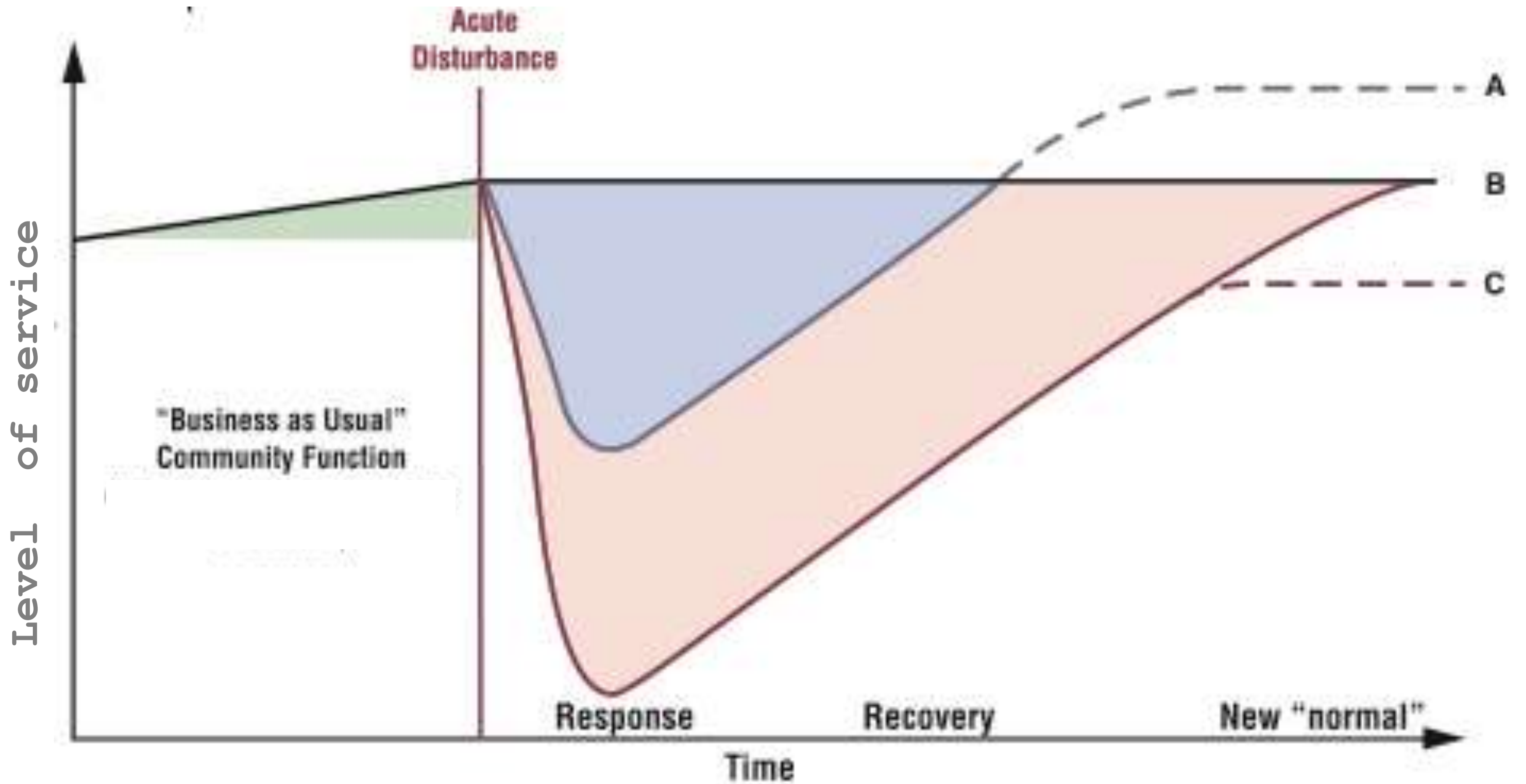
Dr Francesco Cavalieri *(Sapienza University of Rome)*

Indranil Kongar *(University College London)*

Towards more Resilient Infrastructure Systems

Our Aim: Create scientifically-sound, end-user oriented methods and tools:

- to support resilience assessments for status-quo infrastructure systems, *and*
- to inform decision making processes towards more resilient infrastructure systems



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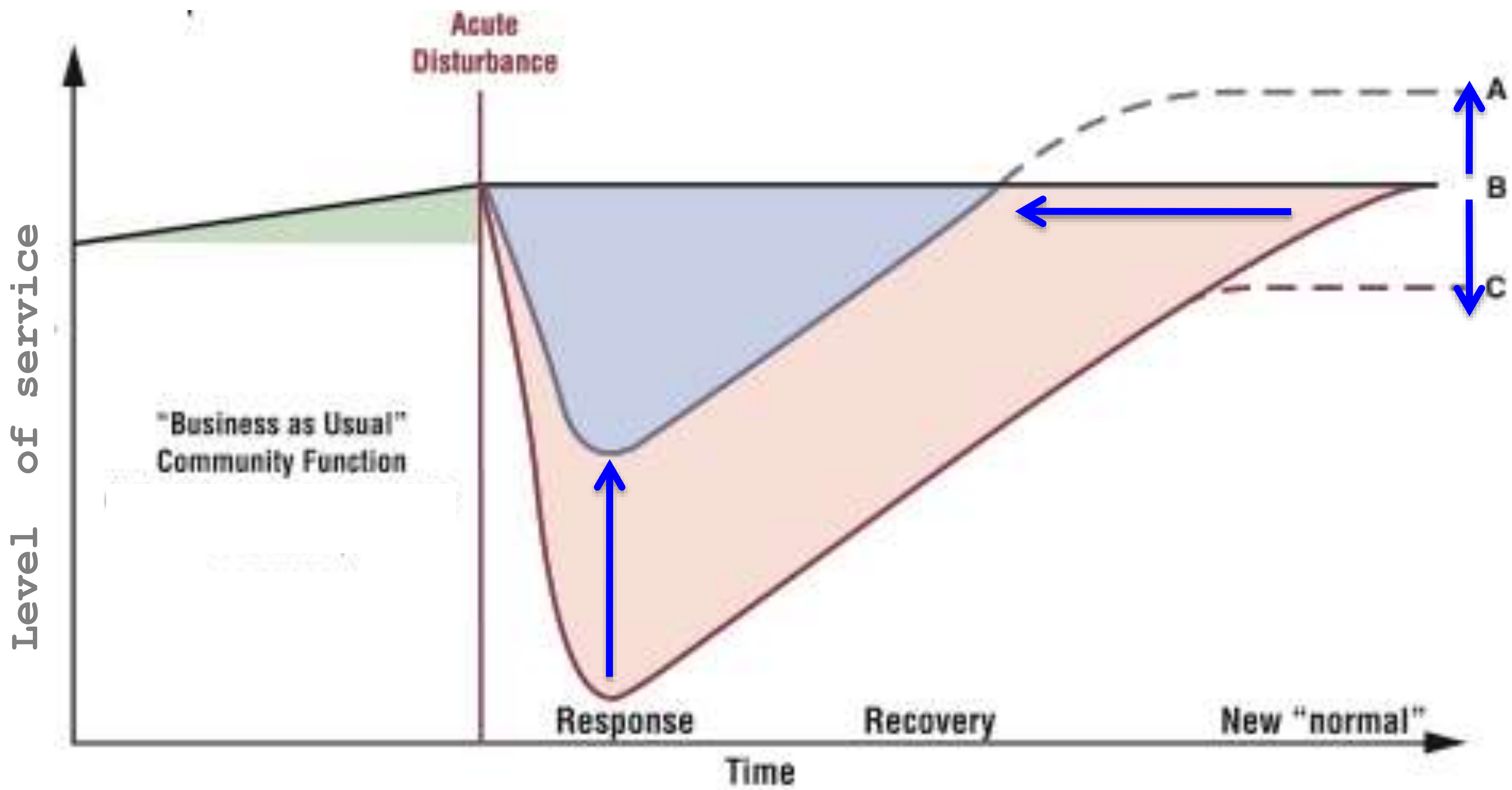

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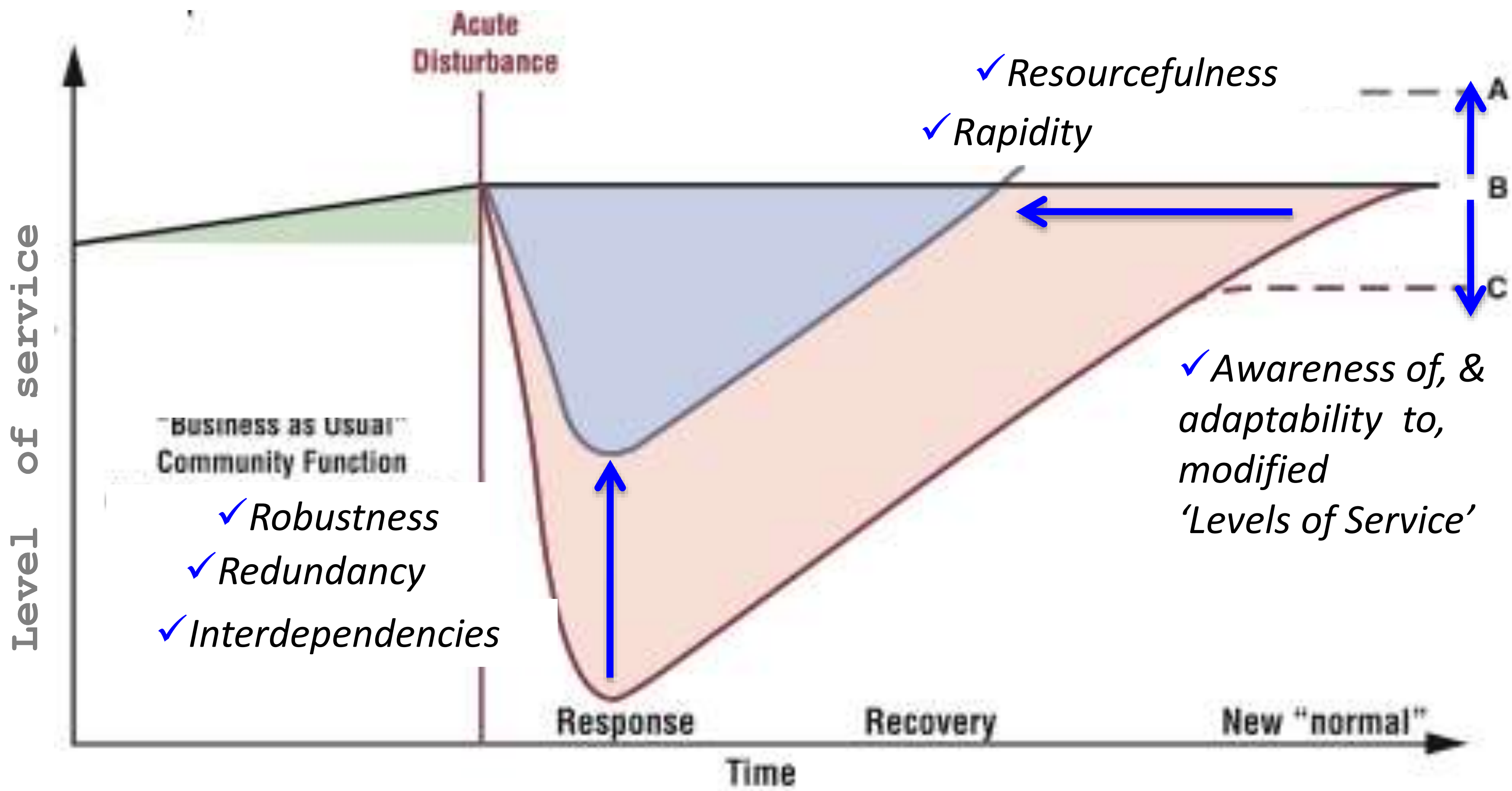
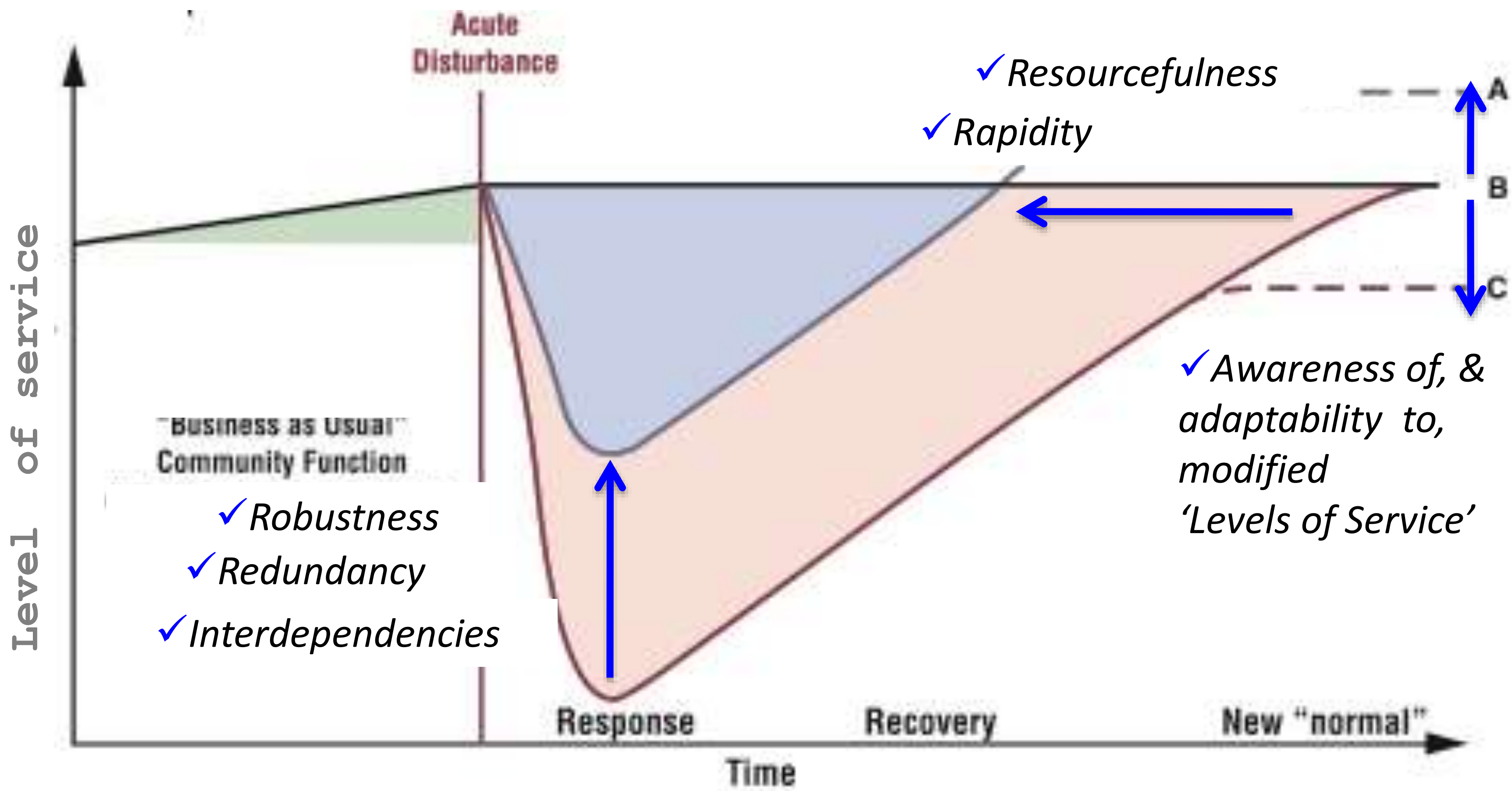


Towards more Resilient Infrastructure Systems

- Resilience to multi-hazards (& shocks) & cascading effects
- Integrating 'technical' dimensions of resilience with 'social', 'organisational', 'economic' dimensions toward an holistic resilience assessment.



Towards more Resilient Infrastructure Systems

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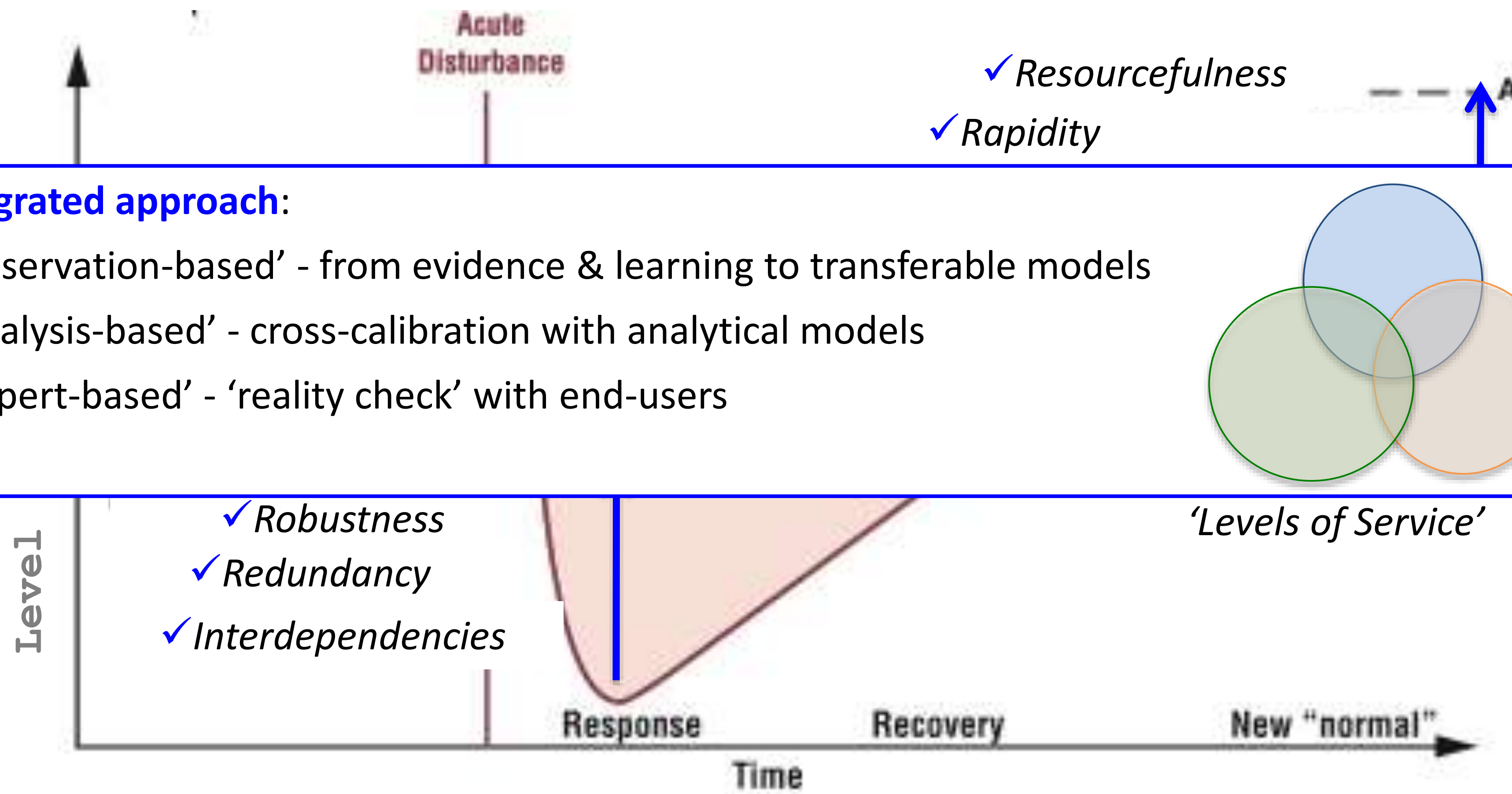


Integrated approach:

- 'observation-based' - from evidence & learning to transferable models
- 'analysis-based' - cross-calibration with analytical models
- 'expert-based' - 'reality check' with end-users

Towards more Resilient Infrastructure Systems

On-going Projects and International Collaborations:

- *Earthquake-Flood Multi-hazard Impacts on Lifeline Systems following the Canterbury Earthquake Sequence 2010-2011*

- *Projecting Damage and Losses for Buildings and Infrastructures from the Canterbury Earthquake Sequence*

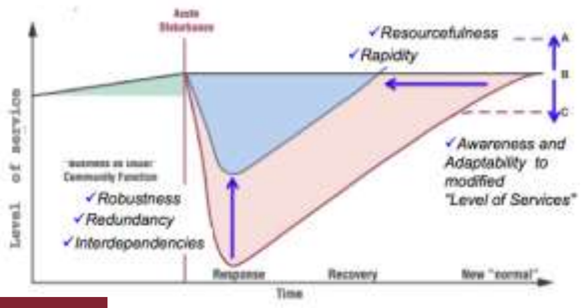
David Holland (MSc)

Su Young Ko (PhD)

A multi-hazard framework for assessing and managing flooding hazard in a seismically active low-lying urban environment

Melanie Liu (PhD)

Decision support system for post-earthquake rehabilitation of sewerage systems: A project management perspective



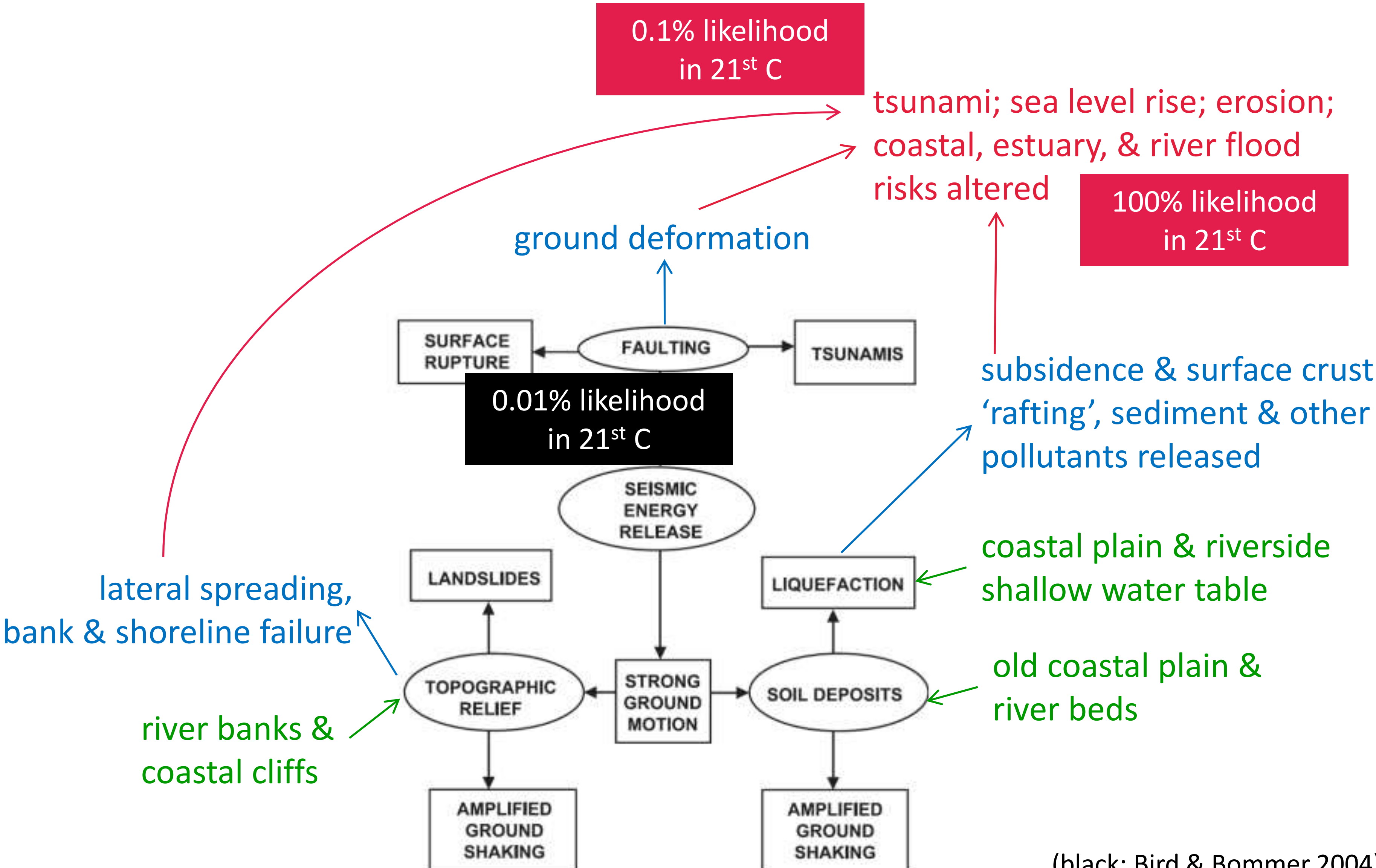
Adnan Rais (PhD)

Integrated bridge-utility systems: performance based assessment and mitigation of earthquake-induced physical and functional impacts

Website under construction

Multi-hazards are?

e.g. coastal & river quakes



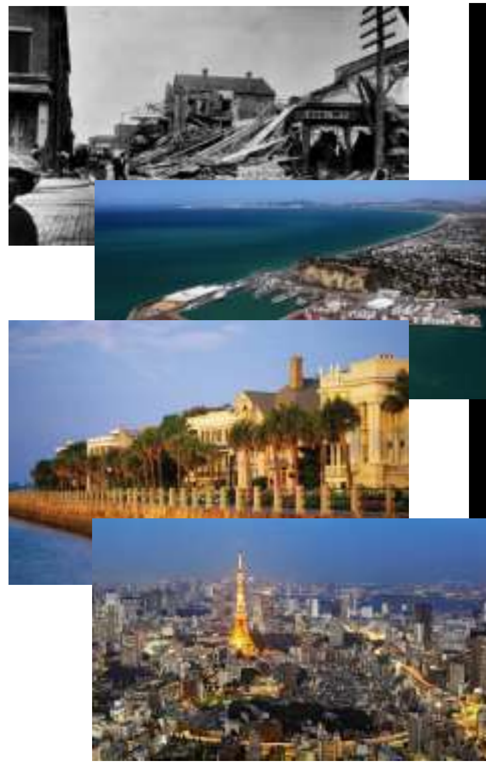
(black: Bird & Bommer 2004)

Multi-hazard prone infrastructure?

e.g. coastal settlements

Line demarcates ?

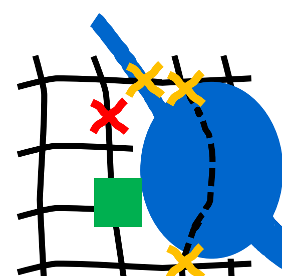
- Holocene coast ~6500 y BP
- Inland extent of heavy lifelines network damage
- Inland limit of increased flooding vulnerability
- Post-sea level rise liquefaction vulnerability zone



Cities on seismically-active recent coastal plains

- Charleston 1886
- Napier 1931
- Anchorage 1964
- Tokyo ???

21st century population concentration in megacities vulnerable to coastal quake multi-hazards



Multi-hazards link the 'un-linkable'

Lifelines & Increased Flooding Vulnerability (IFV) Project

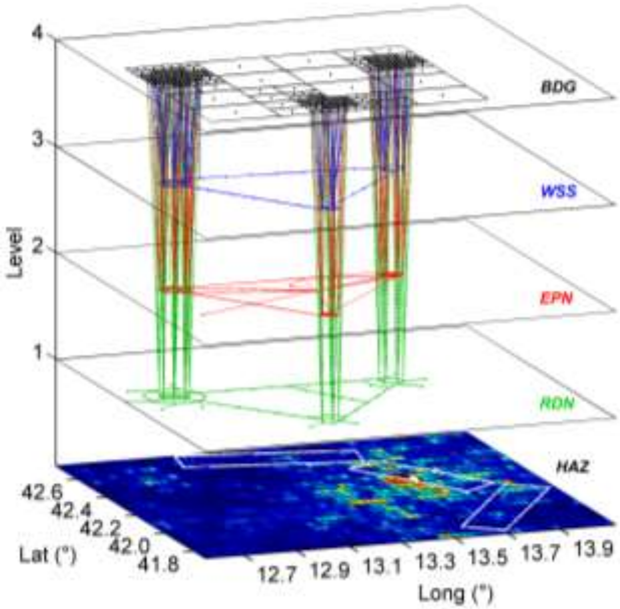
- terrain deformation (river & land profile changes, runoff, swales, pipe strain)
- liquefaction
- river channel capacity loss via constriction from rafting & bed uplift
- relative sea level rise: land levels, estuary/ river drainage, groundwater depths
- pipe network damage (breaks, sediment load & deposits, connection failures)
- domino effects of subterranean erosion (roads), waste water interactions

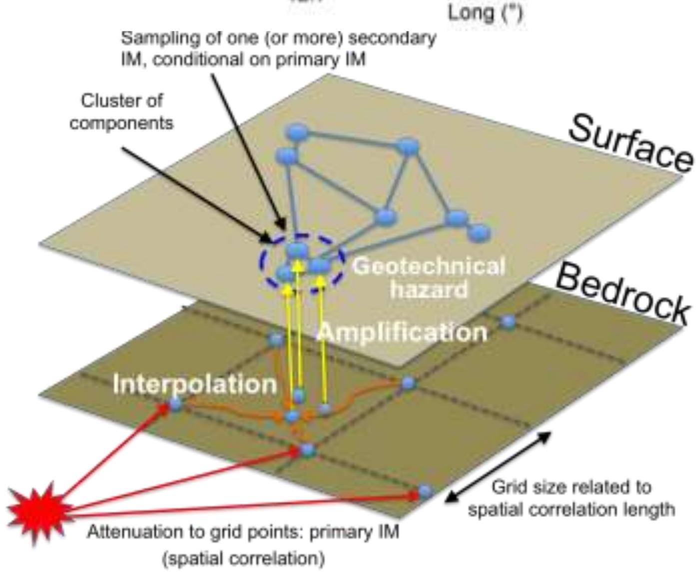
- 2014 GEER Report http://www.geerassociation.org/GEER_Post%20EQ%20Reports/Christchurch_Flood_2014/index.html
- 2013-15 IFV research by Holland (MSc) & Ko (PhD) drainage network & stormwater foci: http://www.civil.canterbury.ac.nz/postgrads/sko.shtml
- 2015-16 TCLEE monograph

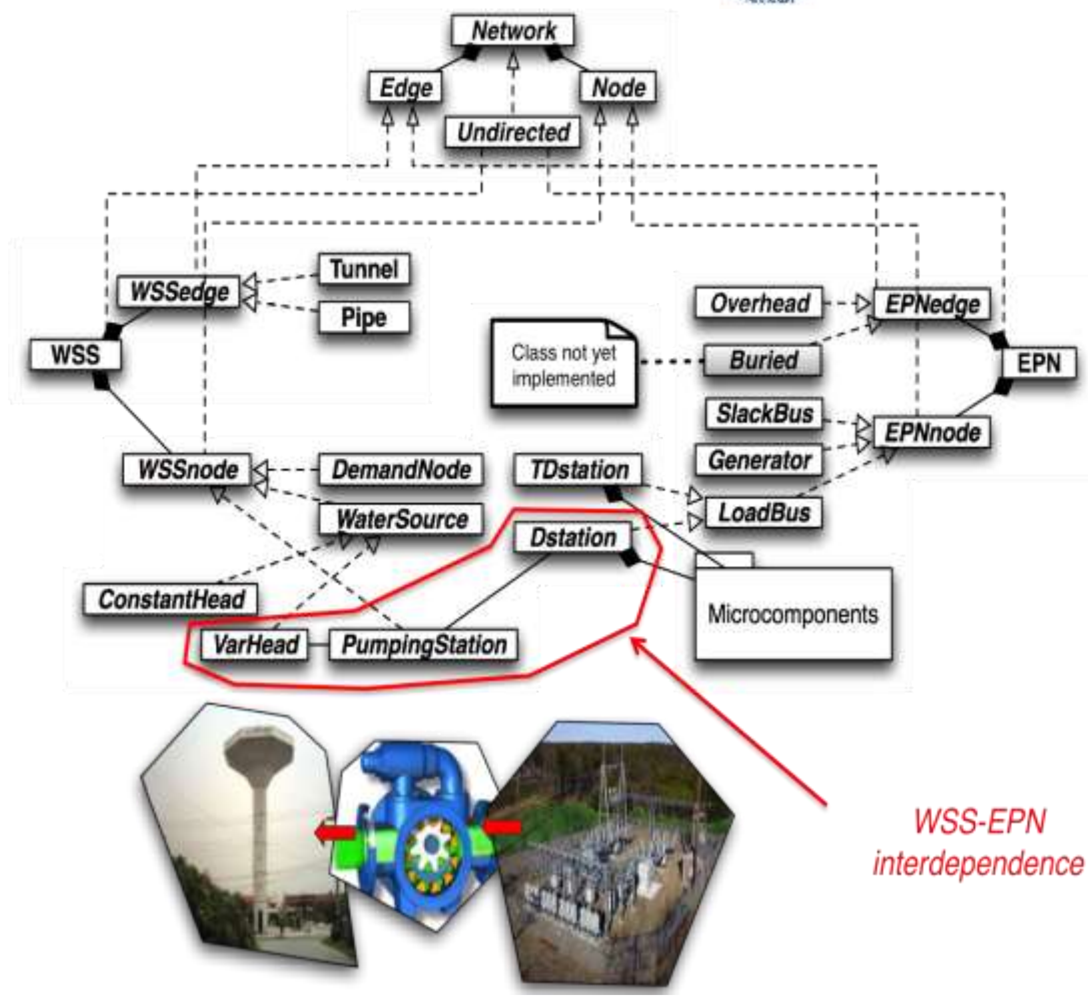
Object-Oriented Framework for Infrastructure Modelling and Simulation (OOFIMS)

The software (in Matlab language) was developed in Rome within SYNER-G

https://sites.google.com/a/uniroma1.it/oofims/home







Christchurch stormwater network

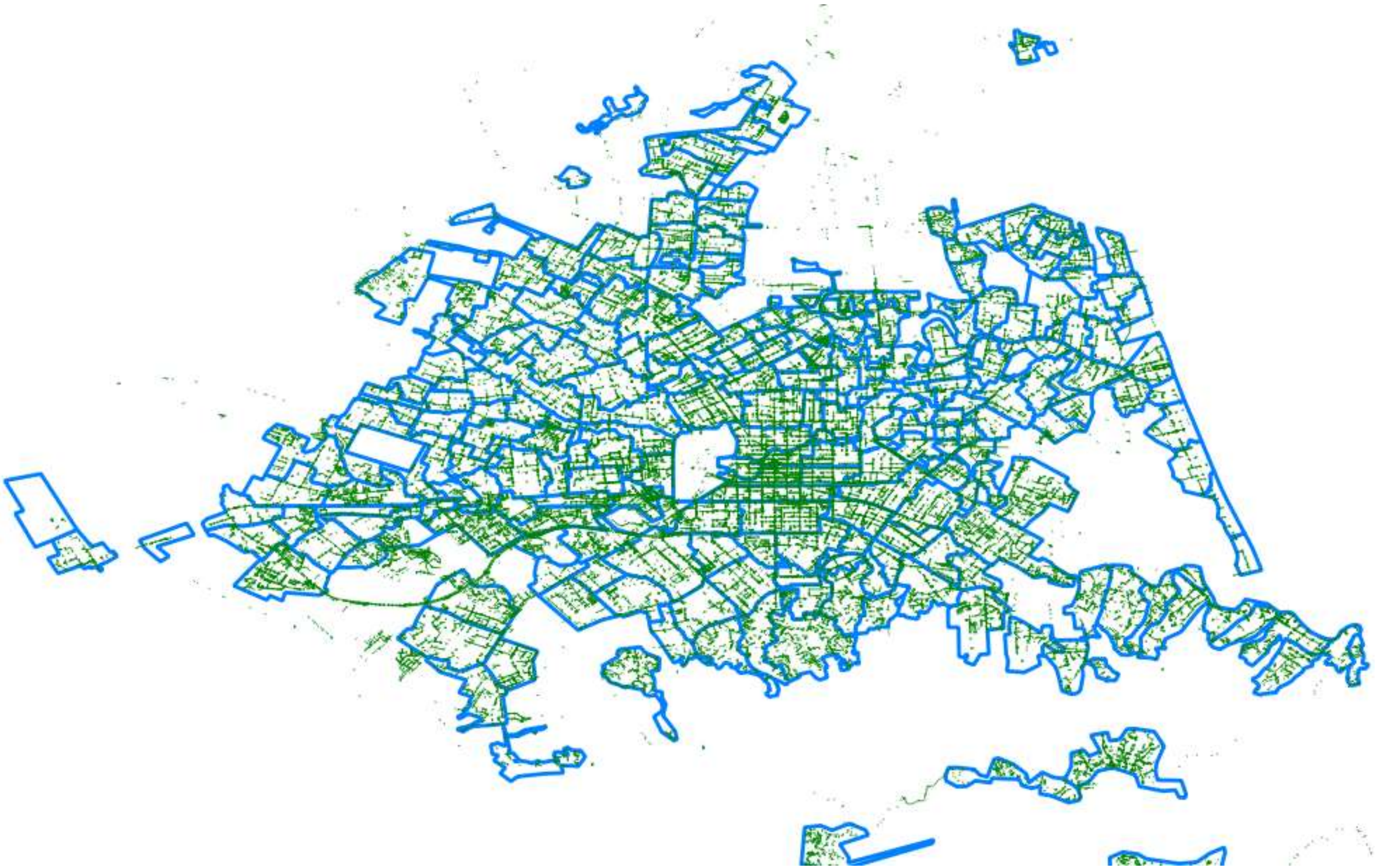
Prediction of physical damage and overflow

Network topology

Christchurch stormwater network

Prediction of physical damage and overflow

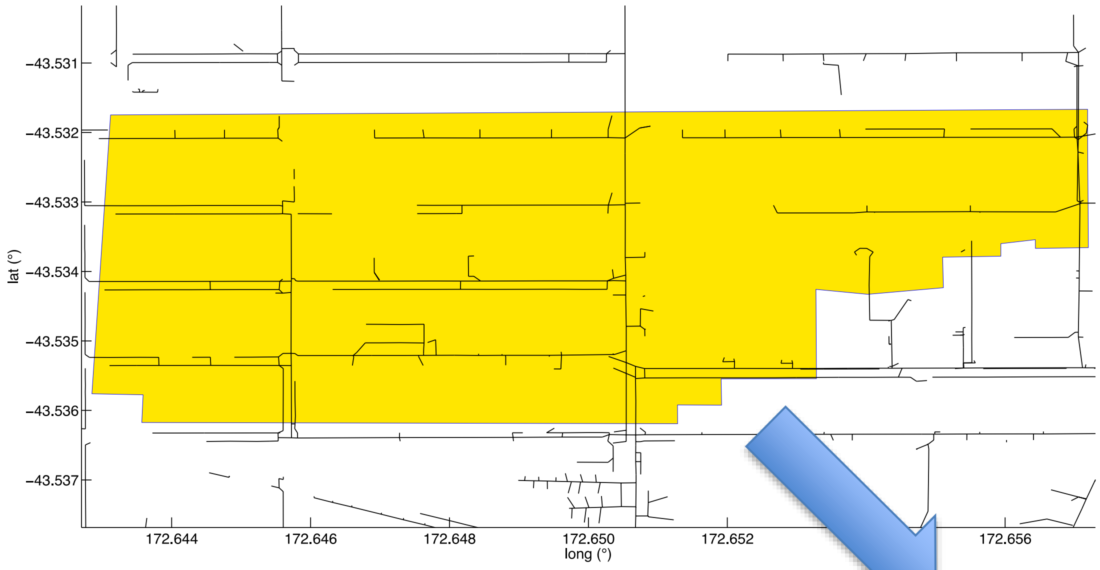
Network subcatchments

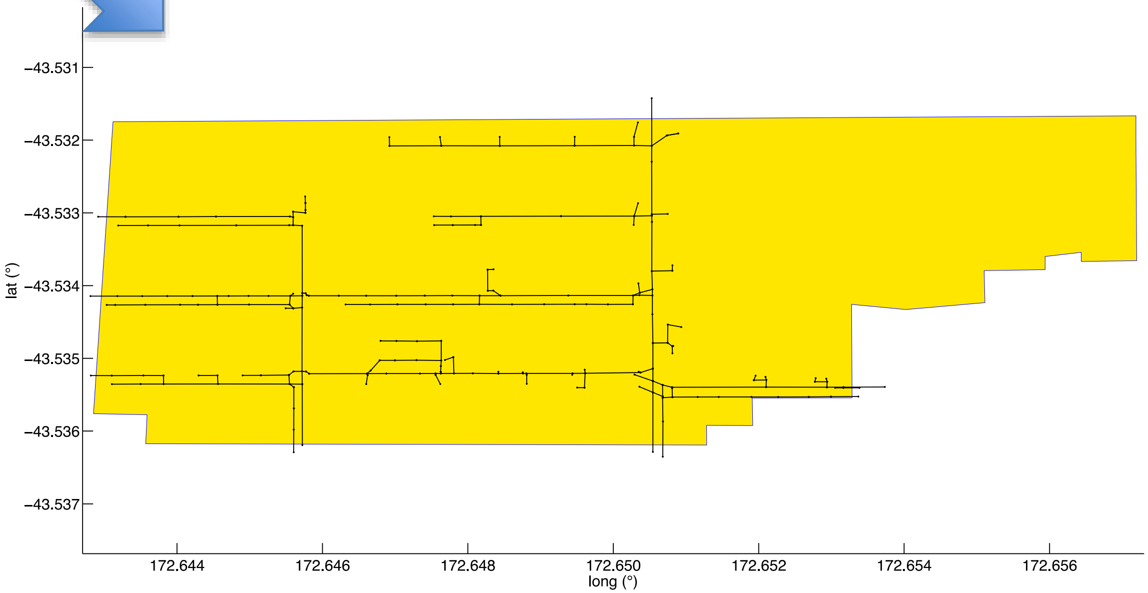


Christchurch stormwater network

Prediction of physical damage and overflow

Analysis of a portion of the network enclosed within one CBD subcatchment



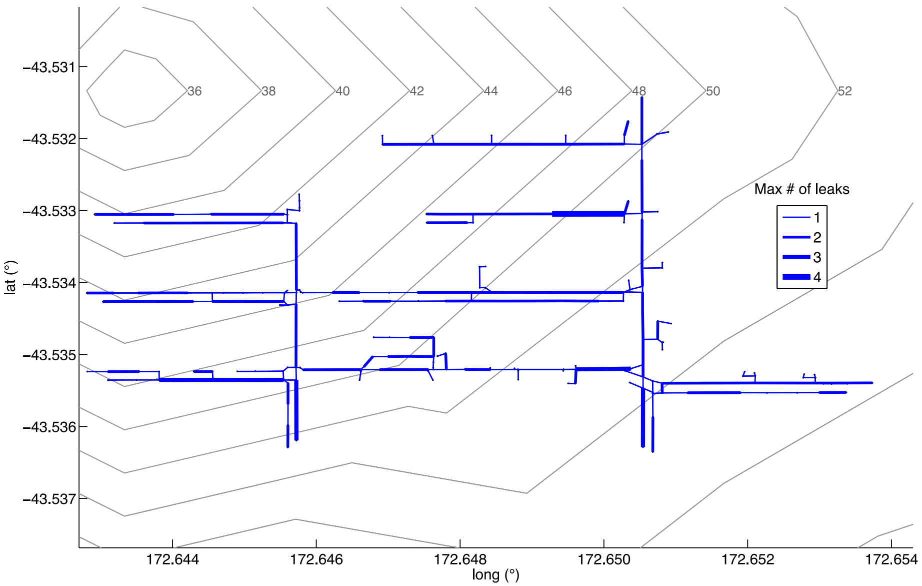


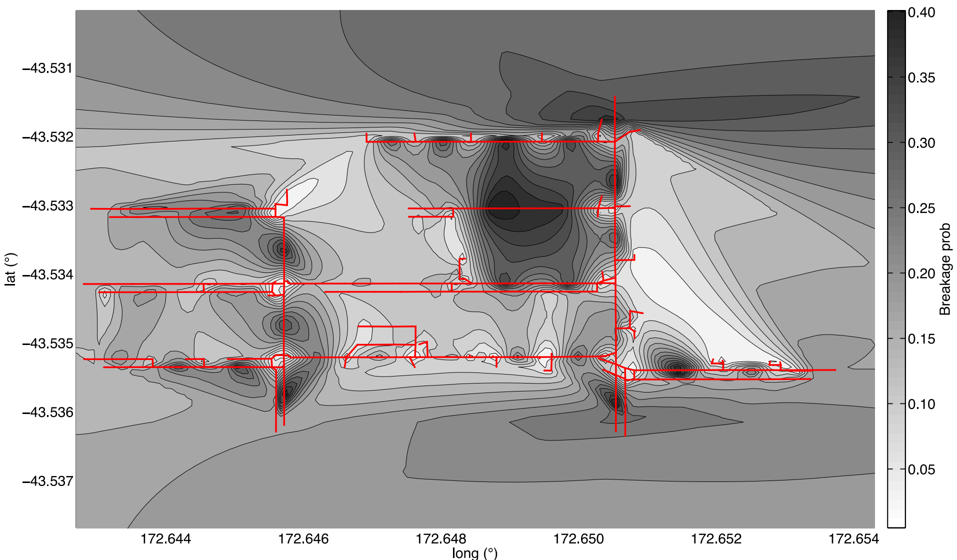
Christchurch stormwater network

Prediction of physical damage and overflow

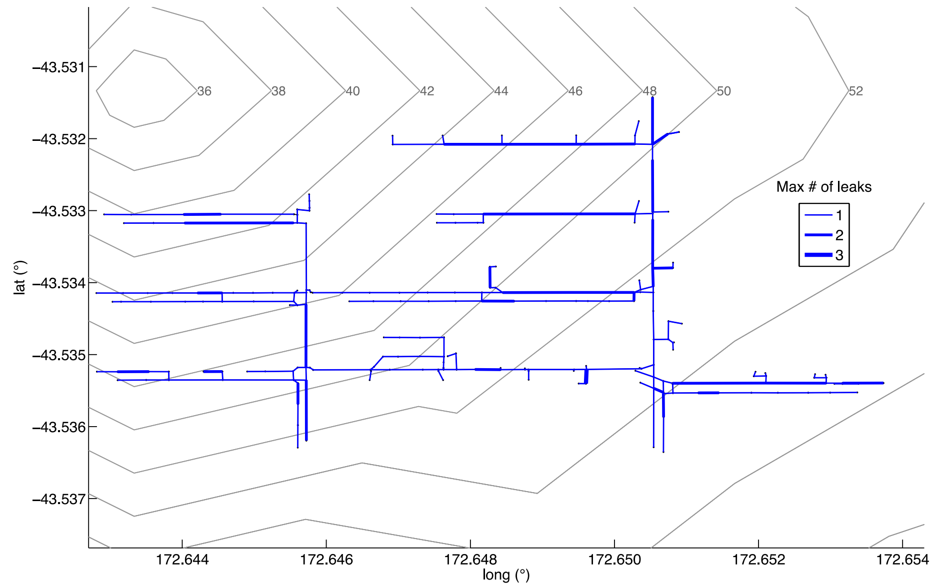
Physical damage indicators: maximum expected number of leaks and breakage probability

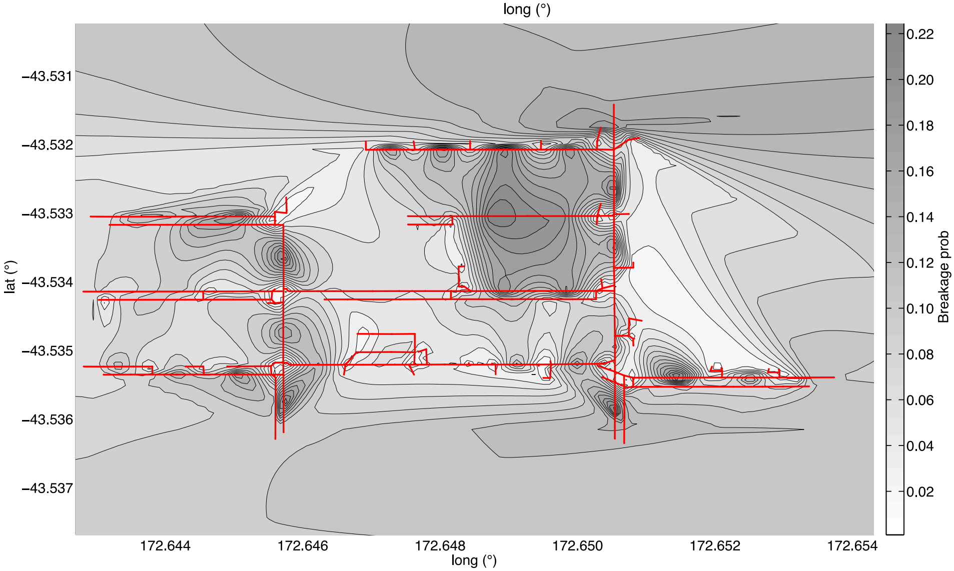
Original materials





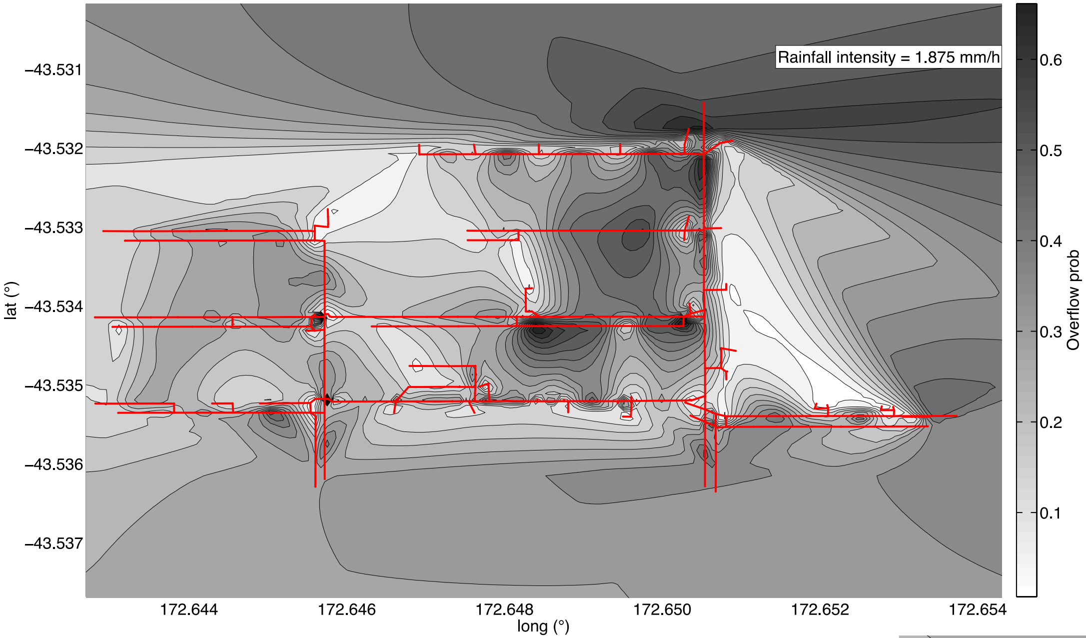
All pipes made of ductile iron



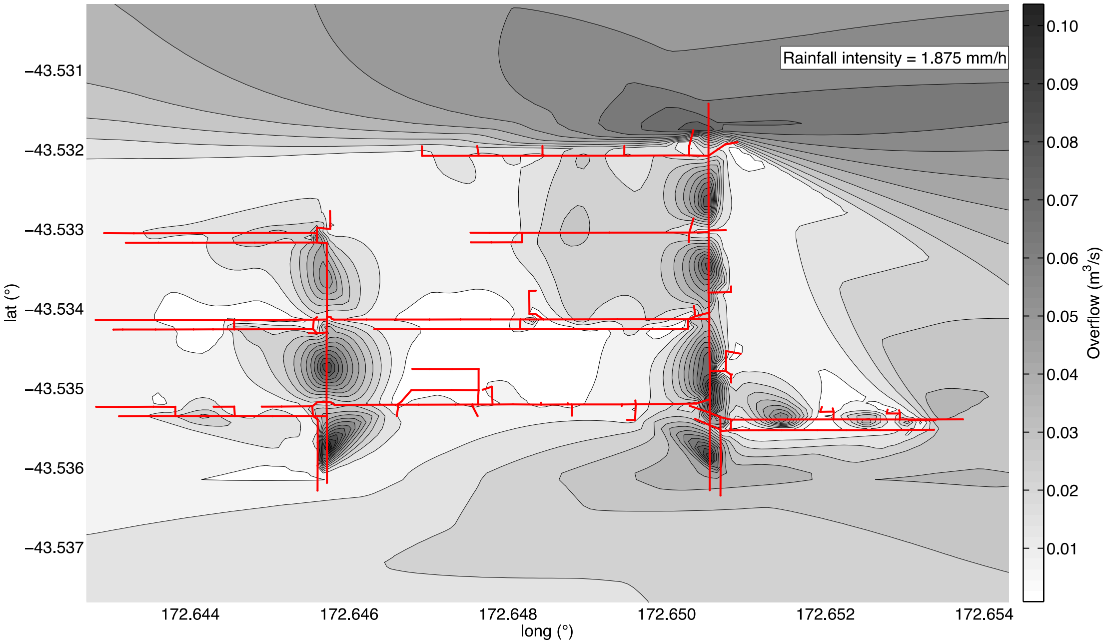


Christchurch stormwater network

Prediction of physical damage and overflow



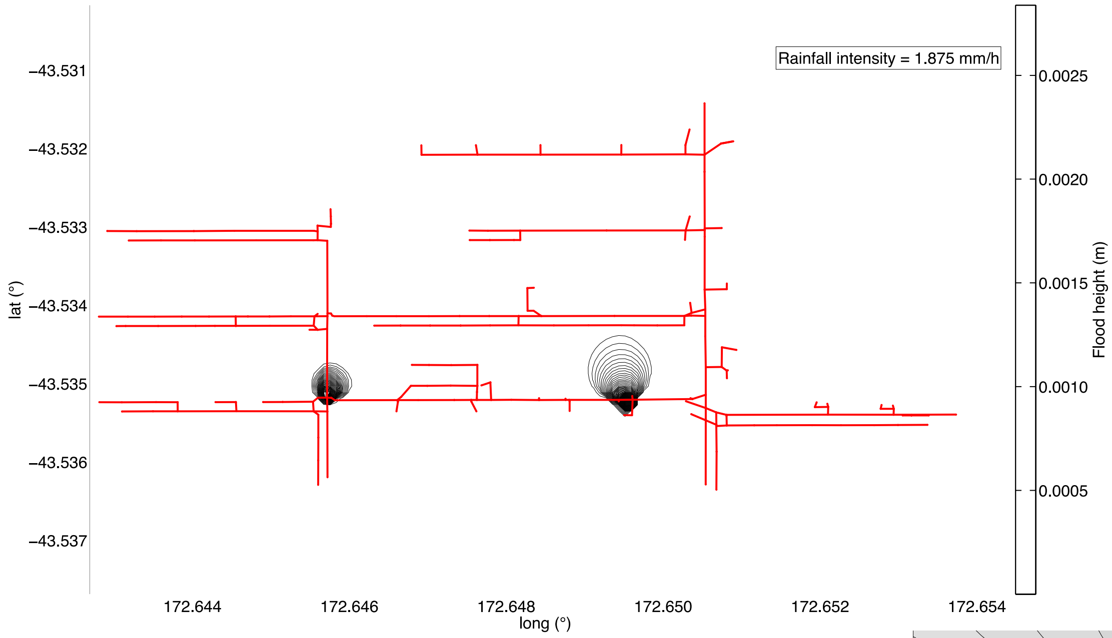
Overflow probability



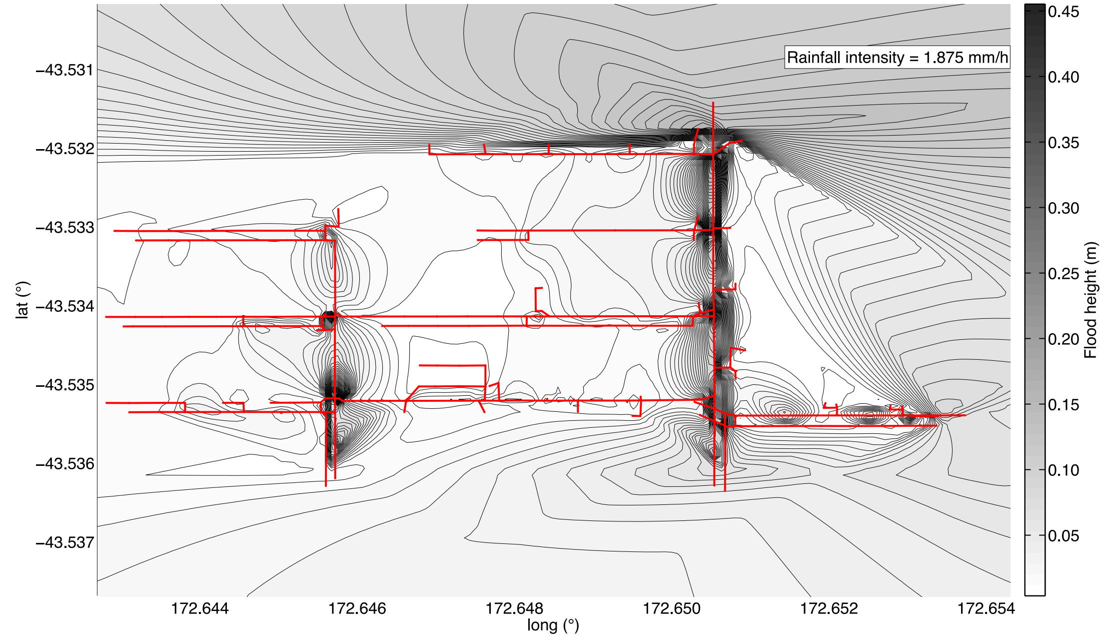
Expected overflow during a given rain event

Christchurch stormwater network

Prediction of physical damage and overflow



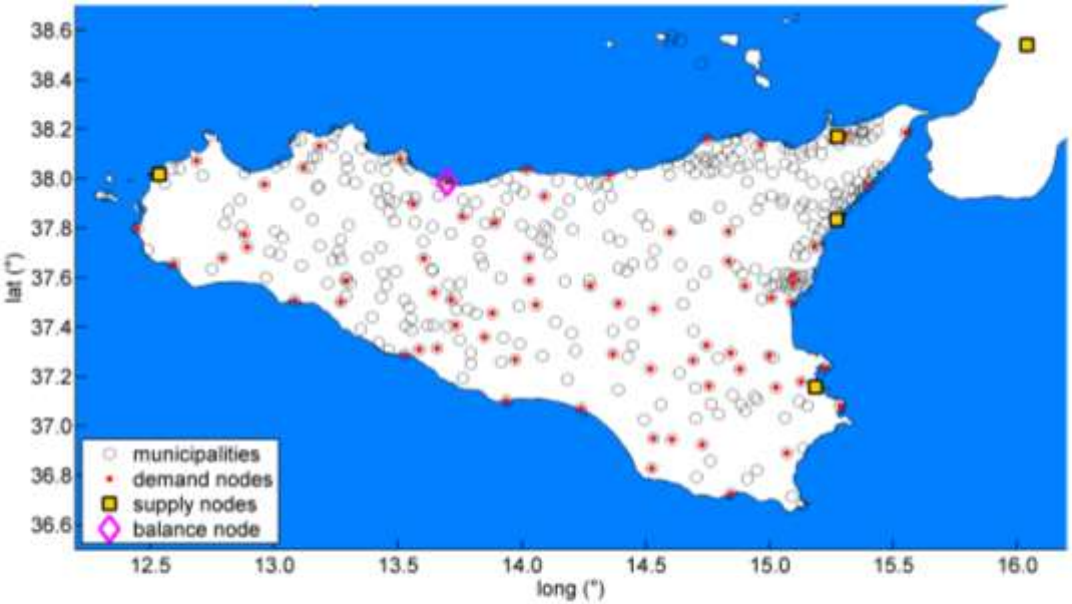
Flood height before and after the earthquake, to assess the Increased Flooding Vulnerability (IFV)



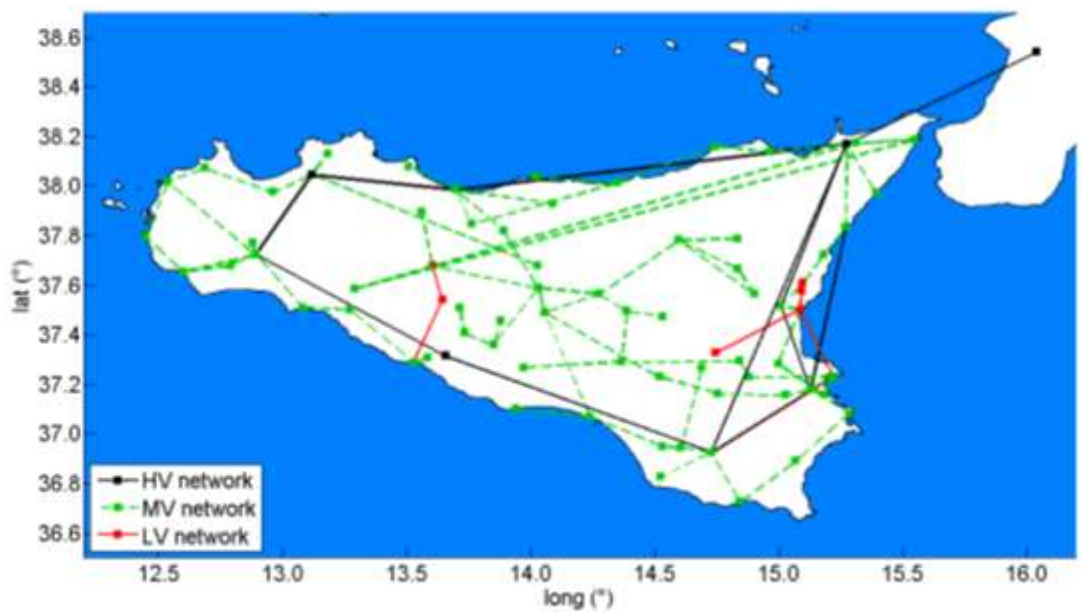
Electric power network case studies

Prediction of physical damage, connectivity and serviceability indicators

Case study #1: Sicily power network



Network nodes and lines



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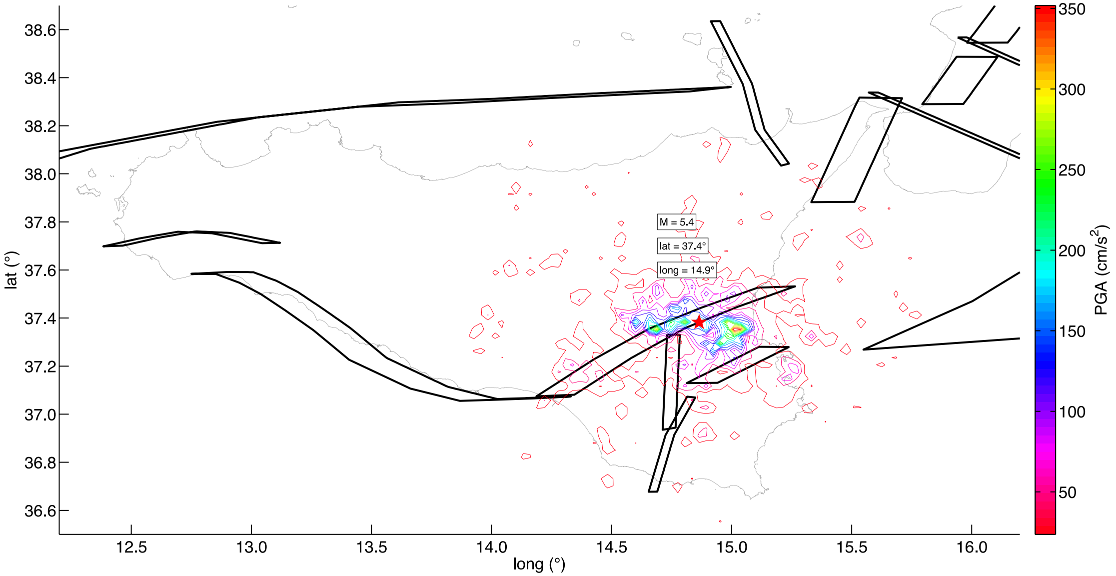
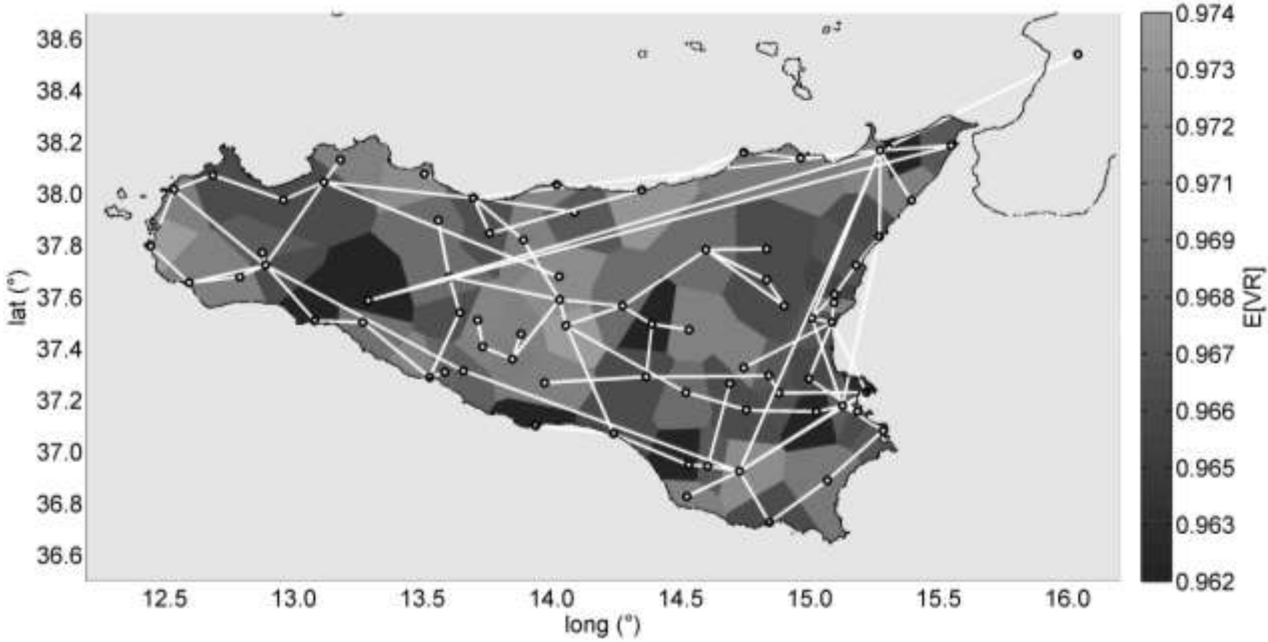


Faults affecting Sicily and simulated PGA shake map



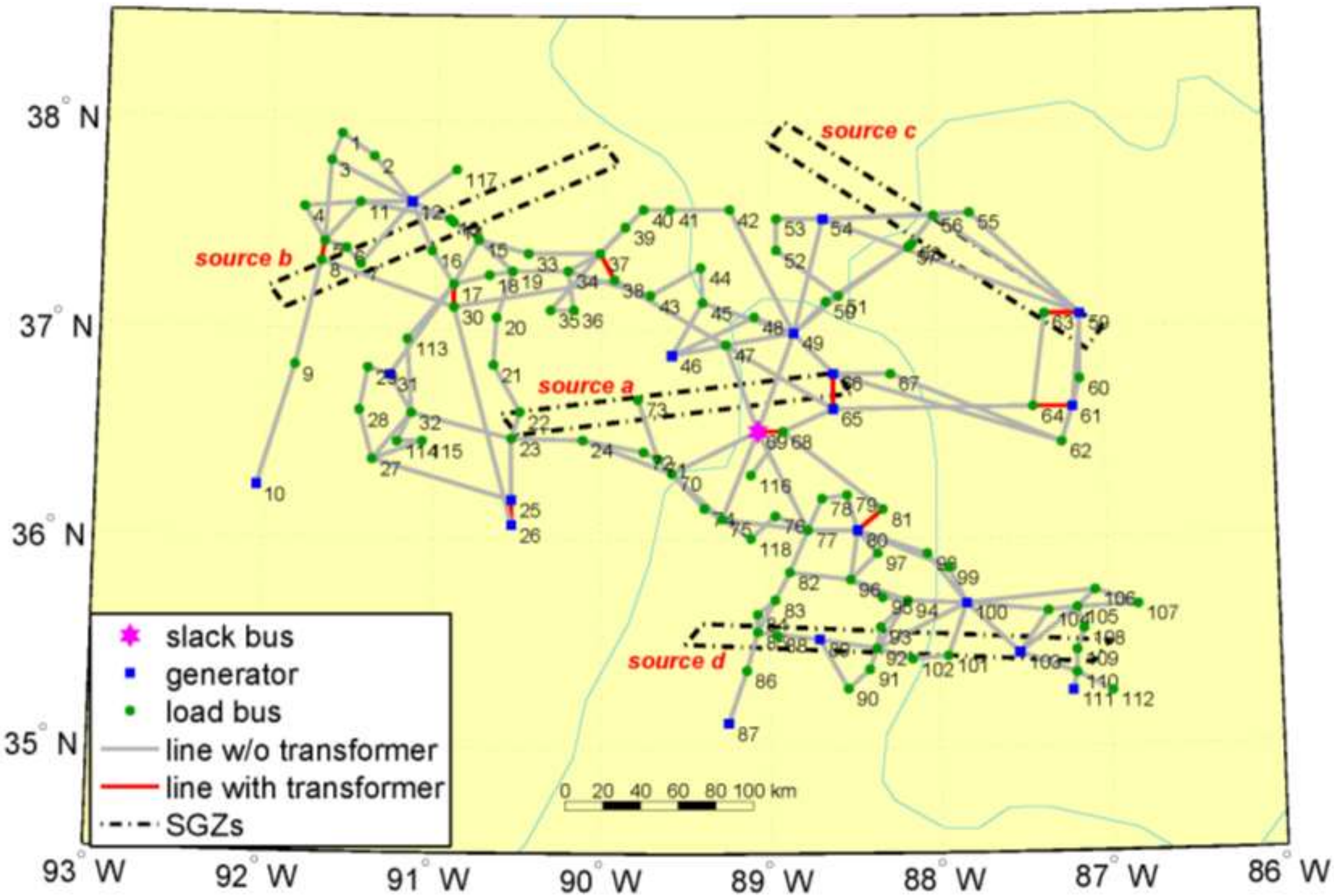
Power flow analysis,

Mean Voltage Ratio (VR), Voronoi diagram

Electric power network case studies

Prediction of physical damage, connectivity and serviceability indicators

Case study #2: IEEE-118 bus power network



Electric power network case studies

Prediction of physical damage, connectivity and serviceability indicators

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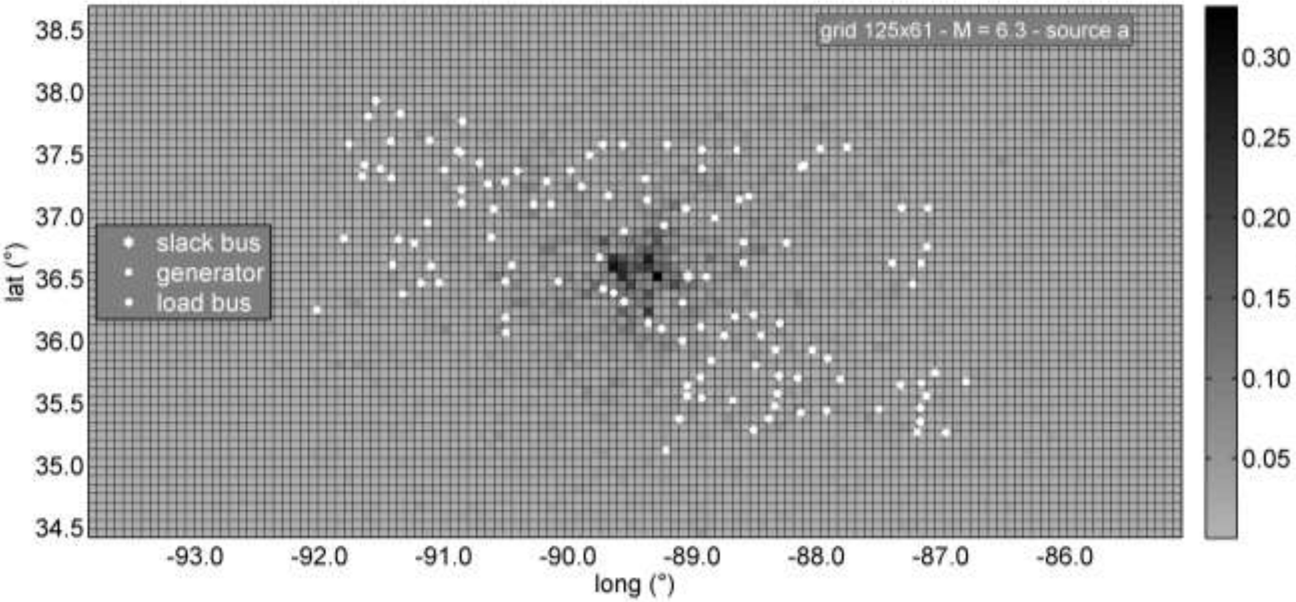

Simulated PGA shake map

Power flow analysis,

Mean Voltage Ratio (VR),
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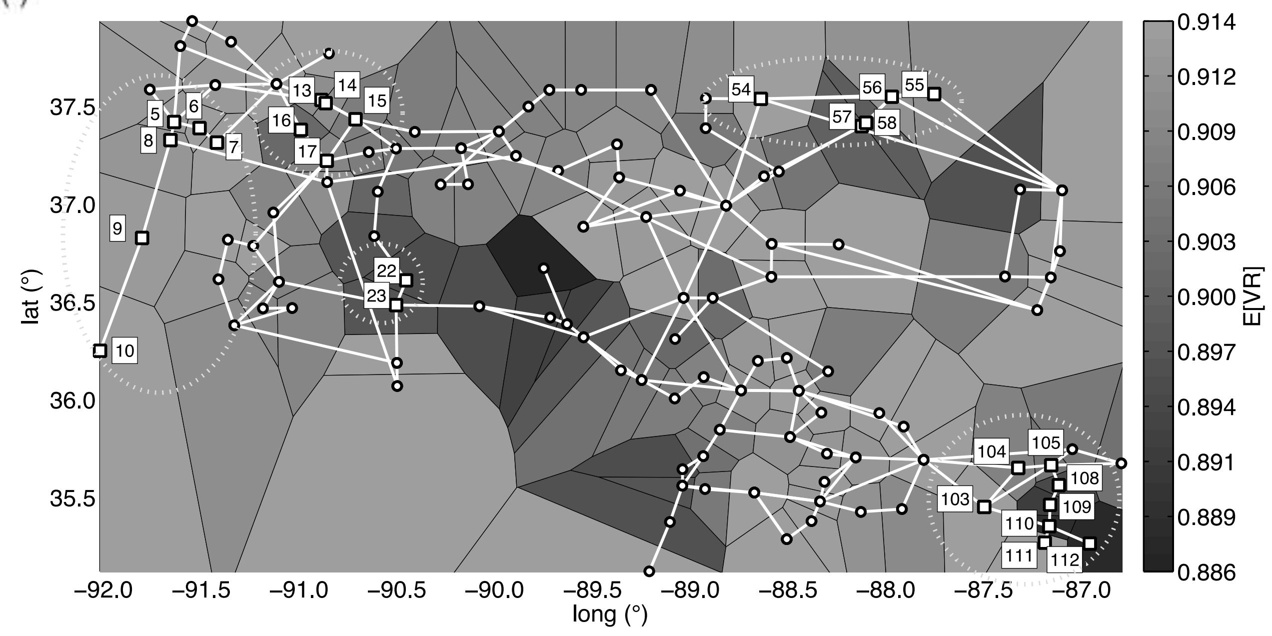
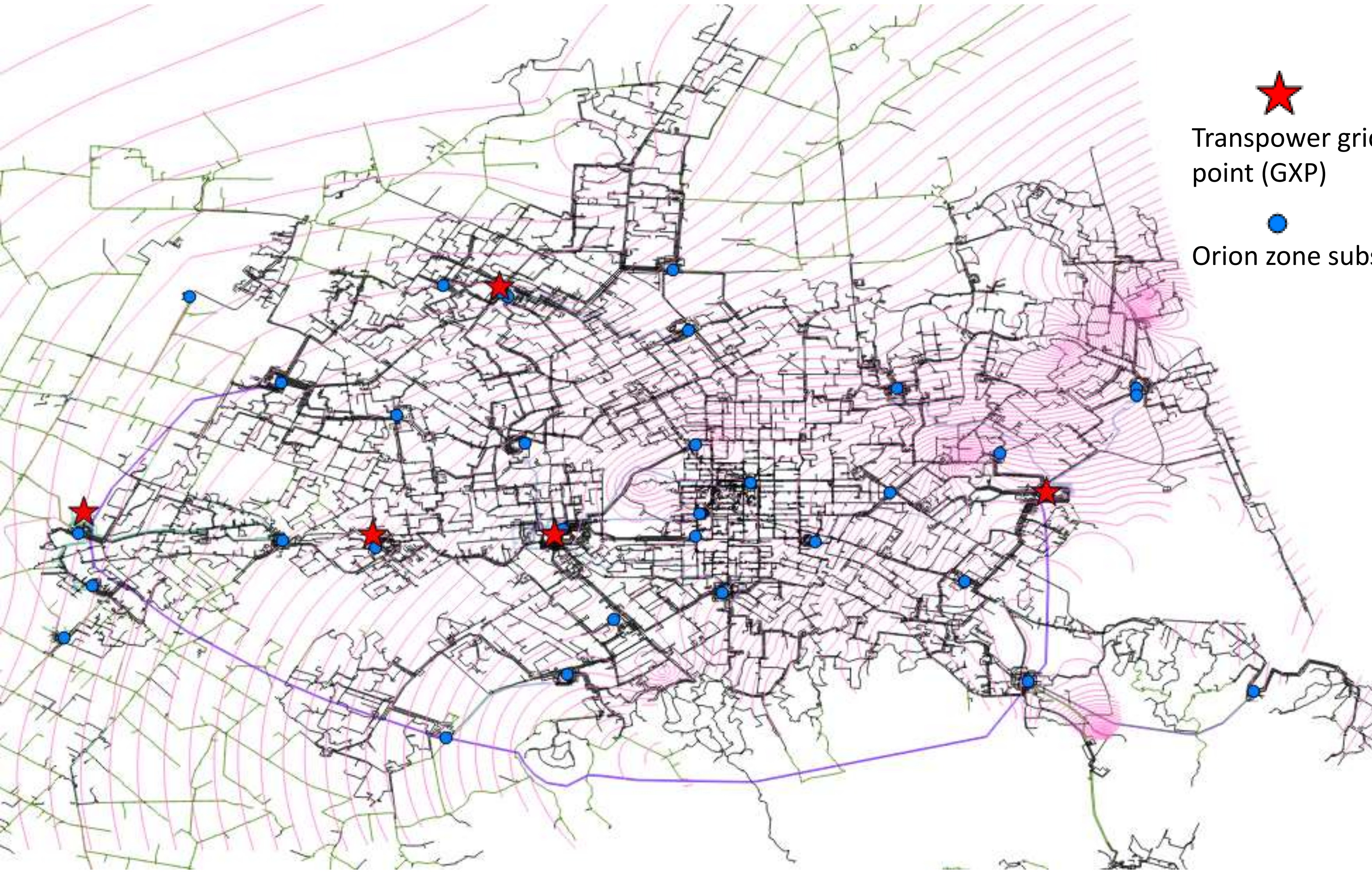


Christchurch electric power network

Prediction of physical damage, connectivity and serviceability indicators

Orion network with PGA shake map, Feb 2011 event

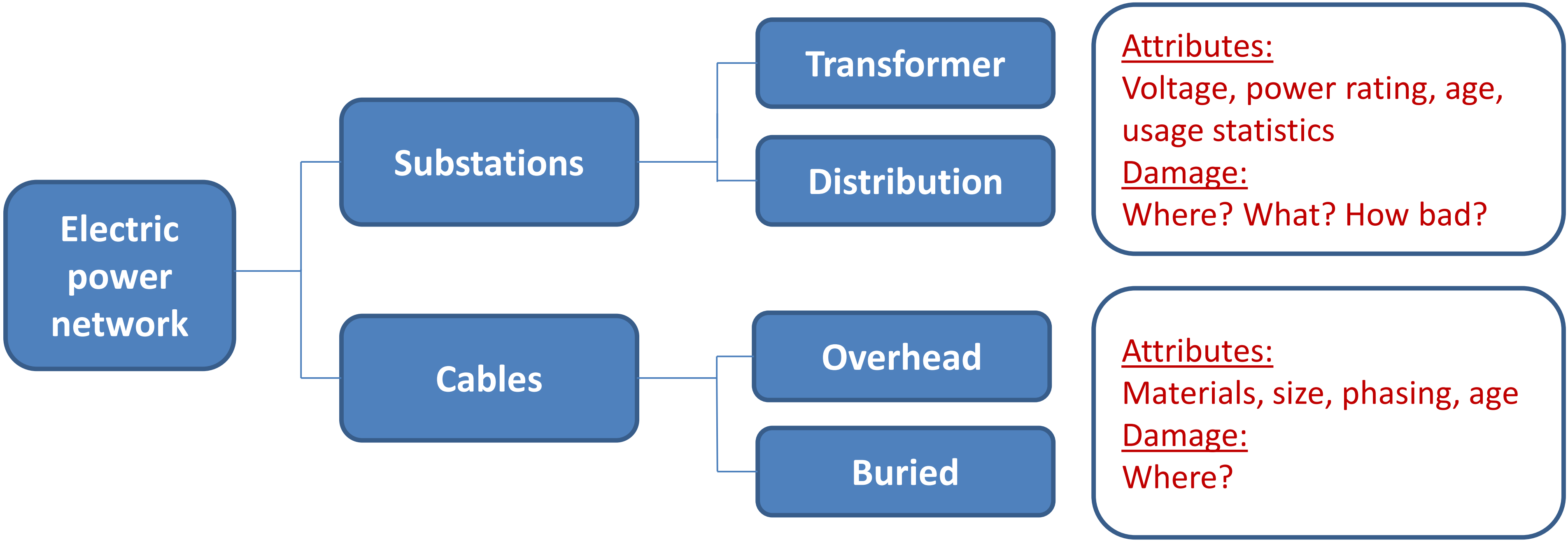


Transpower grid exit point (GXP)

Orion zone substation

Lifelines data management

- *Pre-disaster: classify or 'inventorise' system into hierarchy of elements with locations and attributes*
- *Post-disaster: document damage occurrences and recovery activities*



Lifelines data management

Why is it important?

Vulnerability of elements

Risk assessment of system

Risk-based investment

Insurance

Emergency management

Learn lessons

What can improve?

Lack of standardisation

Post-disaster data collection

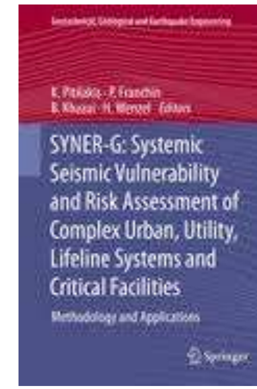
Interdependencies

Resilience aspects

- *robustness, redundancy, resourcefulness, rapidity*
- *technical, organisational, social*

Lifelines data management

Infrastructure system	Components	Component attributes
Electric power	Generation plants	Capacity, seismic design level
	Substations	Voltage, seismic design level
	Cables	Material, size
Potable water	Wells	Seismic design level
	Water treatment plants	Capacity, seismic design level
	Pumping stations	Capacity, seismic design level
	Storage tanks	Elevation, material, geometry, quantity of contents, seismic design level
	Pipelines	Material, joint type, age, diameter
Waste water	Lift stations	Capacity, seismic design level
	Treatment plants	Capacity, seismic design level
	Pipelines	Material, joint type, age, diameter
Natural gas	Pipelines	Material, joint type, age, diameter
	Compressor stations	Capacity, seismic design level
Fuel	Refineries	Capacity, seismic design level
	Pumping stations	Capacity, seismic design level
	Storage tanks	Elevation, material, geometry, quantity of contents, seismic design level
	Pipelines	Material, joint type, age, diameter
Telecommunications	Central offices	Seismic design level
	Cables	Material, size
Highways	Roadways	Importance level
	Bridges	Structural system, material, age, geometry, seismic design level
	Tunnels	Construction method, geometry, local geology
	Embankments	Height, soil type



Thank you for your attention

- Speaker contact details

  - Dr Sonia Giovinazzi *(sonia.giovinazzi@canterbury.ac.nz)*
  - Dr Deirdre Hart *(deirdre.hart@canterbury.ac.nz)*
  - Dr Francesco Cavalieri *(francesco.cavalieri@uniroma1.it)*
  - Indranil Kongar *(indranil.kongar.10@ucl.ac.uk)*

- Acknowledgements

Volcanic Ash Impacts Research – current and future

National Engineering Lifelines Forum

5 November 2014

Tom Wilson and volcanic impacts team

Volcanic Impacts Study Group – Auckland Lifelines Group

University of Canterbury, New Zealand

GNS Science, New Zealand

Massey University, New Zealand

University of Cambridge, United Kingdom

USGS, United States of America

UC UNIVERSITY OF CANTERBURY Te Whare Wānanga o Waitaha CHRISTCHURCH NEW ZEALAND

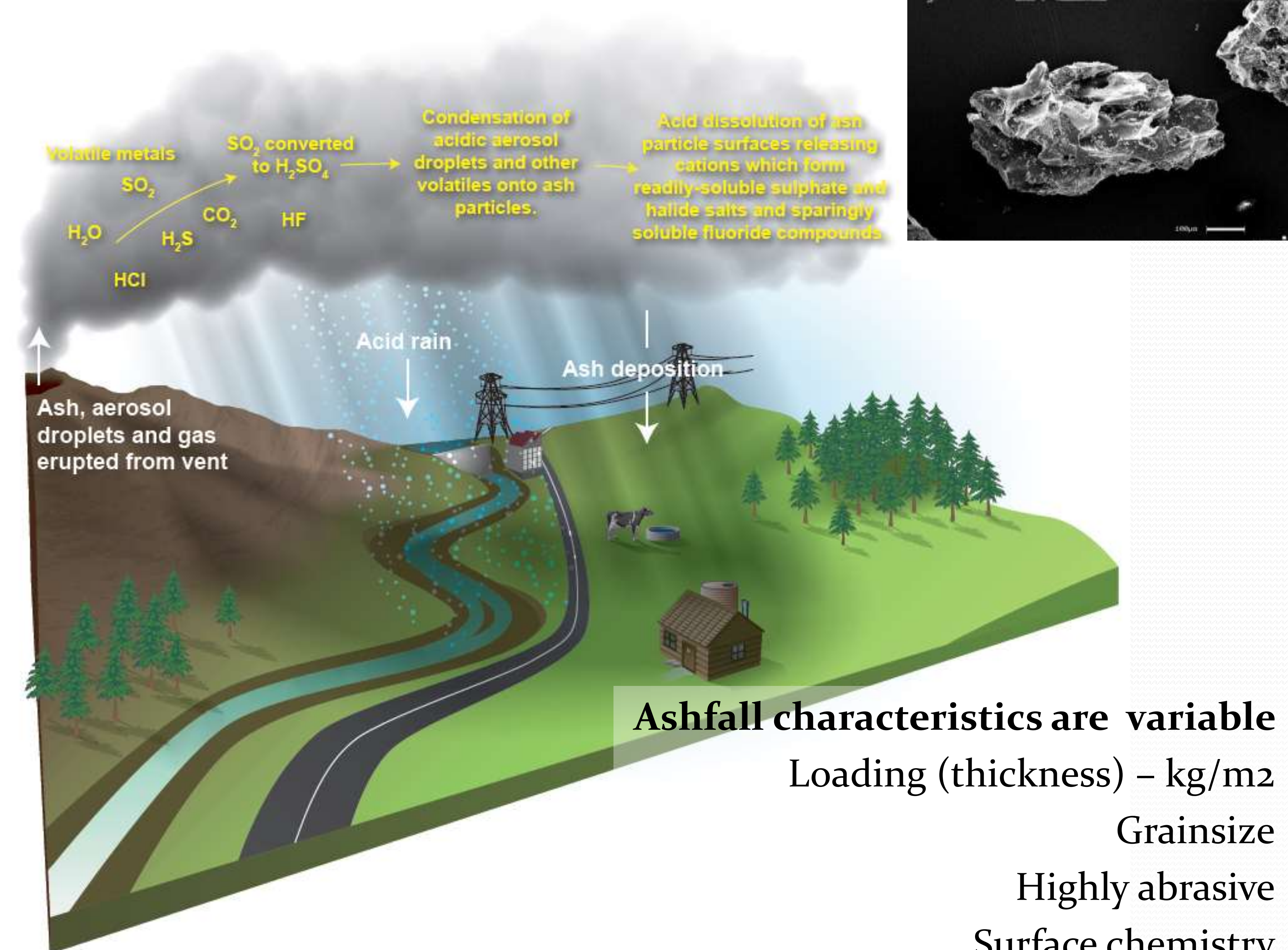
Massey University

GNS SCIENCE TE PŪ AO

Volcanic Ash Research -- Lifelines

- Why worry?
- Current activities
- Case-study:
  - Volcanic risk to electricity systems
- International Contributions
- Resources Available

Why worry?



Ashfall characteristics are variable

Loading (thickness) – kg/m2

Grainsize

Highly abrasive

Surface chemistry

Why worry?

- Volcanic ash is the most likely volcanic hazard to affect the most people during an explosive eruption

- Volcanic eruptions can cause a range of impacts.
  - Exotic impacts. Mitigation options??
  - Potentially long duration, multi-stage, multi-hazard

- Infrequent eruptions
  - Limited opportunities to develop experience
  - So how do we learn?

- Limited knowledge base of impacts + mitigation compared to other perils
  - dominated by only several eruptions

Volcanic Impact Study Group

- Hosted by Auckland Lifelines Group
  - Subcommittee
  - National Focus
  - Researcher + practitioner membership

- Strong user-researcher partnership
  - strong culture of supporting research to practise
  - Multi-disciplinary

- Funding support for applied research project
  - Leveraging off larger Natural Hazard Research Platform + DEVORA funding

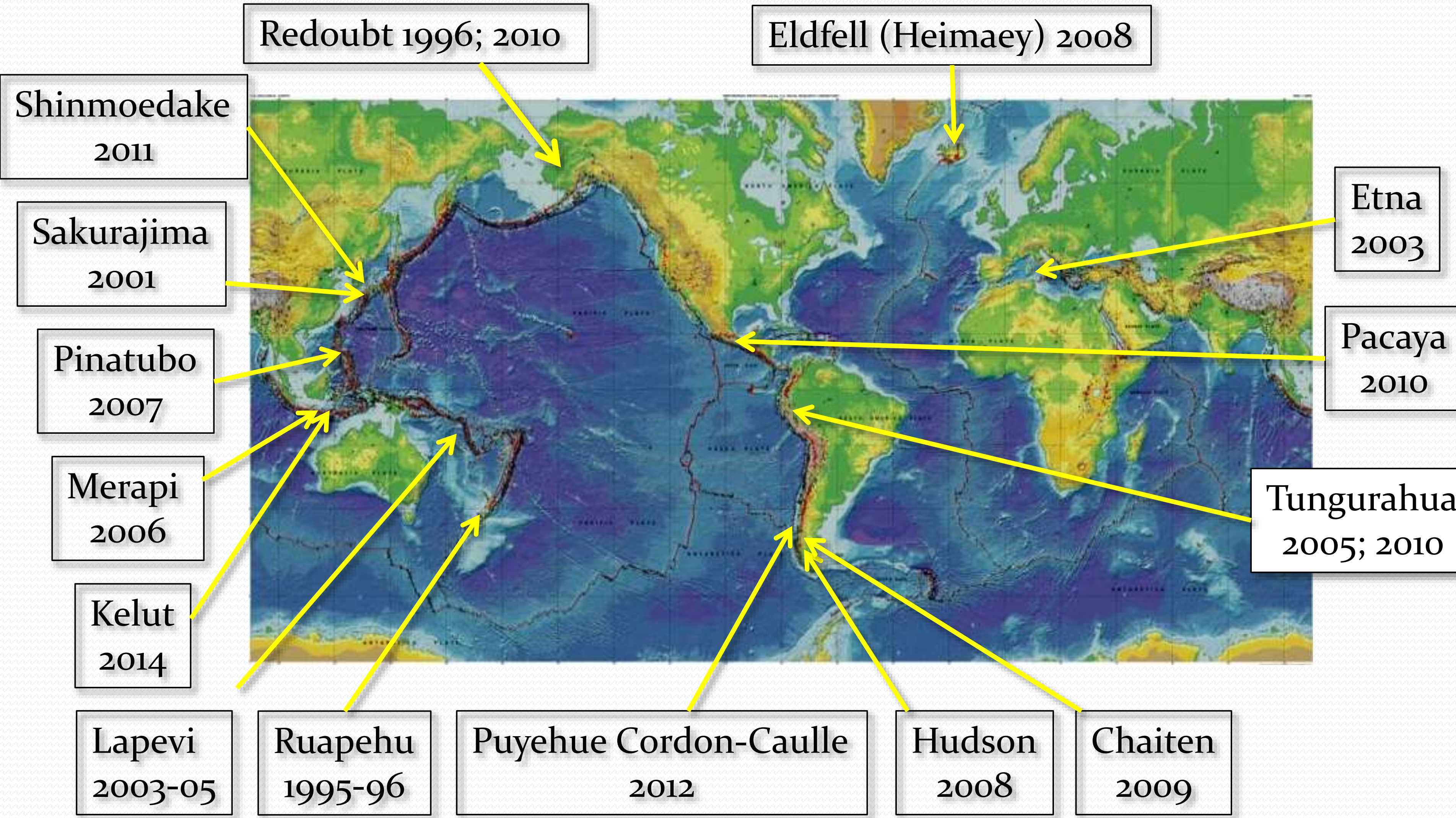
Auckland Engineering Life Lines

CoUGAR
Canterbury University Group for Ash Research.

Research Context – Ash Impact Research

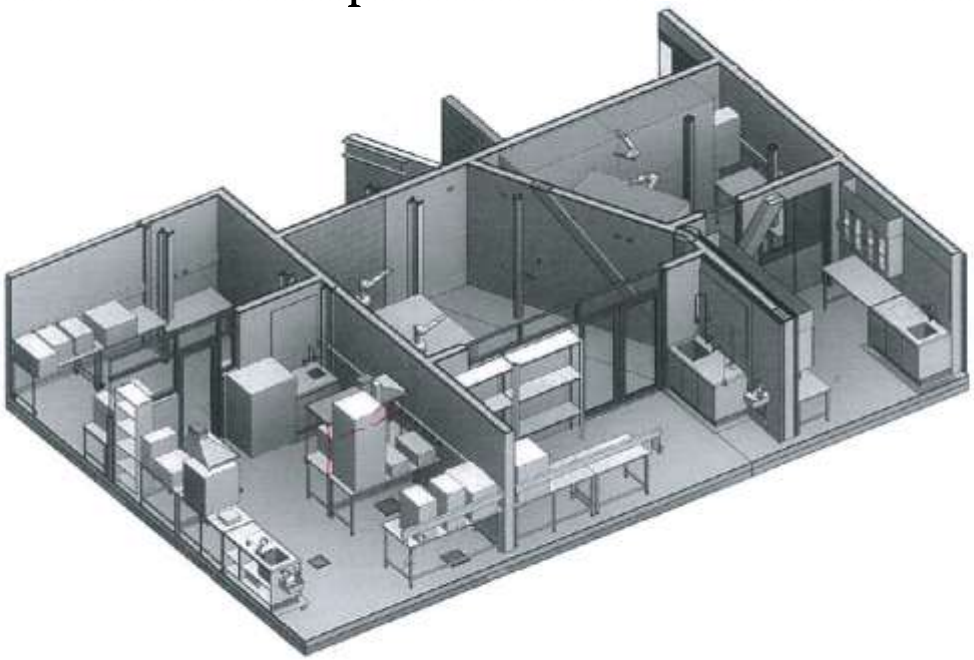
- Over the past 20 years our New Zealand research group (and collaborators) have aimed to undertake a sustained and systematic approach to volcanic impact assessment
  - critical infrastructure: electricity, water supplies, wastewater, land and air transport, telecommunications
  - ash cleanup and disposal
  - primary industries, e.g. agriculture
  - social impacts
  - emergency management

Addressing Knowledge Gap: Recon Trips



Addressing Knowledge Gap

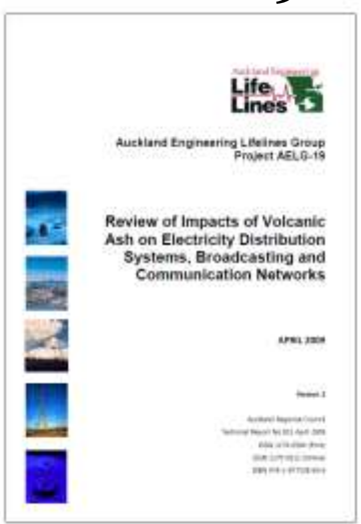
- Volcanic Ash Testing Lab (VATLab)
- Empirical experiments of components and systems which are vulnerable
  - Laboratory testing in controlled environment
  - Engineering College
  - UC re-development – investment

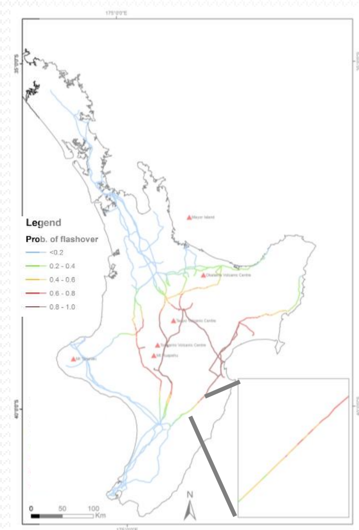


Fostering Research Partnerships

- **2009**: AELG-19: Impact of Ash on Electricity, Telecommunications, Broadcasting Networks
  - Electricity systems susceptible to ash fall induced outage
  - Identified knowledge gaps
    - Threshold for insulator flash-over?
    - What factors influenced resistivity of volcanic ash?
    - Resilient insulator design?

2008-2009


Life Lines
Auckland Engineering Lifelines Group
Project AELG-19
Review of Impacts of Volcanic Ash on Electricity Distribution Systems, Broadcasting and Communication Networks



Case Study: Electricity Systems

The main impacts are:

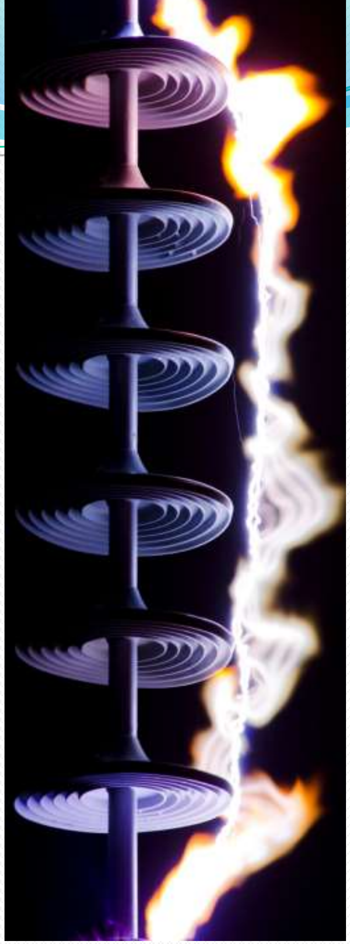
- Supply outages from insulator flashover caused by ash contamination
- Disruption of generation facilities
- Controlled outages during tephra cleaning
- Abrasion and corrosion of exposed equipment
- Line breakage due to tephra loading

Ruapehu 1995

- Flashover and voltage fluctuation
- Exposed surfaces coated in 3mm of ash

Fostering Research Partnerships

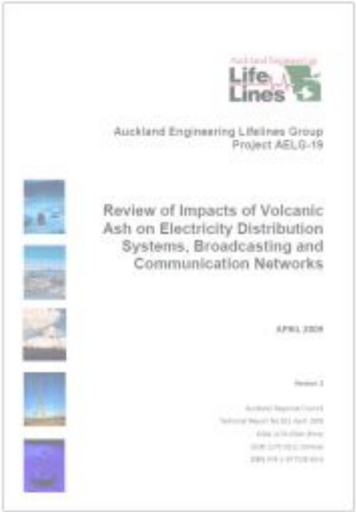
- **2010-2013:** PhD Project: Johnny Wardman
  - Vulnerability of HV Transmission Systems to Volcanic Ashfall Hazards
  - Sponsor: Transpower Ltd.
    - $140,000 + consumables
    - co-funding from NHRP



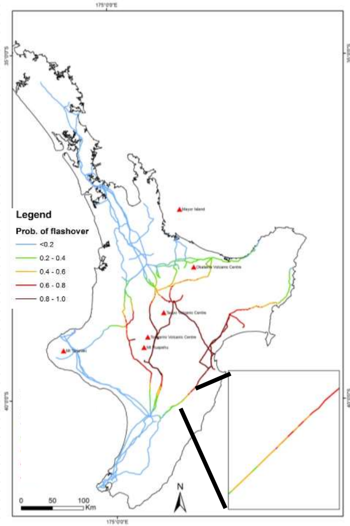
- Aided Transpower volcanic risk management planning

Fostering Research Partnerships

- Volcanic Ashfall Risk on Critical Infrastructure
  - Probabilistic ash fall modelling
  - Refined impact thresholds for:
    - Transmission circuits
    - Grid Exit Points (GXP) – substations
    - Power Stations

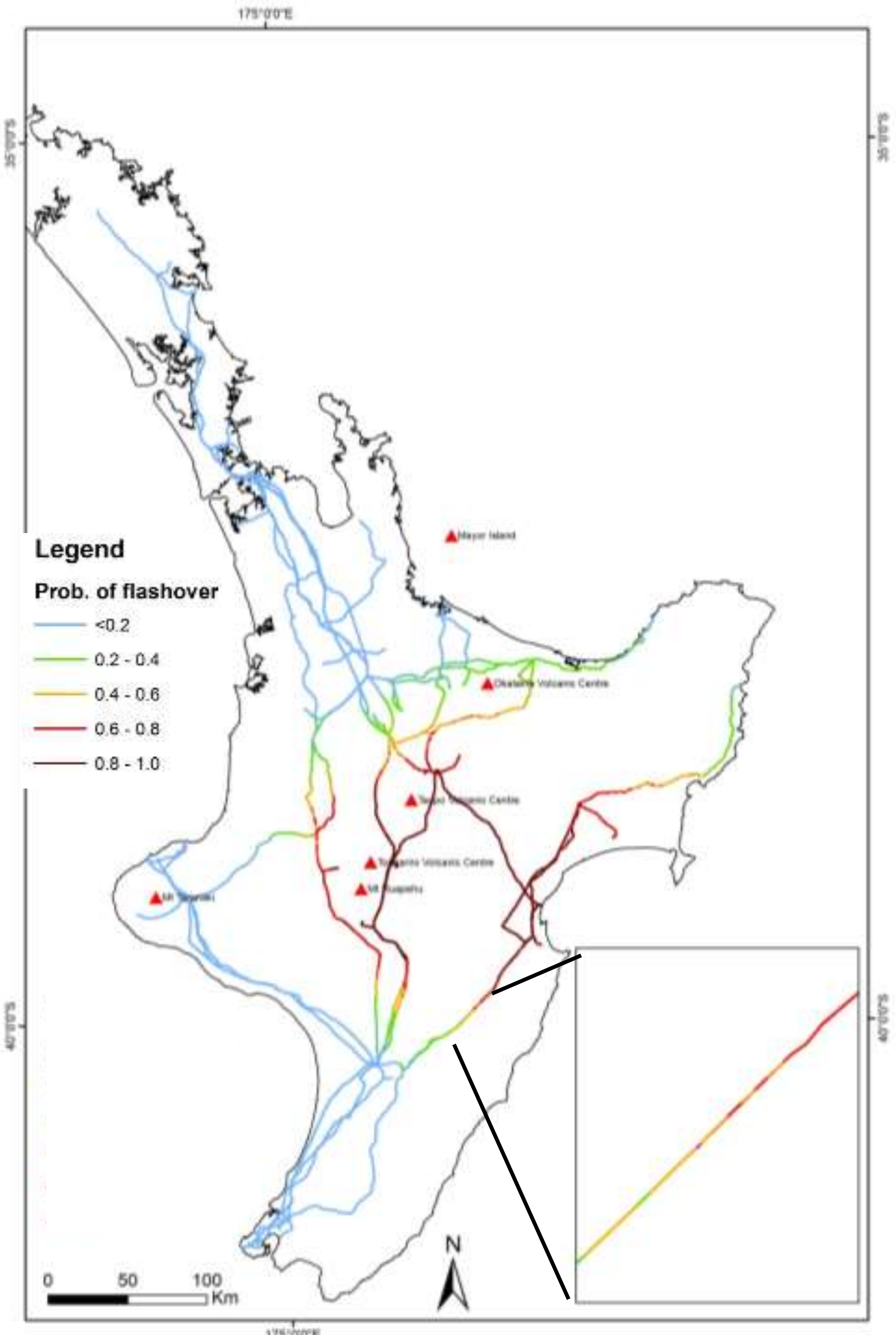


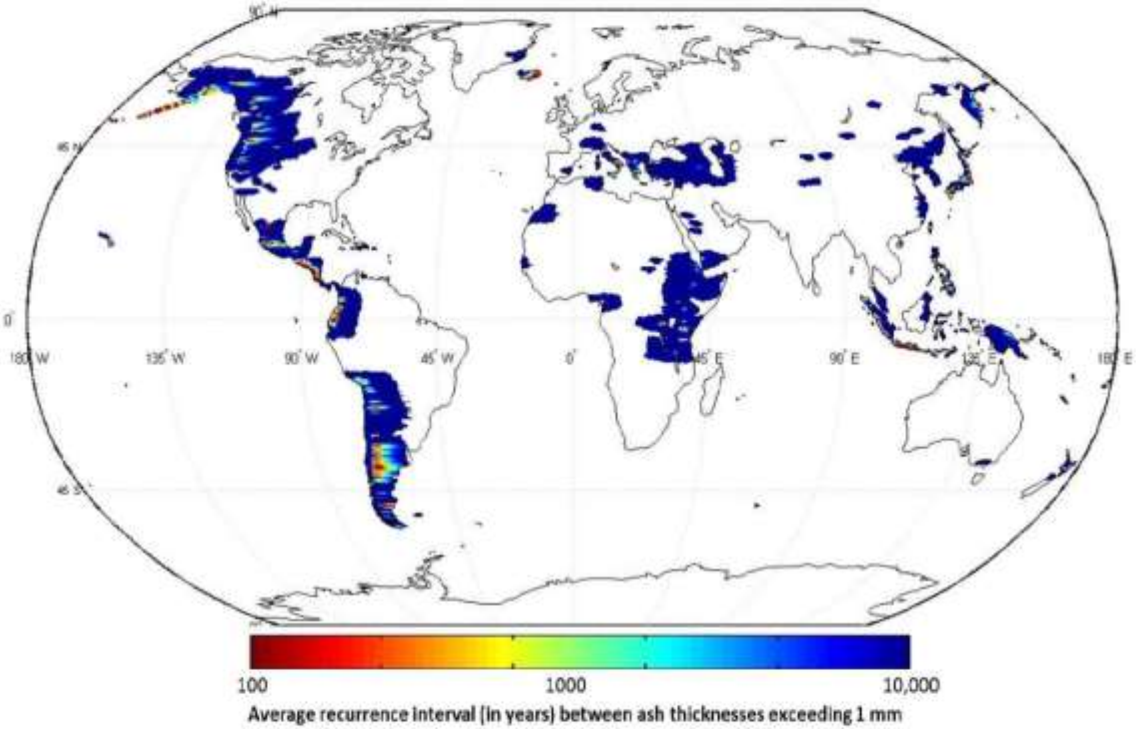
2014-2015



- **2014:** PhD Research Project: Grant Wilson

- **Risk Reduction**
  - E.g. locations for preventative mitigation
  - Compare against other perils + account for uncertainty (probabilistic)
- **Readiness**
  - E.g. prioritisation of cleaning
- **Response**
  - E.g. deterministic scenario





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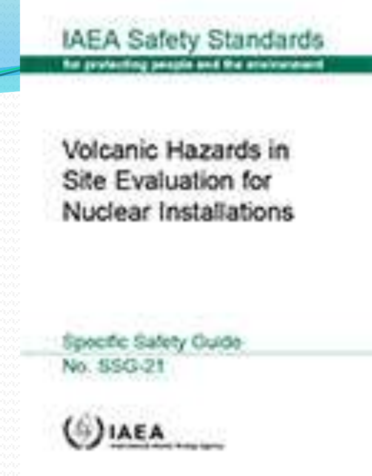

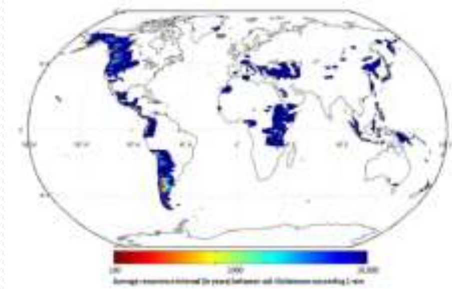

- UNISDR – Global Assessment Report (GAR-15)
  - Global ashfall hazard and risk modelling
  - Impact thresholds…scenario planning

- International partnership
  - South Korea (national scale assessment)
  - UK nuclear generator (site assessment)

- NZ Defence Technology – Aircraft Volcanic Ash Identification Protocol
  - UK + US civilian and military linkages

- **Medium term Research Strategy**
  - Co-development of applied research projects
- **Impact/risk planning + response resources**
- **Natalia Deligne**
  - Presenting tomorrow

CoUGAR

Canterbury University Group for Ash Research.

Thank you

Questions?

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AECOM

Resilience research

Resilient cities are safer, more attractive to investors and new residents, and more able to recover quickly and with less loss of life and assets in the event of crises. **UNISDR**

Research initiatives

- Measuring the resilience of transport infrastructure (NZTA)
- Paper: Review of key terminology: risk, resilience, vulnerability, sustainability
- Canterbury lifelines: ongoing discussion around measurement / benchmark approaches.

- Internationally:
  - Rockefeller 100RC
  - UNISDR Resilient Cities Scorecard (MCR Campaign)
  - World Bank R!SE
  - UN Habitat CRPP

Reasons to Focus on Resilience

By 2050 over 70% of the World's population will live in Cities

Loss of life have decreased from Natural Disasters but….capital losses have exceeded $2.5 T since 2000

Reasons to Focus on Resilience

Direct disaster losses are 50% higher than reported figures

Kobe port before the earthquake in 2005 was 6th busiest port in the world; By 2010 it had fallen to 47th despite massive investment.

Toyota lost $1.2B in product revenue after the 2011 earthquake & tsunami

Reasons to Focus on Resilience

"Economic losses from disasters are out of control and can only be reduced with collaboration with the private sector"

Ban Ki-Moon
Secretary General of
the United Nations

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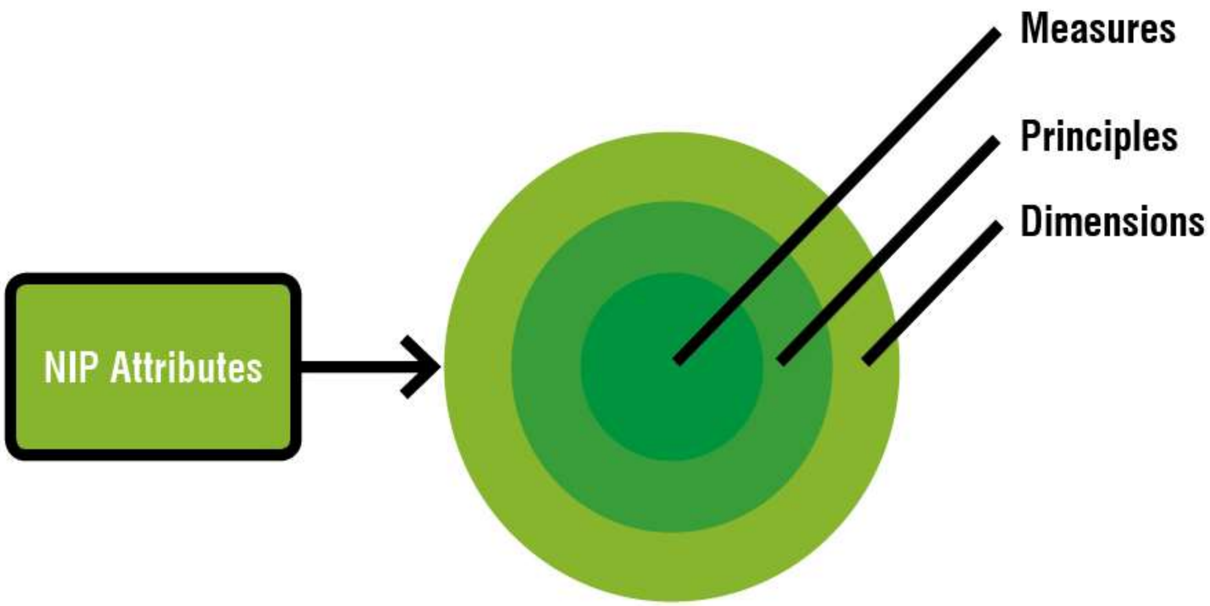
Measuring transport resilience

Resilience framework

– Consists of *Dimensions*, *Principles* and specific *Measures* which can map to the NIP attributes if required.



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How did we categorise resilience of infrastructure?

Dimension	Detail
Technical / Asset	The ability of the physical system(s) to perform to an acceptable/desired level when subject to a hazard event.
Organisational	The capacity of an organisation to make decisions and take actions to plan, manage and respond to a hazard event.

How did we categorise resilience of infrastructure?

Dimension	Principle	Categories
Technical / Asset	Robustness Redundancy Safe-to-fail	Measures
Organisational*	Change readiness Networks Leadership & Culture	Measures

**Refer work by Resorgs*

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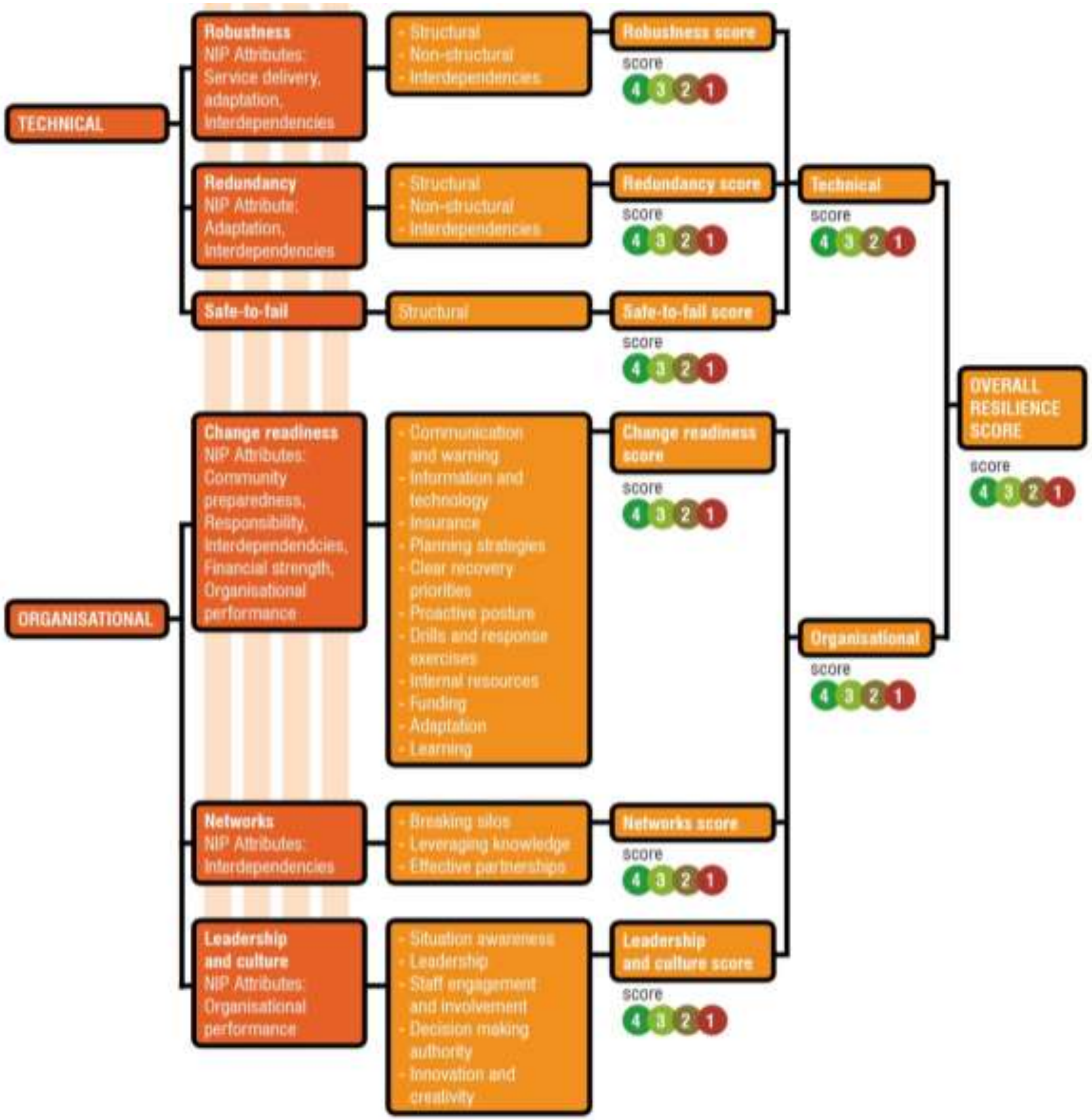
The measurement framework



Measures

ROBUSTNESS — **Weighted Robustness Score** 2.3

Category	Measure	Measurement	Measurement Scale	Individual Score	Category average	Weighting (%)	Weighted Score
Structural	Maintenance	Processes exist to maintain critical infrastructure and ensure integrity and operability - as per documented standards, policies & asset management plans (e.g. – roads maintained, flood banks maintained, stormwater systems are not blocked). Should prioritise critical assets as identified.	4 – Audited annual inspection process for critical assets and corrective maintenance completed when required. 3 – Non-audited annual inspection process for critical assets and corrective maintenance completed when required. 2 – Ad hoc inspections or corrective maintenance completed, but with delays/backlog. 1– No inspections or corrective maintenance not completed.	3	2.8	33.33%	94.4
	Renewal	Evidence that planning for asset renewal and upgrades to improve resilience into system networks exist and are implemented.	4 – Renewal and upgrade plans exist for critical assets, are linked to resilience, and are reviewed, updated and implemented. 3 – Renewal and upgrade plans exist for critical assets and are linked to resilience, however no evidence that they are followed 2 – Plan is not linked to resilience, and an adhoc approach is undertaken 1– No plan exists and no proactive renewal or upgrades of assets.	4			
	Design	Percentage of assets that are at or below current codes	4 – 80%+ are at or above current codes 3 – 50-80% are at or above current codes 2 - 20-50% are at or above current codes 1 - nearly all are below current codes	3			
		Assessment of general condition of critical assets across region.	4 – 80%+ are considered good condition 3 – 50-80% are considered good condition 2 - 20-50% are considered good condition 1 - nearly all poor condition	3			
		Percentage of assets that are in zones/areas known to have exposure to hazards	4 – <20% have some exposure to known hazarrds 3 – 20-50% are highly exposed, or >50% are moderately exposed 2 - 50-80% are highly exposed 1 - 80%+ are highly exposed to a hazard	2			
		Percentage of critical assets with additional capacity over and above normal demand capacity	4 – 80%+ of critical assets have >50% spare capacity available 3 – 50-80% of critical assets have >50% spare capacity 2 - 20-50% of critical assets have >50% spare capacity 1 - 0-20% have spare capacity	2			

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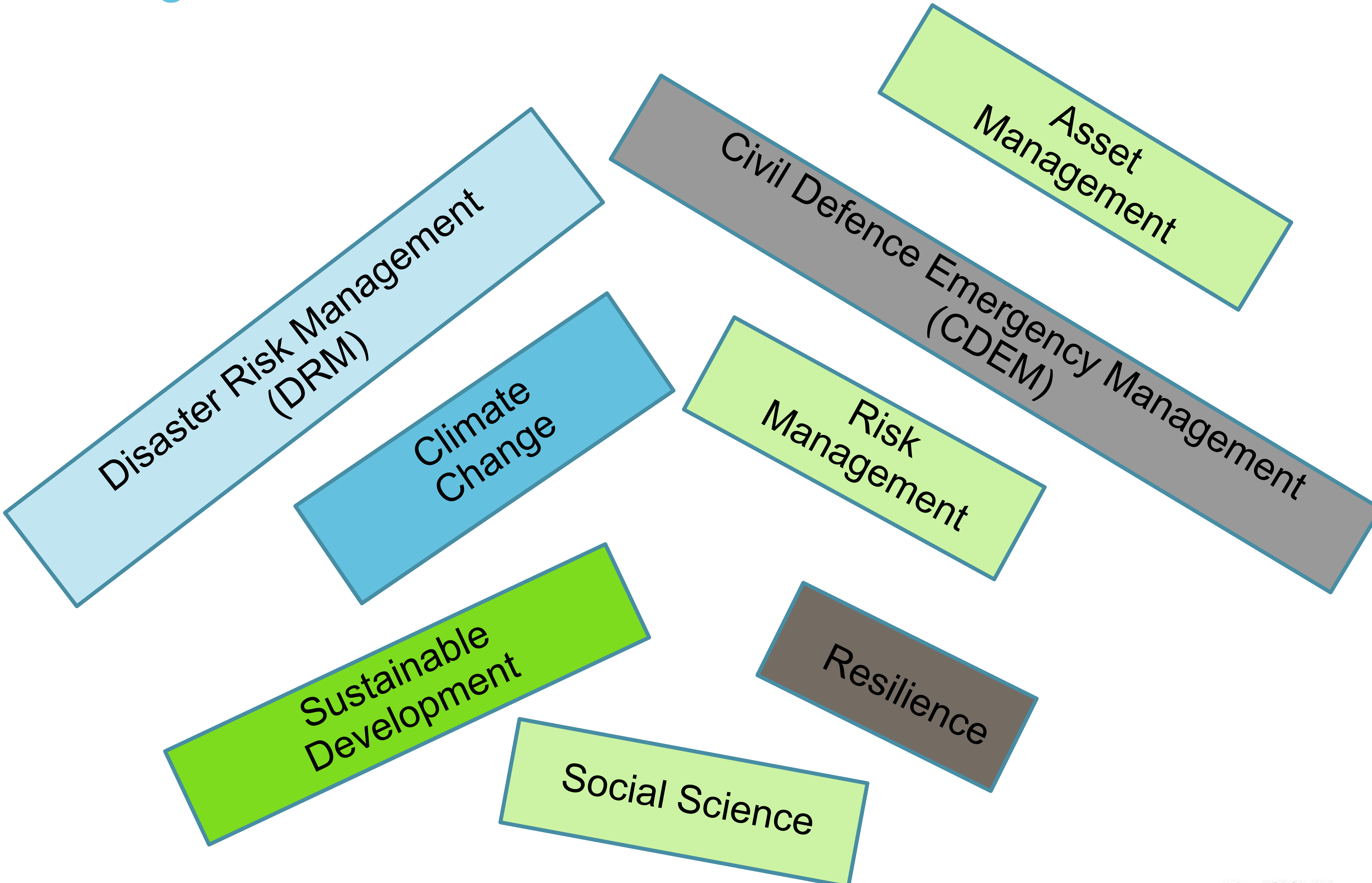
Research paper: hazard, risk, resilience, vulnerability

We investigated

- Consistency across risk management approaches?
- Confusion in terminology - and suggestions for simplification
- Risk approaches vs resilience approaches. What are differences? When to use?
- Recommendations for asset management field and implications for other fields

Range of fields



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Range of terms

Hazard

Risk

Consequence

Likelihood

Robustness

Exposure

Vulnerability

Redundancy

Sensitivity

Sustainability

Resilience

Adaptive Capacity

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Links

- NZTA Research:

  http://www.nzta.govt.nz/resources/research/reports/546/

- Paper on risk, resilience and terminology: Come and see me: james.hughes@aecom.com

Thankyou

“Whilst systems have commonly been designed to be ***robust*** *(designed to prevent failure), increasing complexity and the difficulty it poses to fail-proof planning have made a shift to "resilience" strategically imperative.*

A resilient system on the other hand accepts that failure is inevitable and focuses instead on early discovery and fast recovery from failure”.

David Snowden