Dynamic Vulnerability of Critical Infrastructure During a Sequence of Damaging Events

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Ngā Ngaru Wakapuke

Outline

- Context
- Research Aim
- Initial Results
- Next Steps
- Key Takeaways

Disaster Risk

Currently:

SIMPLIFIED

STATIC

WHAT ABOUT THE

Dynamic

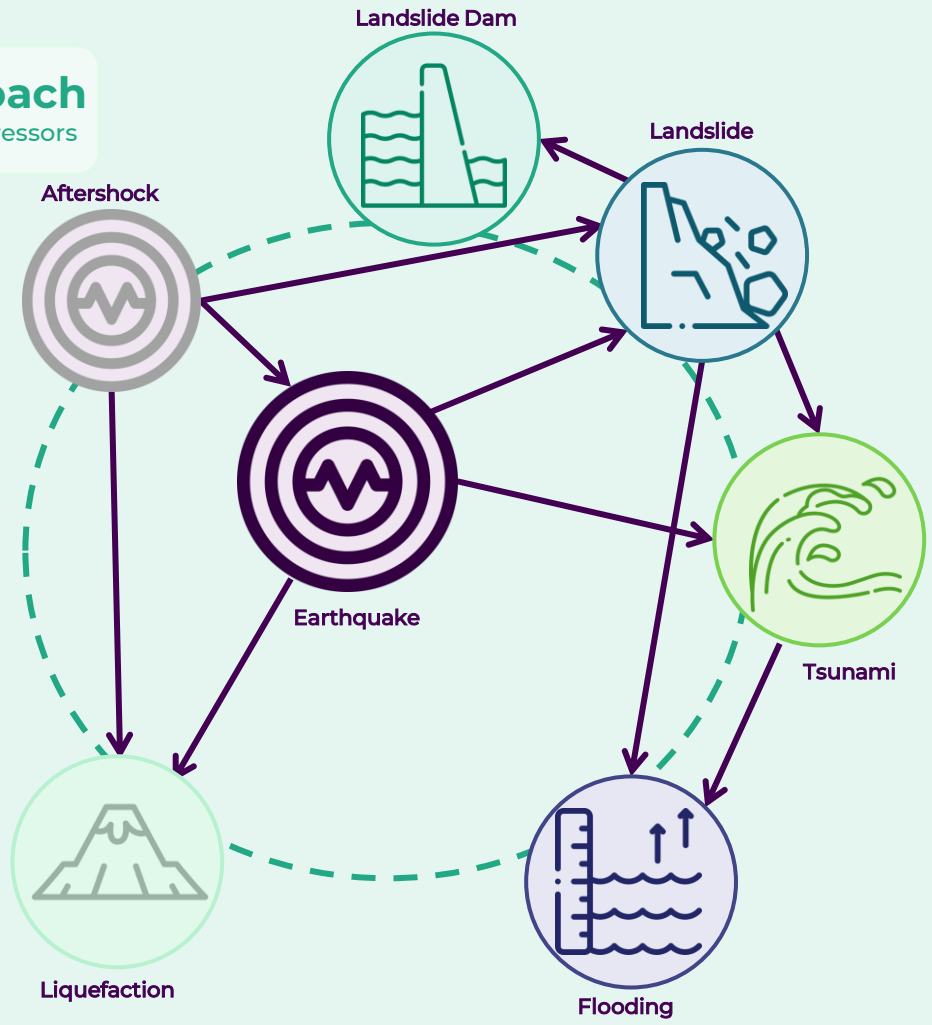
NATURE OF EACH COMPONENT??

Multi-hazard Risk

Multi-Hazard Approach
Multiple hazards | Interactions | Stressors

Traditional
Single hazard focus

One hazard
Analysed in insolation



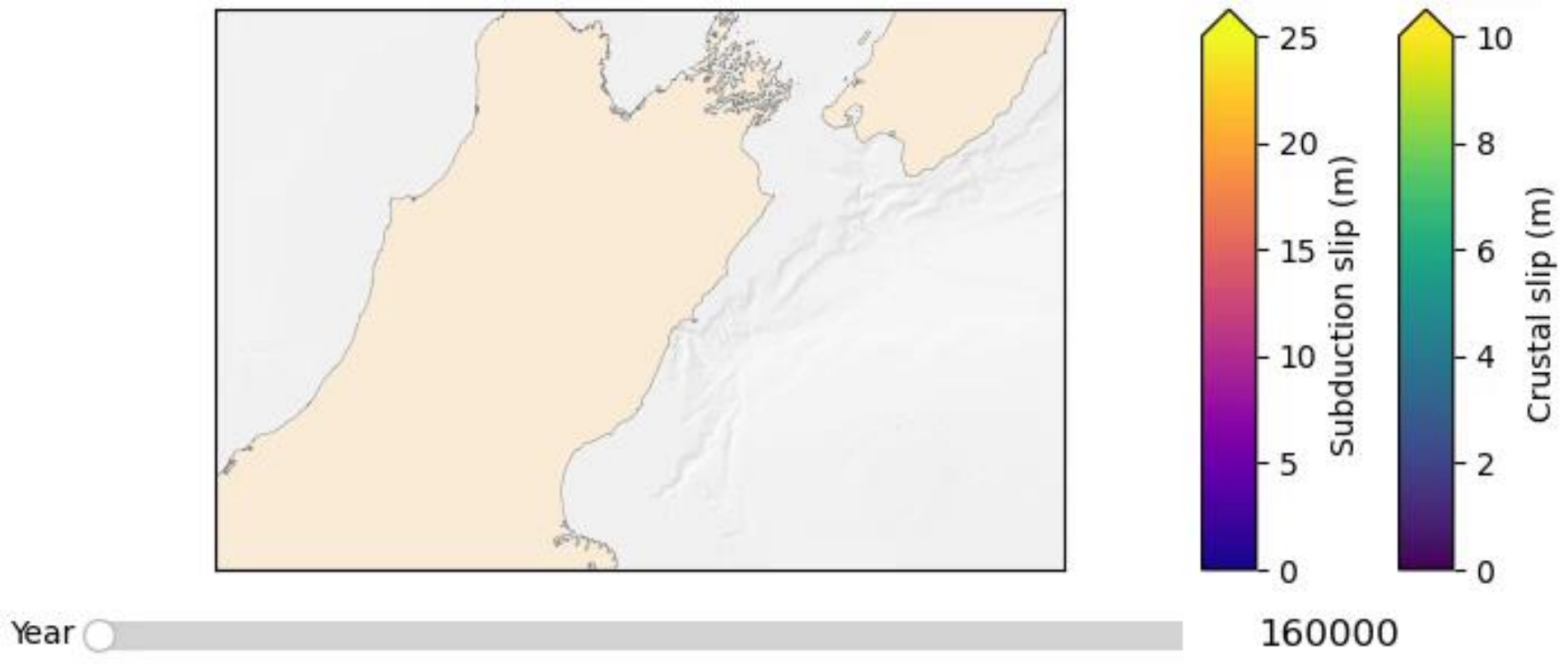
What makes it Multi-Hazard?

Multiple hazards
Considering multiple hazards and how they co-exist or compound one another.

Interactions across space & time
Hazards can trigger, delay, or amplify each other. Occurring consecutively or simultaneously.

Terminology challenge ⚠
Limited consistency in definitions and classification of interactions – similar concepts but different terms.

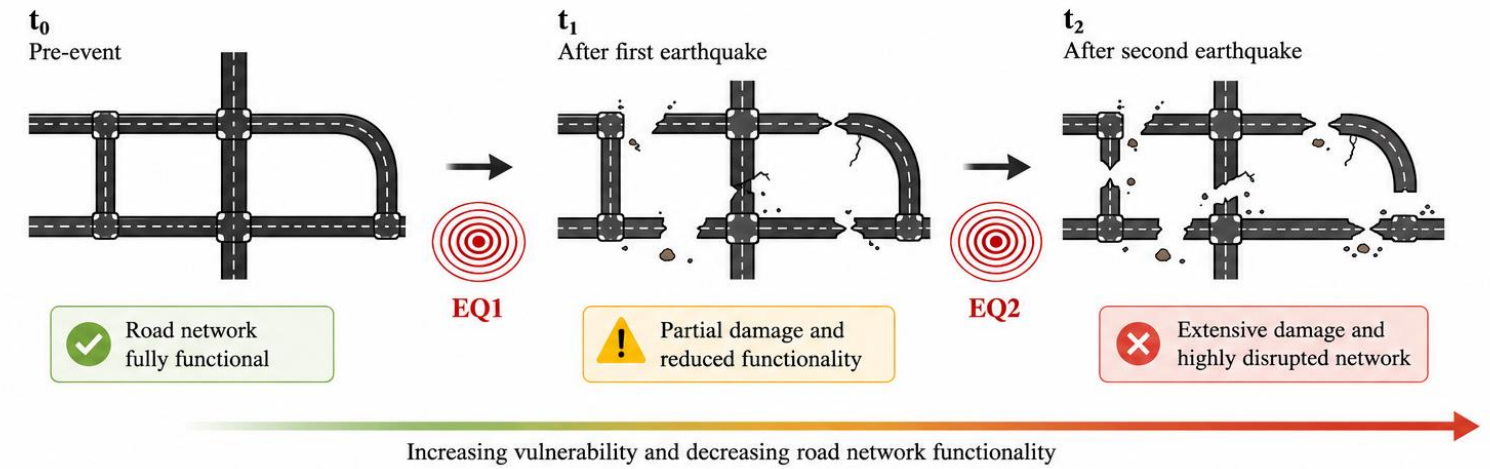
Earthquake Sequences



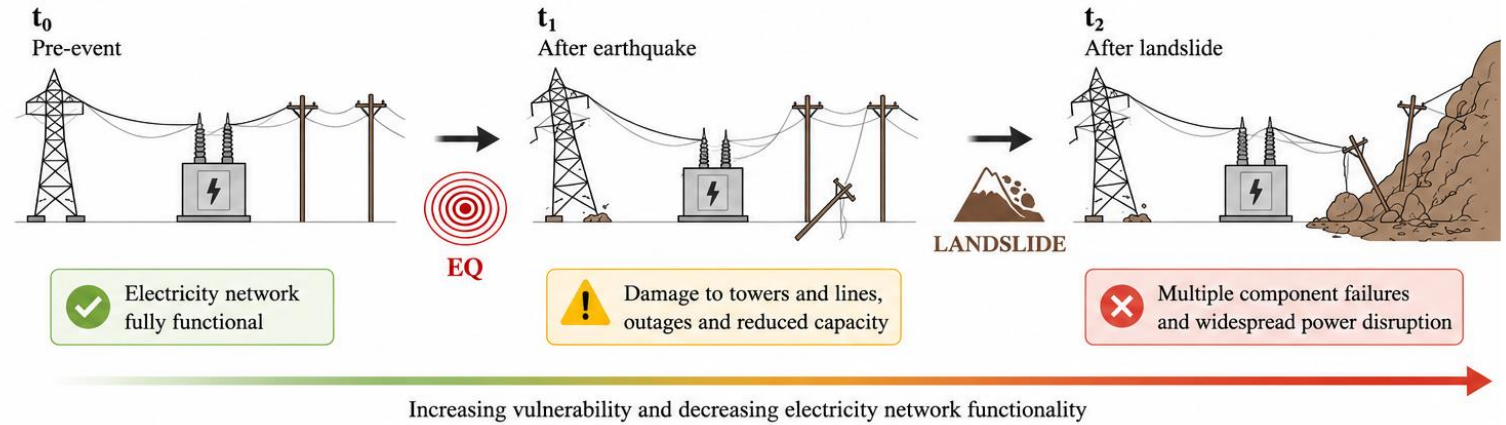
(Penney, 2026)

Dynamic Vulnerability

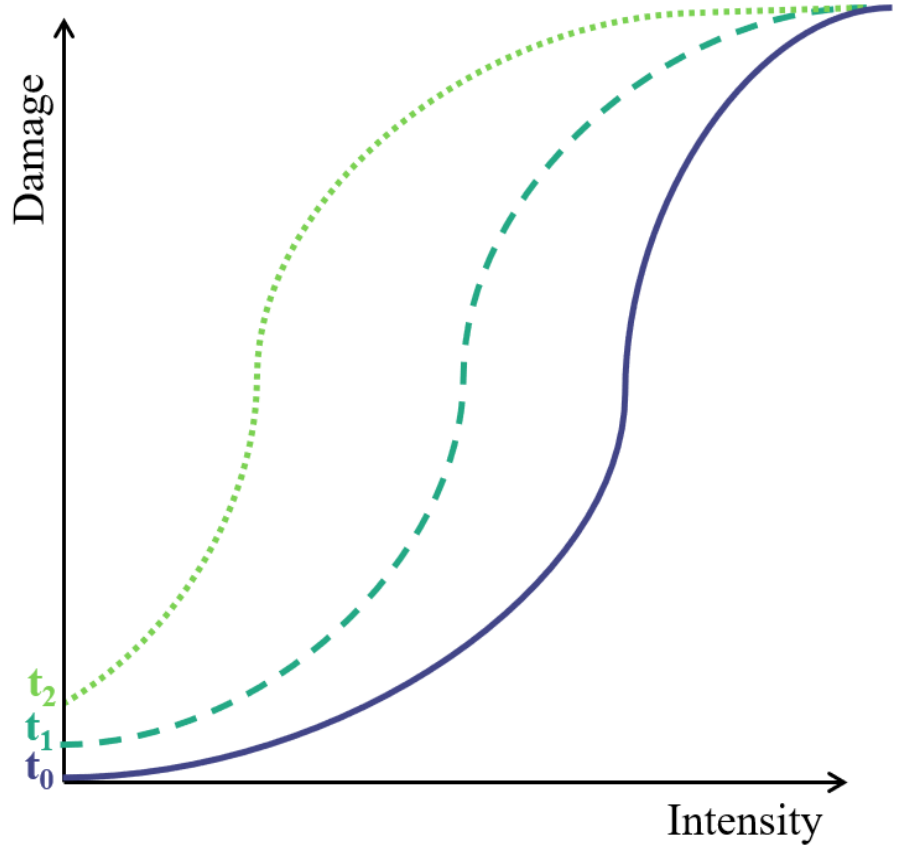
A) Increase of vulnerability of road network due to successive earthquakes



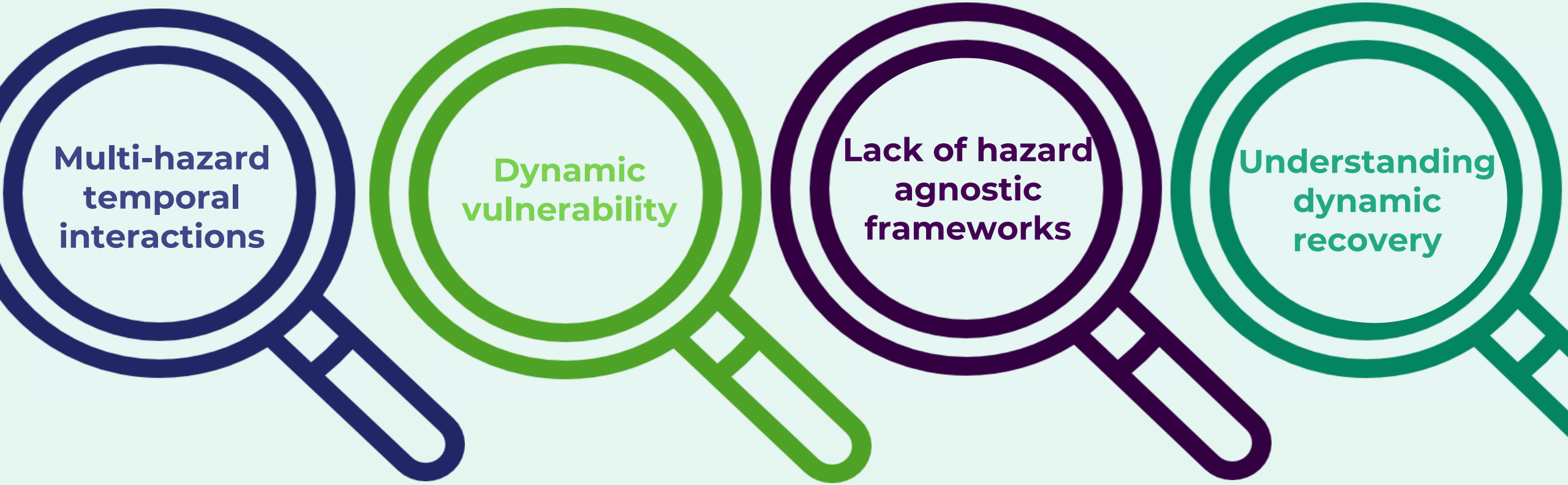
B) Increase of vulnerability of electricity network due to successive hazards



C) Changing vulnerability curve due to consecutive hazards



Research Gaps



Overarching Question

How can dynamic physical vulnerability and time dependent risk be integrated into infrastructure risk models to better inform resilience planning?

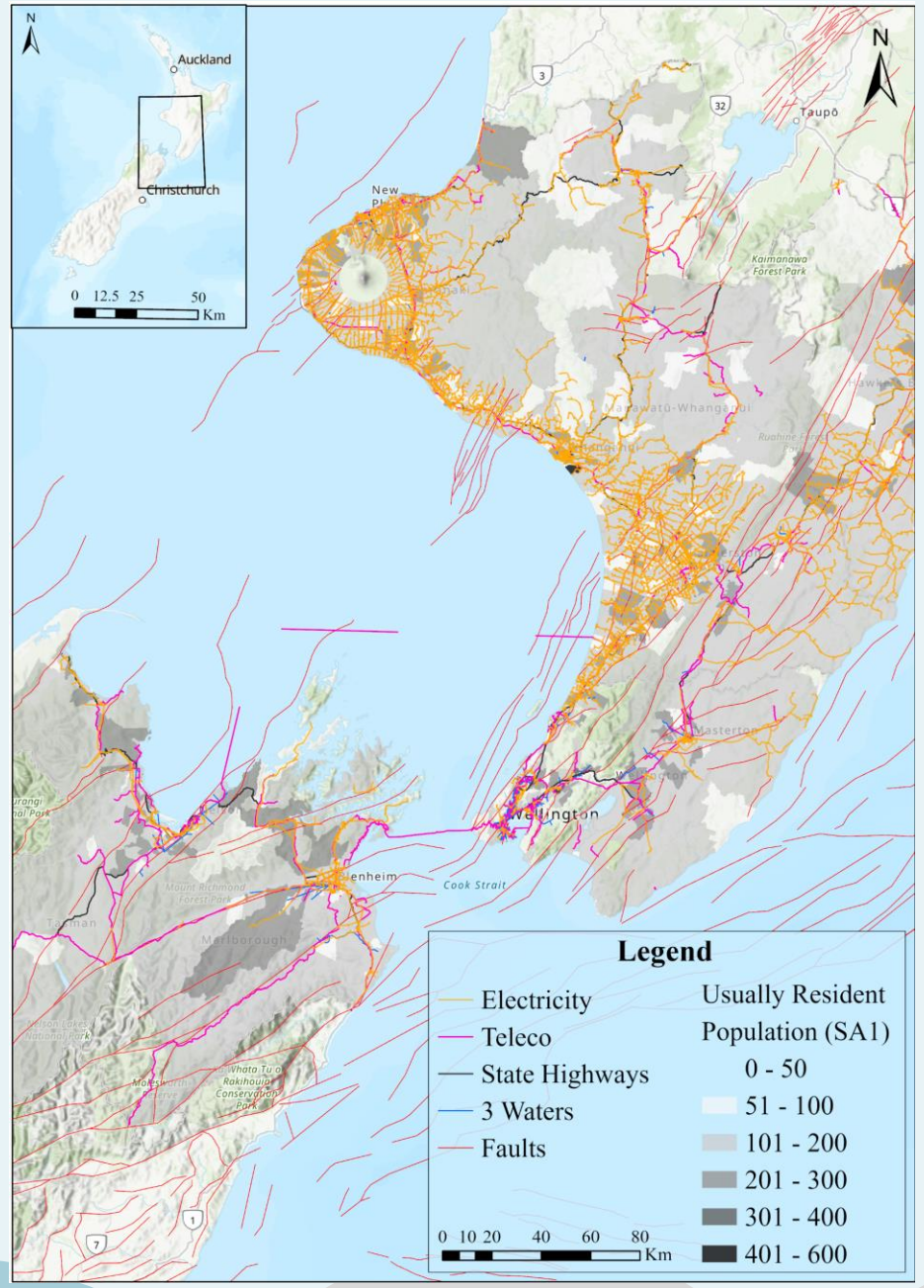
Central NZ Study Area

Critical national infrastructure corridors

Significant population

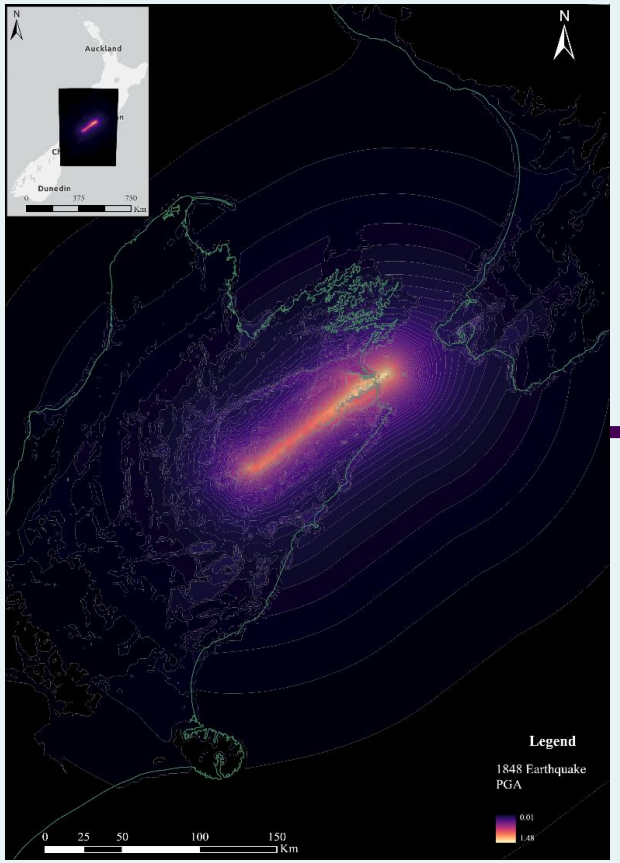
Complex fault systems

High seismic hazard



Initial Results - Scenario

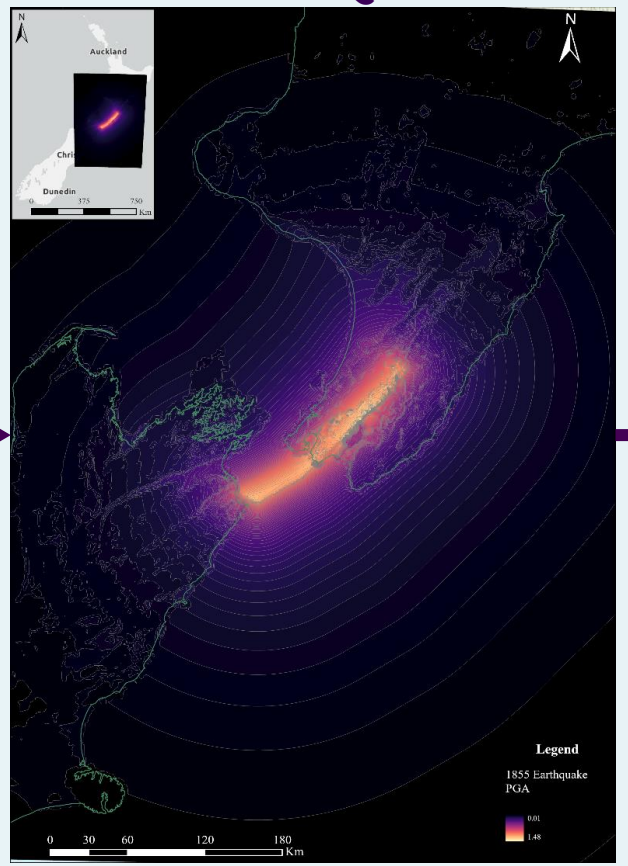
1848 – EQ1



Marlborough
Mw. 7.4

6.3 years

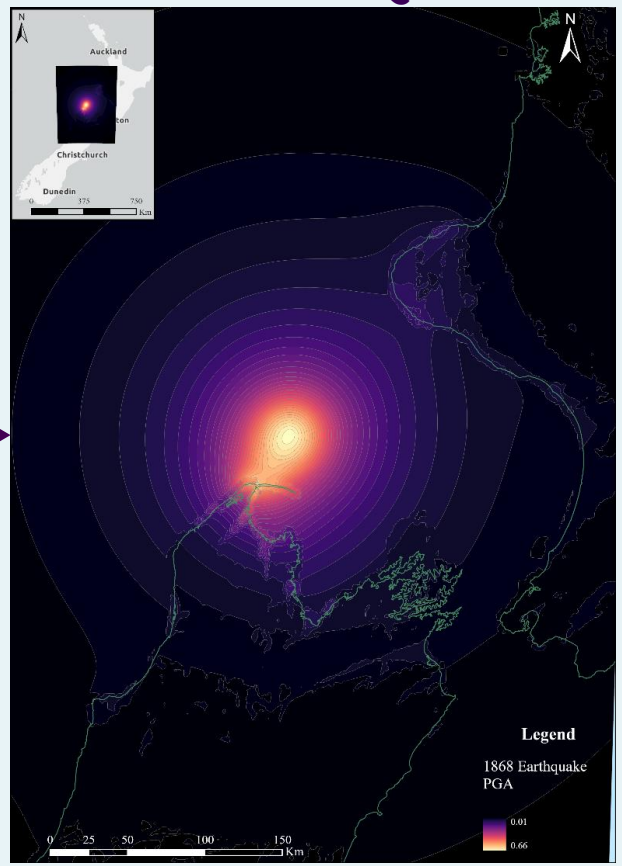
1855 – EQ2



Wairarapa
Mw. 8.2

13.7 years

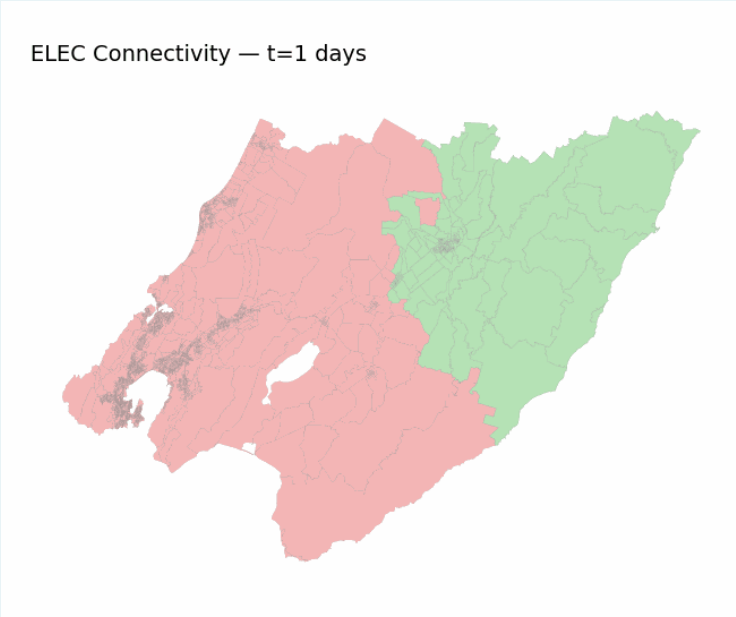
1868 – EQ3

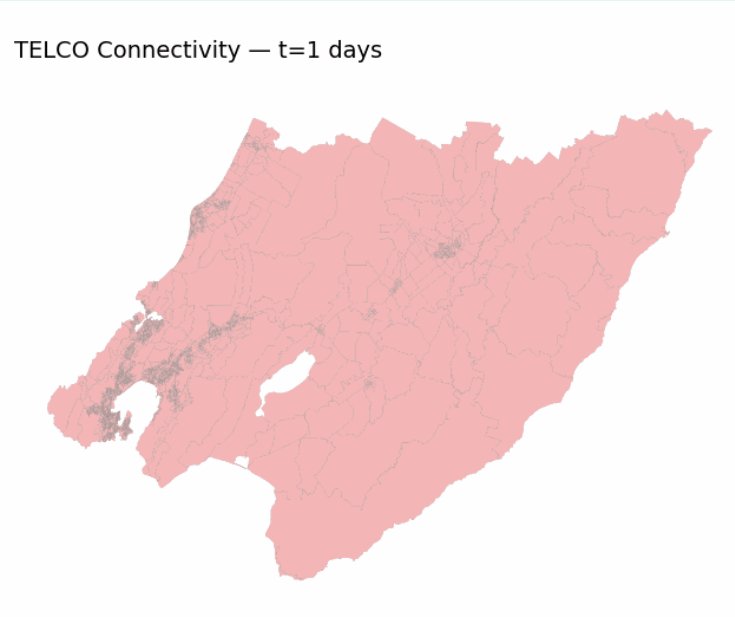


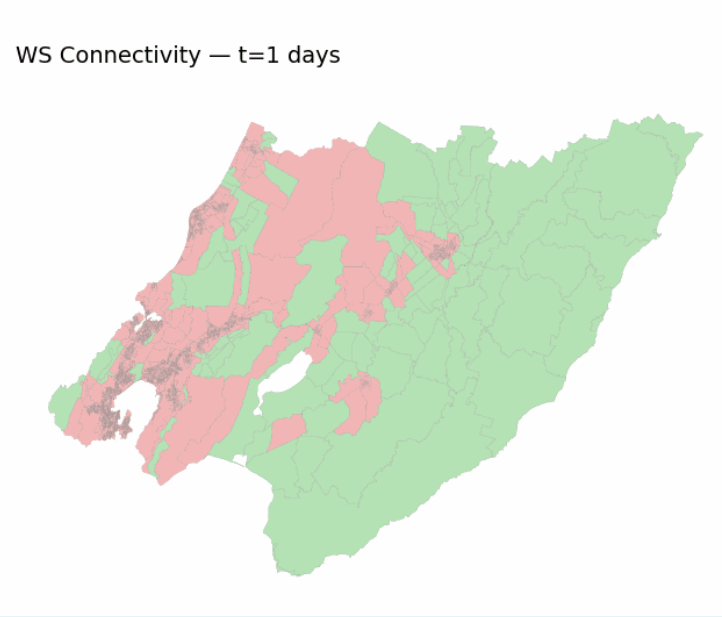
Cape Farewell
Mw. 7.2

Service
No service

Initial Results







Electricity

Longest outages ended after **89 days** after **EQ2.**

Telecoms

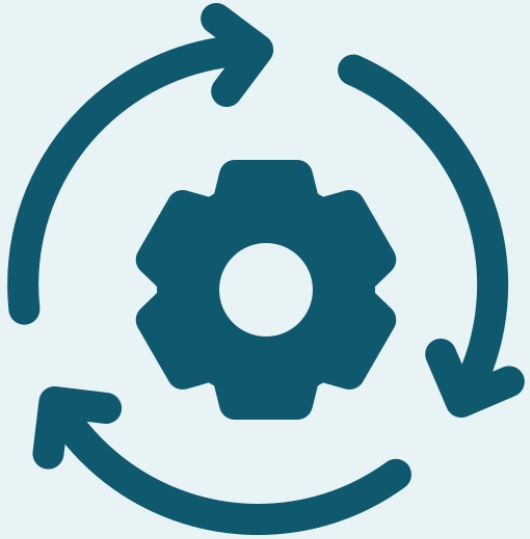
Longest outages ended after **222 days** after **EQ2.**

Water

Longest outages ended after **260 days** after **EQ2.**

Initial Results – Findings

Inter-event timing

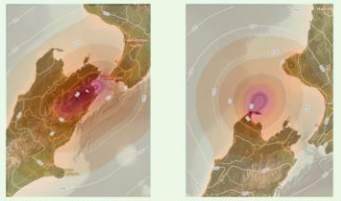


Full recovery

No cumulative or compounding

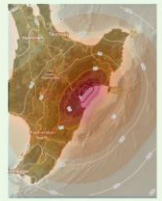
Earthquake Sequence Scenarios

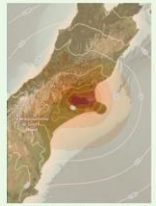
Historical Earthquake Pool

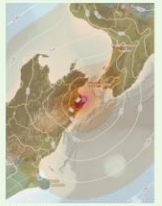

M7.4 Marlborough 1848

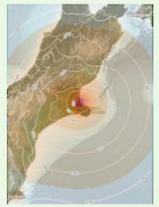
M 7.2 Cape Farewell 186


M 8.2 Wairarapa 1855


M 7.4 Napier 1931


M 7.2 Christchurch 2010


M 6.6 Grassmere 2013


M 6.2 Christchurch 2011


M 7.8 Kaikōura 2016

Experimental Dimensions

Varying sequencing and temporal spacing

A) SEQUENCING

(Order of events)

L M M — **Front loaded** (major event first)

M L M — **Central peak** (major event in middle)

M M L — **Back loaded** (major event last)

B) TIMING

(Event intervals)

Short interval (~6months)

Moderate interval (1-5 years)

Long interval (10-15 years)

Example Scenarios

(illustrative)

L M M
6 months apart, front loaded

M L M
2 years apart, central peak

M M L S
10 years apart, 4 event sequence

S M M L S
Variable intervals, 5 event sequence

S L M M
6 months apart, 4 event sequence

L S M S M
Variable intervals, 5 event sequence

Note: Magnitudes and other event characteristics will be kept constant from historical records.

Earthquake Sequence Scenarios

Example Scenarios
(illustrative)

L M M
6 months apart, front loaded

M L M
2 years apart, central peak

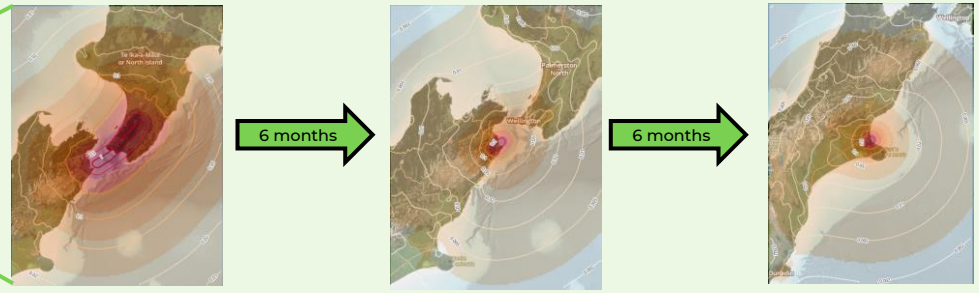
M M L S
10 years apart, 4 event sequence

S M M L S
Variable intervals, 5 event sequence

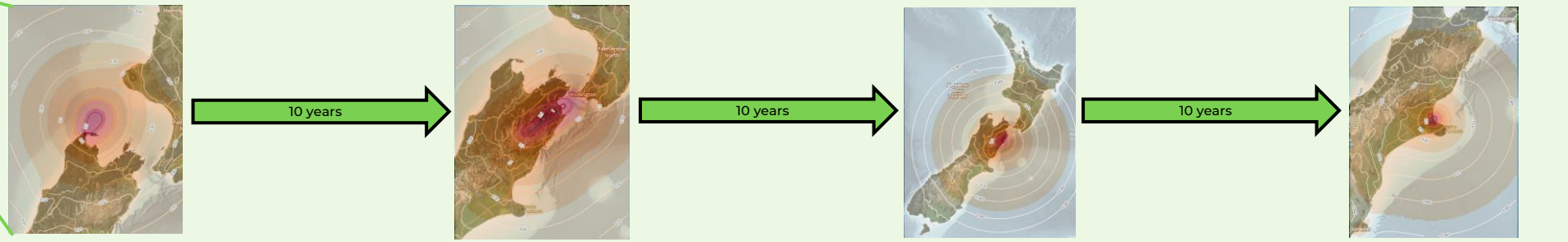
S L M M
6 months apart, 4 event sequence

L S M S M
Variable intervals, 5 event sequence

Note: Magnitudes and other event characteristics will be kept constant from historical records.



M 8.2 Wairarapa 1855 — M 6.6 Grassmere 2013 — M 6.2 Christchurch 2011



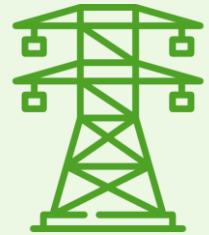
M 7.2 Cape Farewell 1868 — M 7.4 Marlborough 1848 — M 7.8 Kaikōura 2016 — M 6.2 Christchurch 2011

Infrastructure Vulnerability

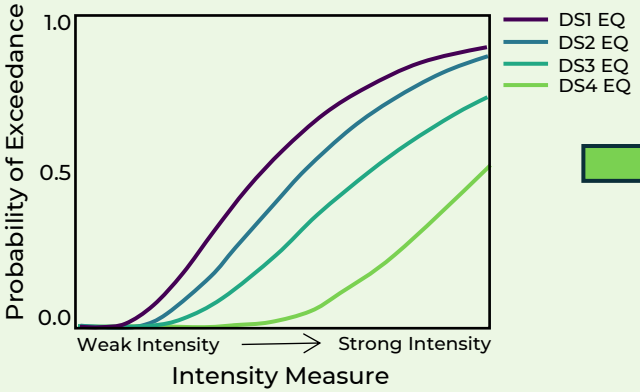
Transport

Telecoms

3 Waters



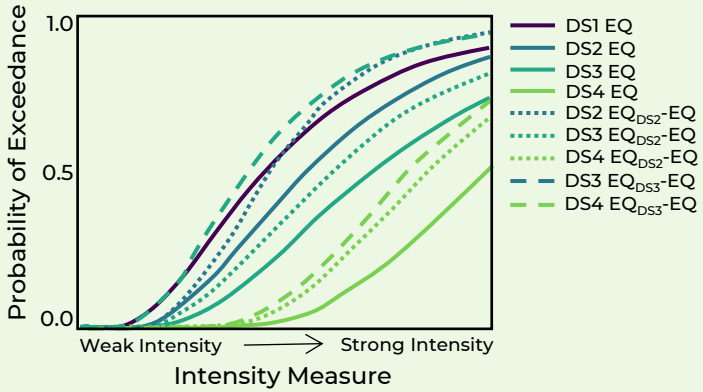
Electricity



Fragility functions

Baseline damage state assigned

Reclassified into updated damage states accounting for previous damage



(Sotiria et al., 2026)

Key Takeaways

Dynamic Risk Assessment

- Move from static to dynamic vulnerability
- Capture cumulative impacts across multiple events

Recovery Planning

- Understand consequences of interrupted recovery
- Support more realistic recovery trajectories

Telecoms	3 Waters	Electricity
222 days	260 days	89 days

Resilient Decision-making

- Support long term planning for regions exposed to successive damaging events
- Improve preparedness for cascading and compounding disruptions

Outputs feed directly into household and economic impact models, to drive preparedness within communities, iwi, businesses, infrastructure providers and government.

Thank you!

Any questions?

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