“Regional resilience” – A framework to assess impact from multiple infrastructure networks

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Risk & Engineering Team

RiskScape

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General framework

Hazard & Risk Models

- Vulnerability models
- Damage states

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Disruption and Outage Models

- Building functionality models
- Infrastructure outage models
- Interdependency models

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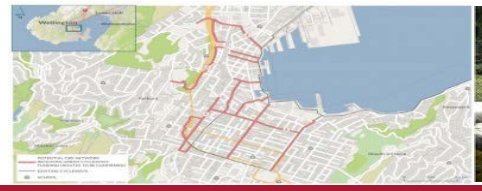
Socio-Economic Models

- MERIT (Economic Impact)
- SIH (Social Impact)





Risk to Recovery

Risk

RiskScape

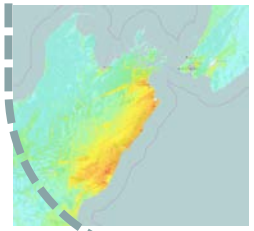
Hazard → Exposure/ Asset → Fragility/ Vulnerability → Impact

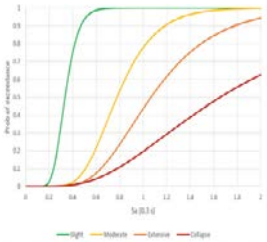
Earthquake, tsunami,flood ,volcano

Buildings, people, infrastructure

How hazards damage assets

Direct Damage, loss ($)





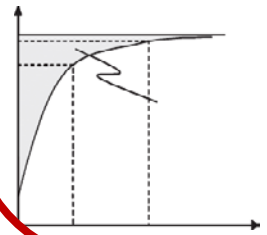
Recovery to full function

Restoration

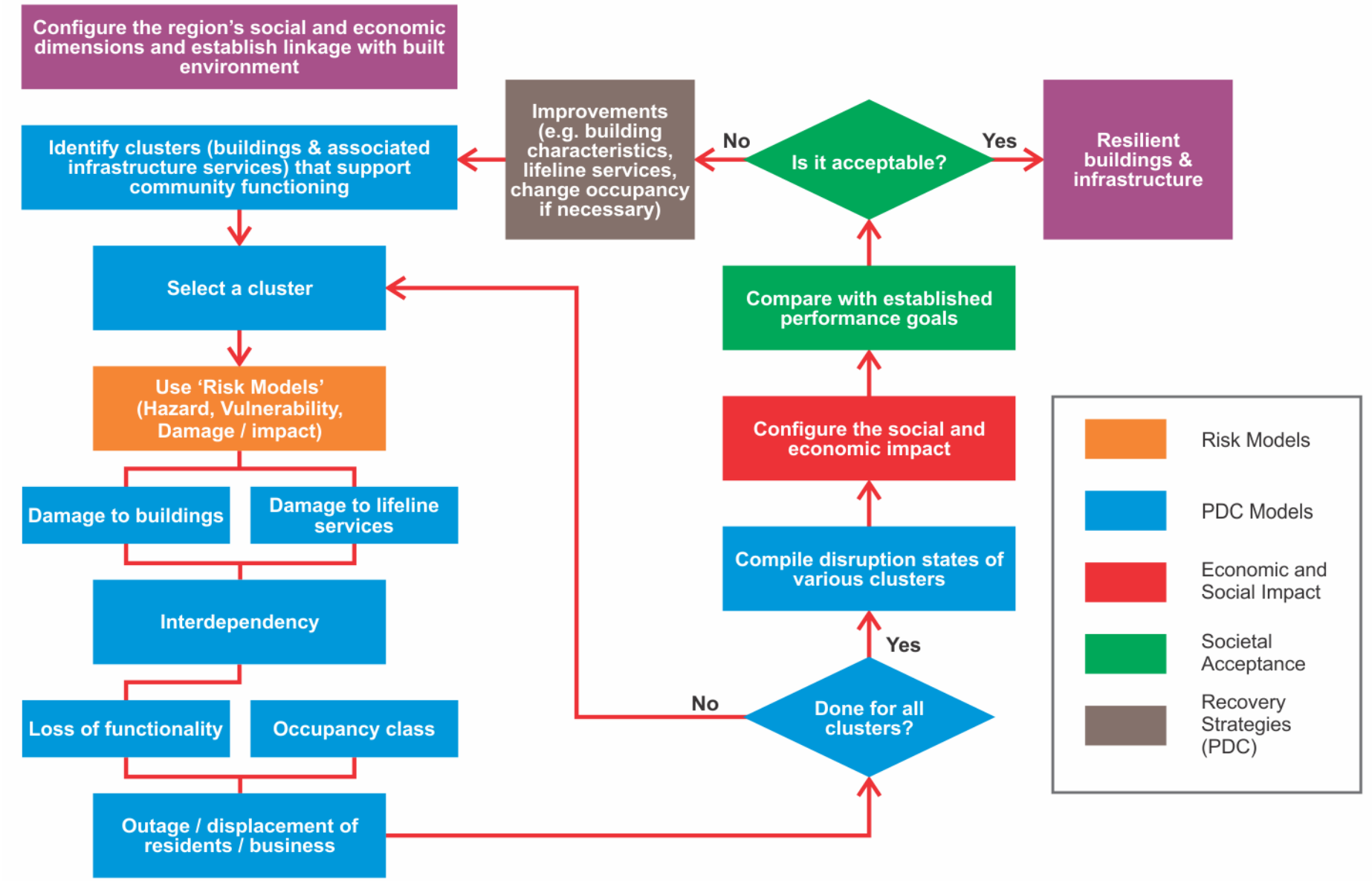
Temporal outage

How asset recovers

Time stamped outage/ functionality



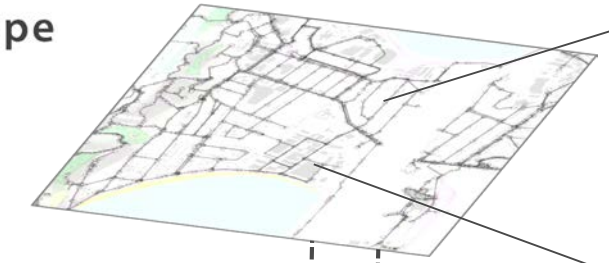
Regional Resilience framework



NIST National Institute of Standards and Technology U.S. Department of Commerce

RiskScape

Asset GIS Layer

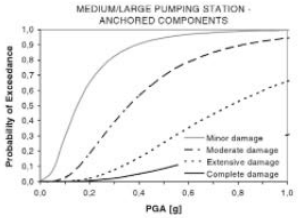


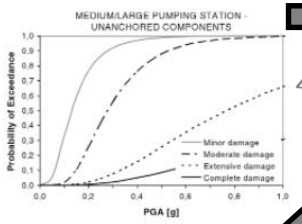
Asset Attributes

GXP Station #215
Lon: 174.33 Lat: -41.5
Building: Reinforced brick masonry
Components Anchored: Yes
……..

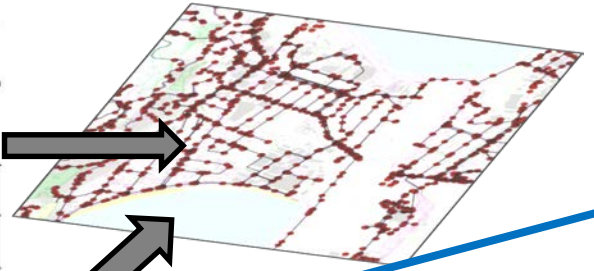
Sub Station #455
Lon: 174.23 Lat: -41.9
Building: Reinforced brick masonry
Components Anchored: No
……..

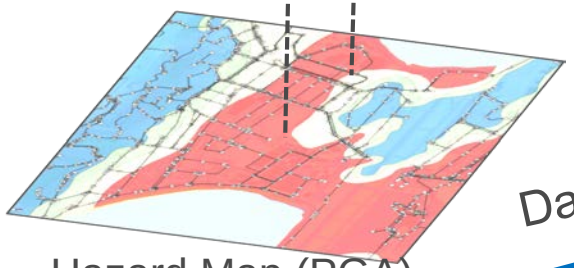
Asset Fragility





Component damage (T_n)





Hazard Map (PGA)

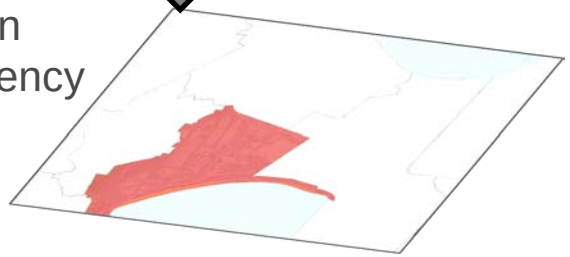
Damage & risk models

Service outage & recovery models

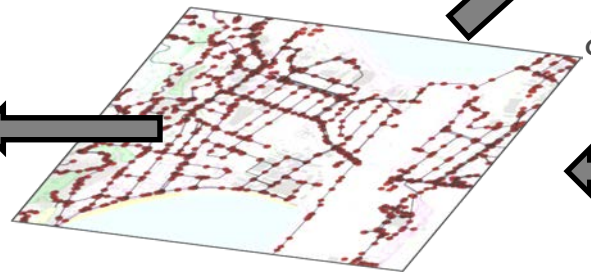
Network Intra-dependency

Restoration &Interdependency Model

EE Workshops / Models (NZ & Intl)



Network Outage Map (T_n)



Building damage → Safe and functional buildings identified

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Wellington Resilience – Programme Business Case

Modelled Infrastructure

- **Roads** **(Vinod Sadashiva)**
- Rail (Vinod Sadashiva)
- **Electricity** **(Sheng-Lin; SR Uma; Yasir, Syed)**
- **Fuel** **(SR Uma)**
- Telecommunications (Sheng-Lin; SR Uma)
- **Potable Water** **(Mostafa Nayyerloo, Rob Buxton)**
- Waste Water (**Mostafa Nayyerloo, Rob Buxton)**
- Gas (Nick Horspool)
- Port (Andrew King)
- Airport (Andrew King)

Hazards considered

- Fault rupture
- Shaking
- Liquefaction and Lateral Spread
- Landslide
- Co-seismic subsidence

Hazard

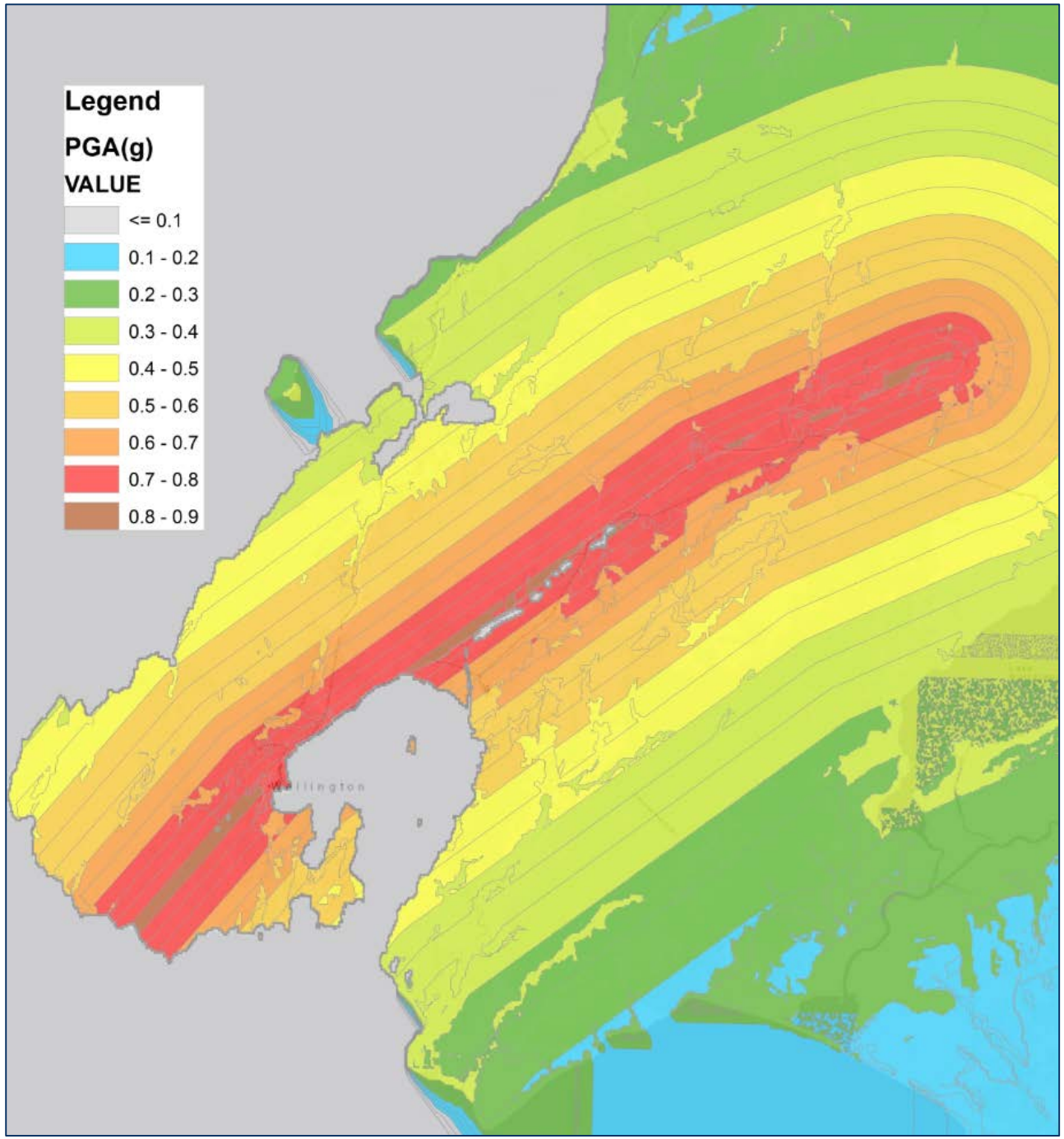
Fault Rupture

Perrin & Wood (2003)

Beetham et al. (2012

Hazard

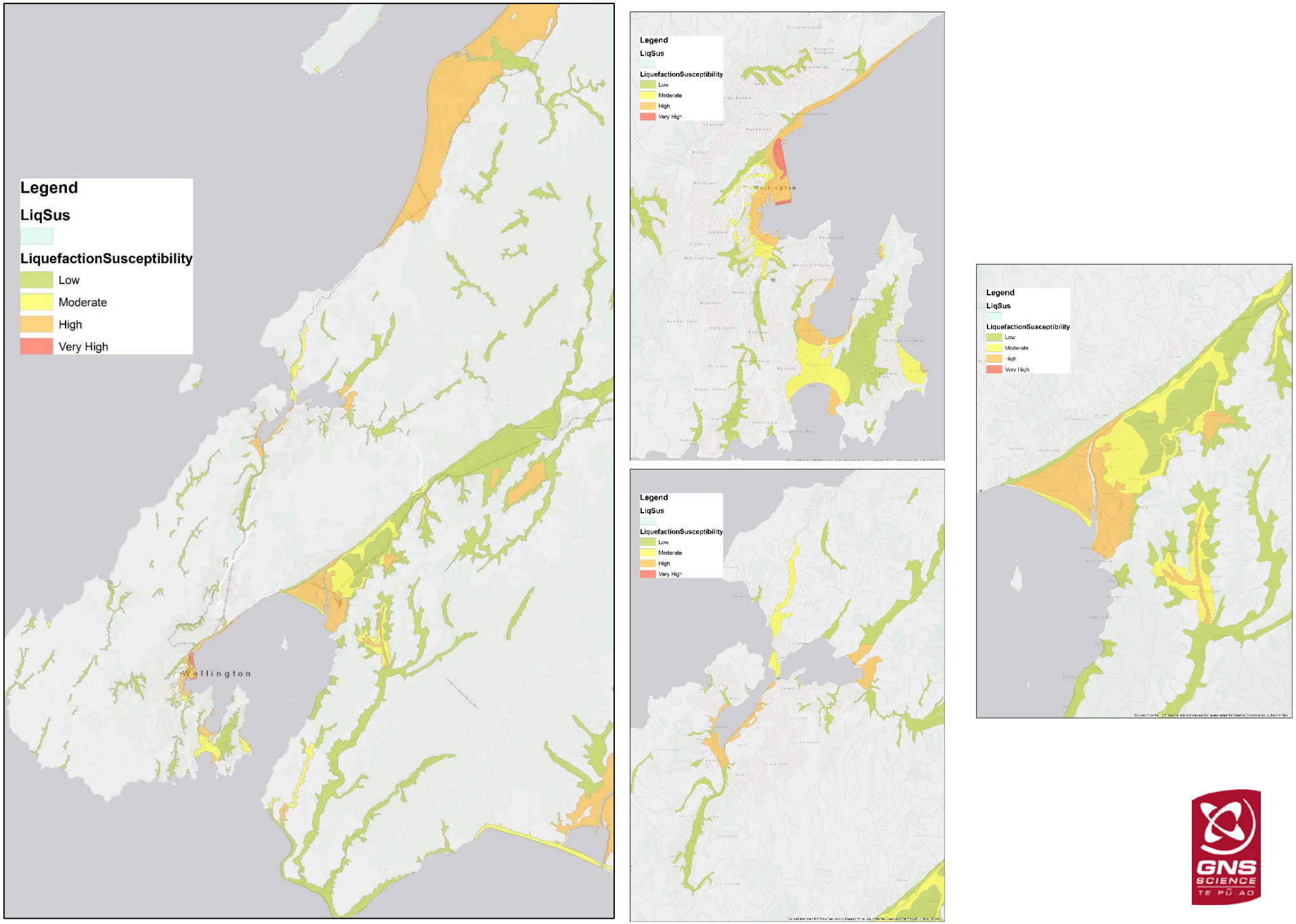
Ground Shaking



Horspool et al. (2015)

Hazard

Liquefaction

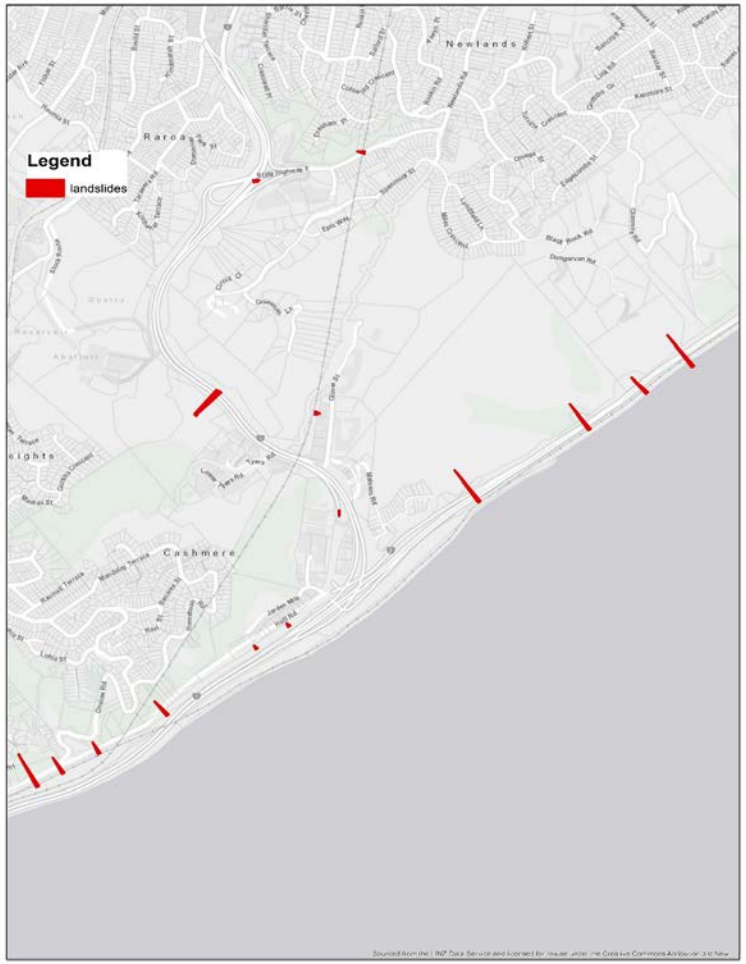


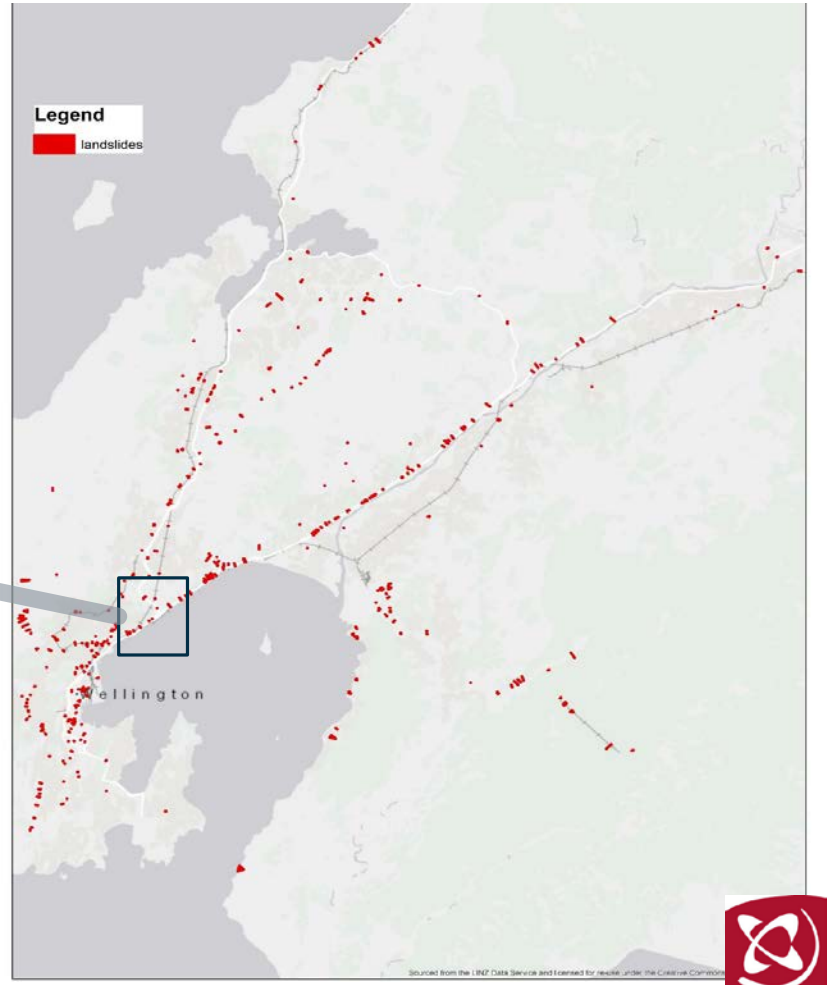
Dellow et al. (2017)

Hazard

Landslide

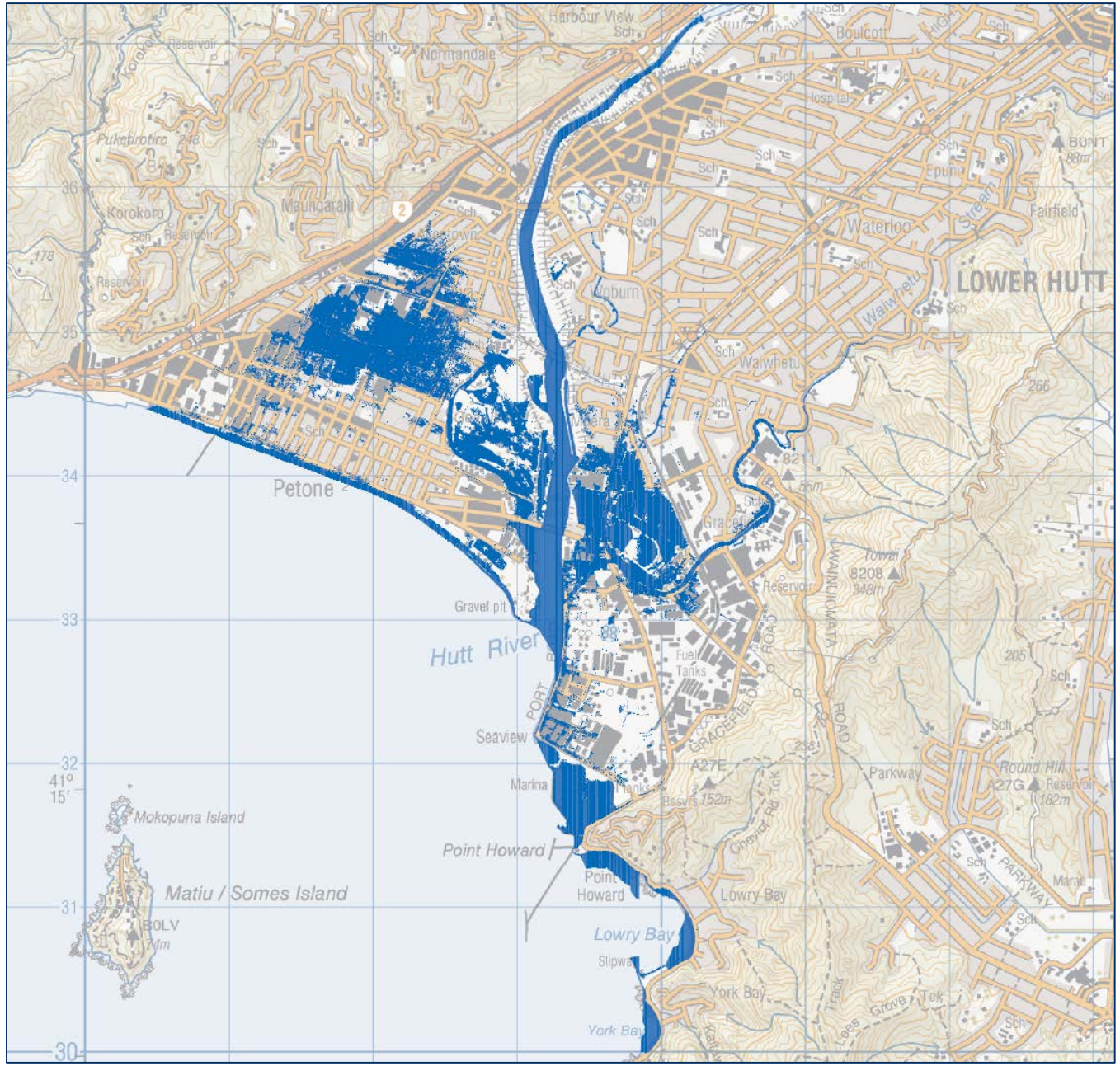
Landslides are explicitly modelled within the project. Slopes in Wellington have been mapped and assigned a probability of failure (and size of failure) given a level of PGA. These are then modelled stochastically based on the input PGA map provided from the ground shaking model. This is modelled from the GNS-NZTA Road Risk Evaluation Tool (Sadashiva et al. 2017).





Hazard

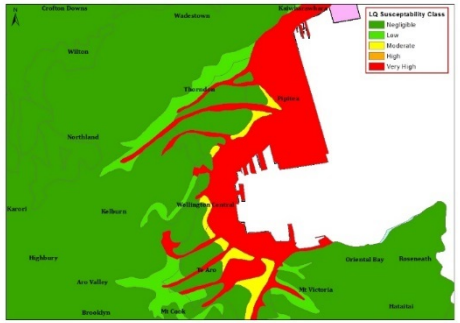
Co-seismic Subsidence

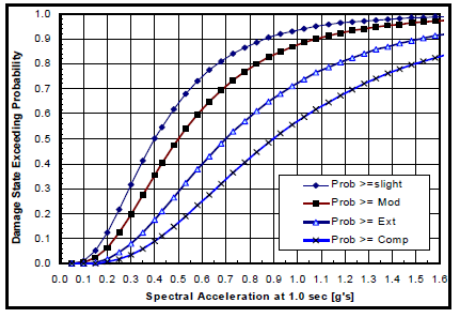


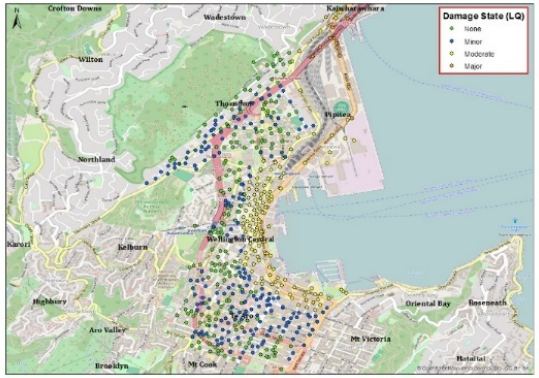
Townsend et al. (2015)

Risk Modelling: Road Network

Exposure + **Hazard** + **Fragility** → **Consequence**







- Transport disruption
- Freight / Business disruption
- Direct and indirect economic loss
- Casualty and fatalities
- Restoration of other services etc.

Exposure Data

One Network Road Classification (ONRC) – developed by local Govt. & NZTA

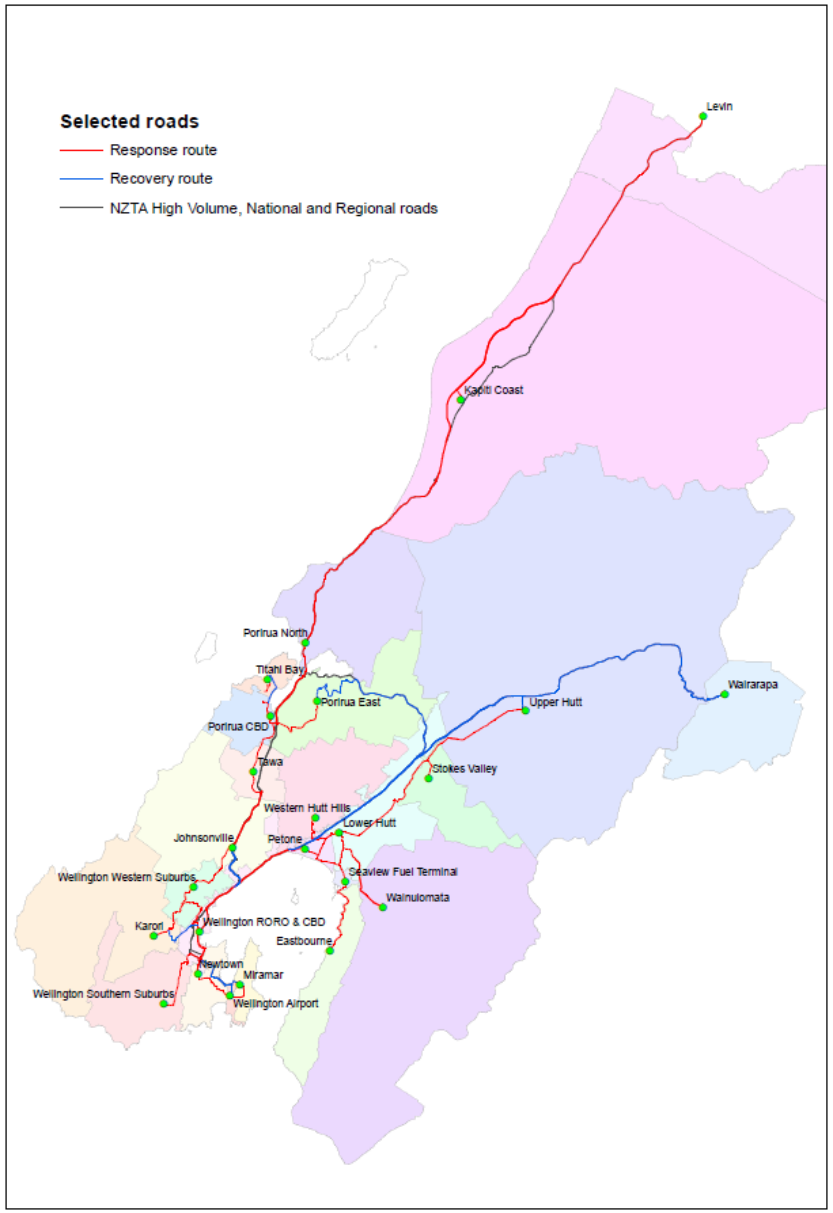
Roads categorised based on how busy they are, connectivity to key destinations, availability of alternate routes:

- National – link major population centres and transport hubs
- Arterial – link regionally significant places and industries
- Regional – major connectors between and within regions; often public transport routes
- Primary collector – link significant local populations and industries
- Secondary collector – provide secondary routes, can be the only route to some places
- Access – small roads facilitating daily activites

https://nzta.govt.nz/roads-and-rail/road-efficiency-group/onrc/

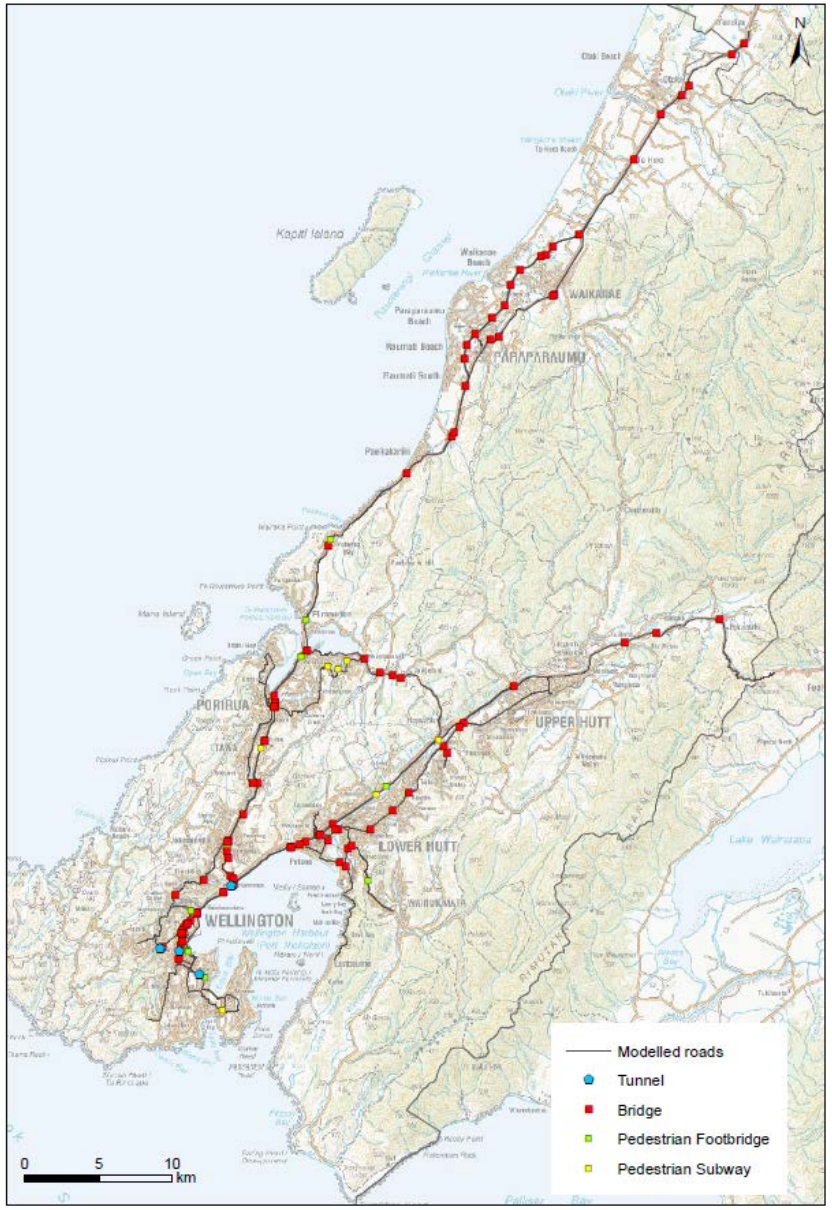
Exposure Data

- 24 transportation zones defined
- Routes between zones likely to be first open for two levels of service (response and recovery)
    - All National, High Volume and Regional roads in study area
    - Some Arterial and Collector roads included



Exposure Data

- Network data from NZTA, WCC, HCC, UHCC, PCC, KCDC
- GIS layer identifying road centreline and carriageway details (width, number of lanes, traffic counts etc.)
- GIS layer locating structures along selected routes. Assets information collected to assist with damage assessment for:
    - Bridge structures
    - Tunnels
    - Retaining walls
- Network segmented: Average length of a segment (approx.) ≈ 200m

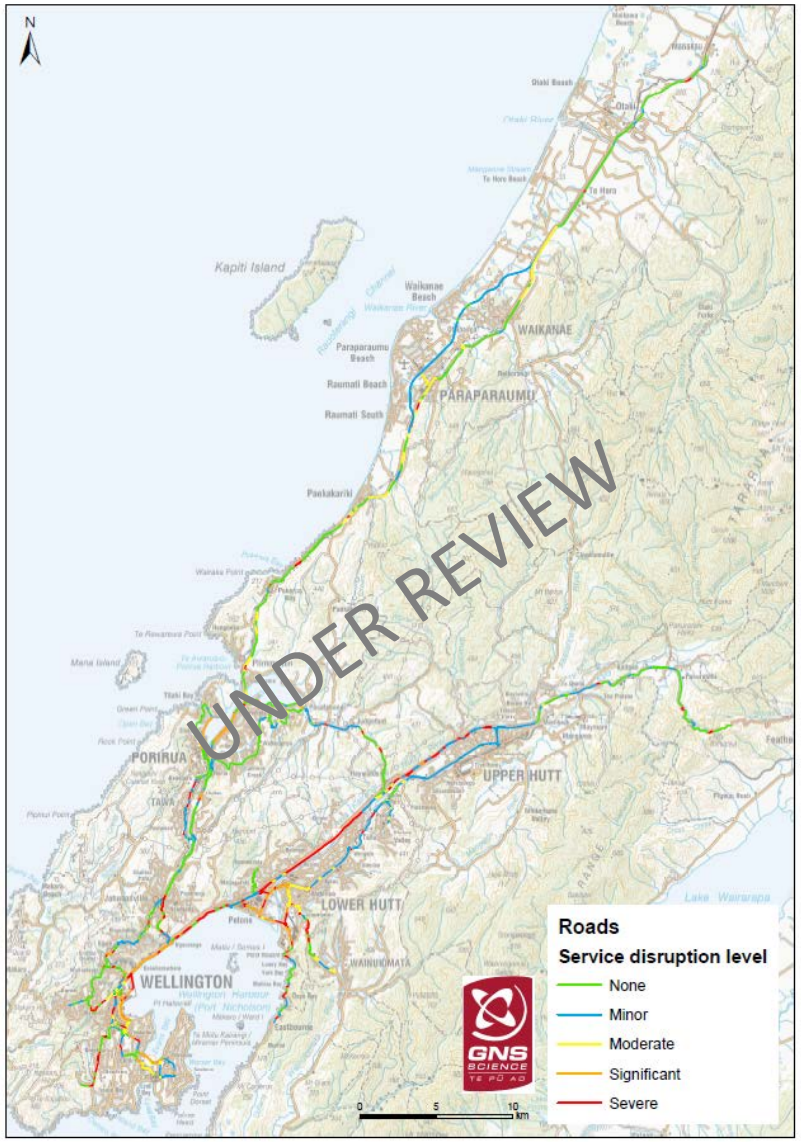


Fragility

Service Disruption Level (SDL)	Disruption State	Percent Functional	Extent of damage affecting	Likely damage characteristics
SDL0	None	100	None	None
SDL1	Minor	90	Fringe / shoulder	Requiring visual inspection & "patch-up" / clearing / cosmetic nature works due to any of following: (a) Debris deposition; (b) Slight settlement or minor offset of ground; (c) Minor damage to protection works such as a seawall; or (d) Minor abutment settlement, bridge expansion joint & bearing showing movement, hairline cracking and spalling to bridge elements / tunnel liner
SDL2	Moderate	75	Single lane	Requiring visual inspection & moderate amount of clearing works / repairing components (as required) due to any of the following: (a) Moderate volume of debris deposition; (b) Moderate settlement or ground offset; or (c) Cracking and spalling of bridge piers / tunnel liner exposing core, abutment backwall / wing wall cracking, anchor bolt damage, extensive cracking and spalling of shear keys, damage to restrainers, moderate offset of bearings
SDL3	Significant	50	Several lanes	Requiring detailed inspection & moderate-to-significant repair / stabilisation works, some rebuild / replacement may be required due to any of the following: (a) Significant volume of debris deposition, significant structural damage or collapse of short-medium high retaining walls; (b) Ripple distortion or loss of foundation support of carriageway; or (c) Bridge structural significantly compromised, tilting of substructure, approach slab rotation, joint seal failure, large spalls due to pounding, significant cracking and spalling in piers / abutment walls, large approach settlements, major ground settlement at a tunnel portal and/or extensive cracking of the tunnel liner
SDL4	Severe	< 50	Complete road closure	Requiring detailed inspection & significant repair / stabilisation works, most likely rebuild / replacement required due to any of the following: (a) Significant volume of debris / ashfall deposition; (b) Major settlement of ground; or (c) Bridge components damaged beyond repair, loss of bearing support / one or more spans dropped, foundation failure, excessive tilting and movement of abutments, culverts scoured, major cracking of tunnel liner which may include possible collapse, complete failure of a steep and / or a high retaining wall

Sadashiva, V.K.; King, A.B.; Matcham, I. 2017. Exploring a risk evaluation tool for New Zealand State Highway network national resilience project. Paper No. 3957. 16th World conference on earthquake engineering, Chile.

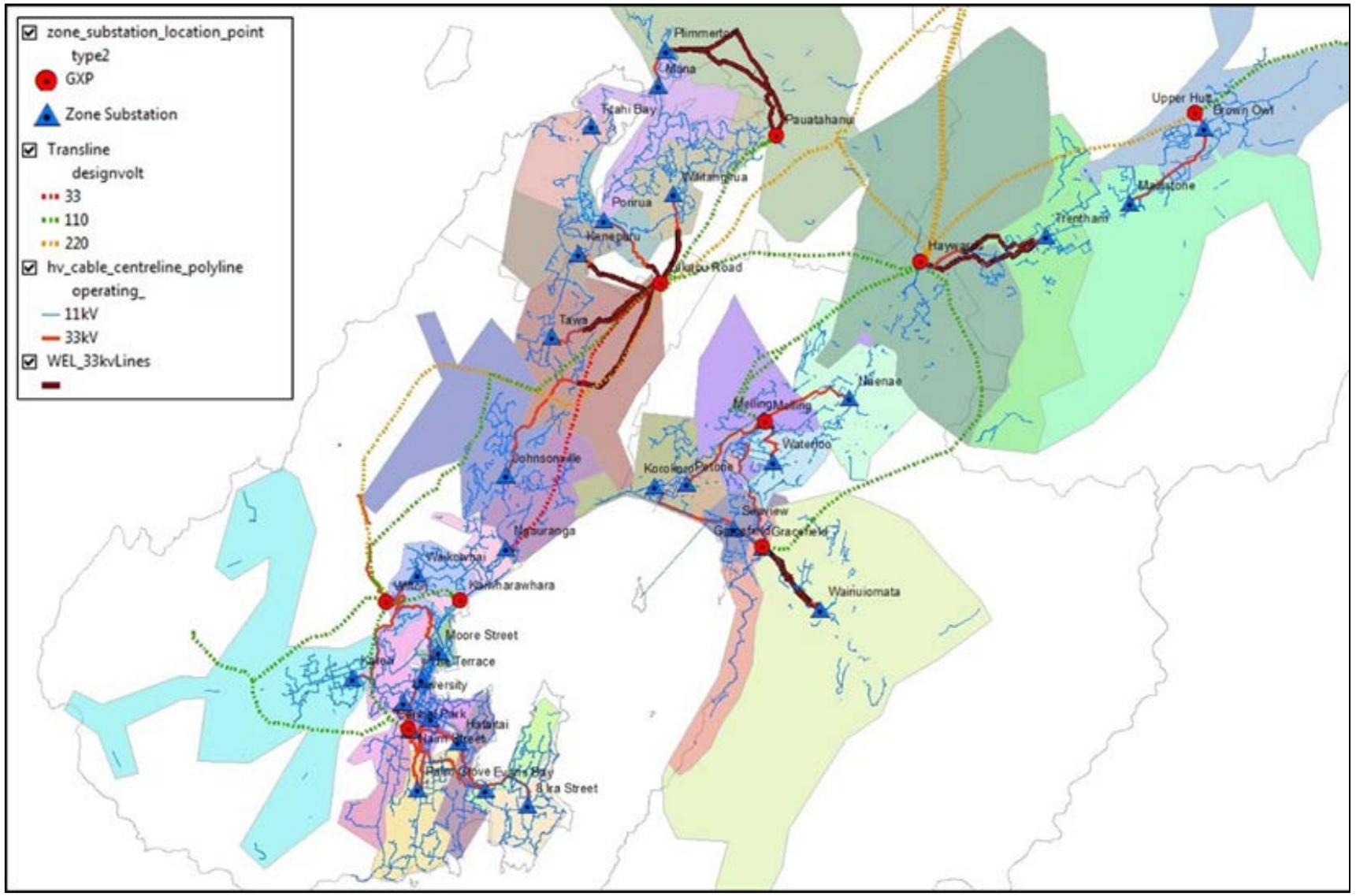
Road Network Service Disruption



Service disruption levels displayed at a segment level

At each road segment: critical (maximum) disruption state from all assets and perils reported

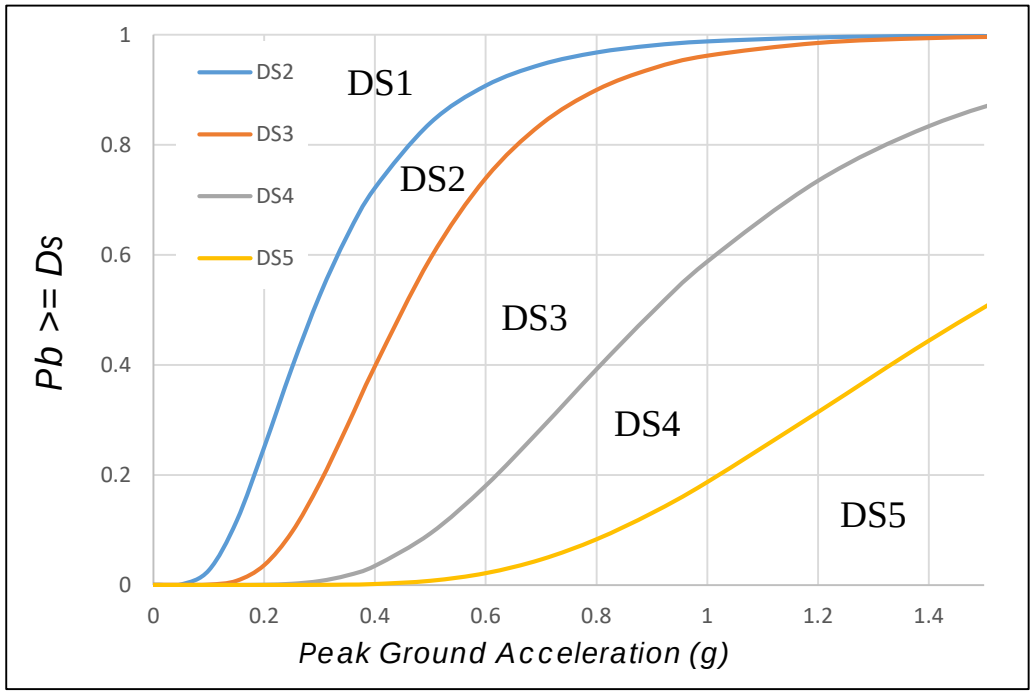
Electricity



- 33 kv Cables
- Zone Substation
- Grid Exit Point (GXP)
- Transmission Structures

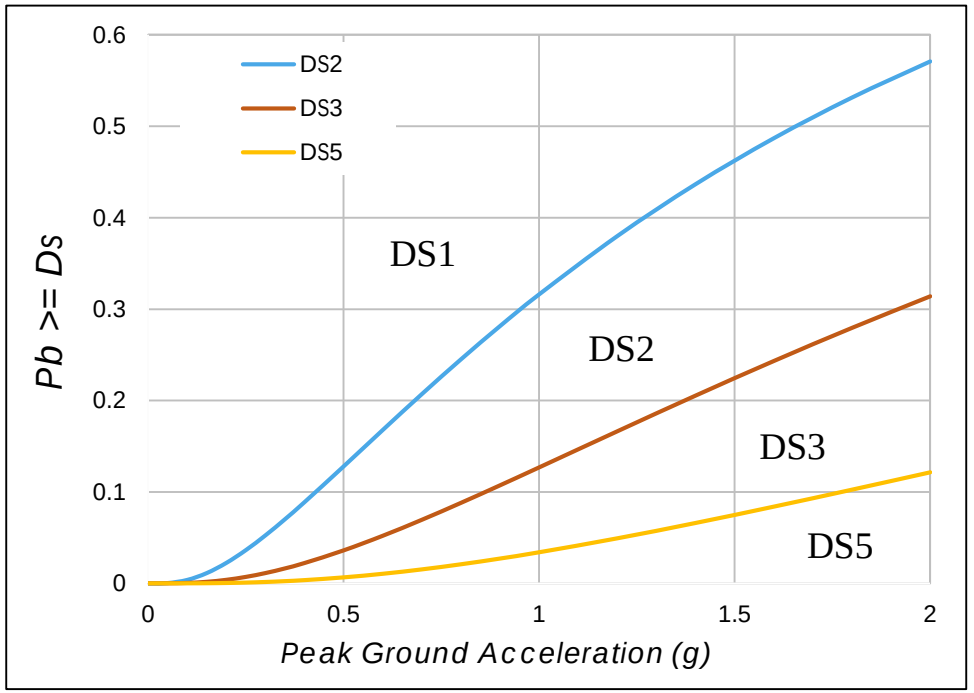
Electricity Vulnerability

Low Voltage Substation with Anchored Components



National Institute of Building Sciences (NIBS) 2003, "HAZUS-MH Technical Manual", NIBS, Washington, DC

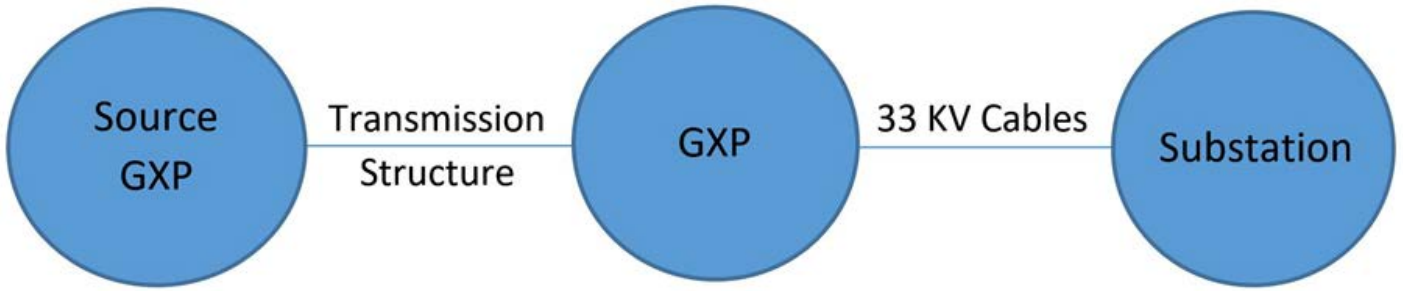
Transmission Structures



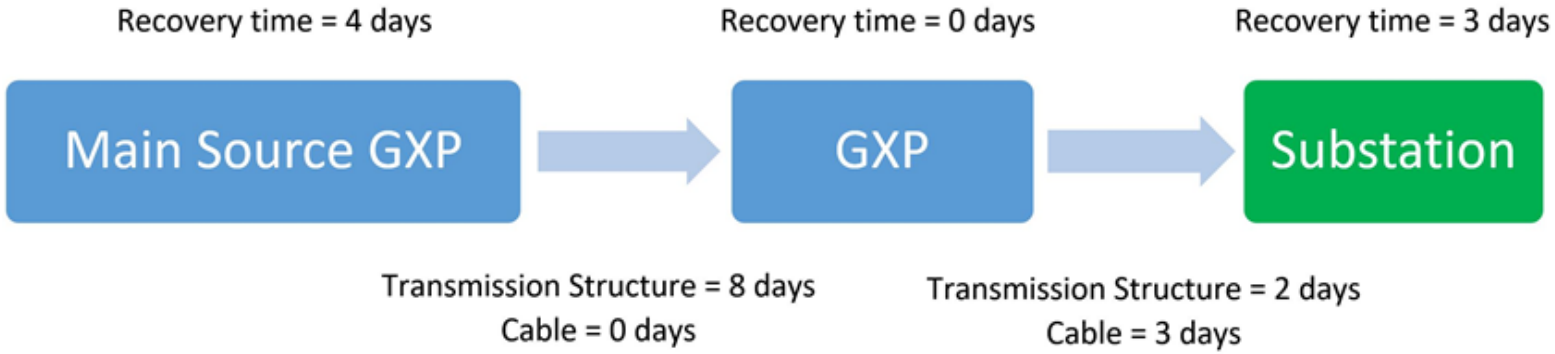
L. Xie, J. Tang, H Tang, Q. Xie and S. Xue 2012, "Seismic Fragility Assessment of Transmission Tower via Performance-based Analysis"

Outage
Electricity

a) Establish Connectivity

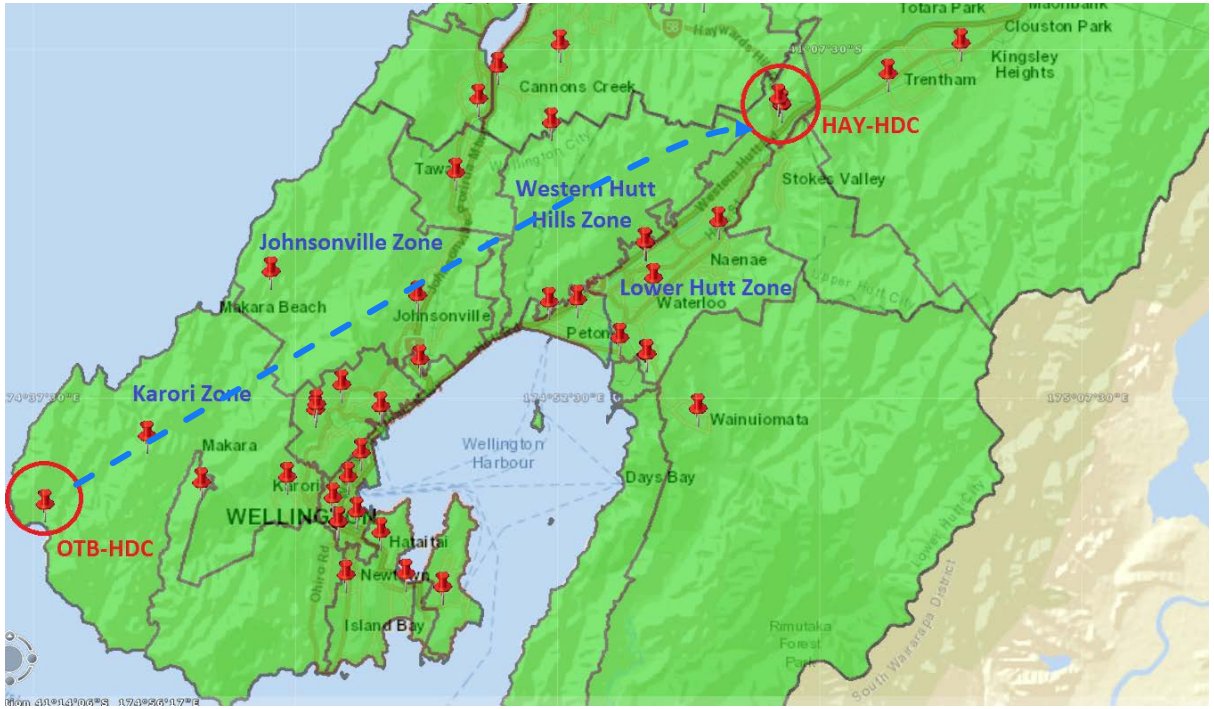


b) Apply Intra-dependent Restoration Times



Outage
Electricity

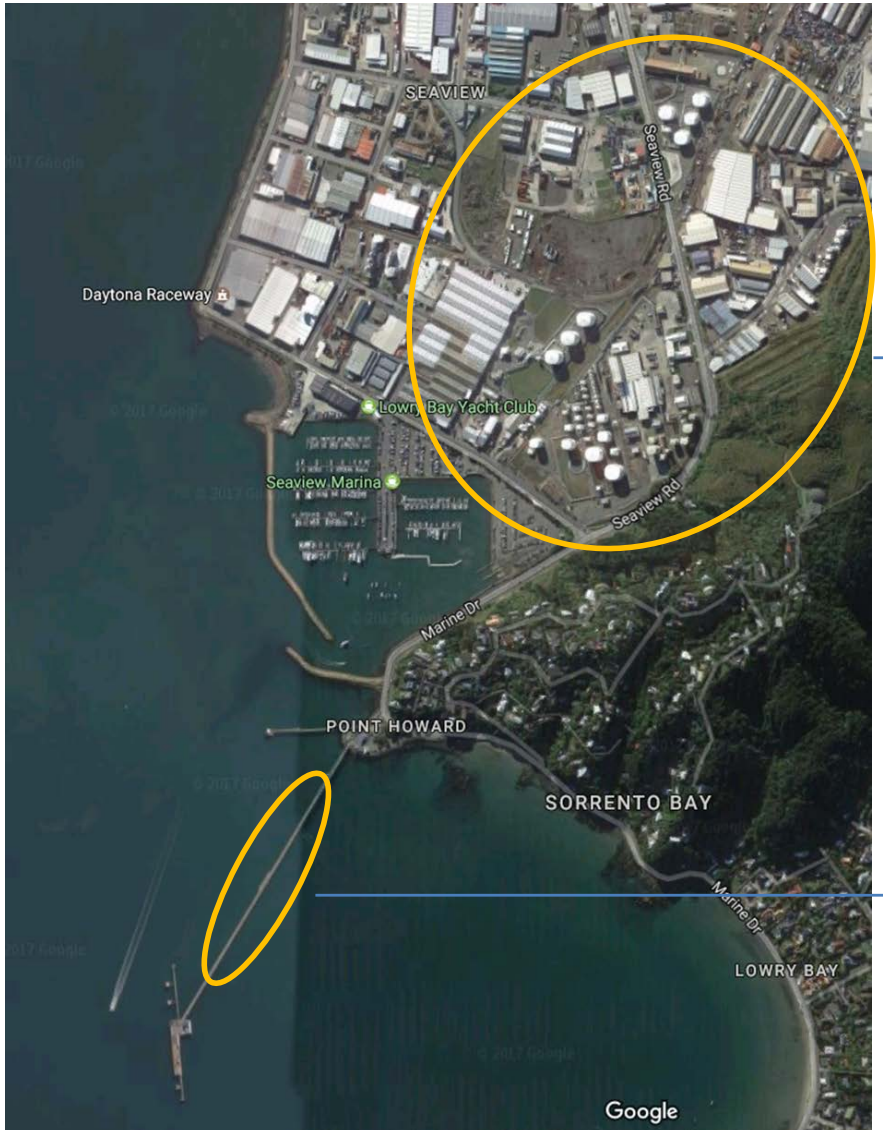
c) Add Interdependencies including Roads



OTB → HAY → GFD → SEA

GXP Recovery = 4 Days Road Zone Time = 90 Days	GXP Recovery = 0 Days Road Zone Time =0 Days	GXP Recovery = 0 Days Road Zone Time = 0 Days	SS Recovery = 3 Days Road Zone Time = 0 Days

Fuel Assets: Seaview



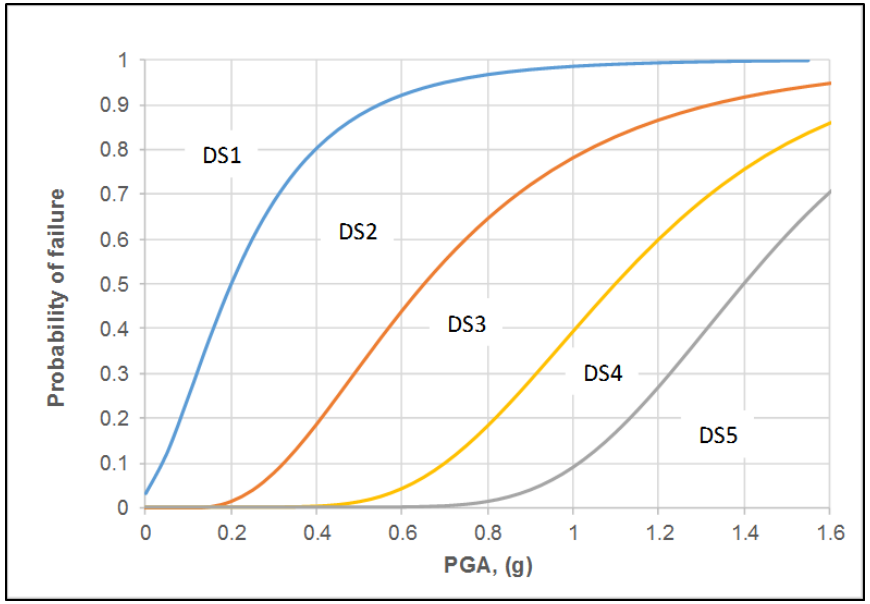
Oil tank farms

Wharf and pipeline

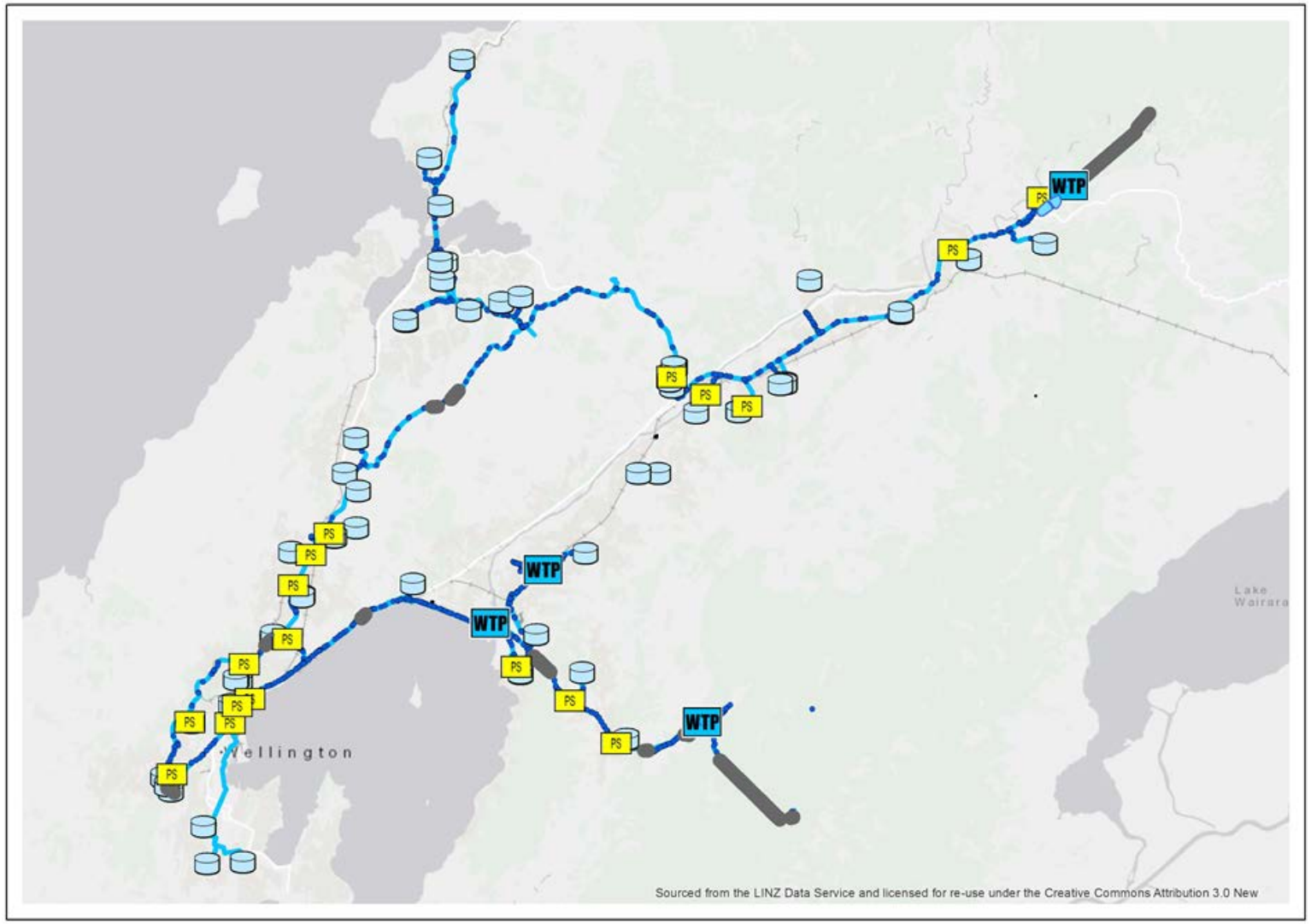
Fuel Considerations

1. *The hazard at Seaview site*
2. *The characteristics of the tank farm site*
3. *The performance of tanks*
4. *Liquefaction damage*
5. *Damage to berthing structure*
6. *Damage to Wharf*
7. *Road access to Seaview site from nearby road zones*

Ground Shaking fragility of oil storage tanks



Potable Water



- Water Treatment Plants
- Pumping Stations
- Wells
- Tunnels
- Transmission (Bulk) Pipes
- Distribution Pipes
- Reservoirs (Storage Tanks)

Potable Water Vulnerability

Transmission Pipes

$$BR\ (km) = K1 * K2 * K3 * K4 * K5 * RR_{GS}$$

Factor	Name	Conditions	Value
K1	Pipe Material Factor	Cast-Iron	2
K2	Coupling Age Factor	Couplings more than 50 years old	2
K3	Size Factor	Diameter < 400 mm	4
K4	Landslide Hazard Factor	Moderate	3
		High	9
		Extreme	27
K5	Liquefaction Hazard Factor	Moderate	3
		High	9
		Extreme	27

(Function assumes K value of 1 unless specified in table)

Cousins, W. J. (2013). Wellington without water – Impacts of large earthquakes. GNS Science Report 2012/30. 124p.

Distribution Pipes

Liquefaction or lateral spreading exposure

LSN	Ductile Mains BR (km)	Non-ductile Mains BR (km)	Ductile Submains BR (km)	Galvanised Iron Submains BR (km)
0-16	0.11	0.58	0.23	2.26
16-25	0.42	1.80	0.46	5.21
25+	0.61	2.21	0.62	5.49
Lateral Spreading	2.57	5.65	1.88	9.30

Pipe Class	a	b
Ductile Mains	3.10e-11	10.116
Non-ductile Mains	8e-11	10.116
Ductile Submains	3e-9	8.3389
Non-ductile Submains	7.75e-9	8.3389
Galvanised Iron Pipes	2e-9	9.4409

Ground shaking only

$$BR\ (km) = a \times MMI\ b$$

Nayyerloo, M.; Sherson, A.K. 2016. Seismic Performance of Underground Pipes during the Canterbury Earthquake Sequence, GNS Science Report [in preparation]

Acknowledgements

- Infrastructure providers
- Councils
- Wellington Resilience Project Team (GNS Science)
  - Michele Daly
  - Emily Grace
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  - Mostafa Nayyerloo
  - Rob Buxton
  - Andrew King
  - James Williams
  - Yasir Syed
  - David Heron
  - Biljana Lukovic

Thank You!

Any Questions?

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