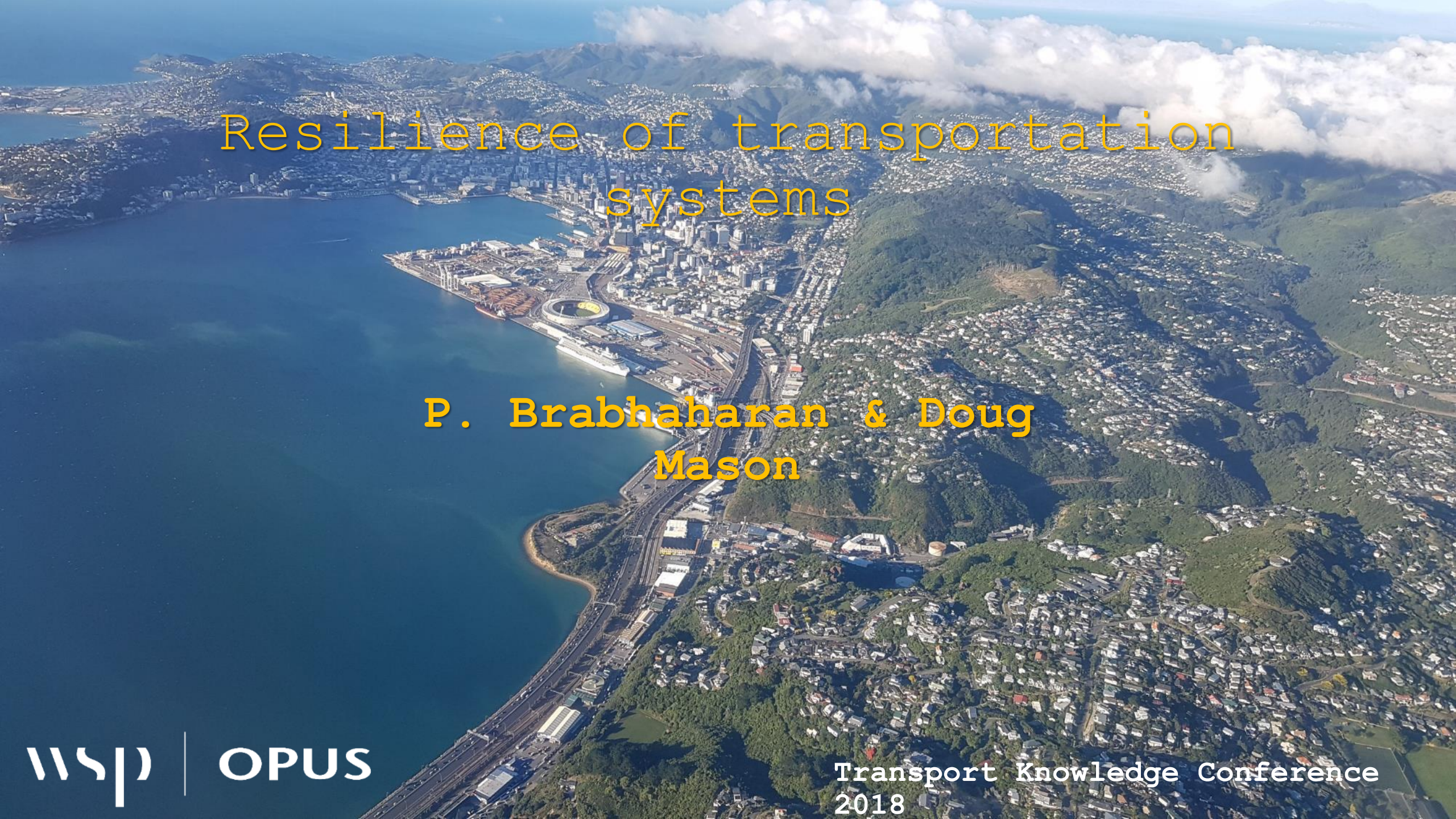




Resilience of transportation systems

P. Brabhakaran & Doug
Mason

High impact – low frequency



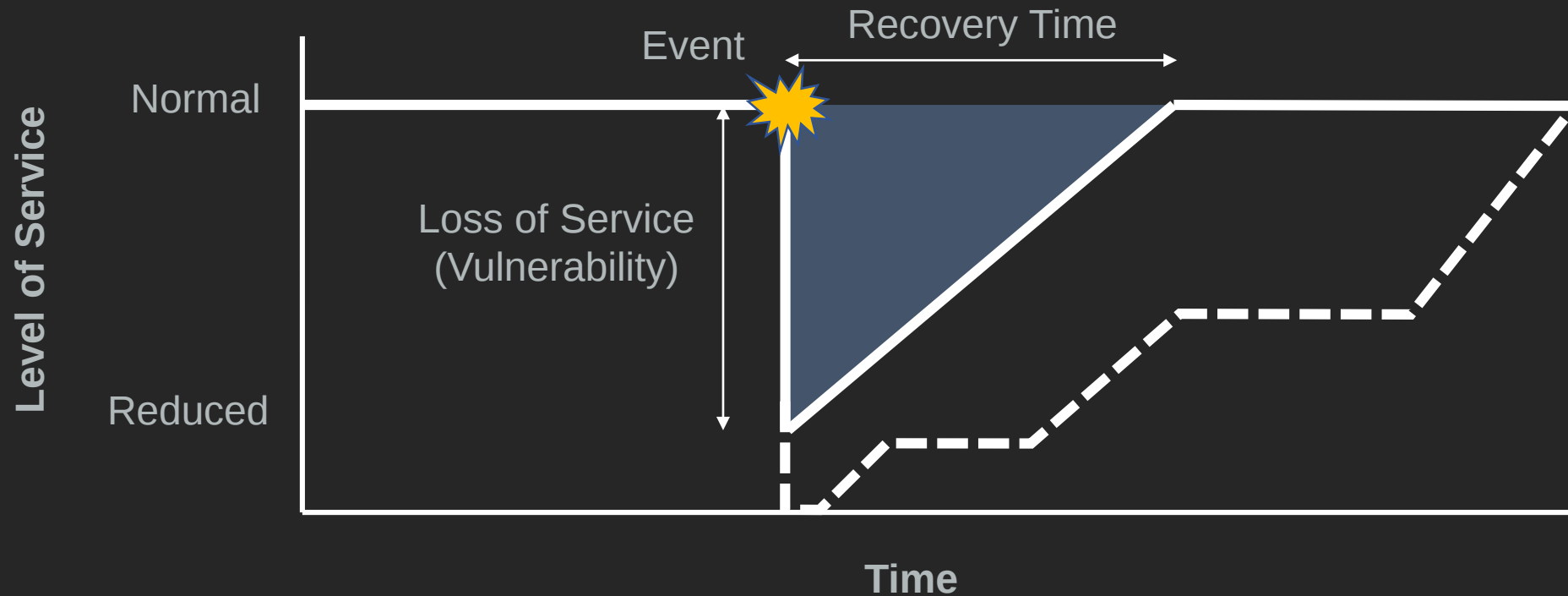
2016 Kaikōura earthquake

Lower impact - higher frequency



Resilience

- *Ability to recover quickly and resume original service after damage*



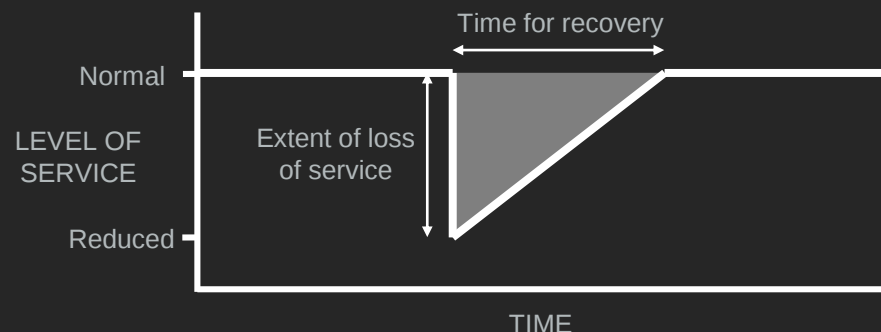
Resilience metrics

Availability State

Level	State	Description
1	Full	Full access except condition may require care.
2	Poor	Available for slow access, but with difficulty by normal vehicles due to partial lane blockage, erosion or deformation.
3	Single lane	Single lane access only with difficulty due to poor condition of remaining road.
4	Difficult	Road accessible single lane by only 4x4 off road vehicles.
5	Closed	Road closed and unavailable for use.

Outage State

Level	State	Description
1	Open	No closure, except for maintenance
2	Minor	Condition persists for up to 1 day
3	Moderate	Condition persists for 1 day to 3 days
4	Short term	Condition persists for 3 days to 2 weeks
5	Medium term	Condition persists for 2 weeks to 2 months
6	Long term	Condition persists for 2 months to 6 months
7	Very long term	Condition persists for greater than 6 months



Resilience metrics

Disruption

Outage State

Availability State

	Open	< 1 day	1-3 days	3 days - 2 weeks	2 weeks - 2 months	2-6 months	>6 months
Full	None	None	None	None	None	None	None
Poor	None	Limited	Limited	Limited	Moderate	High	High
Single Lane	None	Limited	Limited	Moderate	High	Severe	Extreme
Difficult	None	Limited	Limited	Moderate	High	Severe	Extreme
Closed	None	Limited	Moderate	High	Severe	Extreme	Catastrophic

- **National state highway assessment**

Objectives

- Assess the resilience of the whole state highway network.
- Assess at a broad brush high level, efficiently and quickly.
- Assess resilience to large natural hazard events.
 - Large earthquake
 - Large storm / flooding
 - Tsunami
 - Volcanic eruption
- Use a consistent basis applied across the country.



Methodology

- Develop resilience metrics
- Gather national data
- Identify hazard impacts of relevance
- Characterise road corridors
- Capture into GIS & prepare resilience maps
- Assessment of key resilience issues



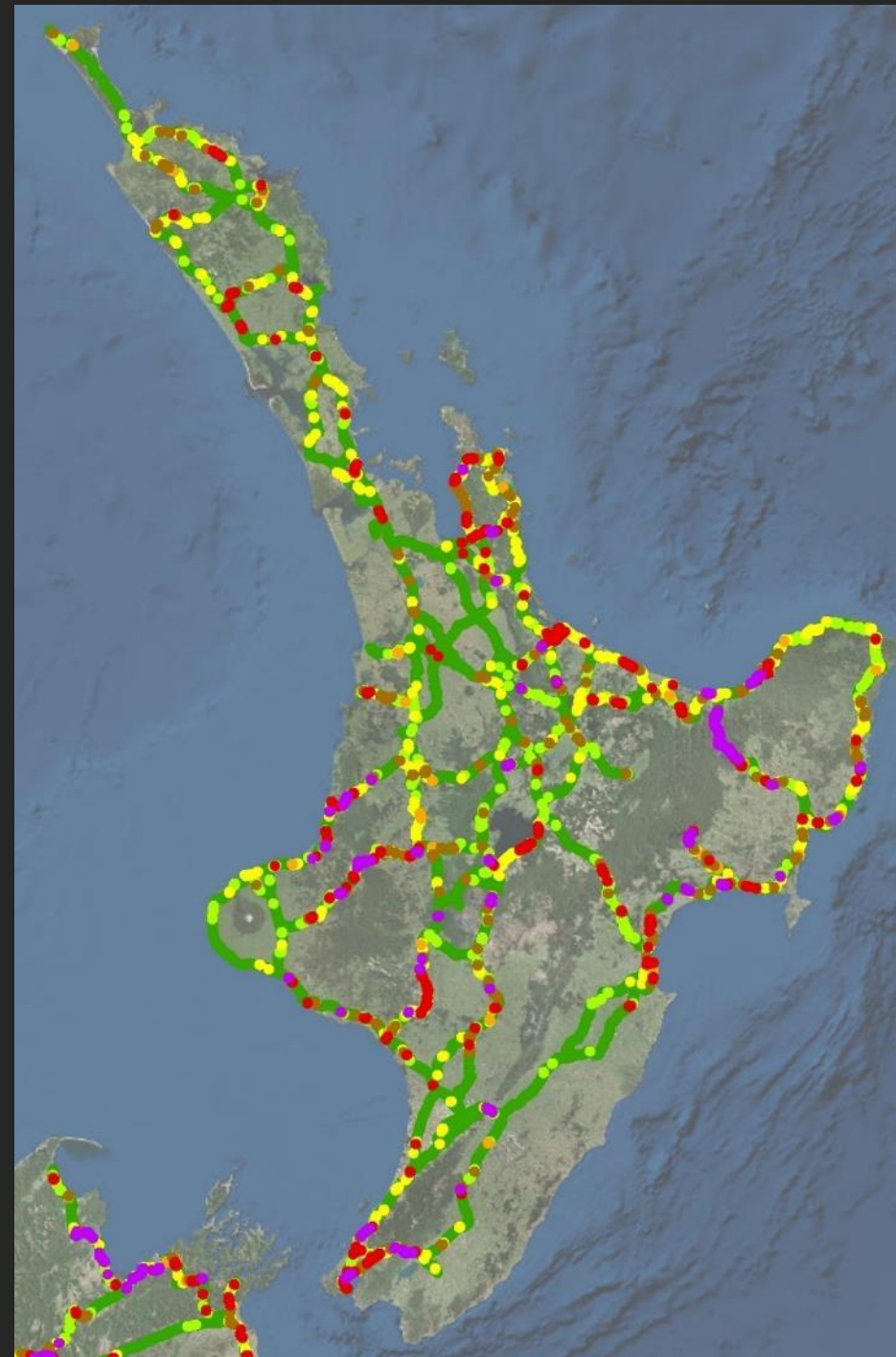
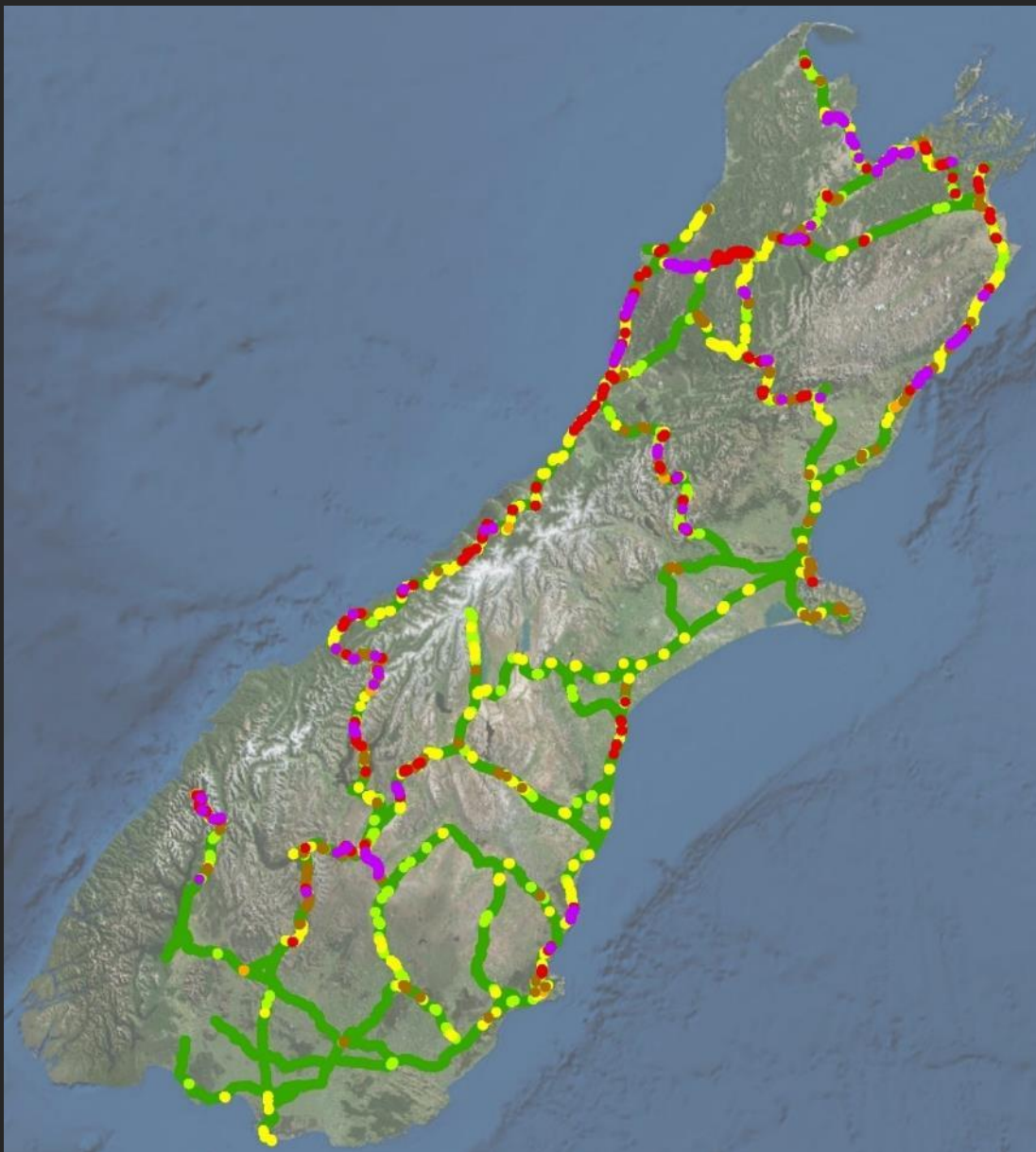
Road characterisation

1. Characterise road corridor into categories
 - Terrain
 - Geology
 - Hydrology
 - Hazards
 - Road environment
2. Assess type & extent of potential hazard impacts for road categories, and typical duration of repair
3. Apply metrics of availability & outage to hazard impacts
4. Assign to road categories



Resilience maps – earthquake

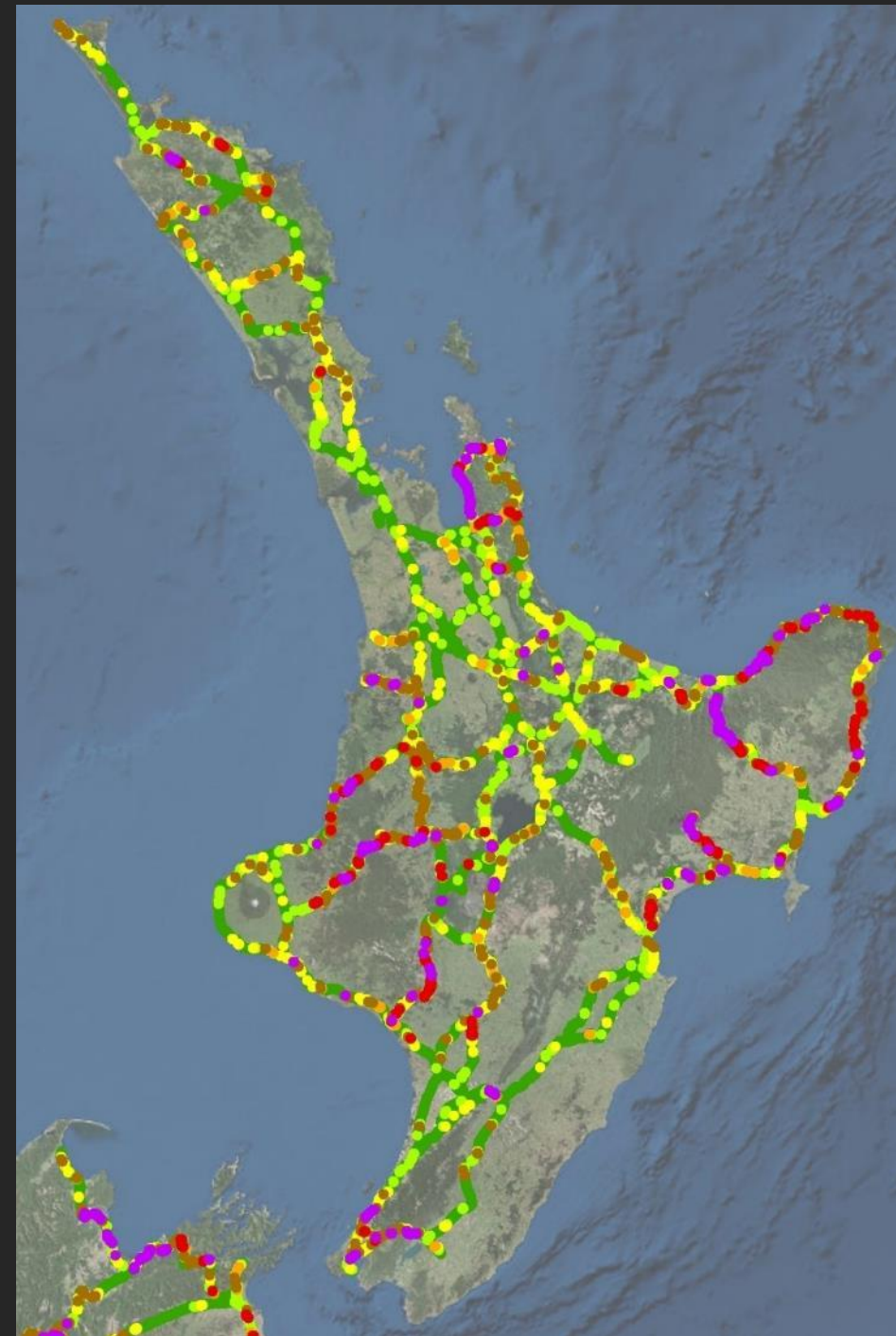
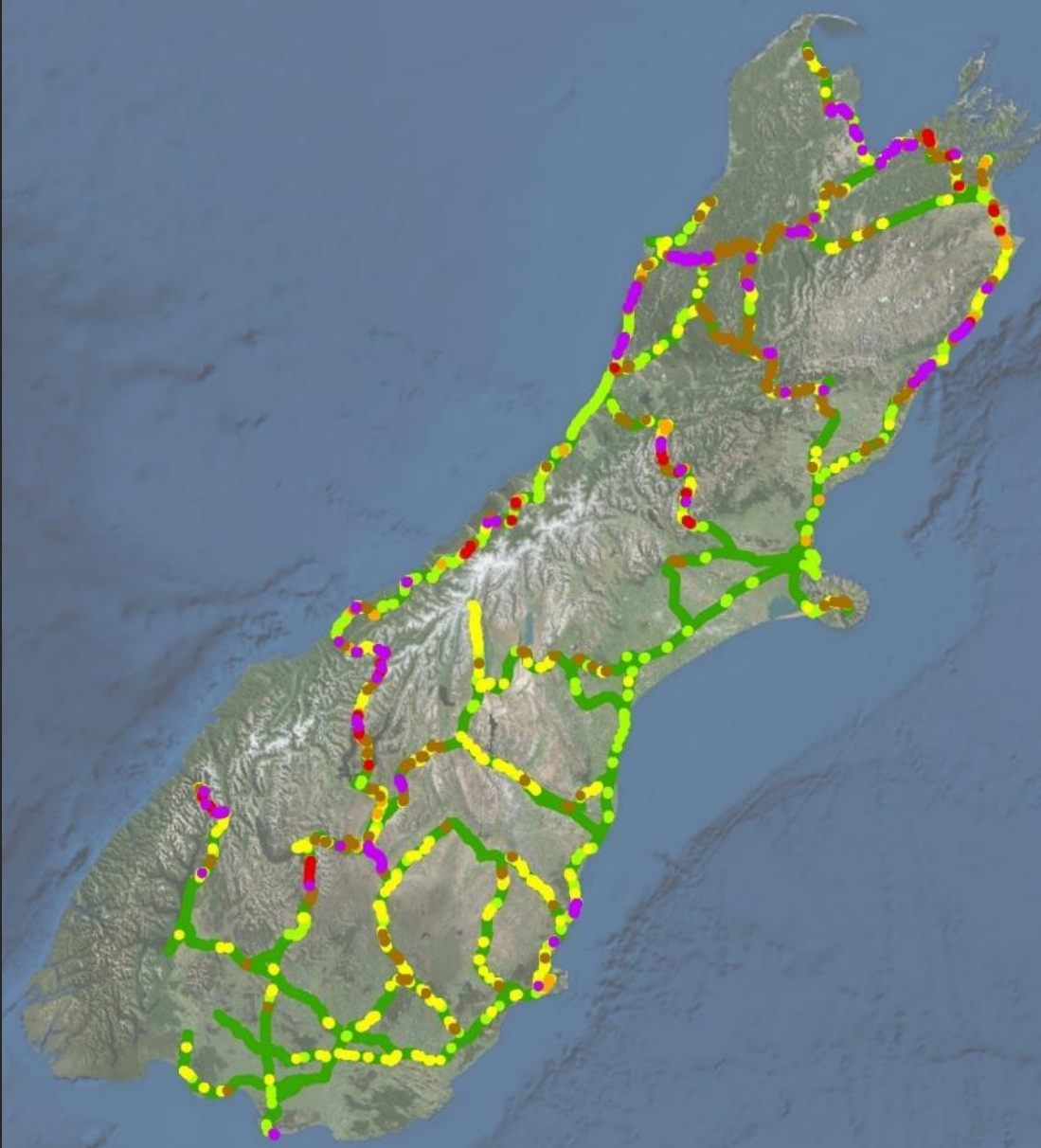
Disruption State



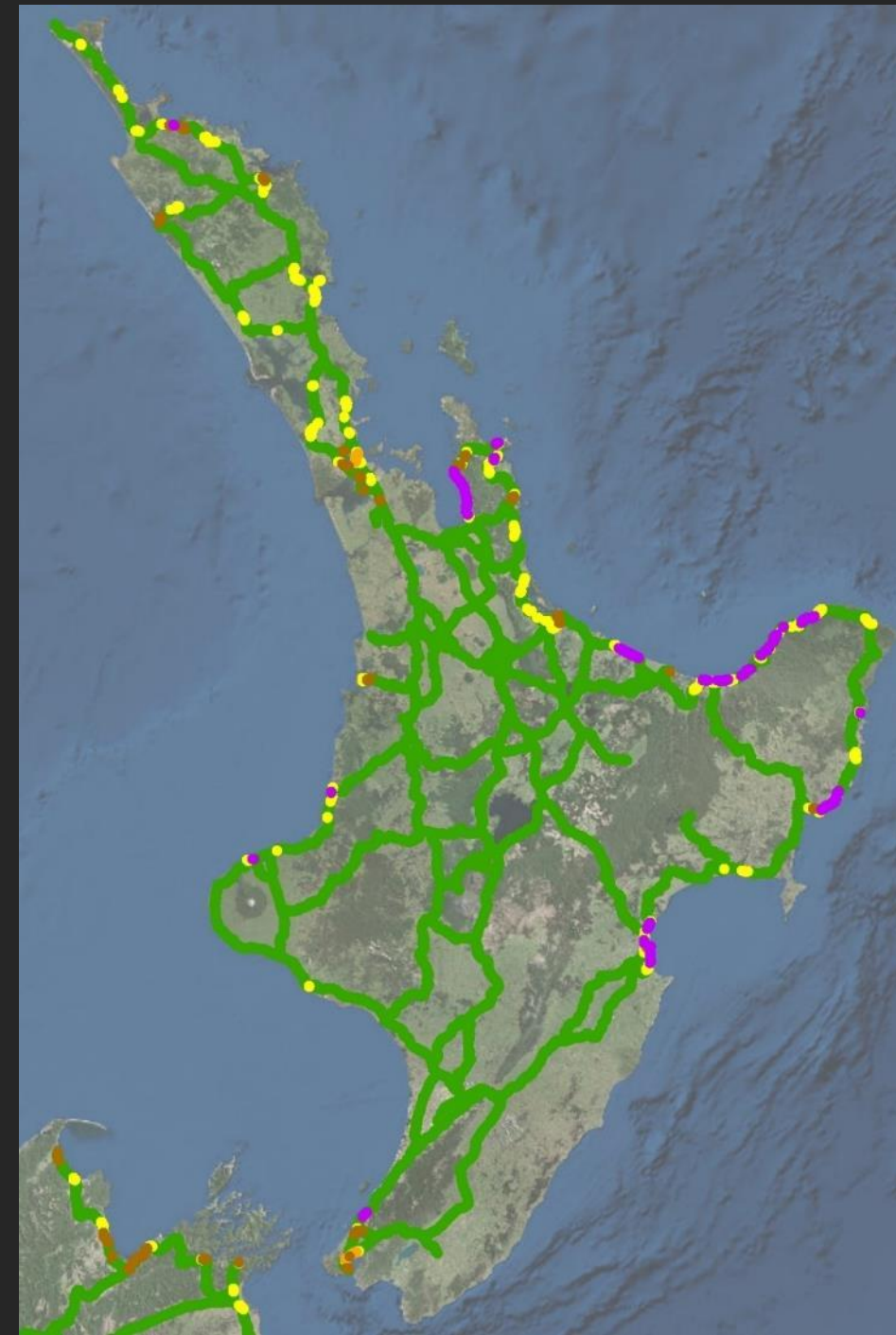
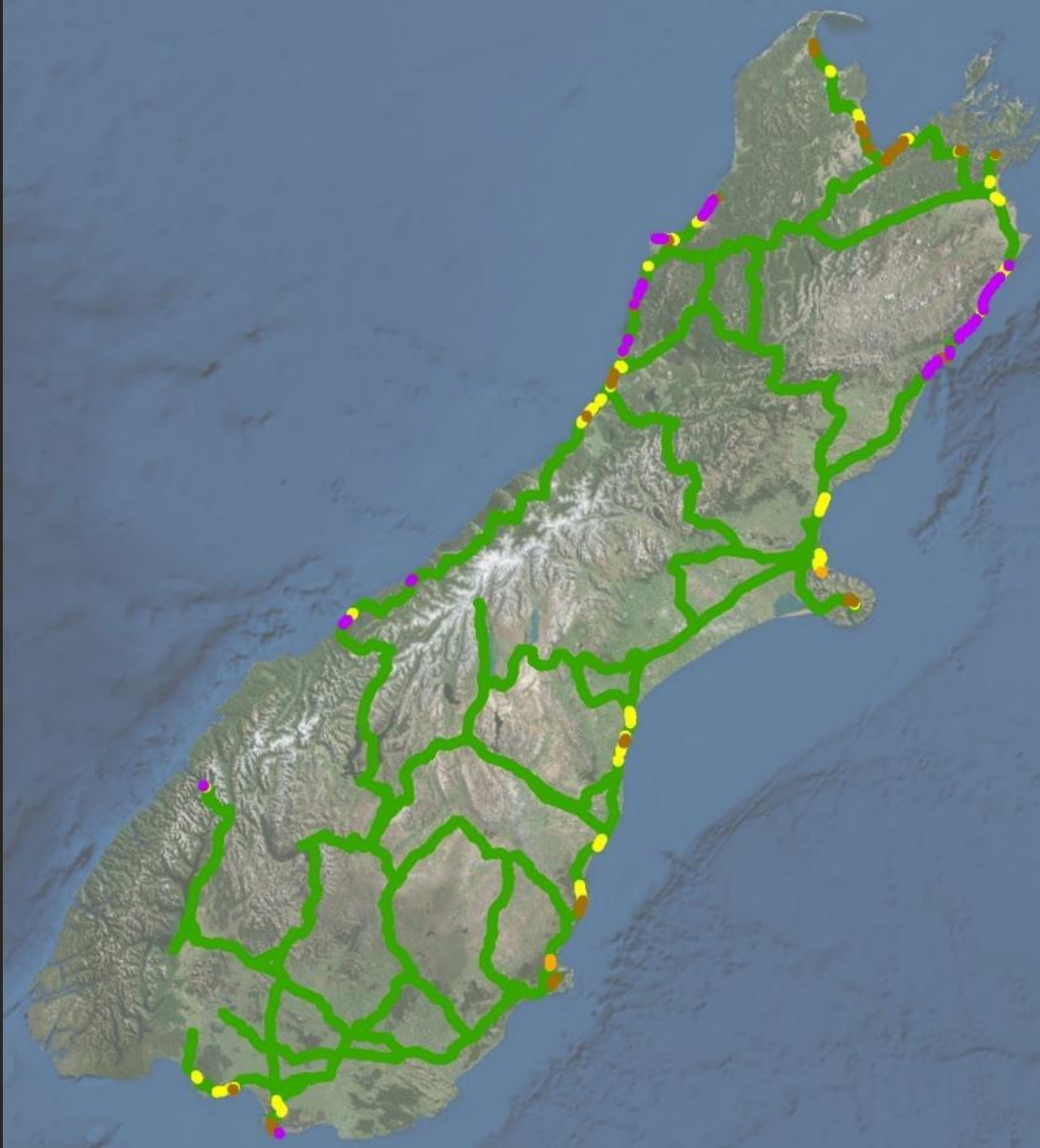
Resilience maps – storm

Disruption State

- None
- Limited
- Moderate
- High
- Severe
- Extreme
- Catastrophic



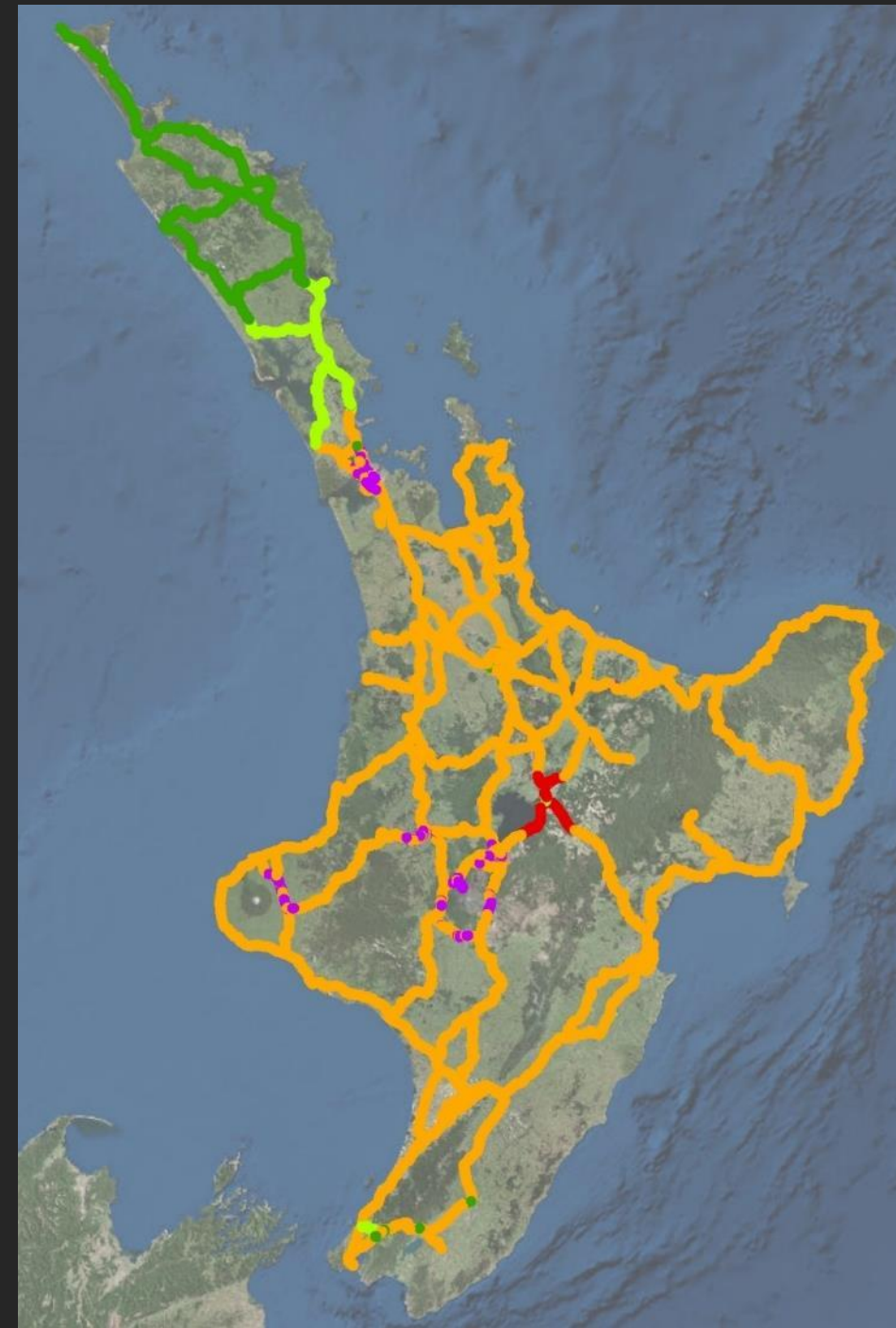
Resilience maps – tsunami



Resilience maps – volcanic

Disruption State

- None
- Limited
- Moderate
- High
- Severe
- Extreme
- Catastrophic



• Why Resilience?

THE PRESS
EARTHQUAKE
CHRISTCHURCH, NEW ZEALAND 22 FEBRUARY 2011



Max DVD with
Orion looking
looking the
New Zealand
recovery



Proceeds of this book go to Earthquake Recovery

*Transport is critical
for Response and
Recovery*



© Neil Macbeth / Barcroft Media



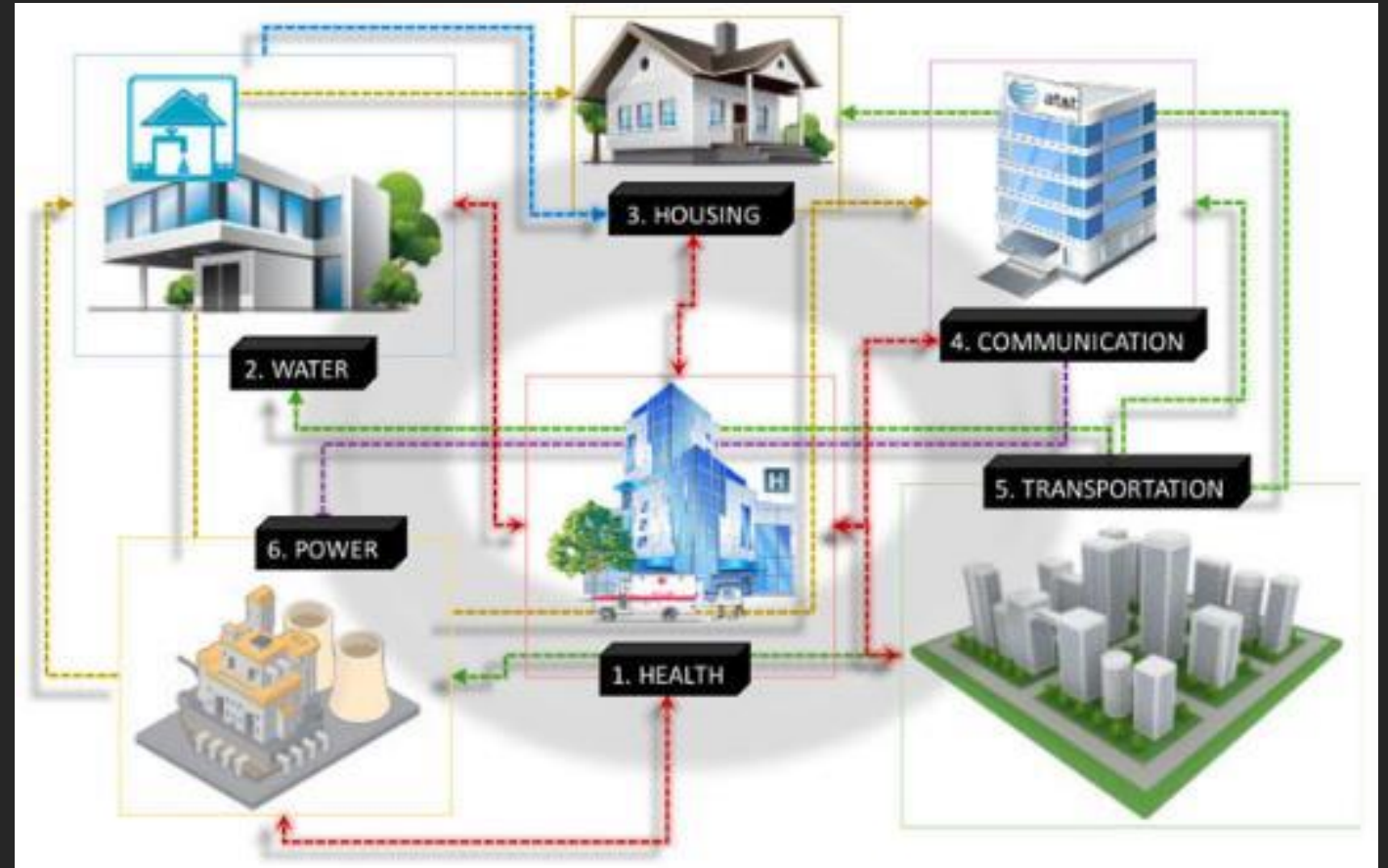
Interdependencies

Transport access is critical for

- Access
- Food and medicine
- Fuel
- Hospital
- Airport
- Port

Recovery of

- Water
- Electricity
- Telecommunications



Government Policy Statement



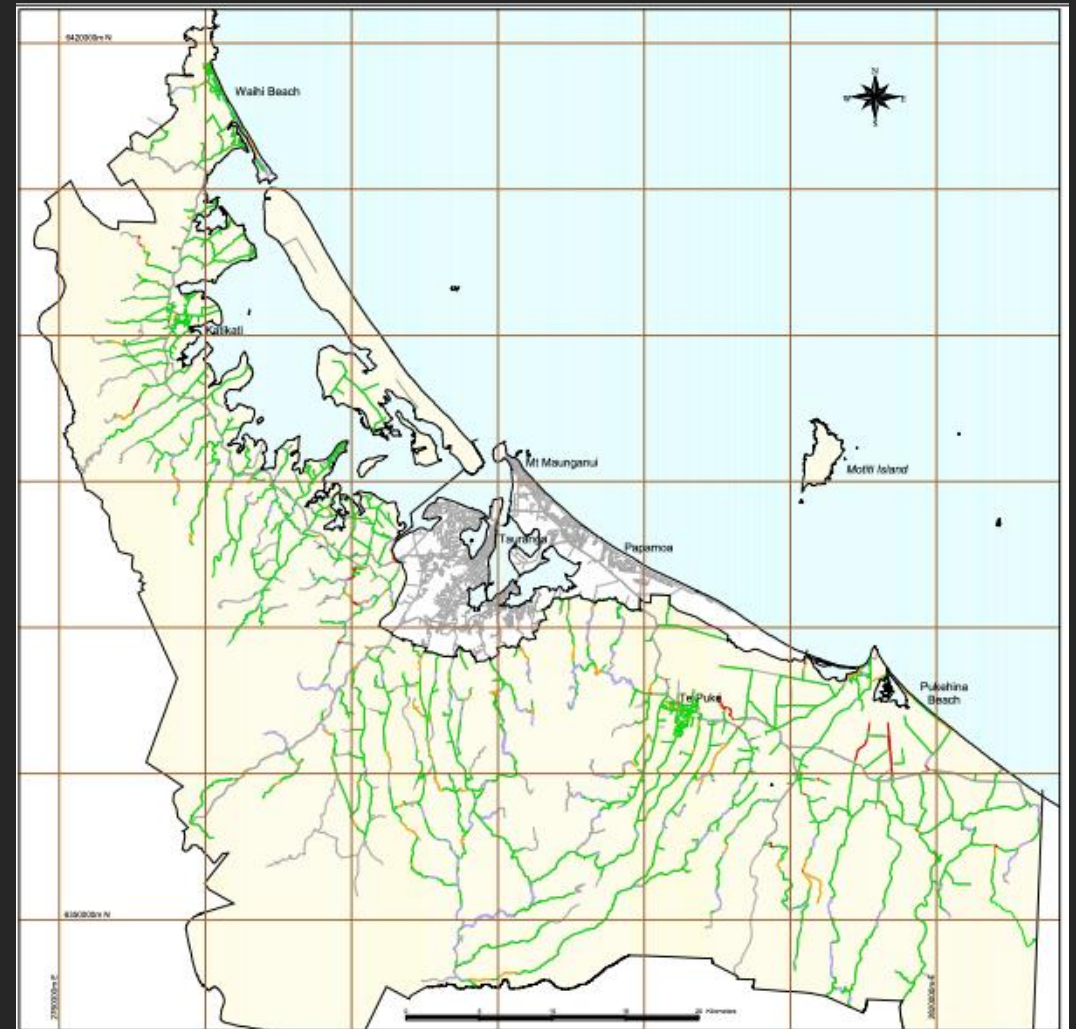
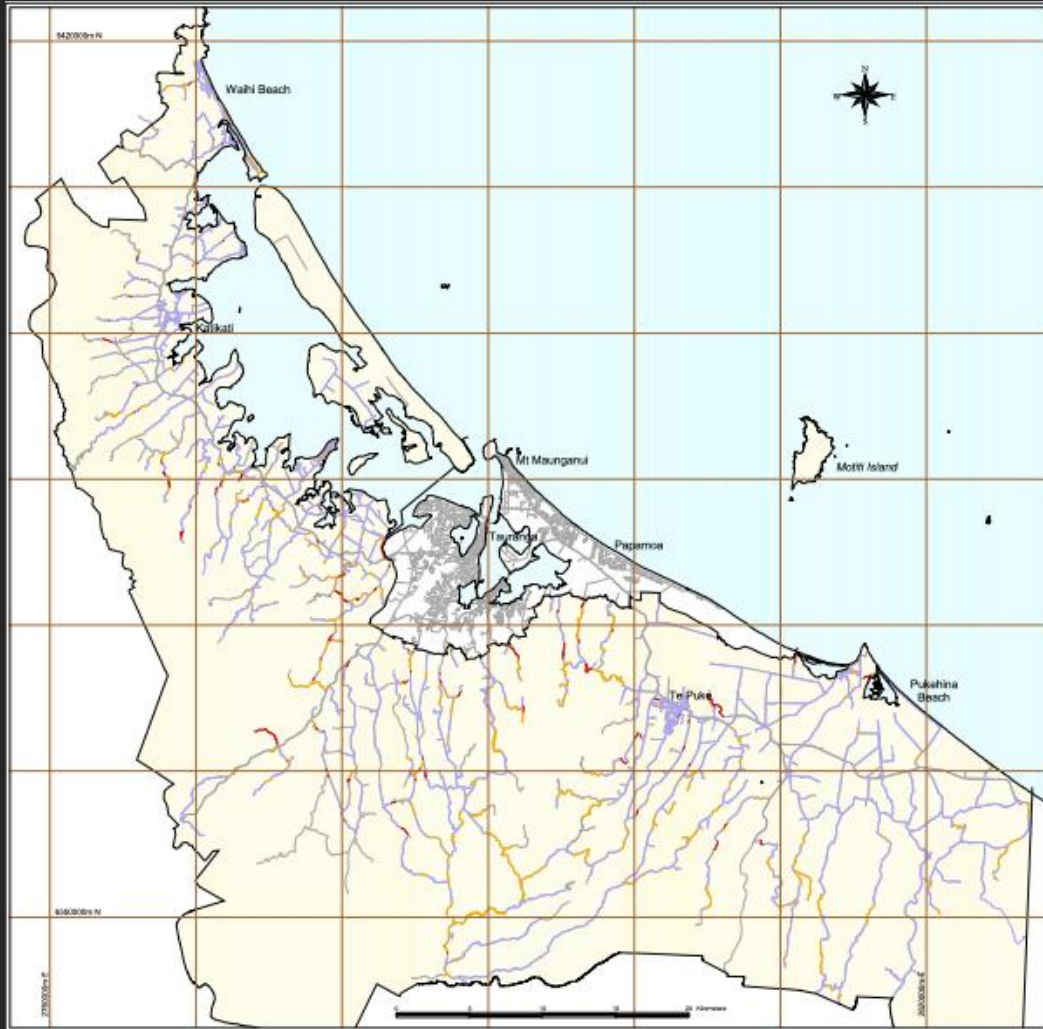
National Resilience Objectives

- 1 Capacity to withstand disruption
- 2 Capacity to absorb disturbance
- 3 Act effectively in a crisis
- 4 Adapt to changing conditions including climate change
- 5 Grow over time change

✓ **Result: Metropolitan and high growth urban areas are better connected and accessible**

Regional network assessments

Western Bay of Plenty – storm & earthquake



Resilience and gaps identified through regional study of local and state highway routes

Taranaki - storm

- Resilience studies helped identify improvements at Awakino and Mt Messenger sections



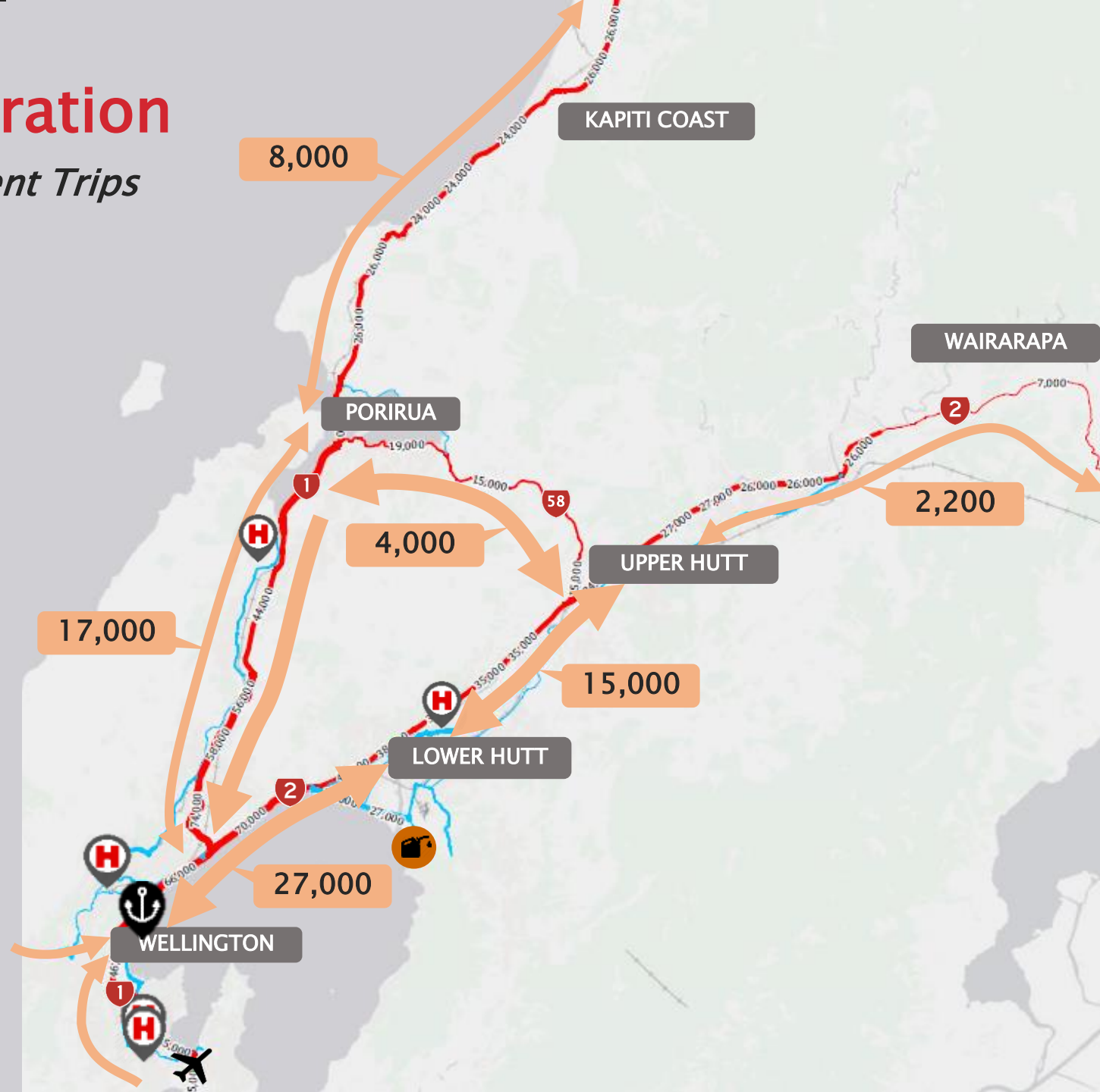
• Wellington Land Transport Resilience

Presents Business Case developed, but yet to be confirmed by NZ Transport Agency

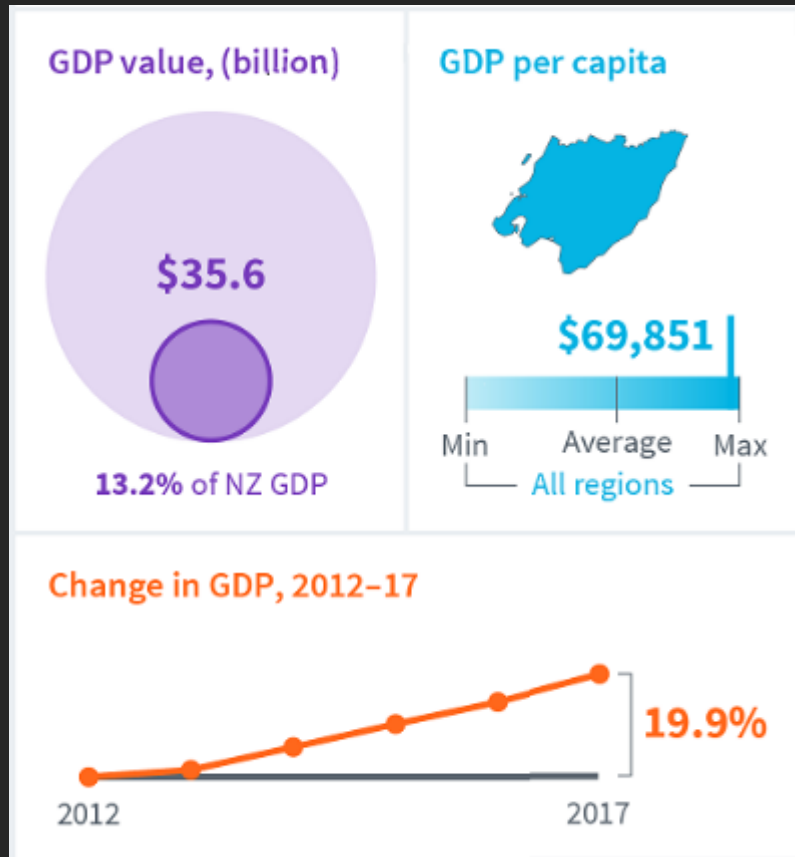
Trip Generation

*Daily Employment Trips
(Road / Rail)*

LEGEND	
	Employment travel
	Hospital
	Fuel depot
	Airport
	Port



Wellington's Economic context



Location of:



Central Government



½ of employed population



International airport



International port



\$16B

Potential GDP impact of a major event occurring on the Wellington Fault

SEVERE impact on NZ's economy and admin

Learnings from Christchurch and Kaikoura Earthquakes

Christchurch

- Earthquakes in 2010 & 2011
- Major road closures (45% of roads damaged)
 - Passenger + freight rail disruption
- Extensive road network redundancy, response and recovery largely unaffected

Wellington has very little transport redundancy

- 1 DECREASED productivity
- 2 INCREASED costs
- 3 OPPORTUNITY to rebuild, strengthen and refresh

Kaikoura

- 2016 Earthquake
- Rail closures, disruption to rail passenger + freight, for over 1 year . . . and disruption continuing
- Community isolation
- Loss of resilience, illustrated the effect of lack of redundancy on small centre

Resilience impacts are not just from an earthquake, but ongoing for many years from storms

Kaikōura earthquake



- **\$360M impact** to National GDP
- **18 months** to rebuild
- **\$2bn** rebuild cost (SH1 and rail along coast)
- **Closure of SH1** for over a year

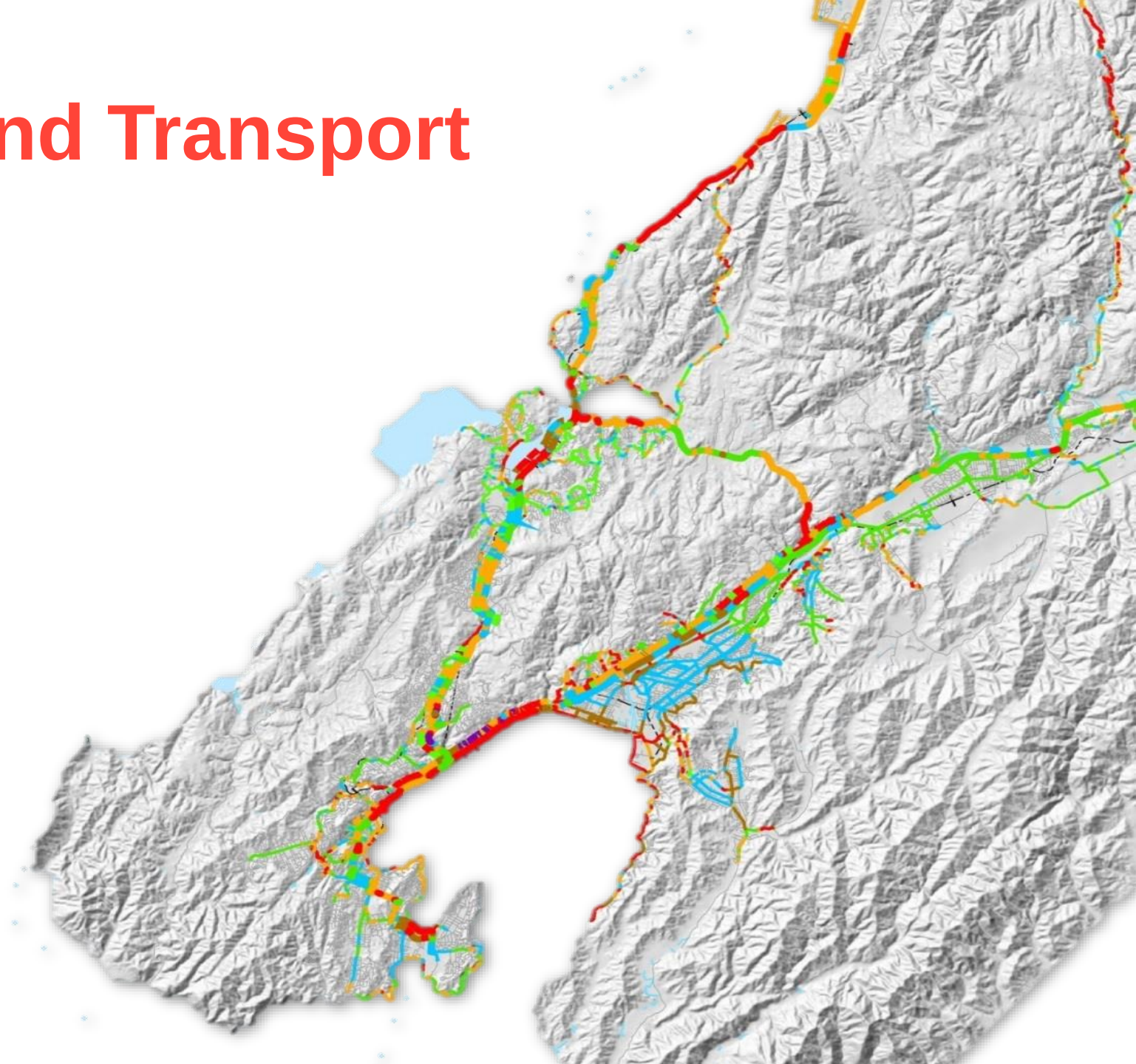
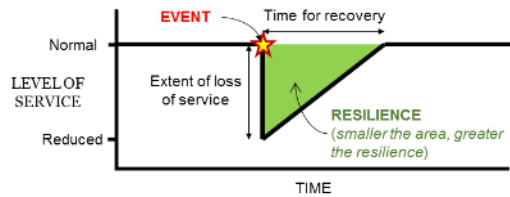
Land Transport Resilience Business Case



Resilience of Land Transport

Availability

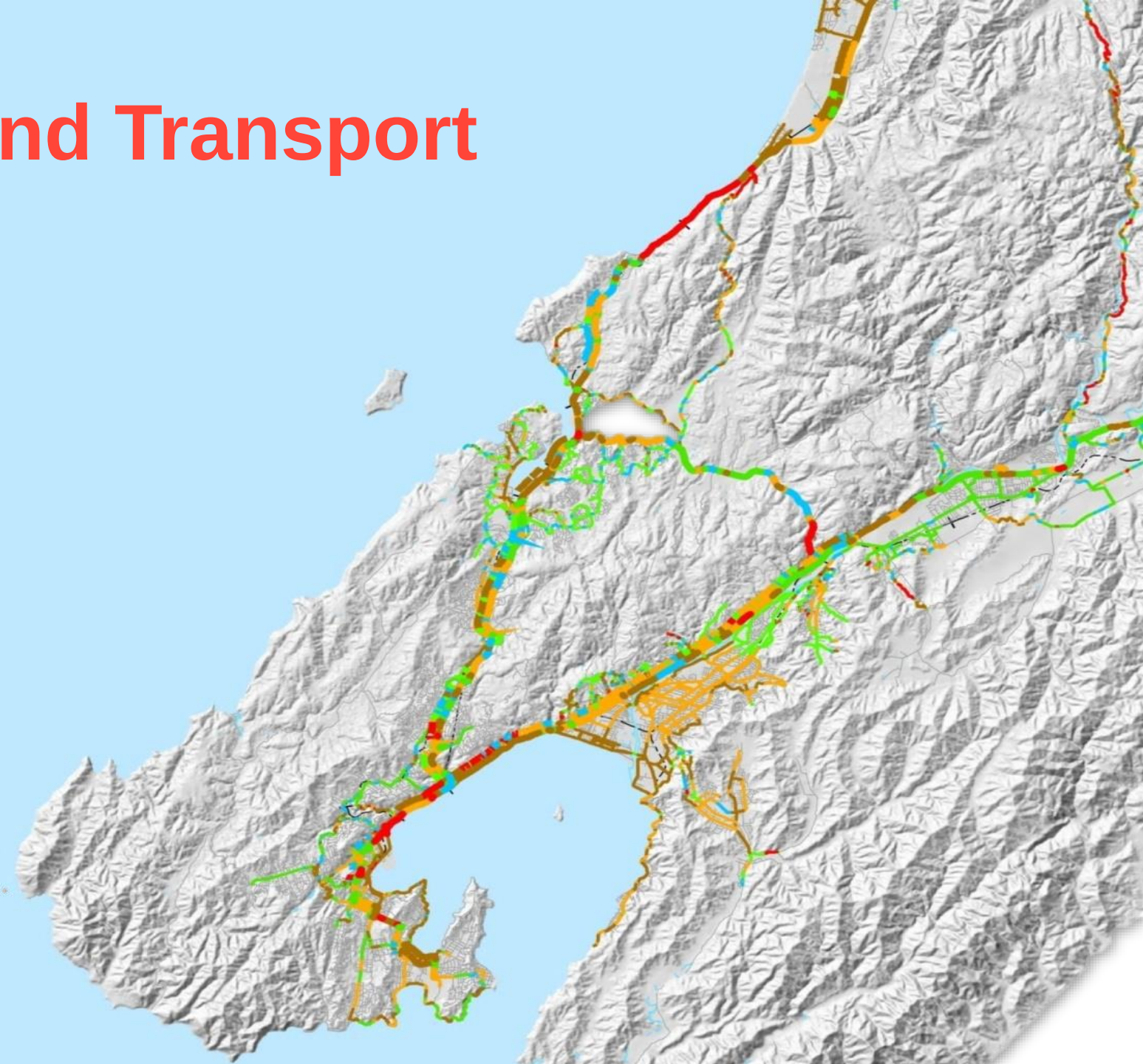
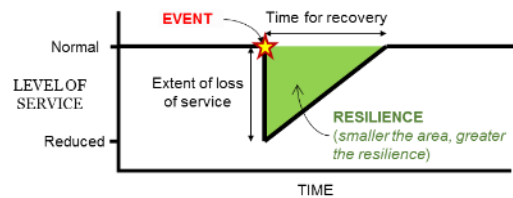
- 5 - Closed
- 4 - Difficult
- 3 - Single Lane
- 2 - Poor
- 1 - Full



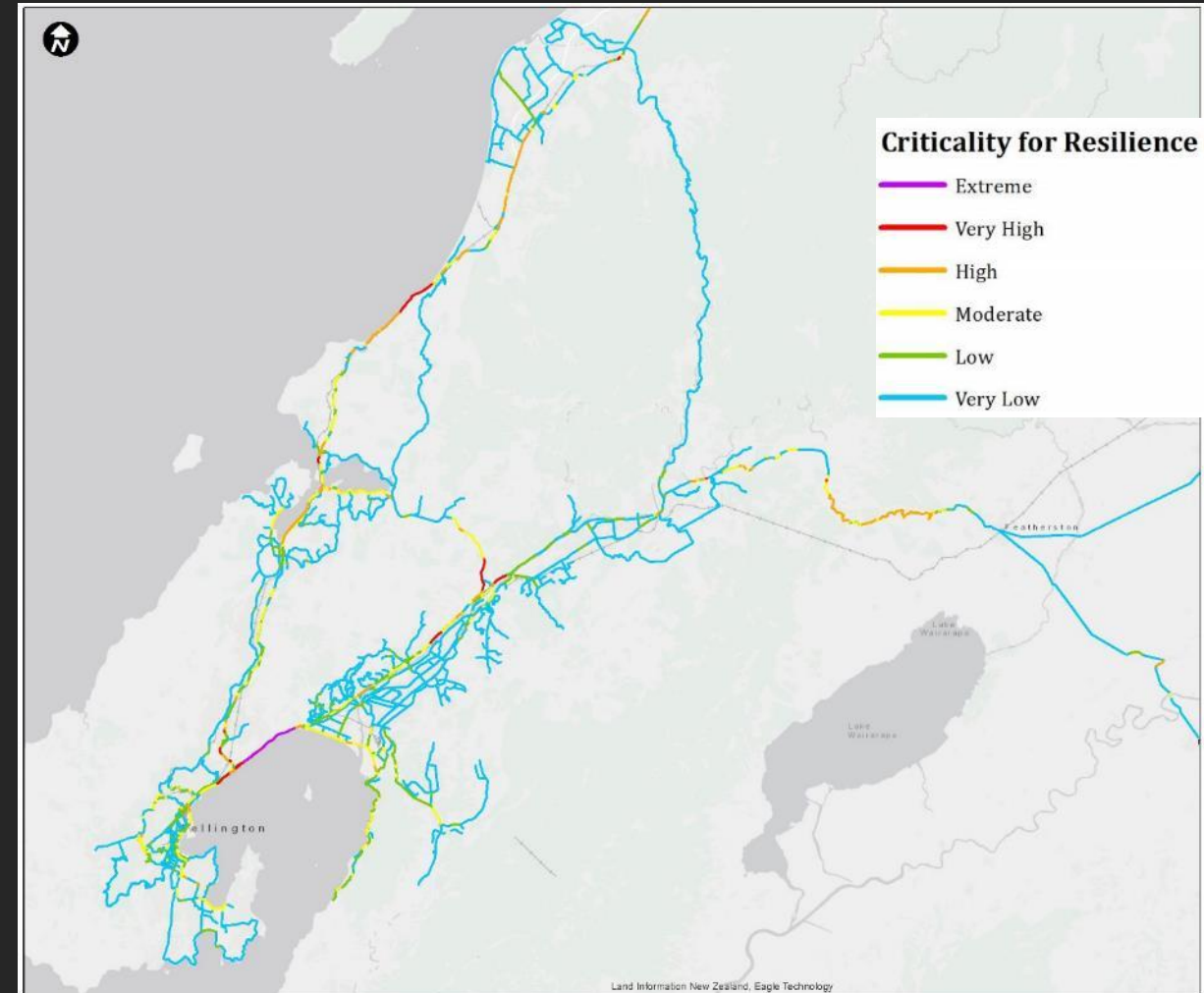
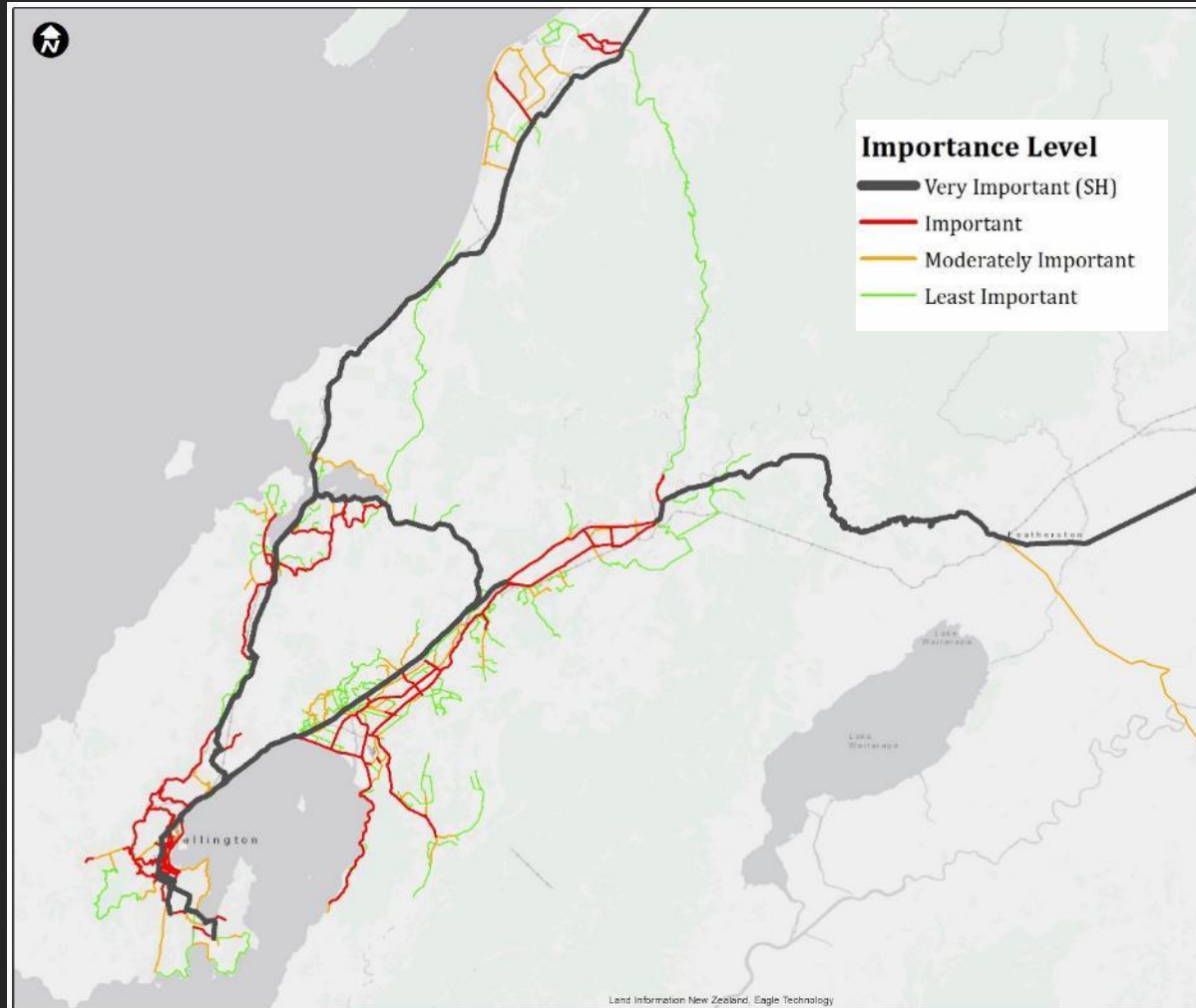
Resilience of Land Transport

Outage

- 5 - Long Term (> 3 months)
- 4 - Severe (2 weeks to 3 months)
- 3 - Moderate (3 days to 2 weeks)
- 2 - Minor (up to 3 days)
- 1 - Open (no closure)



Importance and Criticality of Links



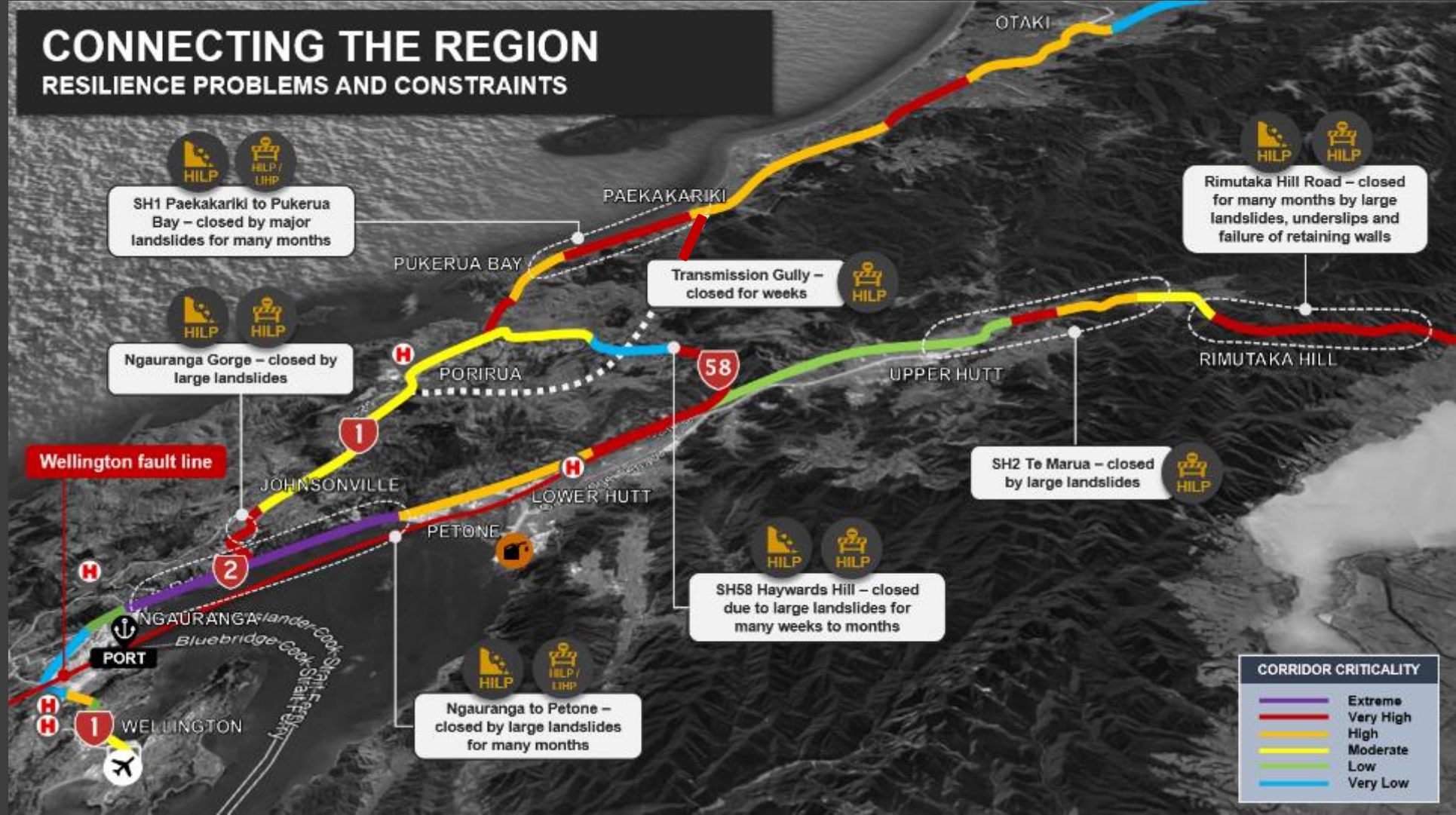
Wellington Land Transport Resilience Programme Business Case covers local roads and state highways

Criticality Rating	RCA Owner	Network Segment	Critical Section	Vulnerable to				Nature of Vulnerability	Current Interventions	Effect of interventions	Zone
				E	Quake	Tsunami	Storm				
Extreme	NZTA	SH2 Petone to Ngauranga	Petone to Ngauranga	Yes	Yes	Yes		This is the only and critical access between the Hutt Valley and Wellington. The highway is expected to be closed in moderate to large earthquakes and storms by large landslides on the eroded fault scarp hillside, with run-out extending across the full width of the highway and railway. Likely to be closed for many months after major M7.5 earthquake. Also prone to flooding and debris flows, particularly between Petone and Horokiwi. Also vulnerable to tsunami inundation. Closed by small to moderate events with closure of days to a week. Recovery will be slow as access only available from Ngauranga (Kiwi Point Quarry) and Petone (Hutt Valley) ends and possibly from Horokiwi Quarry near Petone. The corridor is also shared by the railway line and bulk water main and hence is of greater importance than road access issues.	None funded. HV to W cycleway and P2G under consideration.	HV cycleway could provide pedestrian access. P2G would provide limited alternate access into Hutt Valley, but no direct access from Wellington City. P2G also likely to be closed for several weeks in major event, and could not provide capacity between Wellington and Hutt Valley in small to moderate events because of limited capacity of SH1.	Wellington North / Hutt City
Extreme	NZTA	SH1 Ngauranga Interchange		Yes	Yes	Yes		Key SH1 motorway access into Wellington and Hutt Valley. In major earthquakes and tsunami likely to be closed by liquefaction / lateral spreading towards the harbour, retaining wall damage and slips from hills above. The section can be also affected by performance of the railway bridge above at the south end of Ngauranga Gorge. The corridor is shared with railway line and bulk water main.	None funded.		Wellington North
Very High	NZTA	SH2 Manor Park to Silverstream	Taita Gorge: Manor Pk to Silverstream	Yes	No	Yes		SH2 section through Taita Gorge between SH58 Interchange and Silverstream Bridge access, is vulnerable to landslides. Expected to be closed for weeks in a major M7.5 earthquake. The tight corridor is shared with the railway line and the Kaitoke bulk water main. The Wellington Fault runs in close proximity to this section of road.	None		Hutt City
Very High	NZTA	SH1 Southern Rail Overbridge	Full	Yes	Yes	No		This is a bridge which carries the SH1 motorway over the Masterton – Hutt Valley railway line, and the structure has poor capacity and is also vulnerable to damage from liquefaction and lateral spreading. Collapse of bridge will also close the Wairarapa railway line.	None		Wellington North
Very High	NZTA	SH1 Thorndon Overbridge	Full length	Yes	Yes	No		This is a 1.1 km long overbridge over the Ferry terminal, main railway line and railyards, which is adjacent to a high seawall. The bridge was partially retrofitted in the mid-1990s, but remains vulnerable to liquefaction and lateral spreading and failure of the seawall, and also rupture of the Wellington Fault. The fault rupture will lead to loss of a span, and while there are catch frames to prevent the span falling on the railyards, access will still be disrupted.	None	NZTA considering limited resilience improvements to prop the span vulnerable to fault rupture, the overbridge is still likely to be affected by liquefaction, lateral spreading and fault displacements.	Wellington North
Very High	NZTA	SH1 Thorndon to Ngauranga	Kaiwharawhara to Ngauranga IC	Yes	Yes	Yes		The motorway is expected to be damaged by liquefaction and lateral spreading. While this may not entirely close the motorway, this section also has the Southern Rail Overbridge and Thorndon Overbridge which are more vulnerable to longer period closure. The corridor is shared with railway lines.	None		Wellington North
Very High	NZTA	SH1 Ngauranga Gorge	Johnsonville Bypass and Ngauranga wall	Yes	No	Yes		SH1 Ngauranga Gorge is vulnerable to landslides and retaining wall failure / dropout at the south end just north of rail overbridge. Single lane access can be quickly restored except along Johnsonville bypass which is likely to be fully closed by landslides and underslips. Also failure of the Helston Road bridge will affect access at the north end of this section.	Limited resilience improvements being considered.	NZTA considering limited resilience improvements which is as yet undefined.	Wellington North
Very High	NZTA	Transmission Gully	Battle Hill to Paekakariki	Yes	No	Yes		The steep very high hillside terrain and the very high and steep cut slopes proposed make the Battle Hill to Paekakariki section of TG vulnerable to landslides and debris flows, and closure for long periods in large earthquakes and possibly major storm events.	None		Kapiti
Very High	NZTA	SH1 MacKays Crossing to Raumati Road	South of Poplar Avenue	Yes	No	Yes		Key SH1 western spine access into greater Wellington. Highway expected to be closed by landslides from the terrace and hills to the east and lateral spreading towards swamp to the west, in major M7.5 earthquakes and storm events.	M2PP expressway	Provides alternate access with greater separation from hillside. But a section of the route between MacKays Crossing and the Poplar Road Interchange will still be affected by run out from major landslides.	Kapiti
Very High	NZTA	SH 58 Haywards to Moonshine	Haywards Hill	Yes	No	Yes		The Haywards Hill section of SH 58 is vulnerable to closure by large landslides, debris flows and some underslips in large earthquake and storm events. Expected to be closed for many months in a major ~M7.5 earthquake.	None	NZTA considering limited resilience improvements which is as yet undefined.	Hutt City
Very High	NZTA	SH2 Rimutaka Hill Road	Pakuratahi to Featherston	Yes	No	Yes		SH2 Rimutaka Hill section expected to be closed in moderate to large earthquakes and storms by large landslides, failure of retaining walls, underslips and debris flows. Likely to be closed for many many months in a major M7.5 earthquake. This is the only access in the Wairarapa from Wellington Region, and one of two access routes (SH1 and SH2) into the Region from outside.	None		UpperHutt - Rimutakas
Very High	NZTA	SH2 Brown Owl to Te Marua	Birchville to Mangaroa River Bridge	Yes	No	Yes		SH2 section expected to be closed by landslides and underslips in major earthquake or storm events. This is a critical access to Te Marua bulk water facilities as well as from the Wairarapa and outside the region. This section is likely to also be closed by flooding and river erosion in a major storm event.	None		UpperHutt - Rimutakas
High	NZTA	SH1 Paremata to Plimmerton	Paremata & Goat Point	Yes	Yes	No		SH1 vulnerable to liquefaction lateral spreading north of Paremata bridges, and landslides at Goat Point. This corridor is also shared by the railway line.	Transmission Gully expressway under construction.	Transmission Gully will provide alternate route when completed. Vulnerability of TG will then become critical. Will remain critical for Plimmerton and Pukerua Bay communities.	Porirua
High	NZTA	SH1 Cobham Drive	Kilbirnie Crescent – Calabar Rd	Yes	Yes	Yes		Key SH1 access to Wellington Regional Airport and Miramar peninsula. Highway expected to be closed by liquefaction/ lateral spreading towards Evans Bay in a major M7.5 earthquake and tsunami. Will take several weeks to few months to restore access. Also provides access to Miramar and Seatoun communities.	None		Wellington East
High	NZTA	SH 1 Mt Victoria Tunnel	Portal / Approaches	Yes	No	Yes		The Mt Victoria Tunnel on SH1 is a key route to the Wellington Regional Airport, and while the tunnel is expected to be resilient, the steep slopes adjacent to the portal areas are likely to fail in a large ~ M7.5 earthquake leading to closure of the tunnel access for days to few weeks.	Mt Victoria Tunnel duplication		Wellington East

Prioritised resilience risk register

CONNECTING THE REGION

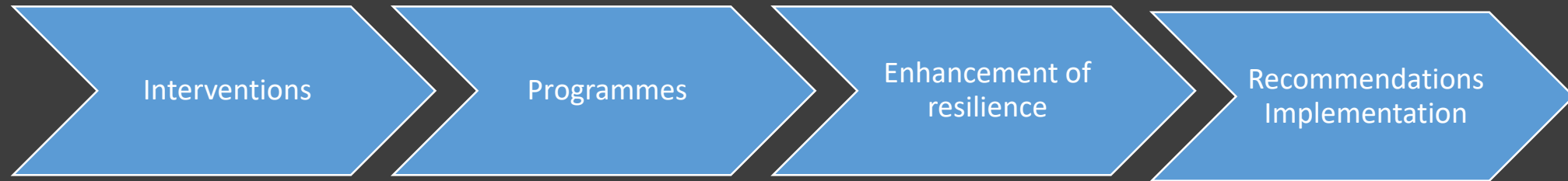
RESILIENCE PROBLEMS AND CONSTRAINTS



Impacts on Society

<i>L I H P</i>		<i>H I L P</i>
Potentially large economic disruption	<i>TRANSPORT ROUTES</i>	MAJOR disruption / closures
OPEN but disrupted	<i>INTER-REGIONAL JOURNEYS</i>	CLOSED
Potentially large losses, unnecessary	<i>ECONOMY</i>	MAJOR losses, completely stopped
Minimal / no disruption	<i>CENTRAL GOVT</i>	MAJOR disruption; contingency plan required
Temporary loss of access to jobs, schools, emergency services, supplies	<i>SOCIAL WELLBEING</i>	Potential for isolation, harm, lack of access to basic needs. Longer term disruption of access 
Variable cost to society		Differential impacts – lower socio- economic classes are less resilient

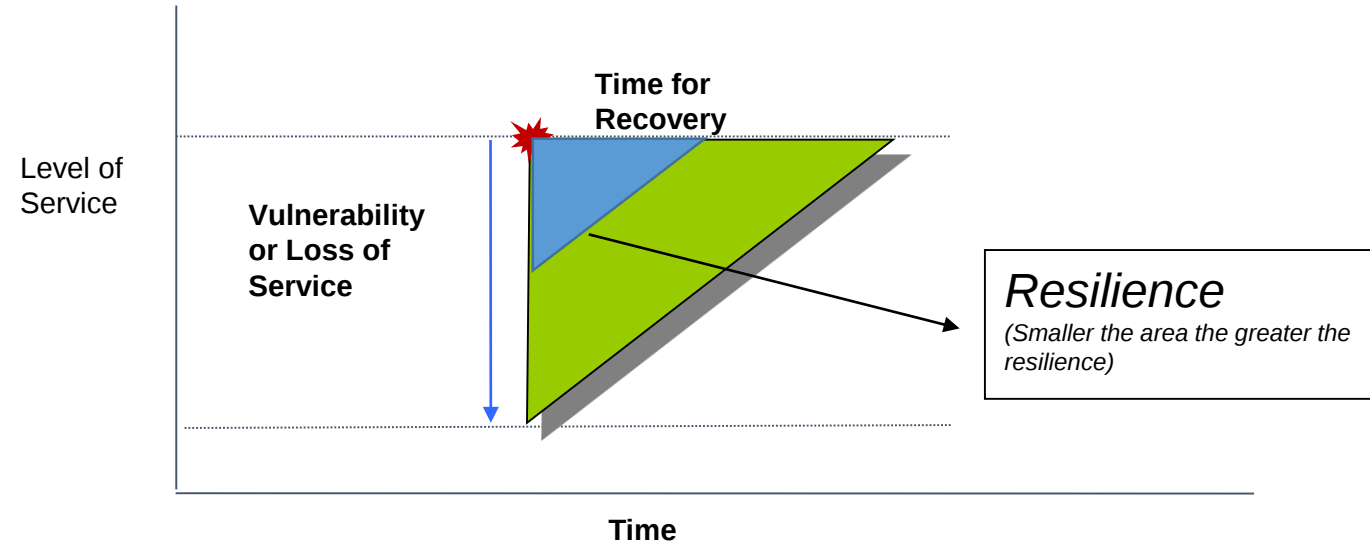
Land Transport Resilience Business Case



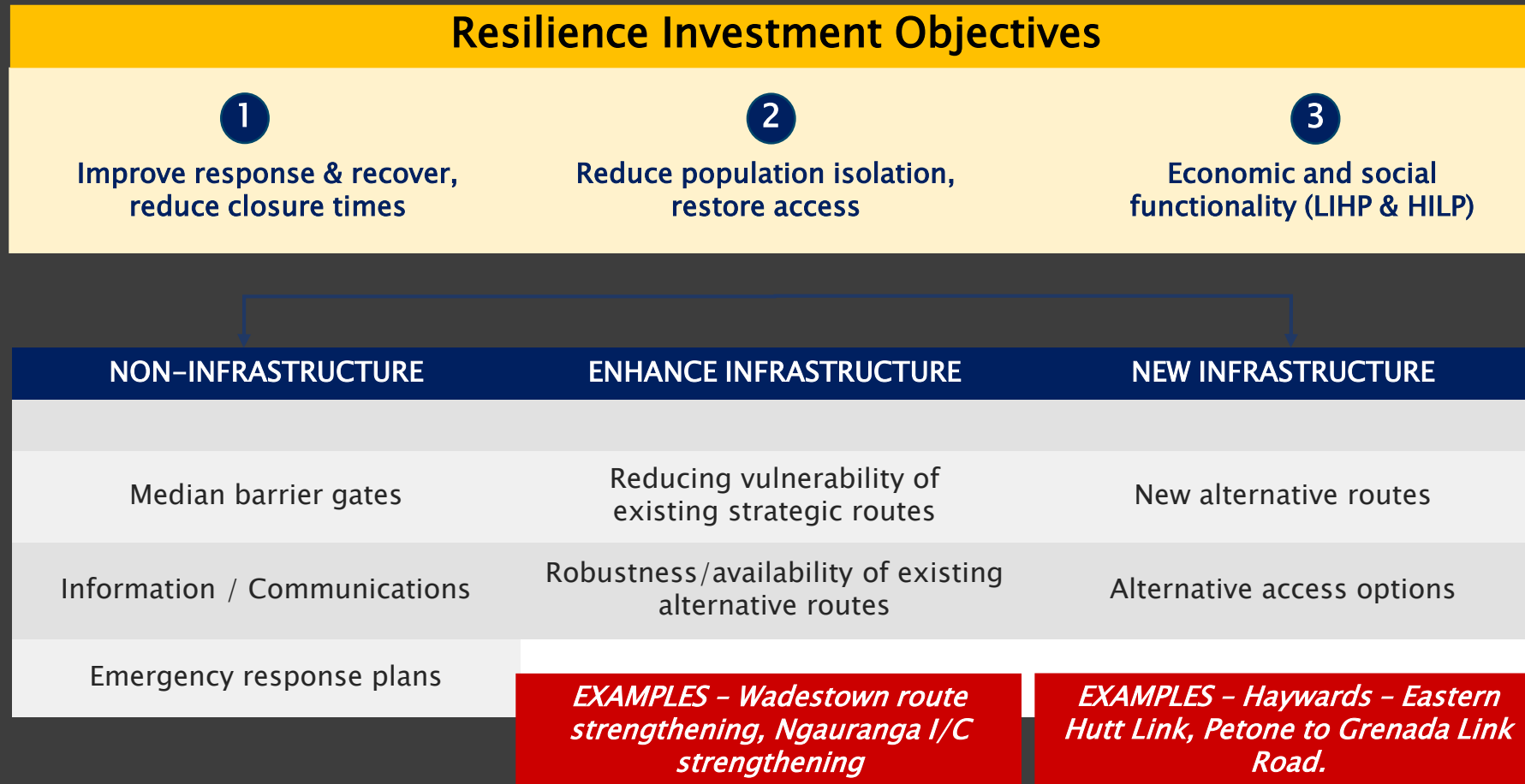
Resilience interventions

Resilience interventions consider

- minimising the loss of access and
- enabling quick recovery
- Alternate routes
- Response
- Recovery
- Range of HILP, LIHP and routine events



Resilience enhancement



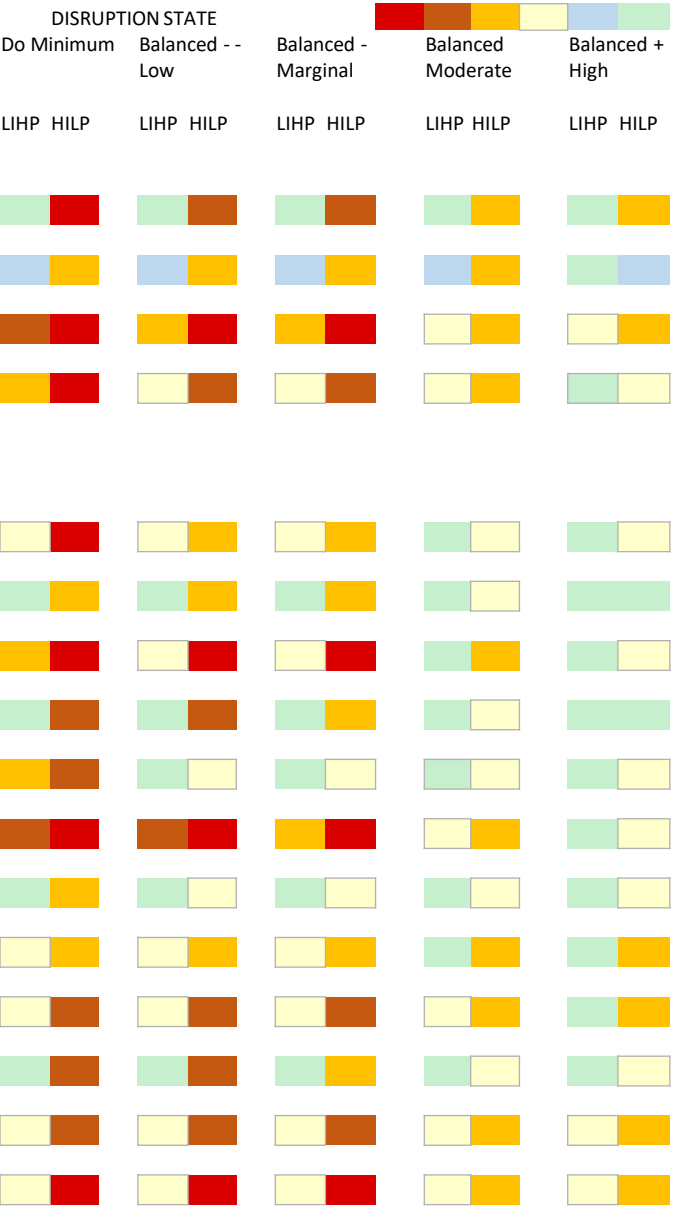
Improvement of Critical Journeys

Obj 2 External Access

- Manakau ⇄ Tawa (Wellington District) via SH 1
- Mt Bruce ⇄ Masterton (Wairarapa) via SH2
- Masterton ⇄ Upper Hutt (Hutt Valley) via SH 2
- Kapiti ⇄ Hutt Valley (via SH58)

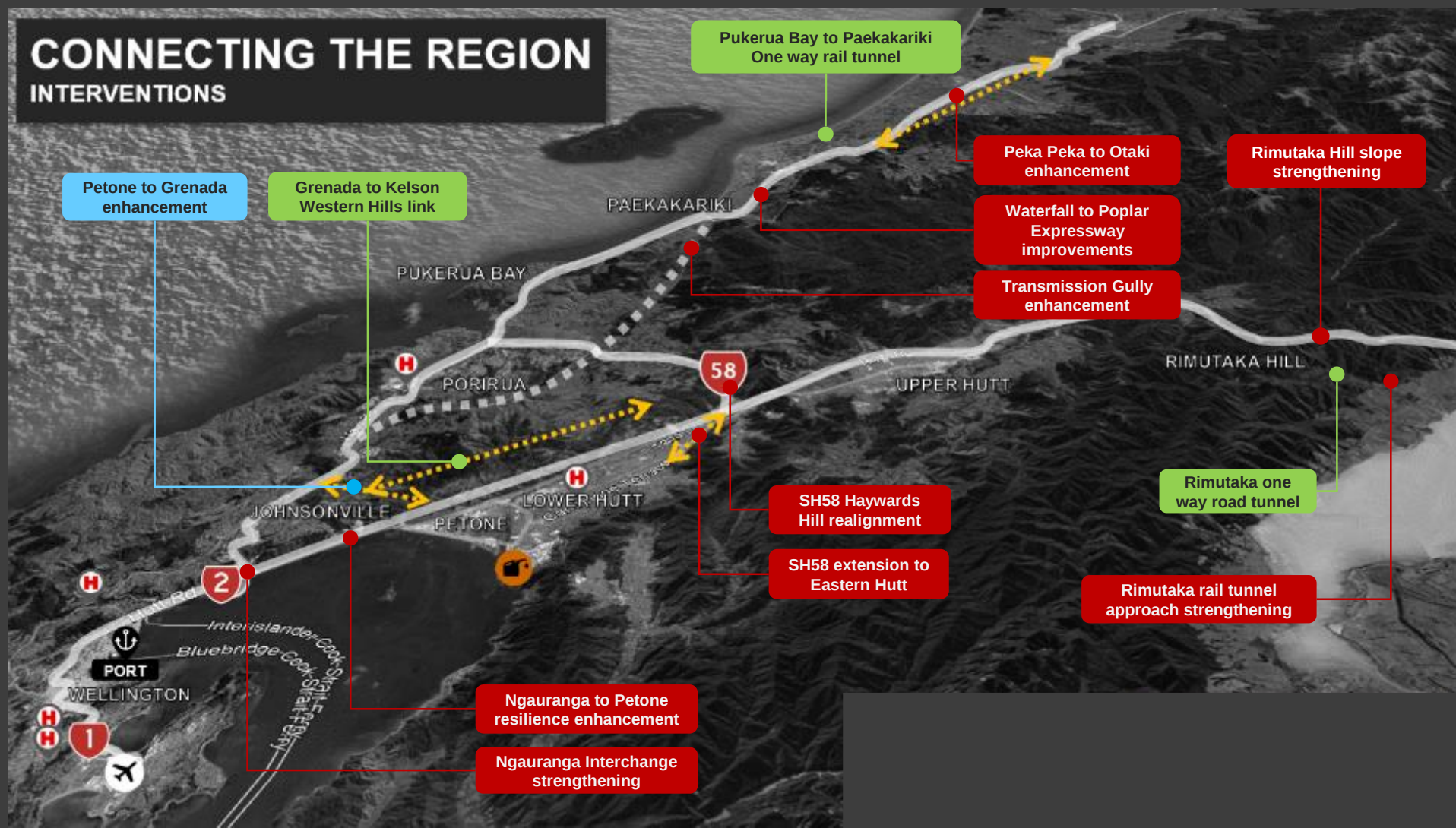
Obj 1 Internal Access

- Porirua / Tawa ⇄ Wellington CBD
- Airport ⇄ Wellington CBD
- Petone (Hutt Valley) ⇄ Wellington
- Seaview / Hutt East ⇄ Hutt West /SH2
- Upper Hutt ⇄ Lower Hutt
- Masterton (Wairarapa) ⇄ Wellington CBD
- Karori ⇄ Northern Suburbs ⇄ Johnsonville
- Lower Hutt ⇄ Wainuiomata / Moores Valley
- Western Hill Linkage: Grenada ⇄ Haywards
- Porirua East ⇄ Porirua West / Titahi Bay
- Porirua ⇄ Pukerua Bay
- Featherston ⇄ Martinborough

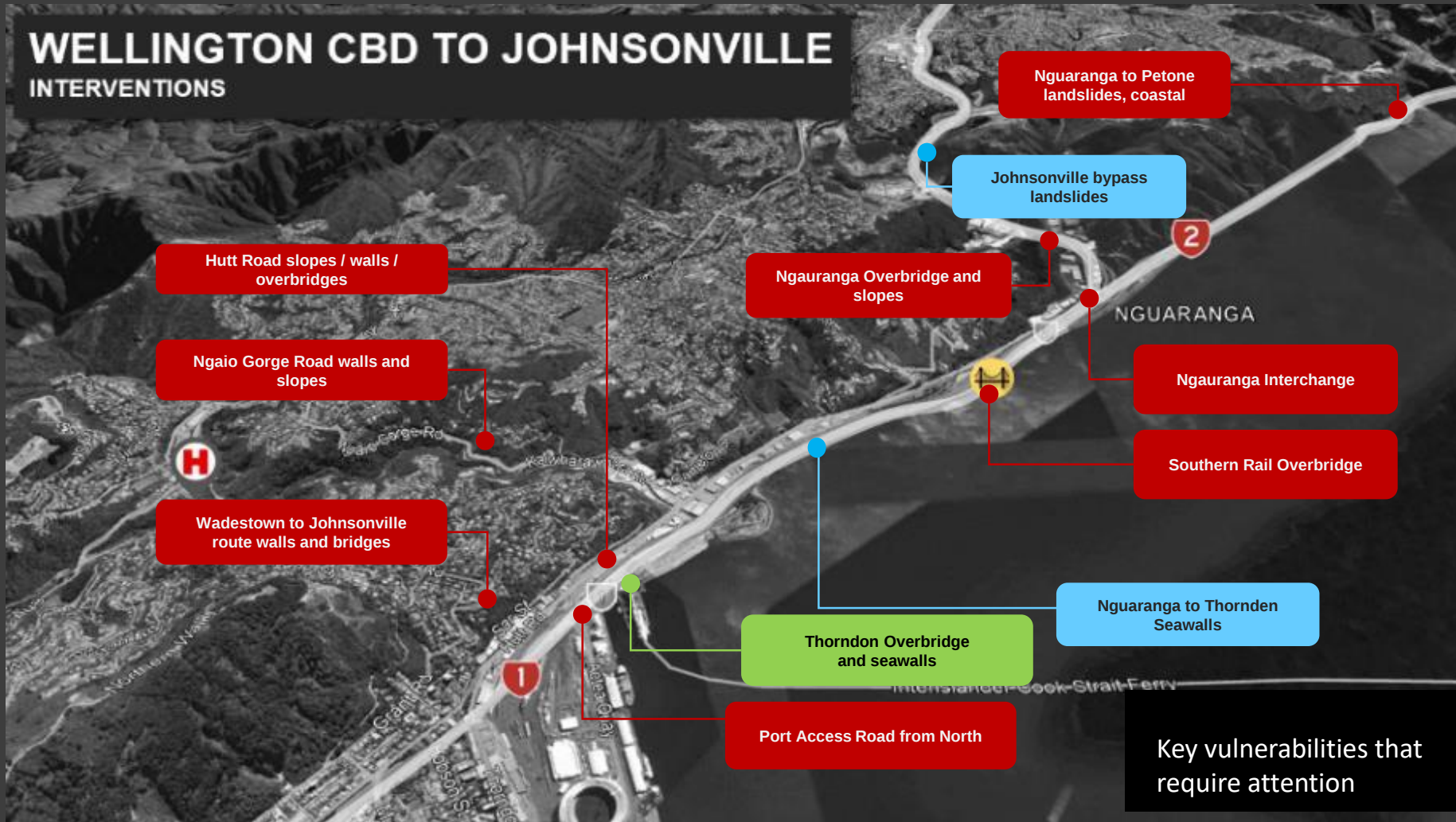


CONNECTING THE REGION

INTERVENTIONS



WELLINGTON CBD TO JOHNSONVILLE INTERVENTIONS



WELLINGTON CBD TO AIRPORT

INTERVENTIONS

Sea walls Waterloo to Jervois
Quay strengthening

Urban motorway retaining wall
assessment and strengthening

Slope strengthening for Mt
Victoria tunnel approaches

Wellington St / Crawford Road
strengthening

Cobham Drive strengthening



PORT

MT VICTORIA
TUNNEL

WELLINGTON
INTERNATIONAL
AIRPORT



Recommended Management Case

Recommendations to infuse resilience into existing projects

Stand-alone strengthening works – pre-implementation study

Local road strengthening

New transport links – detailed business case

Recommendations to address resilience as part of planned projects

Consider as part of Corridor improvements

Integrated with Urban and land use planning

Improving resilience



Strengthening of key structures to enhance resilience of key routes

Summary

- Resilience metrics and consistent assessment helped address complex issues.
- Spatial GIS helped consider across geographies and society
- Multi-hazards and spectrum of hazard levels need consideration – addressed through LIHP and HILP events.
- Integrated approach with local road and rail essential to address transport resilience issues.
- Impact on customers – society – is important, and addressed by considering:
 - Response
 - Recovery
 - Socio-economic functionality
 - Social resilience
- Business case approach adopted and this has never been used for resilience projects – required some innovative thinking.
- Affordability and risk appetite is a challenging issue – introduces personal views.