New Zealand Transport Agency

National State Highway Resilience

9 Priority Programme Business Case Corridors

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Date: June 2016
Reference: GER 2016-40
Status: Issue 1

Project No: 5-C2934.01

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1 Introduction

The New Zealand Transport Agency (the Agency) is developing its strategy to understand and enhance the resilience of its state highway network. As part of this strategy, the Agency has engaged Opus International Consultants (Opus) to assess the resilience of the state highway network at a broad national level, and develop a methodology for implementation at regional level for low frequency, high impact natural hazards.

The project has involved collection of national data on natural hazards for use in the assessment of the resilience of the state highway network, and existing assessments of the vulnerability of components of the state highway (eg. bridge seismic assessment or scour).

The national level resilience assessment has been initially carried out for 9 priority programme business case corridors, located throughout the country.

The outcomes of the national level resilience assessment are:

- Maps showing the resilience states for the state highways, presented as availability, outage and disruption states, and highlighting key areas of vulnerability of the state highways.
- Map showing prioritisation of the state highway network.
- A brief report summarising the results of the assessment.

This report presents the maps and summarises the results of the assessment.

2 Scope of the study

2.1 Overall staged resilience study

The scope of the national resilience assessment comprises 2 parts, as follows:

Part 1: National resilience framework

a) Review previous relevant work on the assessment of the resilience of the road networks in New Zealand.

b) Develop a methodology for a national level assessment of the resilience of the state highway network.

c) Implement the national resilience assessment methodology to assess the resilience of the state highway network at national level, initially for 9 priority PBC corridors.

d) Implement the national assessment methodology for the High Volume, National and Regional state highway links under the One Network Road Classification (ONRC).

e) Implement the national assessment methodology for the remaining state highway network.

Part 2: Regional resilience framework

a) Development of a methodology for regional level assessment of the resilience of the state highway network, for implementation by Agency regional offices.

The scope was discussed at the workshop on 7th April 2016, and the following were decided:

» Safety – Although the Transport Agency's National Programme Business case identifies safety as one of the aspects of resilience to be considered, it was decided that the focus of this resilience assessment should be on resilience that affects access or level of service rather than safety.

» Organisational Resilience – Previous studies identify organisational resilience is a key aspect of resilience. It identified leadership, culture and planning as organisational issues that would impact on the overall resilience. However, this aspect would vary from region to region depending on personnel not only at the Transport Agency's offices but also its network management consultants and contractors, or the Network Outcomes Contract (NOC) staff, and would also vary over time. This does not represent the resilience of the asset itself, although this is a relevant issue at operational level. Therefore, it was decided to exclude organisation resilience aspects from this national level resilience assessment of the state highway assets.

» Routine Events – Higher frequency, lower impact events occur regularly, and the current Network Outcome Contracts are organised to deal with these events that occur regularly. Therefore, it was decided to exclude these from the national resilience assessment. The focus is on lower frequency but higher impact events, as this project aims to understand the impact of these events.

2.2 Scope of current study for 9 priority PBC corridors

This report presents the results of Part 1 (c) of the national assessment as described above. The following 9 priority PBC corridors have been mapped using the national resilience assessment framework:

- SH1, between Whangarei and Auckland
- SH29, between Tauriko and Piarere
- SH1, between Piarere and Taupo
- SH1, between Taupo and Waiouru
- SH2, between Masterton and Te Marua
- SH2, between Te Marua and Ngauranga
- Access routes to Wellington Port
- SH73/77, between Lyttelton and West Melton
- SH1, between Christchurch and Dunedin

The locations of these corridors are shown on the location map in Figure 1.

3 Road resilience & performance

Resilience is the ability to minimise loss of service and readily recover and return to its original form from adversity.

Knowledge of the resilience of the road network in natural hazard events is important to understand the impact on society – the people, emergency services, economic activity etc. This would also enable the estimated natural hazard resilience to be compared against desired level of service targets, and help develop resilience enhancement measures.

Resilience of roads is dependent on the loss of quality or serviceability, and the time taken to bring the road back into its original usage state. This is shown conceptually in Illustration 1 (after Brabhaharan, 2006). The smaller the shaded area, the more resilient is the lifeline. The greater the area, the poorer is the resilience.

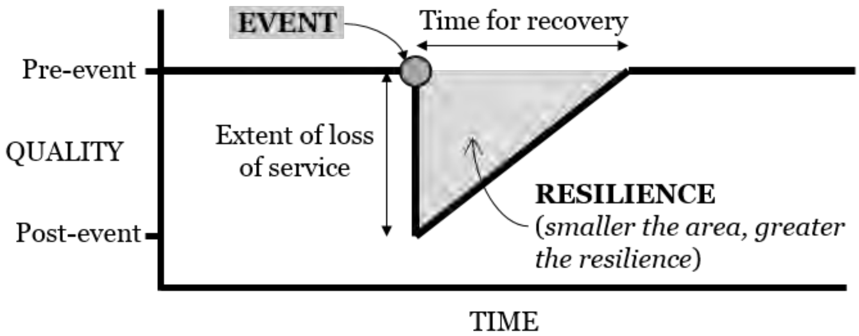


Illustration 1 Resilience of route/network

"Resilience States" representing the performance of the road network have been developed by Brabhaharan *et al*. (2006) to consider the impact of various natural hazards on the road network on a similar basis. These states are summarised in Table 1.

Table 1 Resilience states

Resilience State	Description of State
Damage state	Damage State represents the severity of damage to the road and represents the damage and cost of damage repairs.
Availability state	Availability State indicates whether the road section would be able to be used either at full level, at various reduced levels or not at all. This gives an indication of the degree of access on a link after an event.
Outage state	Outage State indicates the duration over which the road will be in the Availability State above. This gives an indication of the duration of loss or reduced access in links along the road network.

The damage state is used to consider the potential cost of the effects, but is not considered directly useful to evaluate the resilience of the network, and therefore will not be used for this national-level assessment.

4 Methodology

4.1 Objectives

The national resilience assessment methodology addresses the following objectives:

- Enables assessment of the resilience across the whole state highway network.
- Assesses at a broad brush high level, efficiently and quickly.
- Assesses resilience to large natural hazard events.
- Uses a consistent basis applied across the country.
- Assesses to screen and understand the resilience of the network, to appreciate differences, and identify areas of concern.
- Enables further consideration of areas with poor resilience, and inform and link with more detailed assessments at corridor levels by regional Agency teams.

These objectives have been the basis of the development of the national assessment methodology for resilience.

4.2 Resilience metrics

It is important to use appropriate metrics that are meaningful, to assess the resilience of the state highway network. State highways provide access for communities, and in evaluating their resilience, it is important to represent the availability or lack of access in the event of natural hazards. Therefore it is appropriate to use metrics that reflect the level of service, and be understandable to stakeholders. This enables everyone to relate to the metrics that represent the performance of the state highway network.

Similar metrics should also be able to be used for further consideration of the resilience at regional level. The metrics used should be able to underpin decision making relating to actions to enhance the resilience of the state highway corridors, as well as related local road routes.

For the successful execution of the project at both national and regional scales, it is important to select metrics that have been proven in the assessment of resilience, as well as used in initiatives to address the resilience, through emergency preparedness measures or appropriate mitigation measures.

The two key dimensions of resilience (refer Illustration 1) are:

- The reduction in access as a consequence of the event, and hence the degree of access available, and
- The time taken for access to be restored, or the duration of access impairment.

Therefore, the resilience metrics have been used to represent these two dimensions, through the resilience states developed by Brabhaharan *et al*. (2006) of:

- *Availability state* – level of access after the event, representing the level of service.
- *Outage state* – the duration of reduced access at the above availability state.

These states have been represented as the following levels given in Table 2 and Table 3, subject to adjustment during the finalisation of this study (after Brabhaharan, 2006).

Table 2 Availability state

Availability Level	Availability State	Availability Description
1	Full	Full access (perhaps with driver 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.

Table 3 Outage state

Outage Level	Outage State	Damage 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 3 weeks
5	Medium term	Condition persists for 3 weeks to 3 months
6	Long term	Condition persists for > 3 months

A '*Disruption state*' combining the availability and outage states was proposed by Brabhaharan (2006), to provide a single parameter indicating the level of disruption caused by the hazard event at each road section. The disruption state levels are provided in Table 4. The derivation of the disruption state from the availability and outage states is presented in Table 5.

Table 4 Disruption state

Disruption Level	Disruption State
0	None
1	Limited
2	Moderate
3	High
4	Severe
5	Extreme

Table 5 Disruption state derivation

Disruption State		Outage state & level					
		Open 1	Minor 2	Moderate 3	Short term 4	Medium term 5	Long term 6
Availability state & level	Full 1	None	None	None	None	None	None
	Poor 2	None	Limited	Limited	Limited	Moderate	High
	Single lane 3	None	Limited	Limited	Moderate	High	Severe
	Difficult 4	None	Limited	Limited	Moderate	High	Severe
	Closed 5	None	Limited	Moderate	High	Severe	Extreme

4.3 Hazard event levels

Appropriate hazard event levels were discussed at the workshop on 7th April 2016, and it was agreed to use event levels consistent with common design levels (e.g. Bridge Manual requirements). These have been adjusted for the return periods associated with the available hazard assessment data, as shown in Table 6.

Table 6 Hazard event levels for resilience assessment

Hazard	Recurrence Interval for Assessment of Resilience
Storm / Flooding	1 in 100 years (Bridge Manual – 1 in 100 years)
Earthquake	1 in 1,000 years (Bridge Manual – 1 in 500 to 1 in 2,500 years)
Volcanic hazards	Lahar – 1 in ~250 years (specific to lahar source) Ash fall – 1 in 500 years (with comparison to 1 in 10,000 years) Volcanic eruption/lava flow – variable depending on volcano source and eruption volume (1 in ~1,000 years to 1 in ~5,000 years)
Tsunami	1 in 2,500 years

4.4 Data and sources

Data that has been considered in the assessment of the resilience of the road network for various hazards are summarised in Table 7. The sources of the data are also included. The data has been obtained as spatial data in GIS format, where available.

Table 7 Data and sources

Data type	Dataset	Source
Road assets	• State highway centreline (with ONRC data)	NZ Transport Agency
	• State highway corridor vide0	NZ Transport Agency
Geography & geology	• Topographical contours 20 m (part 10 m)	LINZ
	• Digital elevation model (DEM) 8 m	LINZ
	• NZ Land Resource Information System: » Soil/rock lithology » Erosion type/severity » Slope angle class	Landcare Research
	• Geology	GNS Science
	• Erosion susceptibility & limiting factors	MfE
Storms, floods & coastal hazards	• 1% AEP 24 hour rainfall depths	NIWA
	• River Environment Classification (REC)	NIWA
	• Flood hazard screening for bridges	NZ Transport Agency
	• Flood hazard maps	Local authorities
	• Sea level rise predictions	MfE, IPCC
	• Coastal inundation maps (variable coverage)	Regional councils
Earthquake hazards	• Earthquake hazard maps: » Active faults » Ground shaking » Liquefaction	GNS Science, regional councils
	• Seismic screening of bridges	NZ Transport Agency
Volcanic eruption	• Volcanic hazard maps: » Pyroclastic ash fall (tephra) » Pyroclastic & lava flow » Lahar	GNS Science, regional councils, universities
Tsunami	• Tsunami hazard maps	GNS Science, NIWA, regional councils
	• Tsunami impacts on roads	Wellington lifelines group, universities, Opus Information Centre

4.5 Compilation of spatial data

The hazard data, terrain data, geology data and the asset data has been collated as spatial data in GIS format, where this is available.

This enables the state highway centre lines to be overlain on each hazard layer to facilitate consideration of the impact of the hazard on the state highway corridor.

4.6 Site reconnaissance

Site reconnaissance visits by Opus resilience staff have been carried out to better understand the terrain and the potential impact of hazards on the state highway, in less familiar terrain sections of the state highway network. For this stage of the study, reconnaissance has been carried out for the Whangarei to Auckland and Taupo to Waiouru sections of State Highway 1.

4.7 Characterisation of road network

4.7.1 Characterisation approach

The state highway routes have been characterised based on the vulnerability of the road to each natural hazard following the approach developed by Brabhaharan *et al*. (2001, 2006). The characterisation scheme is based on the assessed potential impact of each hazard at the level identified in Table 6, and its consequence to the level of service of the highway. The process chart in Illustration 2 summarises the approach of the characterisation and resilience assessment.

The impact of the various natural hazards have been assessed as outlined in the sub-sections for each hazard.

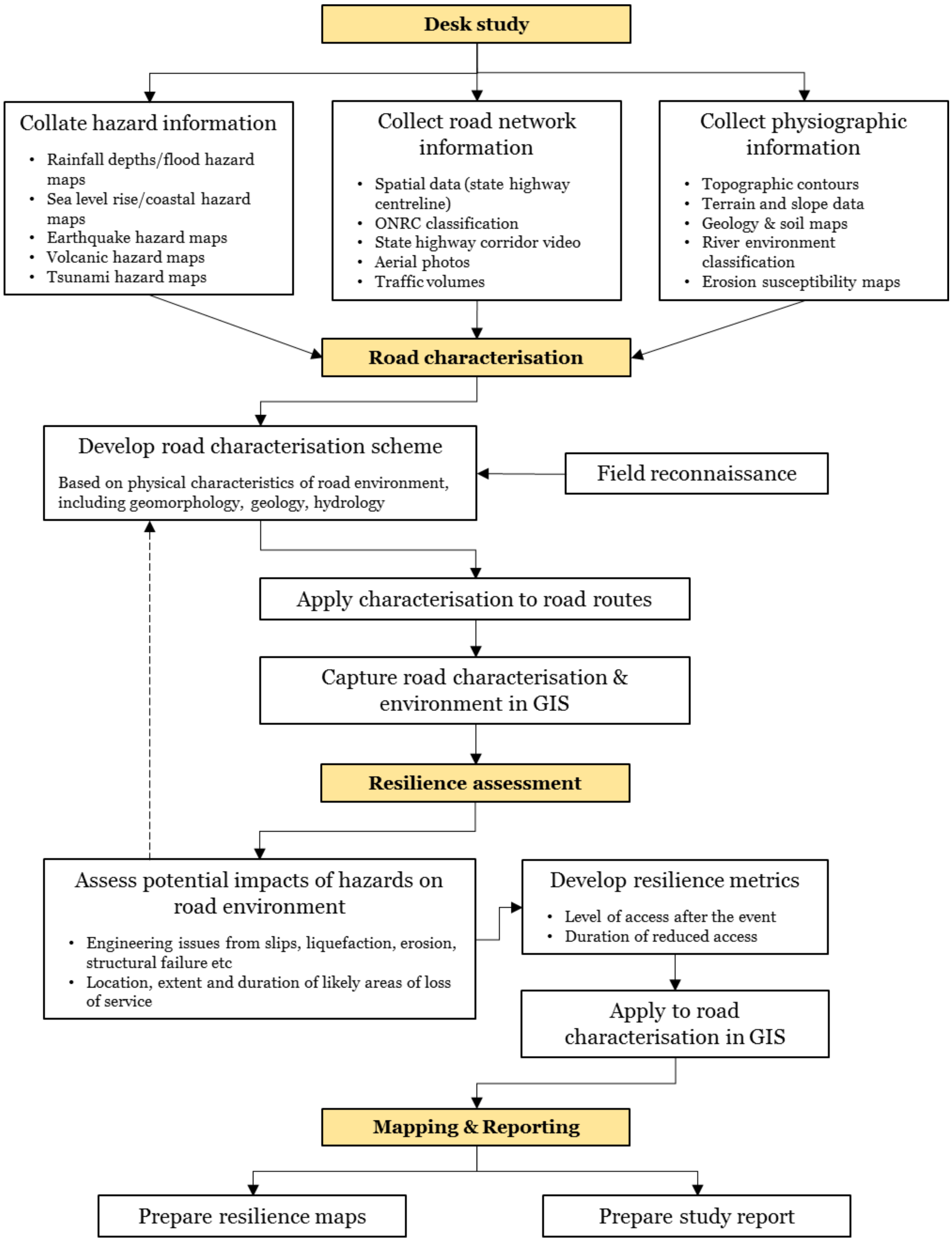


Illustration 2 Resilience assessment methodology

4.7.2 Storms

Flooding

The state highway network has been overlain on the river environment classification map (REC), and used to identify intersections and approaches within 100 m with REC order above 4. The 'flood growth factor' i.e. the ratio of the Q100 to the QMAF was assessed from 1% AEP rainfall and REC data. These parameters (see Table 8) have been used to assess the potential impact on the state highway and hence the characterisation of the vulnerability to flood hazards.

In assessing the vulnerability the following potential impacts have been considered:

- Flood inundation
- Erosion
- Deposition of sediments and debris
- Loss of bridge due to scour / erosion

Table 8 Flood risk parameters used for flood risk characterisation

Potential flood factor	Preliminary flood risk assessment		
	Low	Medium	High
Rainfall (24-hr 1% AEP)	<200 mm	200-300 mm	>300 mm
Nature of interaction		Parallels	Intersects
Mean annual flood (Q_{MAF})	<100 m^3/s	100-300 m^3/s	>300 m^3/s
Peak discharge 1% AEP	<500 m^3/s	500-1000 m^3/s	>1000 m^3/s
Flood growth factor	<2	2-3	>3
Valley gradient	Low	Medium	High
Valley form	Laterally unconfined	Partially confined	Laterally confined
Height offset[1]	>10m	5-10m	<5m

Notes [1] In many cases during the national screening, data were not available at the necessary resolution to allow assessment of the height difference between the state highway and the watercourse. This would need to be undertaken during subsequent regional scale assessments to refine the flood risk.

These potential impacts have been used to derive the relevant characterisation of the vulnerability of the road to flooding, through consideration of the engineering issues associated with flood inundation such as scour, slips, inundation, ponding, debris deposition. High peak flood flows in high gradient, confined valleys are associated with the highest flood risks, and can result in surface flooding to depth that could limit all vehicular access, as well as high potential for scour and erosion that could impact bridge structures and road embankments. Local assessment of the flood and scour risk to roads and bridges would be considered at the regional level.

Coastal inundation

The state highway network has been overlaid on coastal inundation maps (where available) to assess the vulnerability of the route to coastal hazards, similar to the assessment of the vulnerability to flooding. Terrain data (aerial photos, topographic contours and DEMs) and the predicted rise in sea level provided by MfE were used to screen areas where sea level rise may result in increased risk exposure with time.

Storm induced landslides

The state highway corridor has been overlain on the geology and terrain maps, and a characterisation scheme has been developed for the highway. Landslide mechanisms vary depending on local geology and geomorphology, and the potential hazard consequences to the highway will therefore vary spatially across the country. The following factors formed the basis for characterising the road:

- Slope type (cuttings, embankments, natural hillslopes etc);
- Slope angle and height;
- Geomorphology of adjacent slopes/catchments;
- Geology;
- Rainfall;
- Characterisation of likely failure modes and typical runout distances;
- Location and width of any berms/ditches.

The road corridor was characterised by considering geotechnical issues and hazards and their consequences to the road's availability following a large storm, based on Opus staff experience of storm emergency response slope inspections, literature on similar geological conditions, and review with local knowledge. Site reconnaissance visits were carried out to ensure consistency of this assessment across a range of hazardous terrains.

4.7.3 Earthquakes

The seismicity has been considered by identifying areas with low, moderate and high seismicity, based on a 1,000 year recurrence interval earthquake shaking, for example see Illustration 3.

The following potential earthquake hazard impacts on the highways have been considered:

- Fault rupture, and effect on road access based on active fault maps
- Liquefaction, based on geology, and lateral spreading considering the terrain and proximity to slopes or free surfaces such as water courses.
- Earthquake induced slope failures, based on geology, relief (slope heights) and seismicity.
- Bridge / structures damage based on NZTA's seismic screening and assessment of bridges (this data is being sourced from the Agency).

A site reconnaissance visit to the central North Island was carried out to relate the observations of ground damage in the 2016 Kyushu earthquake in Japan to the volcanic terrains in New Zealand, and particularly to consider earthquake induced landslide potential along State Highway 1.

A characterisation scheme for the highway for earthquake hazards has been developed considering:

- Slope type (cuttings, embankments, natural hillslopes etc);
- Slope angle and height;
- Geomorphology of adjacent slopes/catchments;
- Geology;
- Seismicity and active faults;
- Hydrology;
- Characterisation of likely failure modes – e.g. rock slides, slips, rock fall, fault rupture; liquefaction-induced subsidence, lateral spreading – and typical runout distances;

Illustration 3 Indicative earthquake hazard levels across New Zealand

4.7.4 Tsunami

Tsunami inundation maps have been used to identify areas of the state highways vulnerable to tsunami, and an example of such a map is shown in Illustration 4. The highway vulnerability to tsunami has been characterised based on potential damage to roads from tsunami, considering:

- Available tsunami height information
- Reported effects to roads in areas previously affected by tsunami (mainly from overseas reports);
- Relative relief/height of road;
- Distance of road from shoreline or estuary.

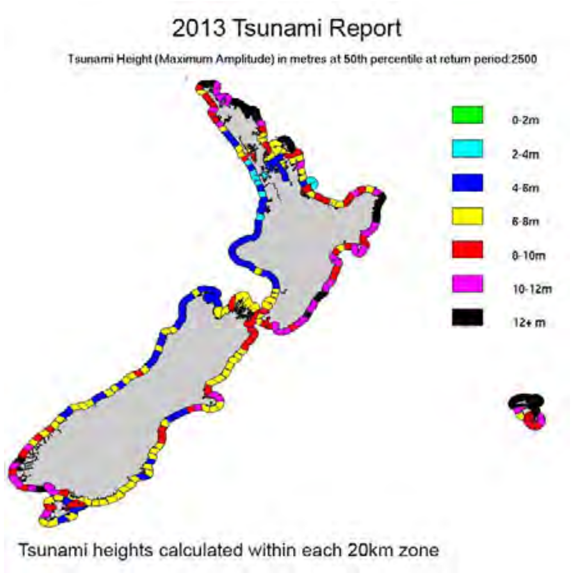


Illustration 4 Indicative tsunami hazard map

The highway has been characterised for the following potential impacts, considering their effects on availability of access:

- Inundation
- Erosion / debris deposition
- Damage to estuarine river bridges

Indicative damage impacts from tsunami are shown in Illustration 5.

Illustration 5 Tsunami impacts in Japan, 2011

4.7.5 Volcanic eruption

The different routes of highway have been characterised considering the different volcanic hazards and their severity:

- Lava flow
- Pyroclastic eruption
- Tephra
- Lahar

An example volcanic hazard map is presented in Illustration 6.

The potential impacts on the highway have been considered in characterising the vulnerability of the highway to these volcanic hazards:

- Destruction, say from lava flow
- Washout / erosion, say from lahar
- Ash deposition, from tephra, affecting access.

Illustration 7 shows some volcanic hazard impacts to roads.

The highway has been characterised considering the impacts on availability of access.

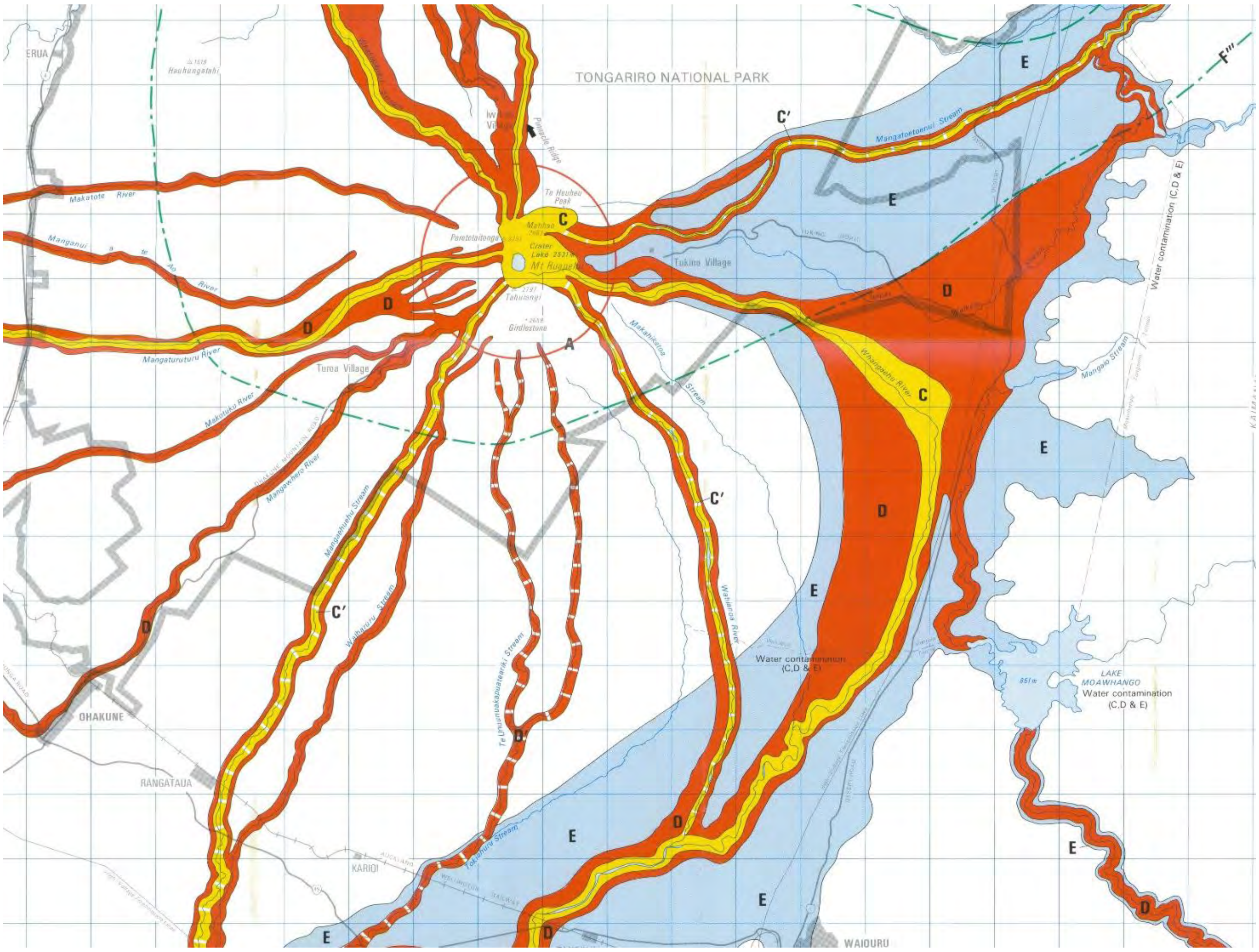


Illustration 6 Extract of volcanic hazard map for Mt Ruapehu


Illustration 7 Indicative volcanic hazard impacts on roads

4.7.6 Characterisation of highway corridors

Using the characterisation scheme developed above, the highway routes have been characterised based on the relevant hazard layers and by using the GIS hazard maps. This has been applied by consideration of the road environment, geology, terrain, and rivers where appropriate, with the aid of Google Earth maps and street view. The characterisation has been carried out by a virtual drive-over of the route with the aid of NZTA's state highway network route videos, google earth maps and the relevant GIS hazard maps.

4.7.7 Future changes in resilience

Consideration has been given to future changes in resilience as a consequence of climate change, say over the next 50 years, and the likelihood of decrease or increase in the resilience of the state highway network in different regions as a result of more frequent storms or sea level rise.

5 Resilience states

5.1 Assessment of resilience states

The information collected during the road characterisation comprised qualitative assessment of the road form and vulnerability of the routes. This required consideration of the size / return period of the natural hazard events of interest, assessment of the effects of the hazards on the availability of access along the route, and assessment of the potential duration of outages.

Performance or resilience states discussed in Section 4.2 have been used to map the resilience of the 9 priority corridors at national level, using the approach developed by Brabhaharan *et al*. (2001) and the performance criteria developed by Brabhaharan *et al*. (2006).

This was carried out by assigning scores of availability (from 1 to 5) and outage (from 1 to 6) to each road category used in the road characterisation as described in Section 4.7. The availability and outage scores were derived from the assessment of the potential hazard impacts on the road segment, in terms of the location, extent and type of damage, and the type of work and time required to remedy the damage and restore access. The resilience states were then added to the road characterisation spatial database using ArcGIS.

5.2 Spatial mapping

The resilience states were spatially mapped and displayed in GIS, so that the results can be visually displayed in its regional and national context. The results of the resilience assessment for the road networks are presented on individual maps of disruption for the natural hazards considered in this study and are shown on the maps in the Appendices. A description of the resilience state levels is provided in Section 4.2.

The following maps have been produced for this study report:

» Availability & outage states – Maps of availability and outage, by hazard, for each corridor. Due to the large number of maps, these layers are provided in the spatial database accompanying this report.

» Disruption state – A series of A3 maps at scales of 1:250,000 to 1:1,000,000 for each hazard, provided in the appendices.

The mapping and road characterisation was carried out at 1:20,000 scale, and thus the GIS data enables specific areas of the maps to be viewed at larger scales.

5.3 Prioritisation

The results of the resilience assessment have been used as the basis for prioritising links in the 9 PBC corridors. The prioritisation maps for the 9 PBC corridors are provided in Figure 2. This has been in terms of the ONRC classification.

The resilience maps show critical sections of the road that are vulnerable to a number of natural hazards that could result in closure of the road for long periods. The key resilience issues for each corridor are summarised in Table 9 below.

Assessment of the criticality of routes should include consideration of other factors not captured in the ONRC, such as:

- Availability of alternative routes
- Importance for lifeline activity
- Importance for post-disaster response and recovery

The suitability and information for this approach will be discussed with the Transport Agency, and will depend on the availability of supporting data. Aspects of the ONRC classification such as tourism routes and economical importance may need to be considered individually as part of this approach.

Table 9 Key resilience issues for the 9 priority PBC corridors

Corridor	Location	Road corridor & hazards description	Loss of Service	Likely Duration	ONRC class
SH1 Whangarei to Auckland	Whangarei Harbour	Potential liquefaction & lateral spreading hazard causing uneven/damaged road surface. This risk is not well defined and will need better characterisation at the regional level to quantify the level of resilience gap.	Reduced speed, possible restricted access to 4WD vehicles only	3 weeks to 3 months	National
	Brynderwyn Hills	Narrow road corridor in steep terrain susceptible to landslides on slopes above and/or below the road.	Closure of road due to landslides and/or underslips.	3 weeks to 3 months	National
	Wellsford to Warkworth	Narrow road through incised valley susceptible to closure from overslips on steep cut slopes above the road.	Single lane to possible full closure.	3 days to 3 weeks	National (high volume)
	Waitemata Harbour	Road along coastal margin susceptible to damage from liquefaction, lateral spreading, volcanic eruption (lava flow, eruptive blast), tsunami inundation/scour. The liquefaction and volcanic risks need characterisation and mapping at the regional level to quantify the level of resilience gap.	Major structural damage or closure	>3 months	National (high volume)
SH29 Tauriko to Piarere	Tauranga Harbour	Road on flat, low-lying land susceptible to damage from liquefaction and lateral spreading, inundation by tsunami, and scour/erosion along sections of Wairoa River.	Uneven road surface from liquefaction or tsunami debris, closure due to lateral spreading or scour/ underslips	3 weeks to 3 months+	National (high volume)
	Kaimai Ranges	Road on western side of hills susceptible to large landslides, rock falls, earth/debris flows and underslips or failure of culverts and retaining walls.	Complete closure of road due to landslides and underslips	3 weeks to 3 months+	National (high volume)
SH1 Piarere to Taupo	Kinleith to Wairakei	Road through undulating/hilly terrain lies in close proximity to steep cuts and natural hillslopes in places, and is susceptible to slips and rock slides.	Closure of road in localised sections	3 weeks to 3 months	National (high volume)
	Wairakei to Taupo	Road through undulating terrain crosses active fault strands of the Taupo Fault Belt	Major structural damage to road due to fault rupture	3 days to 3 weeks; >3 months for bridges	National (high volume)
SH1 Taupo to Waiouru	Taupo to Turangi	Road along east side of Lake Taupo susceptible to liquefaction and lateral spreading, landslides and underslips. High flood risk potential at Tongariro River crossing.	Closure of road due to flooding, landslides and/or underslips; major structural damage to road surface from liquefaction.	>3 months	National
	Turangi to Waiouru	Desert Road crosses rolling to undulating land dissected by very steep, incised gullies. The road sections crossing these gullies are susceptible to landslides, underslips, and inundation and scour from flooding and lahars. The southern section through the Rangipo Desert crosses the active Rangipo Fault.	Closure of road due to landlides, underslips or lahar damage. Structural damage to road surface from fault rupture.	3 weeks to 3 months; >3 months for lahars.	National

Corridor	Location	Road corridor & hazards description	Loss of Service	Likely Duration	ONRC class
SH2 Masterton to Te Marua	Featherston to Te Marua (Rimutaka Hill)	Narrow road corridor through steep, mountainous terrain. Road vulnerable to landslides, underslips, failure of retaining walls, debris flows, fault rupture.	Complete closure of road due to landslides and underslips.	>3 months	Regional
SH2 Te Marua to Ngauranga	Te Marua to Petone	Road alongside Hutt River susceptible to landslides, debris flows, flooding, scour/underslips, liquefaction and fault rupture.	Closure of road in localised areas due to landslides or debris flows from steep hillslopes, underslips/scour along Hutt River, structural damage from liquefaction or rupture of Wellington Fault.	Possibly >3 months in individual sections	National
	Petone to Ngauranga	Road alongside Wellington Harbour susceptible to landslides, debris flows, liquefaction, lateral spreading, erosion/scour from storm surge and tsunami. Possible increased exposure to coastal hazards from sea level rise (may be counteracted by tectonic uplift).	Closure of road due to landslides or debris flows from steep hillslopes, underslips/scour along Wellington Harbour, structural damage from liquefaction.	>3 months	National (high volume)
Wellington Port Access		Road alongside Wellington Harbour susceptible to liquefaction, lateral spreading, fault rupture and erosion/scour from storm surge and tsunami. Possible increased exposure to coastal hazards from sea level rise or from tectonic subsidence (also potential counteraction from tectonic uplift).	Loss of lanes from scour/underslips; major structural damage from liquefaction or fault rupture.	>3 months	National (high volume)
SH73/77 West Melton to Lyttelton	Lyttelton to Hillsborough	Road through Port Hills susceptible to rock fall, earth flows, and liquefaction.	Closure of road due to rock fall or landslides; reduced speed due to deformed road surface from liquefaction.	3 weeks to 3 months	National (high volume)
	Hillsborough to West Melton	Road through southwest Christchurch susceptible to liquefaction.	Reduced speed due to deformed road surface.	3 days to 3 weeks	National (high volume)
SH1 Christchurch to Dunedin	Canterbury Plains	At major river crossings, road is susceptible to liquefaction, flooding, scour, and structural damage to bridges.	Closure of road due to scour, erosion and structural damage to bridges; reduced speed due to deformed road surface from liquefaction or flooding.	Generally 3 days to 3 weeks	National
	Timaru to Oamaru	Road along coastal margin susceptible to tsunami inundation and minor to moderate liquefaction risk.	Possible closure of road due to tsunami inundation; reduced speed due to deformed road surface from liquefaction.	Generally 3 days to 3 weeks	National
	Moeraki to Waitati	Road along coastal margin susceptible to liquefaction, lateral spreading, erosion/scour from storm surge and tsunami. Likely increased exposure to coastal hazards from sea level rise.	Closure of road or major structural damage due to underslips, scour or liquefaction/lateral spreading along coastal sections.	>3 months	National

6 Conclusions & recommendations

6.1 Conclusions

The national level resilience assessment of the 9 priority corridors has identified sections of the state highways that are vulnerable to failure from a variety of natural hazards.

The low resilience of sections of these highways pose a significant risk to access in these areas. Comparison of the resilience and the availability of alternative routes will help identify links where the resilience would have a severe effect on the communities in the area, and in some cases with regional and possibly national consequences.

It would be prudent to consider the resilience at a more detailed regional level, with particular focus on areas that have been identified as having a low resilience from this national resilience screening assessment. This will provide better definition of the issues that can be used for consideration of the development of these routes, as well as enable asset management and emergency response planning.

6.2 Recommendations

It is recommended that:

1. A regional level resilience screening methodology be developed, and then implemented for the 9 Priority Programme Business Case Corridors. This will enable the resilience to be assessed with a better definition of local level hazards and the hazards (e.g. local flooding, liquefaction) in more detail. This will also provide insight into whether some of the PBC corridors would need to consider alternative alignments, and identify which sections of the corridors are more critical from a resilience perspective.

2. The national level resilience screening be continued for the remaining state highway network, after completion of the regional level resilience for the 9 priority corridors. This will enable the programme business cases to proceed, but will also allow testing the methodology for the regional level assessment, and this may provide insights to refine the national resilience screening methodology.

3. The identified national level critical resilience issues be used in asset and emergency management planning for these routes that have been assessed.

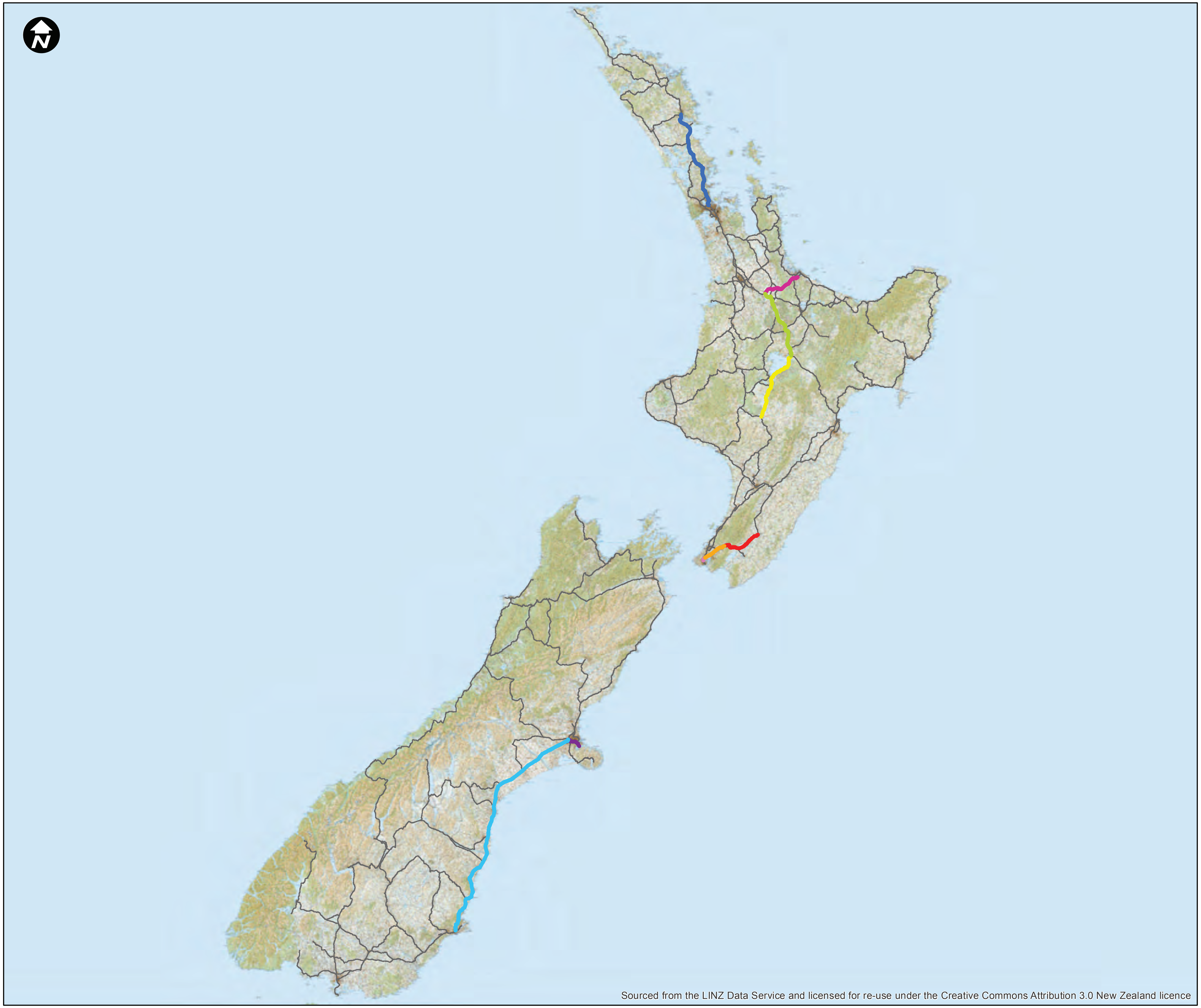
7 References

Brabhaharan, P., Fleming, M.J., Lynch, R. (2001). Natural hazard risk management for road networks. Part I: Risk management strategies. Transfund New Zealand Research Report 217. 75p.

Brabhaharan, P. (2006). Recent Advances in Improving the Resilience of Road Networks. Remembering Napier 1931 – Building on 75 Years of Earthquake Engineering in New Zealand. Annual Conference of the New Zealand Society for Earthquake Engineering. Napier, 10-12 March 2006.

Brabhaharan, P., Wiles, L.M., Freitag, S. (2006). Natural hazard risk management for road networks. Part III: Performance Criteria. Land Transport New Zealand Research Report 296. 117p.

Figures



Legend

PBC Corridors, 2016

Corridor

- SH1 Auckland to Whangarei
- SH1 Christchurch to Dunedin
- SH1 Piarere to Taupo
- SH1 Taupo to Waiouru
- SH2 Ngauranga to Te Marua
- SH2 Rimutaka Hill (Te Marua to Masterton)
- SH29 Piarere to Tauriko
- SH73/76 West Melton to Tunnel (Lyttelton)
- Wellington Port Access
- State highways

Scale:
1:5,000,000
0 50 100 150 200 250 km

Title:

Location map

Project:

National State Highway Resilience
9 Priority PBC Corridors

Prepared For:

NZ TRANSPORT AGENCY
WAKA KOTAHI

Prepared By:

OPUS

Date:	*Project No:*	*Figure:*
June 2016	5-C2934.01	1

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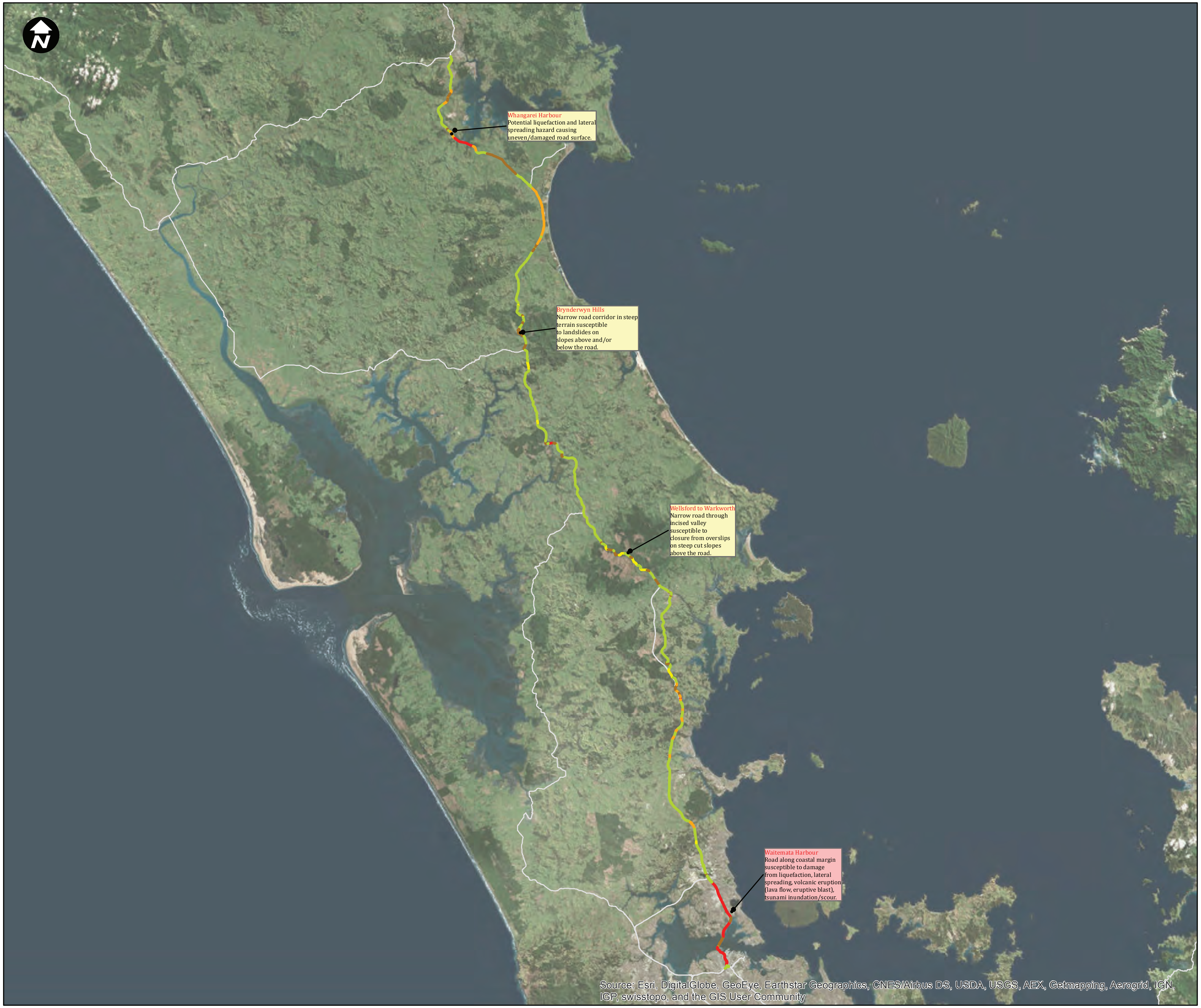

Legend

Prioritisation Map of 9 PBC Corridors

Maximum (All Hazards) Disruption State

- Extreme
- Severe
- High
- Moderate
- Limited
- None
- State highways

Data Sources:

Road Centreline 2016 (NZTA)
Sea Level Rise, Erosion Susceptibilityu & Limiting Factors (MfE)
Aerials, Contour Data, DEM 8m (LINZ Data Service)
Tsunami Layers, Faultline and Geological Data (GNS, Wellington Lifelines Group)
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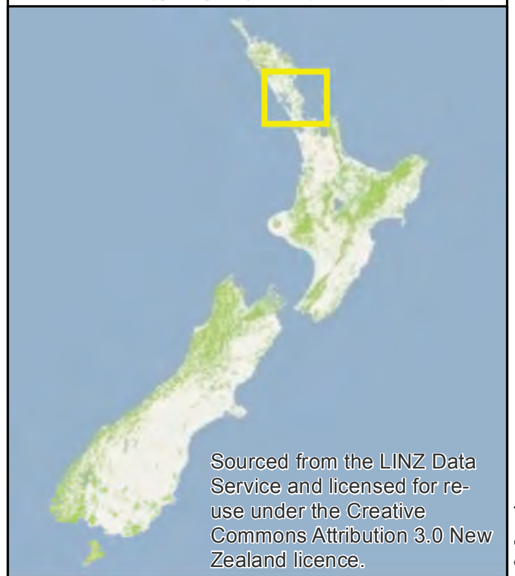
Coastal Hazards (Auckland Council, Waikato Regional Council, Otago Regional Council, Environment Canterbury)
Soil, Rock, Erosion Type, Slope Angle Class (Landcare Research)



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Title:
Prioritisation Map of 9 PBC Corridors

Project:
National State Highway Resilience
9 Priority PBC Corridors

Prepared For:
NZ TRANSPORT AGENCY
WAKA KOTAHI

Prepared By:
OPUS

Date:	*Project No:*	*Figure:*	*Sheet:*
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Legend

Prioritisation Map of 9 PBC Corridors

Maximum (All Hazards) Disruption State

- Extreme
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- Limited
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Data Sources:

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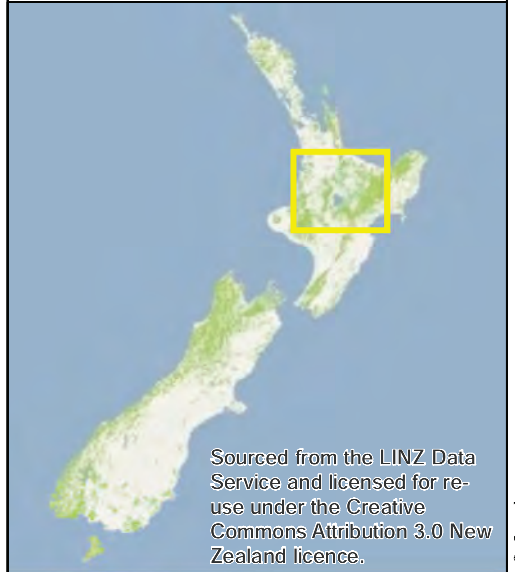

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Title:
Prioritisation Map of 9 PBC Corridors

Project:
National State Highway Resilience
9 Priority PBC Corridors

Prepared For:
NZ TRANSPORT AGENCY
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Legend

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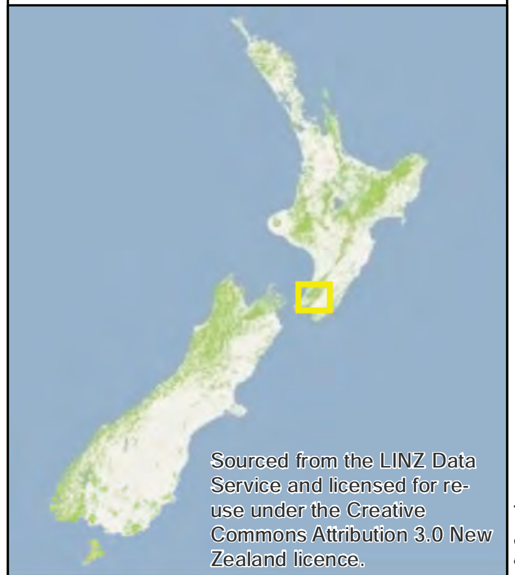

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Title:
Prioritisation Map of 9 PBC Corridors

Project:
National State Highway Resilience
9 Priority PBC Corridors

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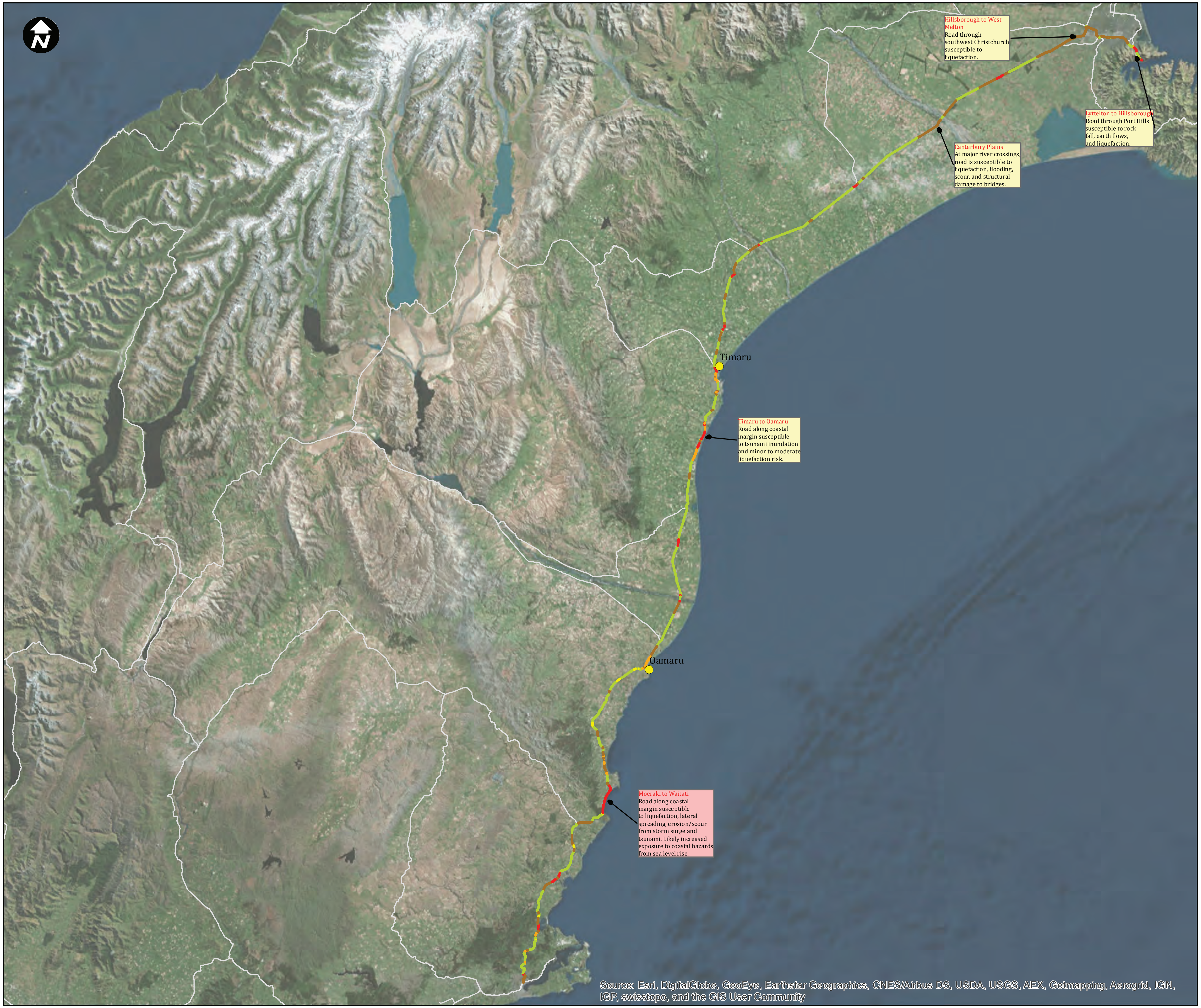

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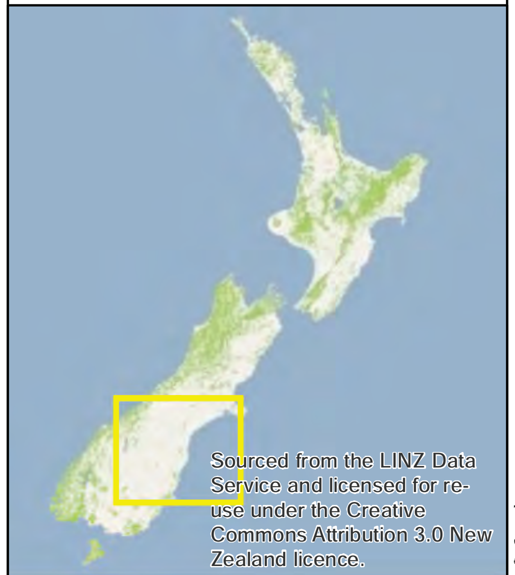

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Title:
Prioritisation Map of 9 PBC Corridors

Project:
National State Highway Resilience
9 Priority PBC Corridors

Prepared For:
NZ TRANSPORT AGENCY
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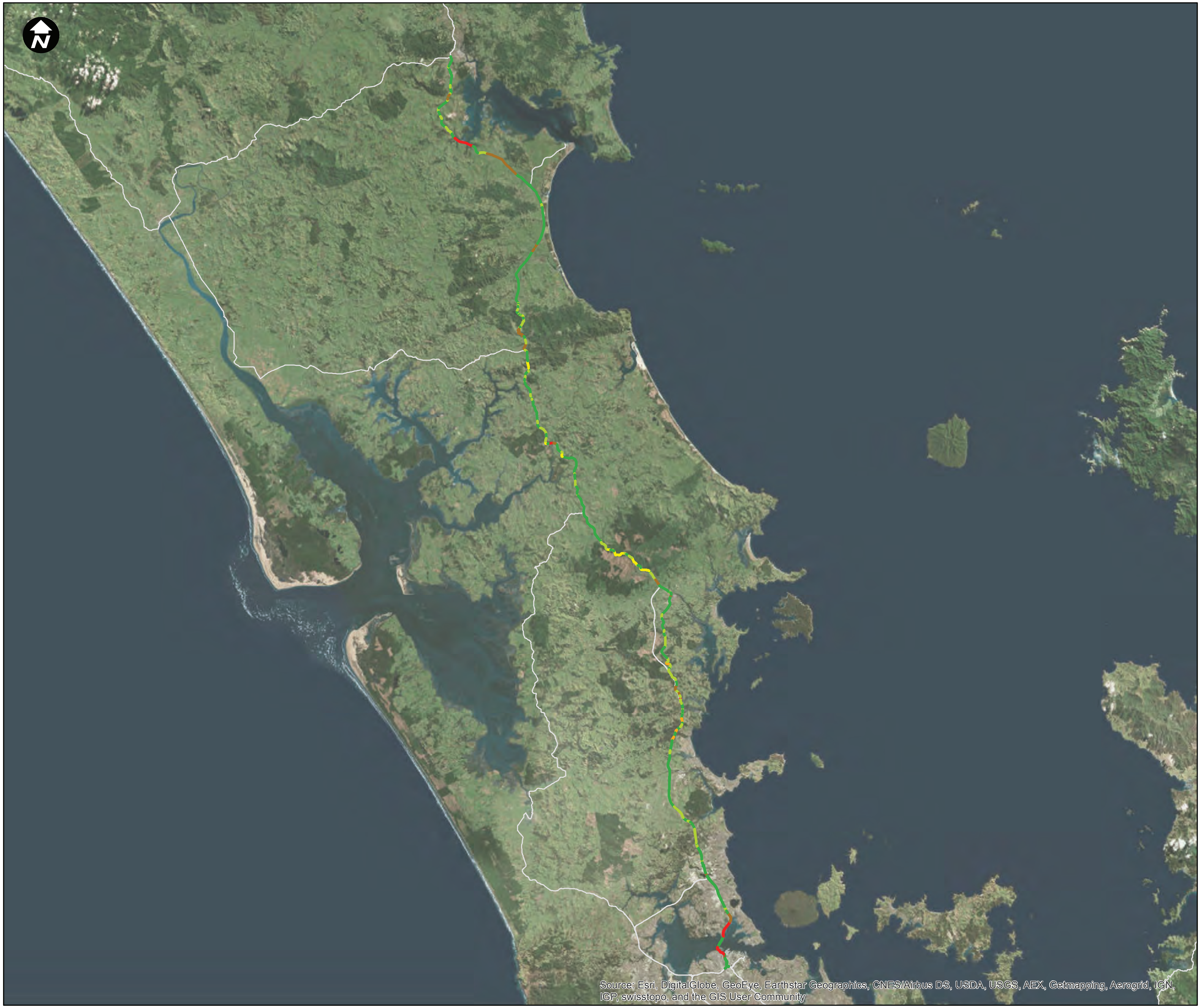
Appendix A
Disruption state maps for earthquake hazards



Legend

Earthquake Disruption State

- Extreme
- Severe
- High
- Moderate
- Limited
- None
- State highways

Data Sources:

Road Centreline 2016 (NZTA)
Sea Level Rise, Erosion Susceptibilityu & Limiting Factors (MfE)
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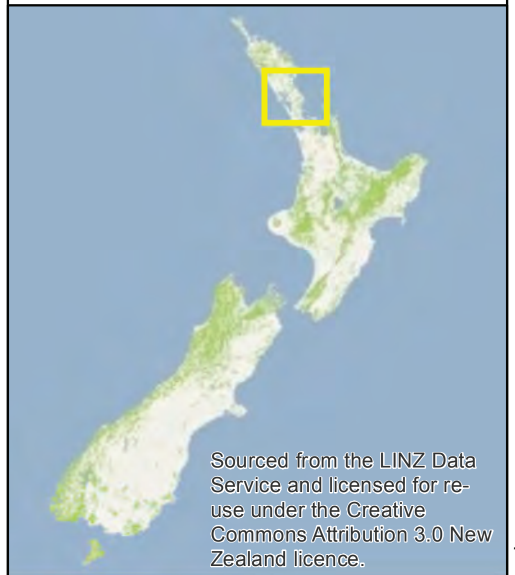

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Title:
Disruption State for Earthquake Hazard

Project:
National State Highway Resilience
9 Priority PBC Corridors

Prepared For:
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WAKA KOTAHI

Prepared By:
OPUS

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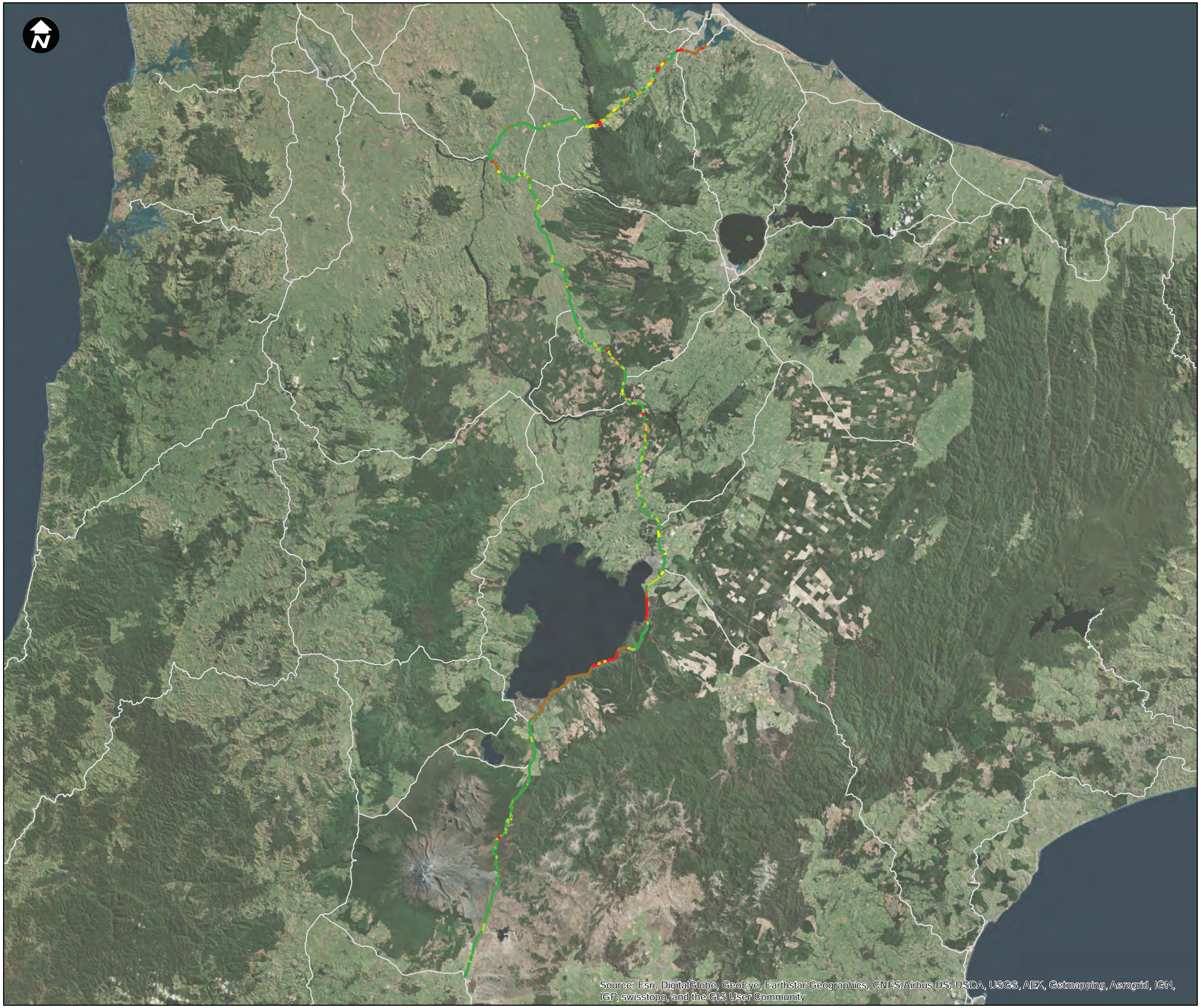

Legend

Earthquake Disruption State

- Extreme
- Severe
- High
- Moderate
- Limited
- None
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Data Sources:

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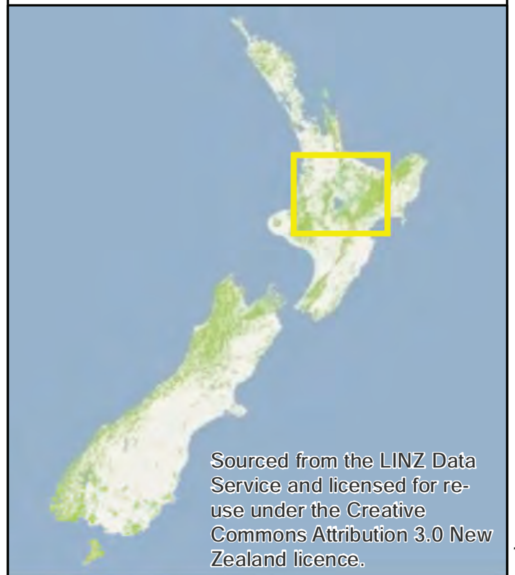

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Title:
Disruption State for Earthquake Hazard

Project:
National State Highway Resilience
9 Priority PBC Corridors

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Legend

Earthquake Disruption State

- Extreme
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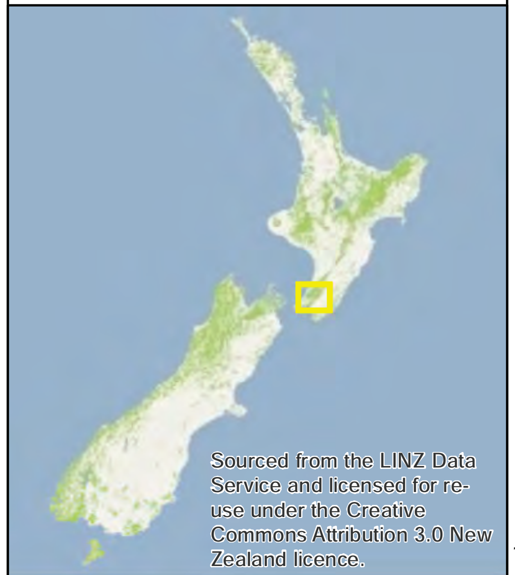

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Title:
Disruption State for Earthquake Hazard

Project:
National State Highway Resilience
9 Priority PBC Corridors

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Legend

Earthquake Disruption State

- Extreme
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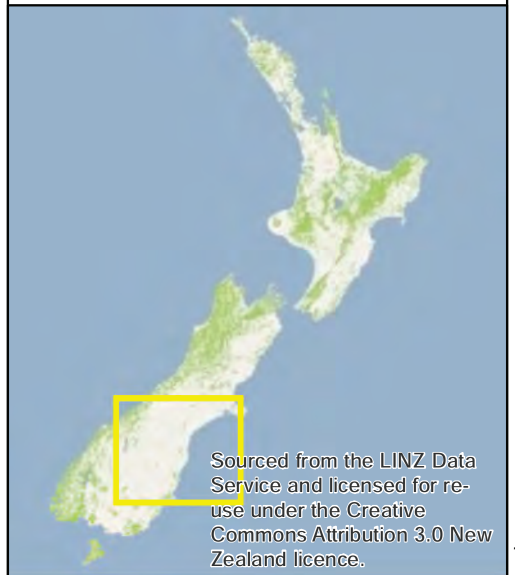

Scale:

1:1,000,000

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Title:

Disruption State for Earthquake Hazard

Project:

National State Highway Resilience
9 Priority PBC Corridors

Prepared For:

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WAKA KOTAHI

Prepared By:

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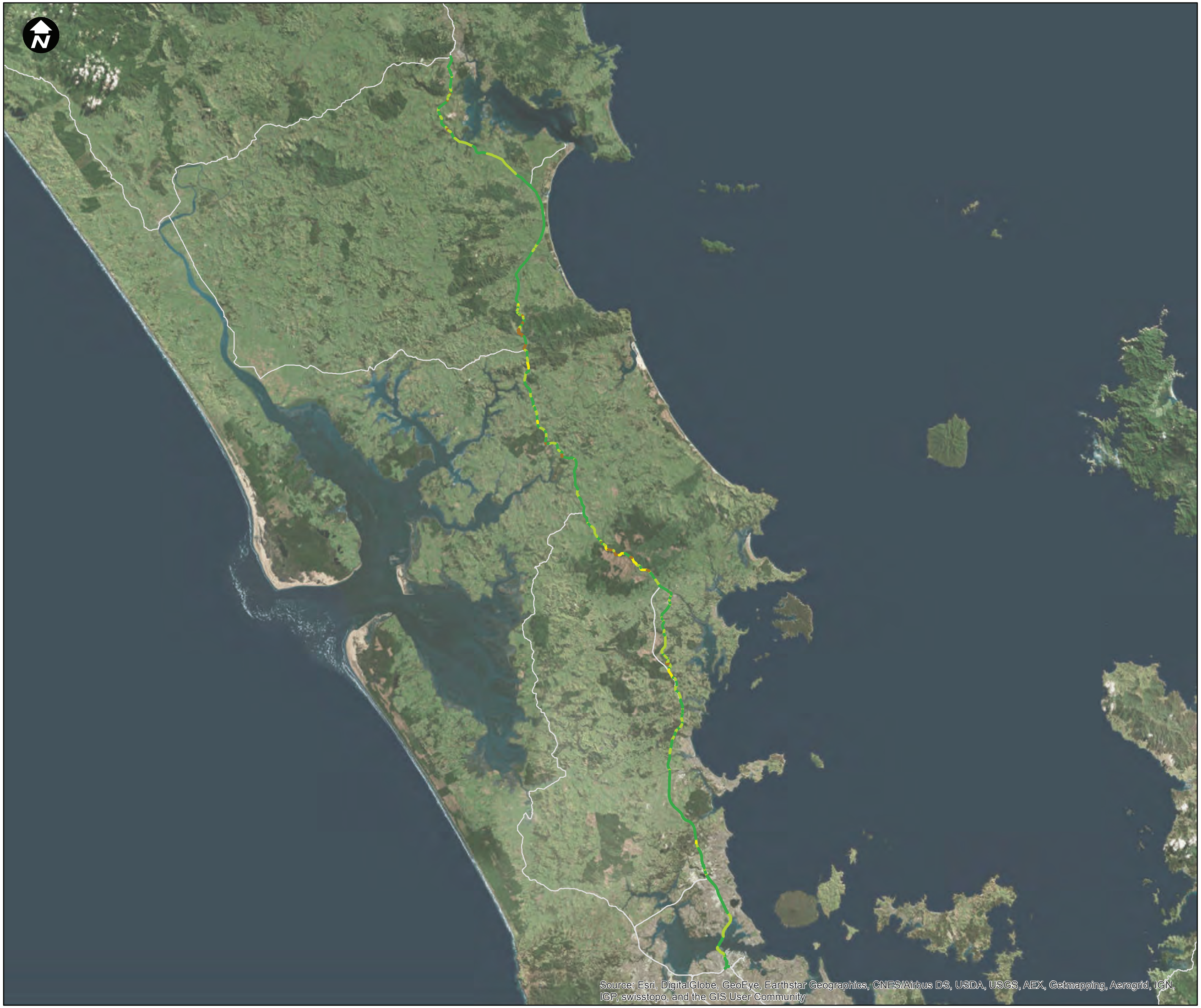
Appendix B
Disruption state maps for storm hazards



Legend

Storm Disruption State

- Extreme
- Severe
- High
- Moderate
- Limited
- None
- State highways

Data Sources:

Road Centreline 2016 (NZTA)
Sea Level Rise, Erosion Susceptibilityu & Limiting Factors (MfE)
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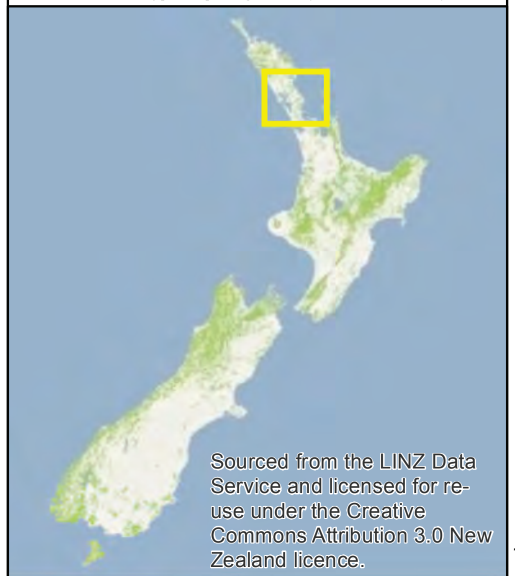

Scale:
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Title:
Disruption State for Storm Hazard

Project:
National State Highway Resilience
9 Priority PBC Corridors

Prepared For:
NZ TRANSPORT AGENCY
WAKA KOTAHI

Prepared By:
OPUS

Date:	*Project No:*	*Appendix:*	*Sheet:*
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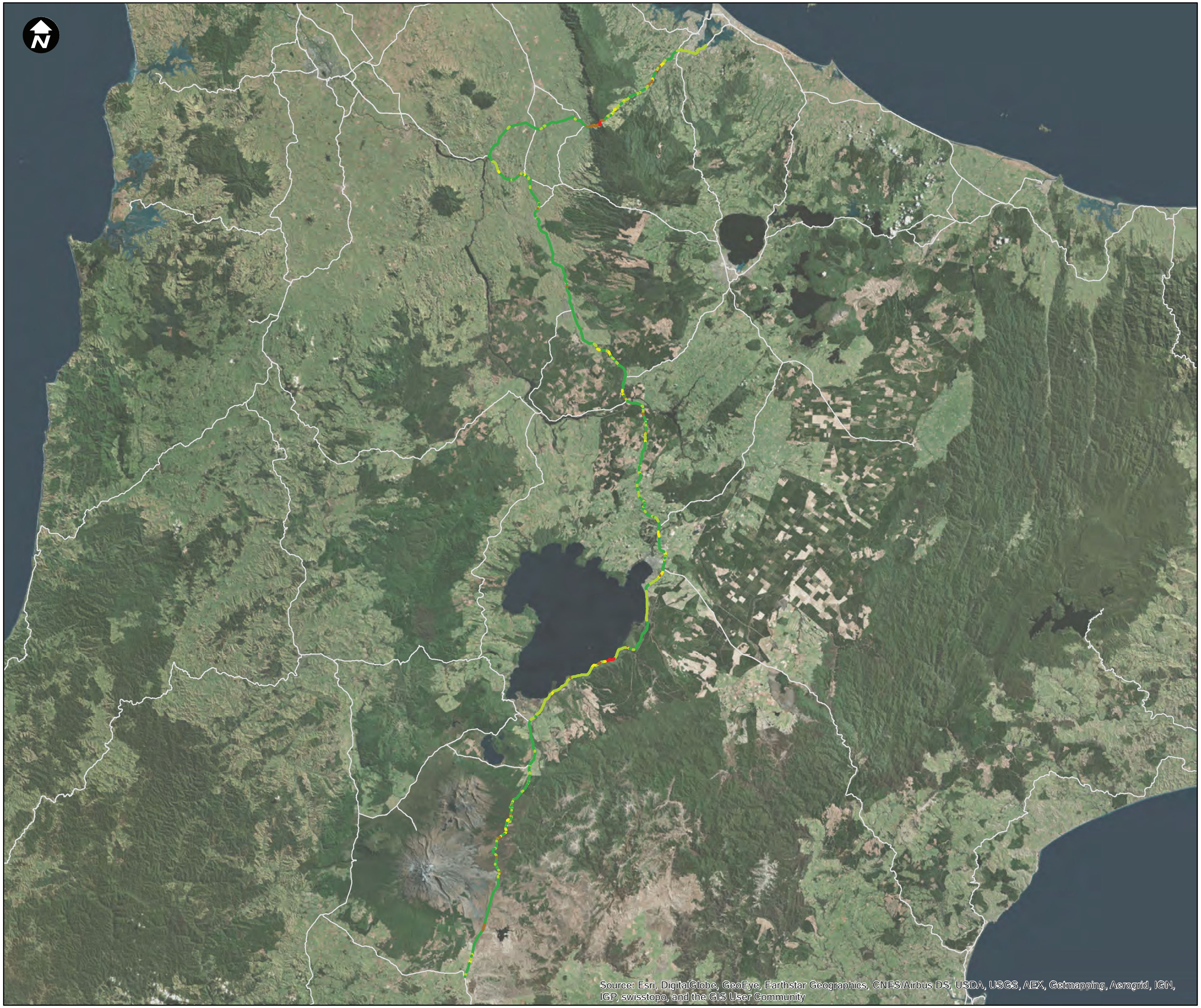

Legend

Storm Disruption State

- Extreme
- Severe
- High
- Moderate
- Limited
- None
- State highways

Data Sources:

Road Centreline 2016 (NZTA)
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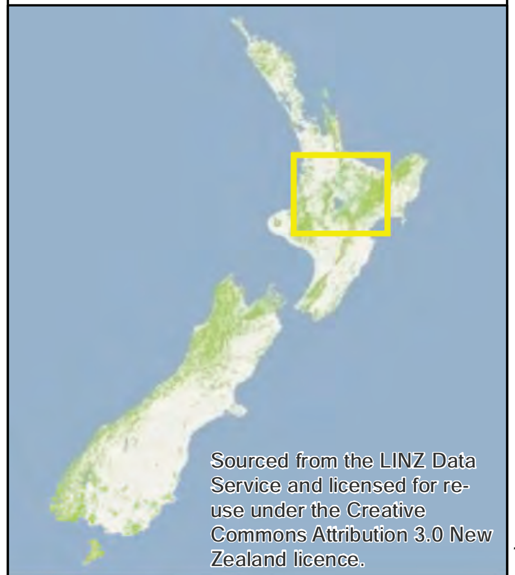

Scale:
1:750,000
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Title:
Disruption State for Storm Hazard

Project:
National State Highway Resilience
9 Priority PBC Corridors

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OPUS

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Legend

Storm Disruption State

- Extreme
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Soil, Rock, Erosion Type, Slope Angle Class (Landcare Research)

Scale:
1:250,000
0 10 km

Title:
Disruption State for Storm Hazard

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National State Highway Resilience
9 Priority PBC Corridors

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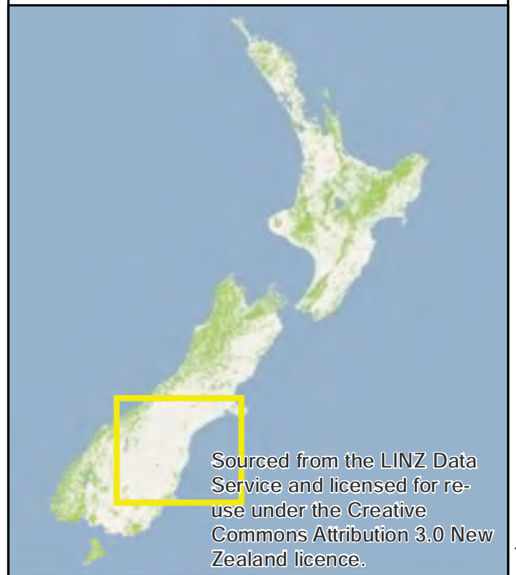

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Prepared For:
NZ TRANSPORT AGENCY
WAKA KOTAHI

Prepared By:
OPUS

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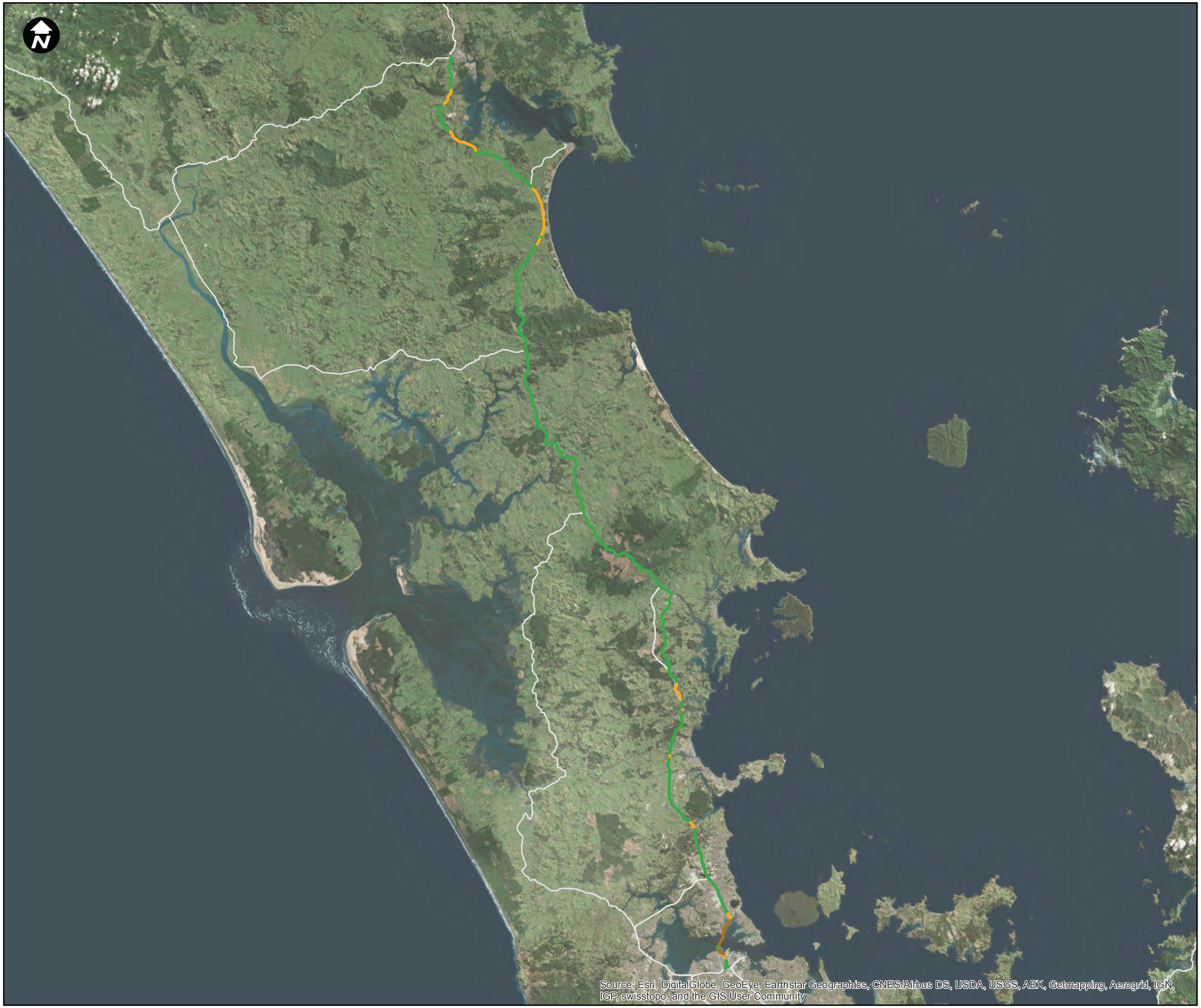
Appendix C
Disruption state maps for tsunami hazards



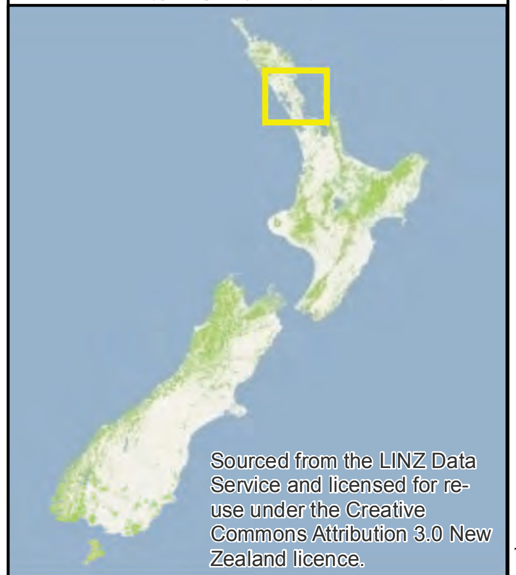
Legend

Tsunami Disruption State

- Extreme
- Severe
- High
- Moderate
- Limited
- None
- State highways

Data Sources:

Road Centreline 2016 (NZTA)
Sea Level Rise, Erosion Susceptibilityu & Limiting Factors (MfE)
Aerials, Contour Data, DEM 8m (LINZ Data Service)
Tsunami Layers, Faultline and Geological Data (GNS, Wellington Lifelines Group)
REC River Data (NIWA)
Volcanic Hazards (Taranaki Regional Council, Institute of Agriculture and Environment, Massey Univ, GNS)
Flood hazard data (Northland Regional Council, Waikato Regional Council, Greater Wellington Regional Council, Environment Canterbury, Otago Regional Council, NZTA)
Coastal Hazards (Auckland Council, Waikato Regional Council, Otago Regional Council, Environment Canterbury)
Soil, Rock, Erosion Type, Slope Angle Class (Landcare Research)



Scale:
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0 5 10 15 20 25 km

Title:
Disruption State for Tsunami Hazard

Project:
National State Highway Resilience
9 Priority PBC Corridors

Prepared For:
NZ TRANSPORT AGENCY
WAKA KOTAHI

Prepared By:
OPUS

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Legend

Tsunami Disruption State

- Extreme
- Severe
- High
- Moderate
- Limited
- None
- State highways

Data Sources:

Road Centreline 2016 (NZTA)
Sea Level Rise, Erosion Susceptibilityu & Limiting Factors (MfE)
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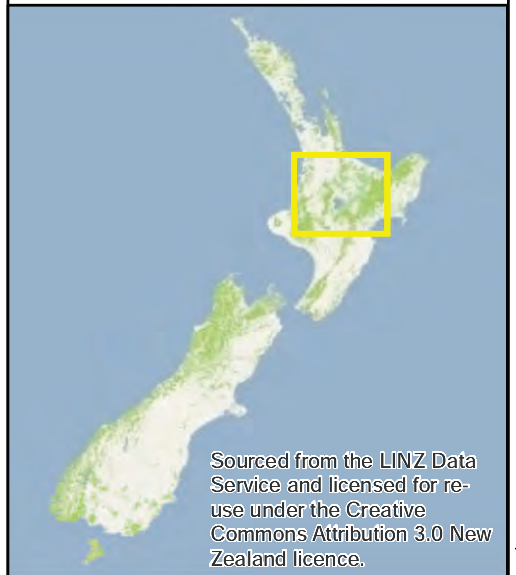
Coastal Hazards (Auckland Council, Waikato Regional Council, Otago Regional Council, Environment Canterbury)
Soil, Rock, Erosion Type, Slope Angle Class (Landcare Research)



Scale:
1:750,000
0 8 16 24 32 40 km

Title:
Disruption State for Tsunami Hazard

Project:
National State Highway Resilience
9 Priority PBC Corridors

Prepared For:
NZ TRANSPORT AGENCY
WAKA KOTAHI

Prepared By:
OPUS

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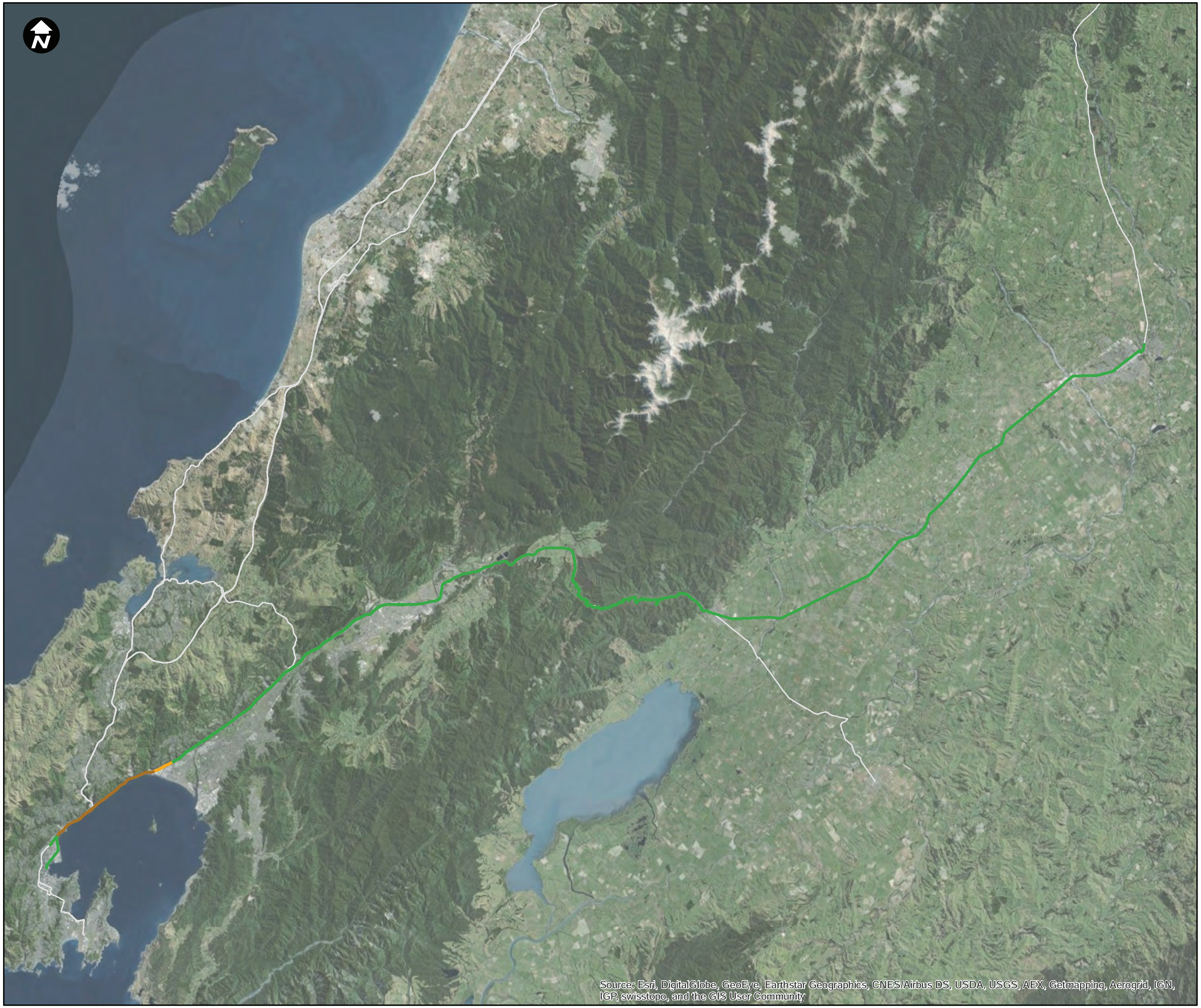

Legend

Tsunami Disruption State

- Extreme
- Severe
- High
- Moderate
- Limited
- None
- State highways

Data Sources:

Road Centreline 2016 (NZTA)
Sea Level Rise, Erosion Susceptibilityu & Limiting Factors (MfE)
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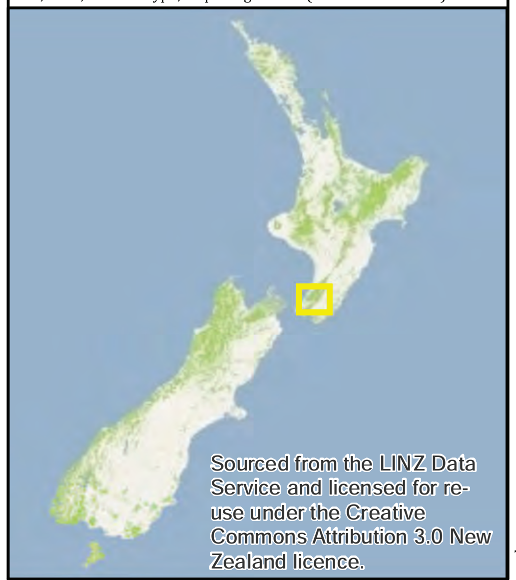
Coastal Hazards (Auckland Council, Waikato Regional Council, Otago Regional Council, Environment Canterbury)
Soil, Rock, Erosion Type, Slope Angle Class (Landcare Research)



Scale:
1:250,000
0 2 4 6 8 10 km

Title:
Disruption State for Tsunami Hazard

Project:
National State Highway Resilience
9 Priority PBC Corridors

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NZ TRANSPORT AGENCY
WAKA KOTAHI

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Legend

Tsunami Disruption State

- Extreme
- Severe
- High
- Moderate
- Limited
- None
- State highways

Data Sources:

Road Centreline 2016 (NZTA)
Sea Level Rise, Erosion Susceptibilityu & Limiting Factors (MfE)
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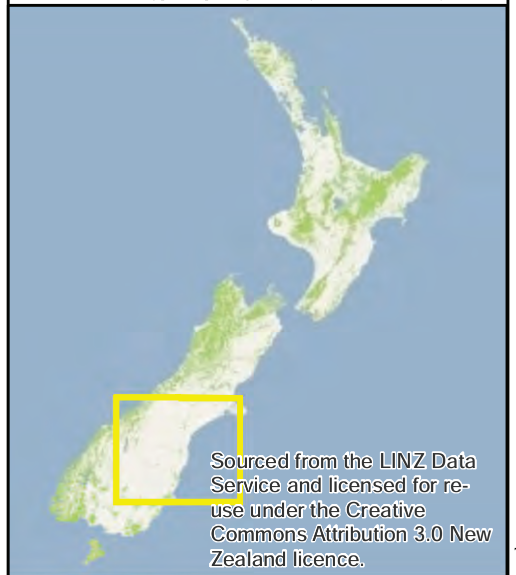
Soil, Rock, Erosion Type, Slope Angle Class (Landcare Research)



Scale:
1:1,000,000
0 10 20 30 40 50 km

Title:
Disruption State for Tsunami Hazard

Project:
National State Highway Resilience
9 Priority PBC Corridors

Prepared For:
NZ TRANSPORT AGENCY
WAKA KOTAHI

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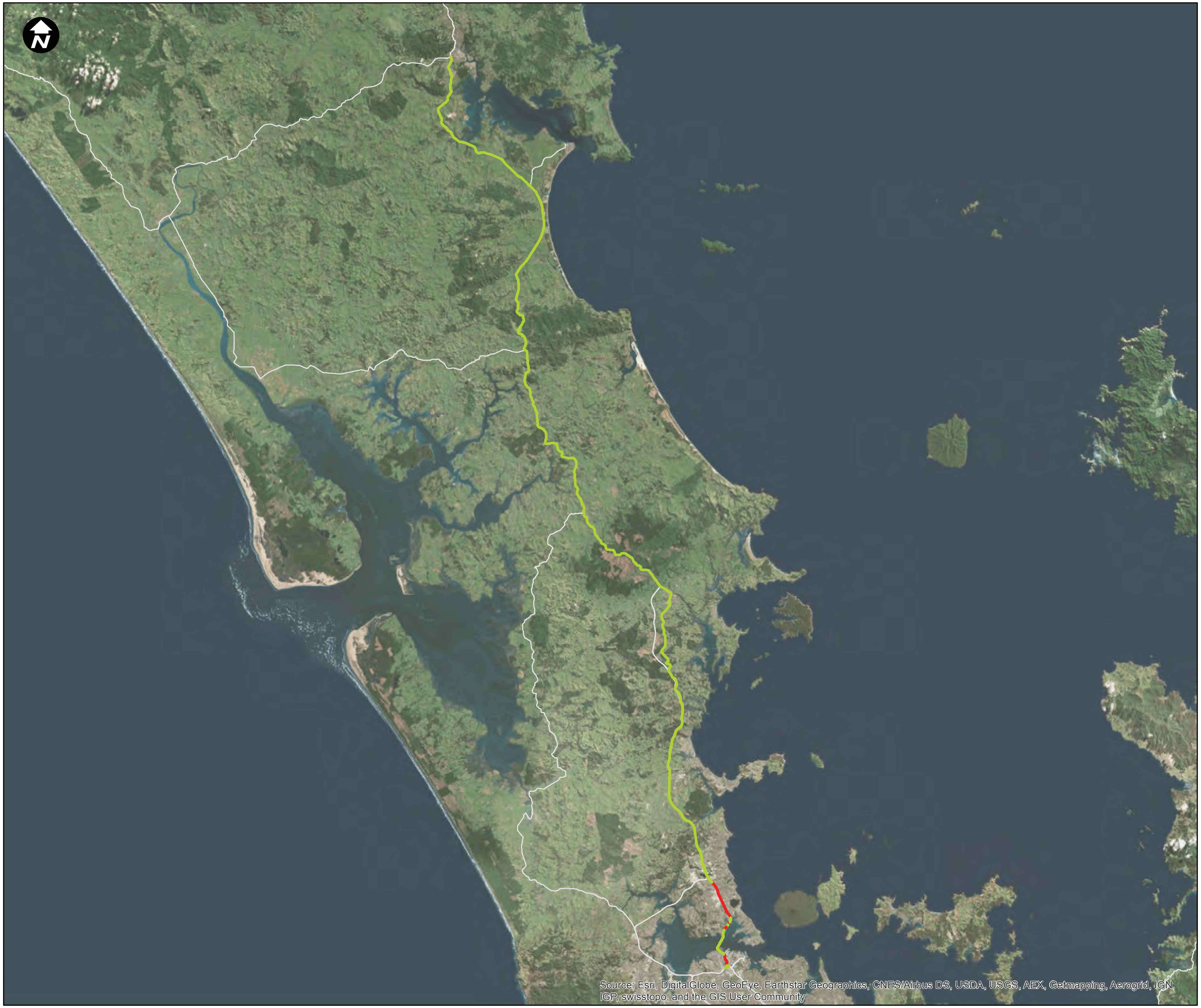
Appendix D
Disruption state maps for volcanic hazards



Legend

Volcanic Disruption State

- Extreme
- Severe
- High
- Moderate
- Limited
- None
- State highways

Data Sources:

Road Centreline 2016 (NZTA)
Sea Level Rise, Erosion Susceptibilityu & Limiting Factors (MfE)
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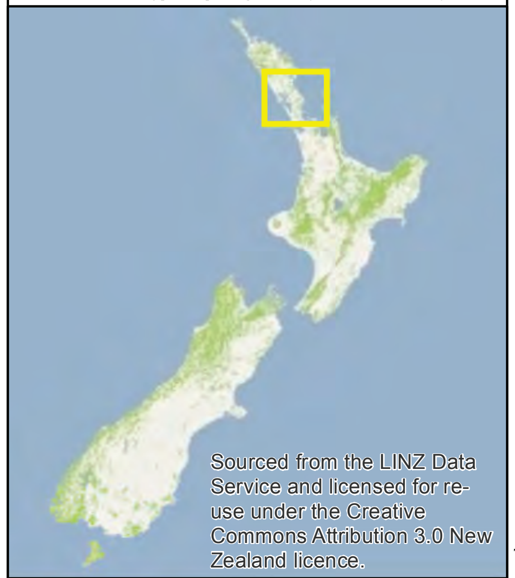
Coastal Hazards (Auckland Council, Waikato Regional Council, Otago Regional Council, Environment Canterbury)
Soil, Rock, Erosion Type, Slope Angle Class (Landcare Research)



Scale:
1:500,000
0 10 20 km

Title:
Disruption State for Volcanic Hazard

Project:
National State Highway Resilience
9 Priority PBC Corridors

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NZ TRANSPORT AGENCY
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Prepared By:
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Legend

Volcanic Disruption State

- Extreme
- Severe
- High
- Moderate
- Limited
- None
- State highways

Data Sources:

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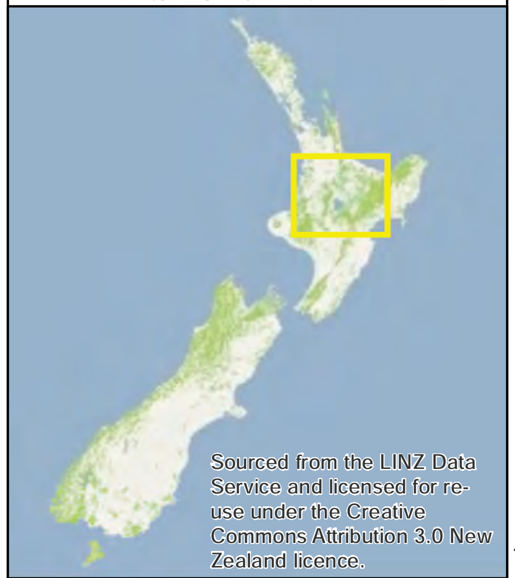
Soil, Rock, Erosion Type, Slope Angle Class (Landcare Research)



Scale:
1:750,000
0 10 20 30 40 km

Title:
Disruption State for Volcanic Hazard

Project:
National State Highway Resilience
9 Priority PBC Corridors

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Legend

Volcanic Disruption State

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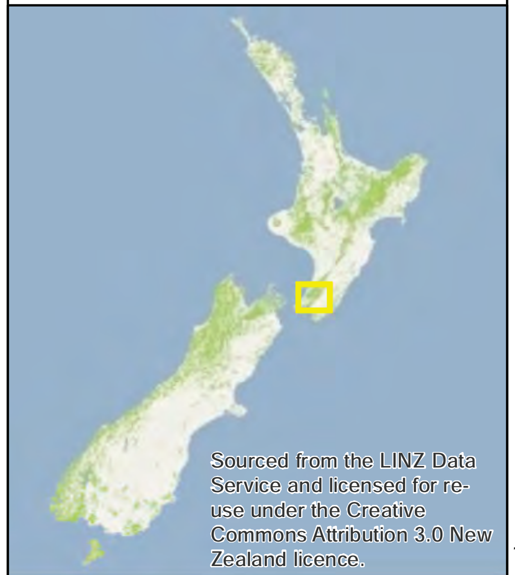

Scale:
1:250,000
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Title:
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Legend

Volcanic Disruption State

- Extreme
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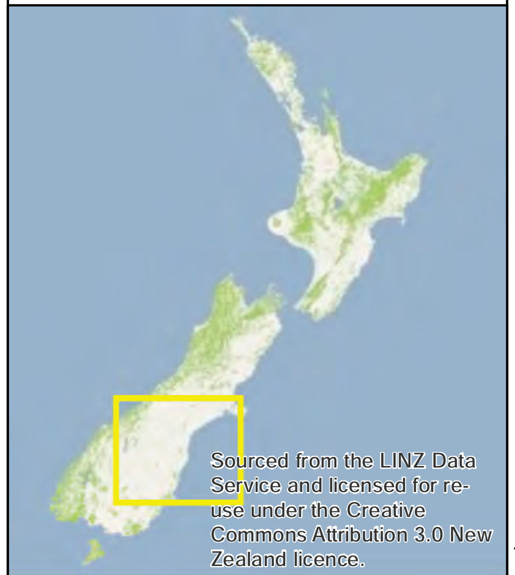

Scale:
1:1,000,000
0 10 20 30 40 50 km

Title:
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Project:
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