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RESILIENCE OF ROAD TRANSPORTATION LIFELINES FOR PORIRUA DISTRICT

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Abstract

Road networks provide a vital lifelines function to society, and their availability is critical for emergency response and recovery after major hazard events. The resilience of the primary road network in the Porirua district to a large magnitude earthquake has been assessed and mapped onto a GIS platform. Slip volumes that could be potentially generated were also assessed, to help response planning. The study highlighted the vulnerability of the network, where the road network could be cut off by major landslides on road through rugged terrain, as well as liquefaction and lateral spreading at low lying areas. The assessment enables the Council to manage the risks to the road network to provide the levels of service to fulfil the Council's social and statutory responsibilities. Together with the needs from future growth in population, industry and traffic and safety improvement needs, the assessment will enable the Council to effectively manage future capital and asset maintenance expenditure for the road network. The study also enables asset managers and emergency management staff to consider the whole inter-connected network in local and regional emergency response planning, as well as assisting the Council in developing initiatives to enhance resilience.

Introduction

Road controlling authorities have a responsibility to proactively manage the risks to their road networks from natural hazards. The Civil Defence Emergency Management Act 2002 identifies roads as one of the key lifeline utilities, and requires its operators to be able to demonstrate that they have assessed the risks to its networks, and taken proactive measures to ensure that the road transportation lifelines are able to function to the fullest extent possible after natural hazard

and other events (Ministry of Civil Defence Emergency Management, 2002).

This project has involved mapping the resilience of the Porirua City Council's primary road network. This primary network includes Principal Roads, Major and Minor Urban Arterial Roads, and Major and Minor Rural Arterial Roads. In addition, the study has involved assessing the rough order volumes of slip materials accumulating on the roads from overslips.

This paper presents the approach used, and the results of the study.

Lifeline Resilience and Performance States

Knowledge of the performance 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 expected performance to be compared against desired performance targets, and help develop risk management measures.

This study considered the risk to the roading lifelines in the Porirua network where both the extent and duration of a loss of functionality are important. The priority was to develop an approach to consider the functionality of the road network as well as provide meaningful parameters for risk mitigation and response planning.

In this context, the concept of resilience of road transportation lifelines is dependent on their vulnerability to a loss of quality or serviceability, and the time taken to bring them back into original usage state after the reduction or loss of access. This is shown conceptually in Figure 1, where following an adverse event there is a loss of service that requires a period of recovery time to restore the network back to its pre-event level of quality. Thus, the smaller the shaded area, the more resilient is the lifeline. The greater the area, the poorer is the performance.

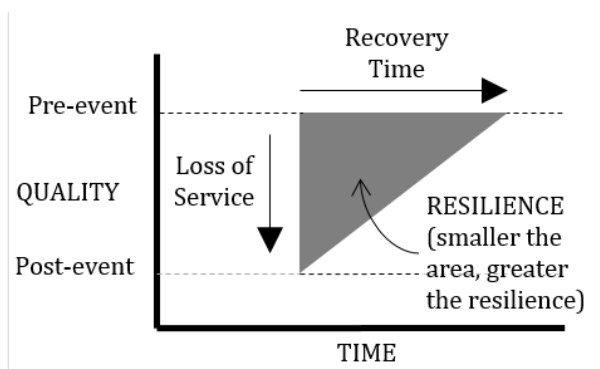


Figure 1: Resilience of network

“Performance States” or “Resilience States” representing the performance of the road network have been developed to consider the

impact of various natural hazards on the road network on a similar basis (Brabhakaran et al., 2006). These states are summarised in Table 1, with explanation of the states in Tables A-1 to A-3 in Appendix A.

Table 1: Resilience states summary

Resilience State	Description of State
Damage state	Damage State represents the severity of damage to the road and cost of damage repairs. See Table A-1 in Appendix A.
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 that section of the road network after an event. See Table A-2 in Appendix A.
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. See Table A-3 in Appendix A.

Road Network Earthquake Resilience Mapping

Study Area

The study comprised the Porirua District, on the southwest coast of the North Island. The roads included in the study are the Council's primary road network, which includes:

- Major urban arterial roads;
- Major rural arterial roads;
- Minor urban arterial roads;
- Minor rural arterial roads;
- Principal roads;
- Other key strategic routes identified through consideration of emergency response priorities.

The location of the primary road network is shown in Figure 2.

The State Highways in the district (SH 1 and SH 58) were excluded because they are managed by the New Zealand Transport Agency, and had already been assessed as part of a previous study (Opus, 2009).

Characterisation of the Road Network

The approach we have used to assess the resilience of the network through performance states, was to characterise the road network using a GIS-based spatial approach developed by Brabhakaran et al. (2001).

The road network was characterised through drive over mapping of the road, and then characterisation using a combination of the GIS and field information, geology and hazard maps and review with the aid of Google Earth Maps. The characterisation was captured into an ArcGIS spatial database.

Earthquake Scenario and Ground Damage Hazards

All the resilience states were developed for a large local earthquake affecting the whole of the Wellington Region, such as a characteristic magnitude 7.5 earthquake on the Wellington Fault or Ohariu Fault for example. Given the general nature of the earthquake scenario across the district, ground damage from fault rupture has not been assumed on any of the faults.

Regional studies of earthquake ground damage hazards such as slope failure and liquefaction were published by Wellington Regional Council in 1993; these maps were used to assess the hazards to the roads.

Resilience State Mapping

Performance or resilience states were developed and used for mapping the vulnerability of the road network in the Porirua City area. This was carried out by assigning resilience states (damage, availability and outage) for each road category used in the road network characterisation as described above. The resilience states from the road characterisation were derived with the aid of ArcGIS.

The resilience states from the road characterisation were spatially mapped and displayed in GIS, so that the whole network can be visually seen together. A description of the resilience state levels is provided in Tables A-1 to A-3 in Appendix A.

The results of the resilience assessment for the road network are presented on individual maps for each resilience state, as listed below.

- Damage State, illustrating the severity of damage to the roads after a large magnitude 7.5 earthquake.
- Availability State, indicating how much access can be expected to be available after the earthquake event.
- Outage State, indicating how long the availability for access may be impaired.

The resilience state maps of damage, availability and outage are shown on Figures 3, 4 and 5, in Appendix B.

Road Network Earthquake Resilience

Resilience Assessment Results

The resilience assessment highlights the vulnerability of the road network to damage from a large magnitude earthquake within the region. The Wellington region is characterised by steep, hilly terrain and roads in the Porirua district are commonly formed on narrow benches excavated into the steep hillslopes. Consequently, these roads will be closed due to large landslides, underslips and failure of unengineered retaining walls. Where roads lie along low lying alluvial and coastal plains there is likely to be extensive damage due to liquefaction and lateral spreading at low lying alluvial, estuarine and reclaimed land.

The resilience maps in Appendix B show that key road transportation lifelines will be closed due to extensive damage from slope failures and liquefaction, and this condition is likely to persist for long periods (2 weeks to 3+ months) in critical locations. This understanding of the location and duration of outages is important for the Council as well as emergency management personnel and others to carry out planning for access and response after major natural hazard events.

Quantity of Overslip Materials

Indicative rough order quantities of slip materials that may fall onto the roads were also assessed. These were derived by considering the various road categories vulnerable to overslips, and summed using the

spatial GIS database. The quantities are based on the records of slips in historical earthquakes in the Wellington Region, experience of the authors from observation of slips in other earthquakes such as the 2010-2011 Christchurch earthquakes and the 2008 Wenchuan Earthquake in China, as well as knowledge of the failure characteristics of slopes in the Wellington region.

The indicative quantities of overslip materials are summarised in Table 2. Ranges of the volume of materials expected in the large earthquake event are given to represent the uncertainties involved in these estimates. The quantities presented are only rough order indicative quantities.

The actual quantities of slip materials will depend on the local soil and rock conditions along the routes, the characteristics of the earthquake event and the season / weather conditions prior to and after the earthquake event. Roads that are susceptible to damage from overslips are also likely to be vulnerable to underslips, due to collapse of unengineered retaining walls and fills. In many cases the damage from underslips will result in more severe outages than the overslips, and these road failures are likely to be the determining factor in considering appropriate emergency response priorities for restoring access.

Table 2: Indicative volumes of overslip materials

Area	Overslip volume ¹ (‘000s m ³)
Paekakariki Hill Road	5 to 75
Grays Road	1 to 10
Plimmerton	1 to 10
Whitby	1 to 10
Porirua East	0.5 to 5
Porirua Central	0.5 to 5
Titahi Bay - Elsdon	0.5 to 5
Total	10 to 100

¹ Rough order volume of possible overslip materials

Conclusions

Road networks provide a vital lifelines function to society, and their availability is critical for emergency response and recovery after major hazard events. Consequently,

managing the risks to roads requires an understanding of the network resilience to hazard events. We have mapped the current resilience of critical lifeline routes across the Porirua district and captured this onto a GIS platform.

The resilience was characterised as Damage, Availability and Outage States based on the concept of resilience developed for lifeline networks, based on research by Opus. Slip volumes that could be potentially generated by a large earthquake were also assessed, to help response planning. The key outcome of the resilience assessment is that parts of the Porirua road network will be closed following a large earthquake, due to major landslides on roads through rugged terrain, as well as liquefaction and lateral spreading at low lying land. Damage to critical road routes will be extensive, and will result in road closures for a long period (>2 weeks to 3 months).

This study highlights the vulnerability of the road network in Porirua. Follow on studies include prioritising the road network links in terms of their importance, which provides the basis for prioritising risk assessment, response, recovery and risk management.

This study has also been meshed with similar resilience studies for the state highways and other territorial local authority road networks. The combined resilience state maps have underpinned regional access and emergency response plans by the Wellington Lifelines Group and emergency management authorities, and provided impetus for projects that enhance regional resilience.

References

- Brabhakaran, 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.
- Brabhakaran, P., Wiles, L.M., Freitag, S. (2006). Natural Hazard Road Risk Management Part III: Performance Criteria. Land Transport New Zealand Research Report 296. 117p.

Civil Defence Emergency Management Act
(2002). Public Act 2002 No 33. Oct 2002.

Opus International Consultants (2009).
Region 9 Road Network Lifelines. Stage 2
Meshing Road Network Lifelines Data for the
Wellington Region. Risk Study Report.
Prepared by P Brabhakaran. Opus Report No.
GER 2008-40.

Appendix A – Resilience States

Table A-1: Damage state

Damage Level	Damage State	Damage Description
1	Slight	Only slight damage that requires routine maintenance
2	Light	Minor damage requiring clean-up of small slips (few cubic metres) and debris and culverts
3	Moderate	Moderate damage requiring removal of moderate volume of slip debris (tens of cubic metres), small scale repair of underslips (less than 2 m high walls) and minor repair to walls, culverts and other structures
4	Severe	Severe damage requiring clearing of large volumes of slip materials (hundreds of cubic metres) and stabilisation, significant structures to repair underslips and major repair to walls, replacement of culverts and other structures.
5	Extensive	Extensive damage requiring clearing of major volumes of landslides and stabilisation, large structures to repair underslips, damages to walls and other structures.

Table A-2: Availability state

Availability Level	Availability State	Availability 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.

Table A-3: Outage state

Outage Level	Outage State	Outage Description
1	Open	No closure, except for maintenance
2	Minor	Condition persists for up to 3 days
3	Moderate	Condition persists for 3 days to 2 weeks
4	Severe	Condition persists for 2 weeks to 3 months
5	Long Term	Condition persists for > 3 months

Appendix B – Resilience Maps

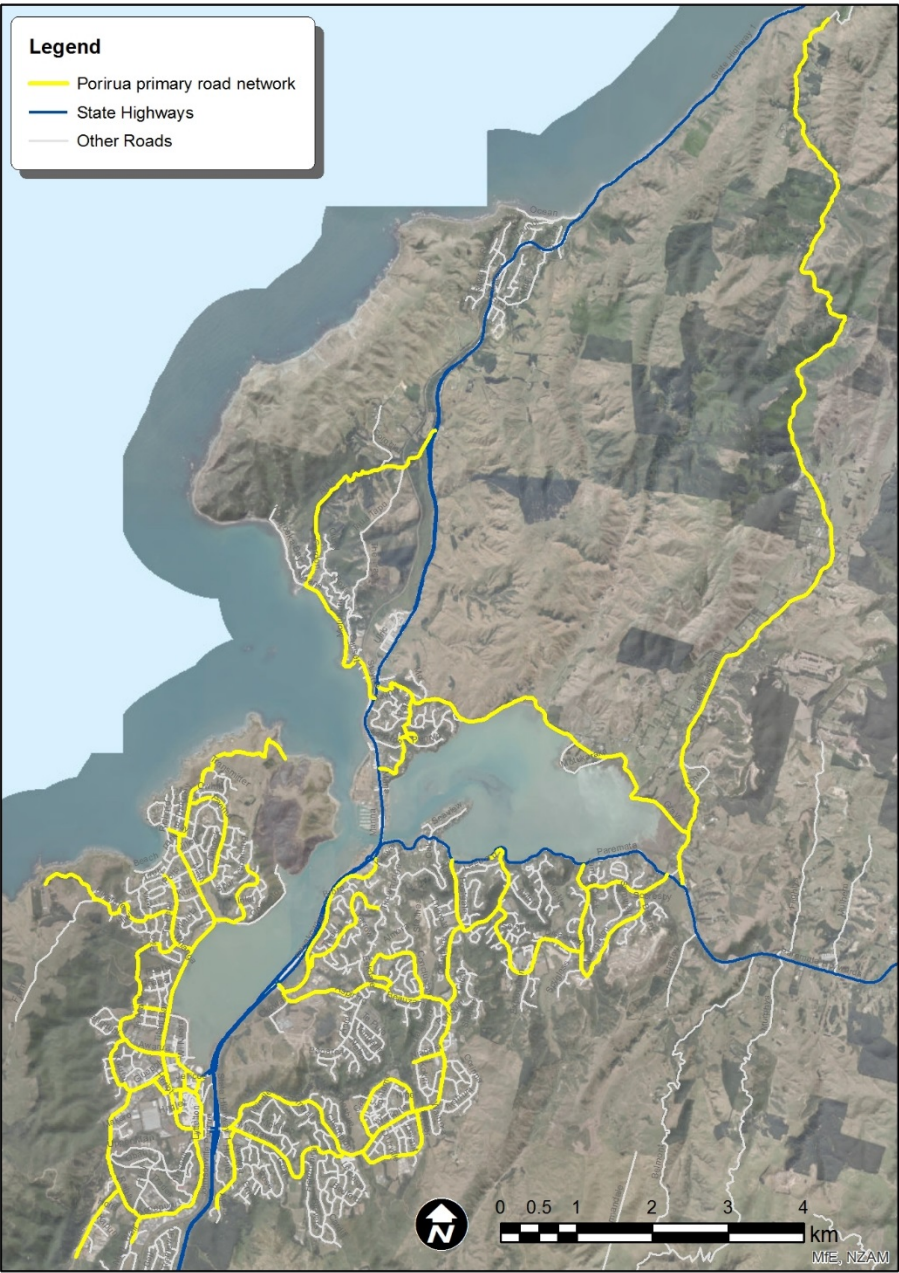


Figure 2: Porirua city road network

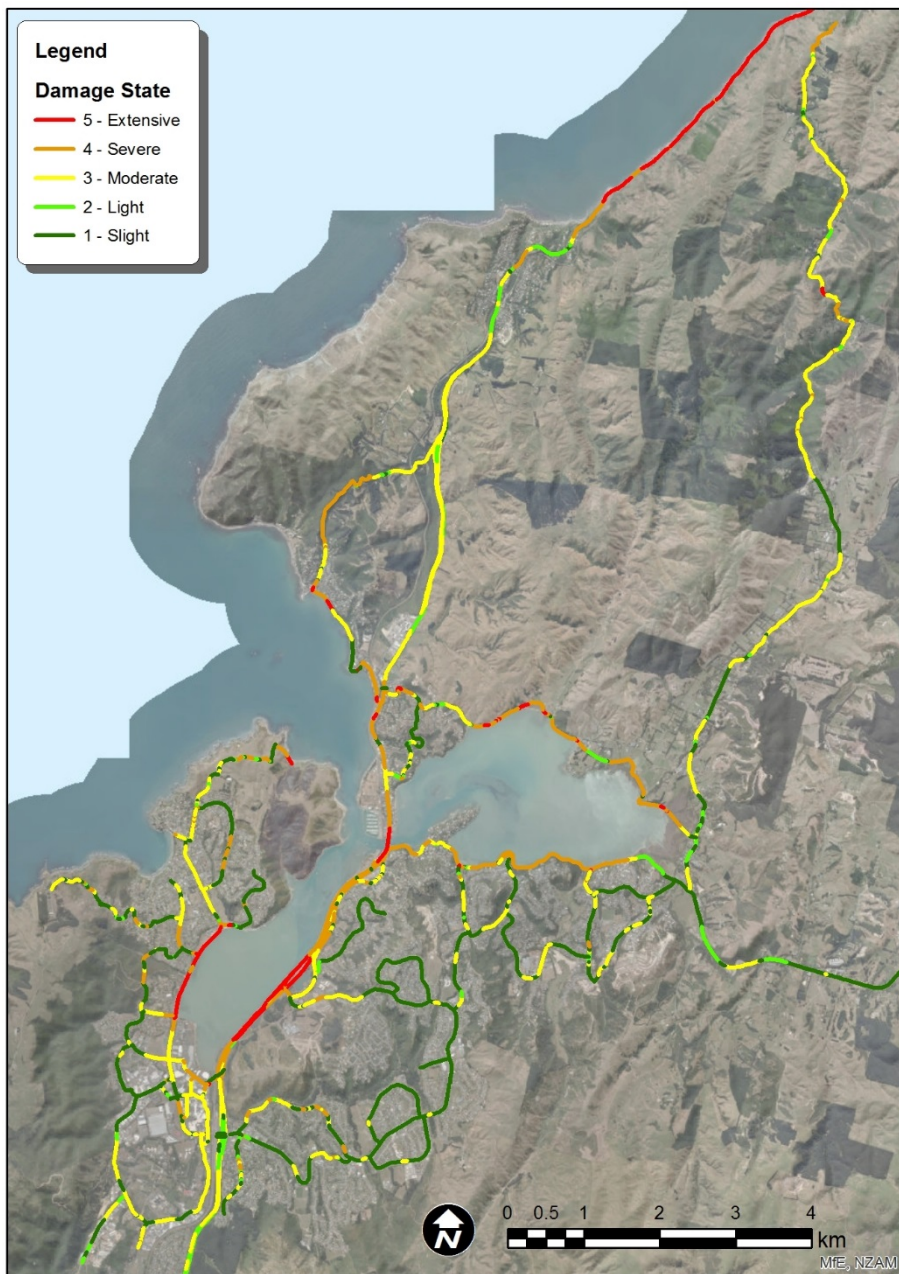


Figure 3: Damage state for large earthquake event

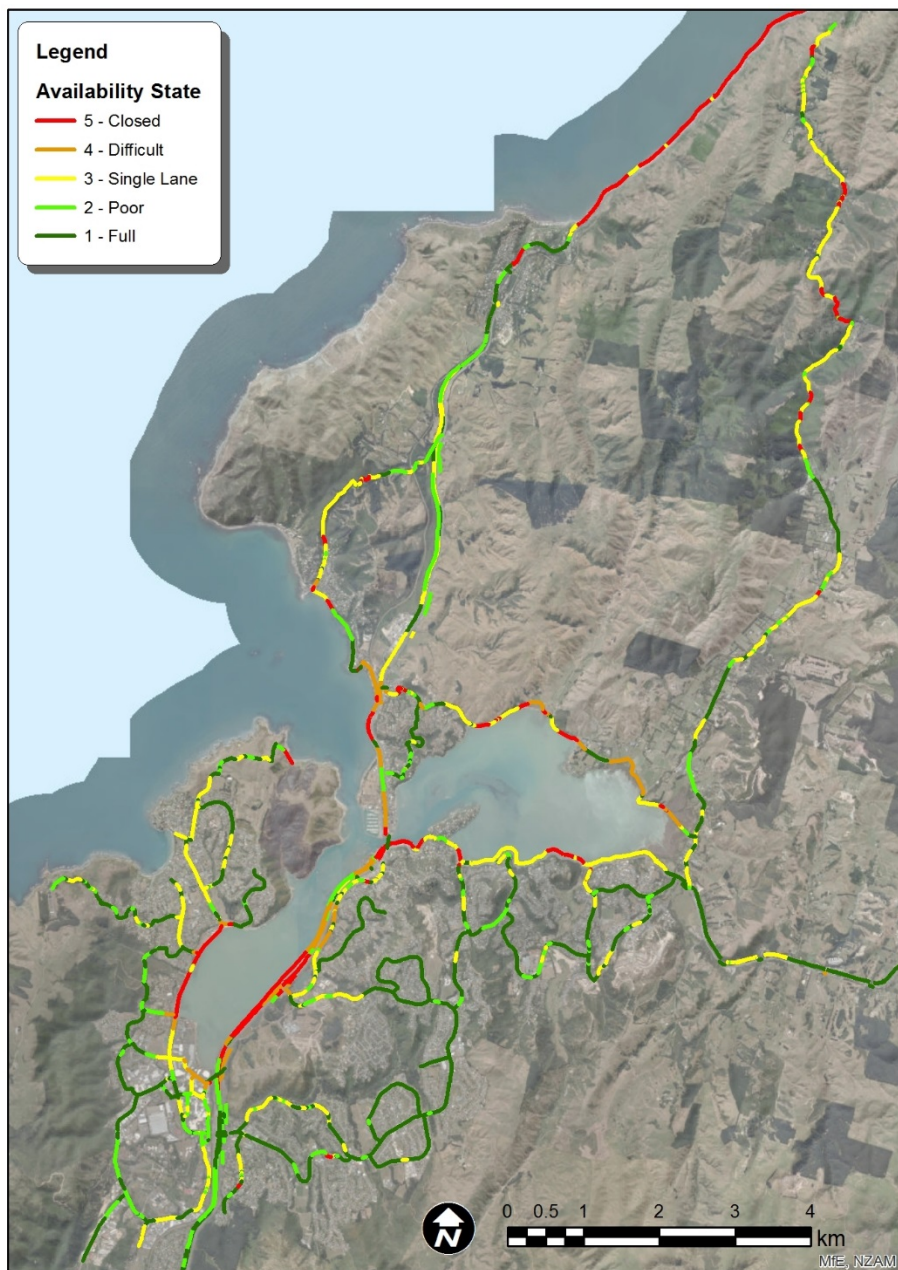


Figure 4: Availability state for large earthquake event

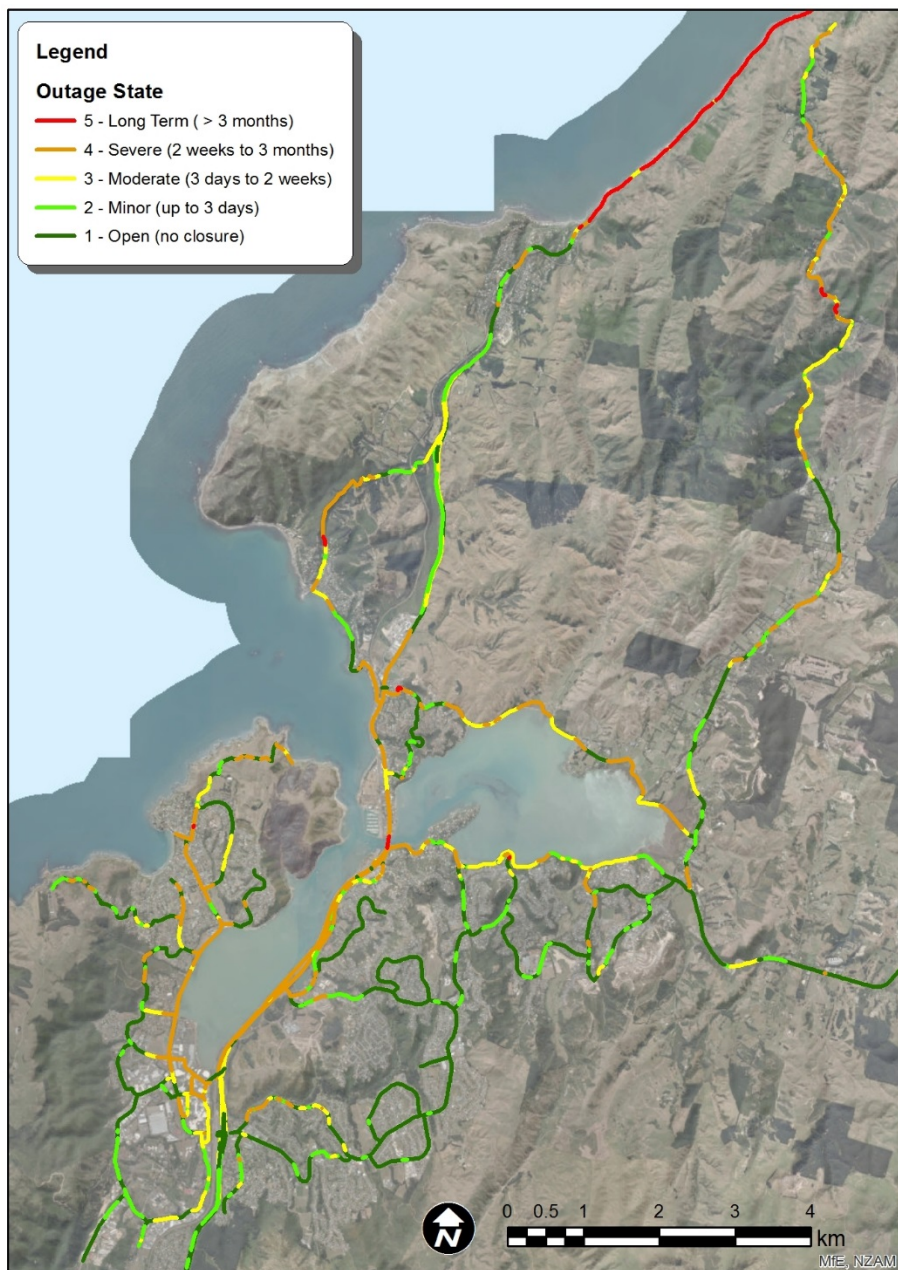


Figure 5: Outage state for large earthquake event

Author Biography



Doug is a senior engineering geologist at Opus in Wellington, and leads a team specialising in engineering geology, natural hazards and infrastructure resilience. He completed bachelor degrees in geology and history and an MSc (Hons) in geology at Victoria University, and worked for GNS prior to joining Opus in 2004. Since then he has worked in NZ and the UK on a variety of geotechnical and geoenvironmental projects including infrastructure seismic resilience, natural hazard risk studies and development of risk management strategies.

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