Project Number: 5-C4397.00

Wairarapa Transport Resilience Study

4 May 2022

CONFIDENTIAL

Masterton, Carterton, and South Wairarapa District Councils

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Disclaimers and Limitations

This report ('**Report**') has been prepared by WSP exclusively for Masterton District Council ('**Client**') in relation to the Wairarapa Transport Resilience Study ('**Purpose**') and in accordance with the Short Form Agreement with the Client dated 27 August 2021. The findings in this Report are based on and are subject to the assumptions specified in the Report and the Offer of Service dated 12 July 2021. WSP accepts no liability whatsoever for any reliance on or use of this Report, in whole or in part, for any use or purpose other than the Purpose or any use or reliance on the Report by any third party.

Executive Summary

The local road network in the Wairarapa region runs through a variety of terrain including steep ranges and rolling hill country, as well as river valleys and broad plains. As recorded in past events, many of these roads are vulnerable to closure in significant storms or earthquakes, due to flooding, landslides, damage to road structures and liquefaction.

The resilience of selected local roads in the Wairarapa region has been assessed by consideration of the extent and duration of loss of functionality in the aftermath of a large storm and a large earthquake. The resilience of these roads is characterised using Availability and Outage states based on the concept of resilience developed for road networks, based on research by WSP (then Opus). The effects of flooding, landslides and liquefaction have been considered in the assessment of resilience, but damage to structures such as bridges and culverts has not been considered in this study.

The resilience assessment highlights several key issues expected to affect road access through the different terrains in the region:

- Flooding of roads situated on flood plains and close to rivers
- Flooding and debris flow from gullies on slopes above the road
- Scour erosion and dropouts of roads adjacent to river slopes
- Shallow slides and flows with long runout distances from rolling hillslopes, particularly in the eastern hills
- Slips from natural slopes and road cuttings, particularly in the steep ranges
- Deep-seated landslides in weak hillslopes, such as at Johnson's Hill on Cape Palliser Road
- Liquefaction and lateral spreading of the road surface and adjacent slopes, particularly in the flat areas on the Wairarapa Plains

Availability for access may be restricted by partial closures due to small overslips or underslips, or full closures may result from larger landslides, underslips, flooding or debris flows. Outages in route access due to flooding and overslips are generally expected to be relatively short, although larger landslides may close roads for several weeks, particularly if stabilisation is required. Other cases, such as underslips that remove the road platform may require the design and construction of retaining structures, may take several months to reinstate full access. Liquefaction could lead to difficult access or only 4-wheel drive access, or complete closure if there is extensive lateral spreading adjacent to water bodies or water courses.

With significant parts of the local road network situated in areas of hill country, there are many roads that are vulnerable to damage from slips, and in a large event it is likely that multiple failures will occur with a resultant long duration of potential closures.

Roads situated in the flatter areas of the region may be affected by large storms or earthquakes causing multiple closures due to flooding and liquefaction, respectively.

We also note that climate change is likely to result in more frequent extreme weather events, and this is likely to result in more frequent closures on the local road network due to flooding and slips caused by heavy and/or prolonged rainfall and storm surge in coastal areas.

Resilience can be enhanced by reducing the reduction in service or loss of access, reducing the time for recovery of access, or a combination of the two.

It should be noted that because of the extent of hill country in the Wairarapa, and because of the size of some of the slopes, many sections with hillsides cannot be practically mitigated to enhance route resilience in large earthquake and storm events. Similarly, it is not practical to mitigate the risk of flooding to all vulnerable areas of the road network. Although vulnerabilities on some sections of the road network can be mitigated through interventions to reduce the frequency of closures, there would remain the residual risk of closure from time to time. We can expect that such closures increase in frequency due to climate change, as noted above.

While some areas may be accessible via multiple routes, there are many isolated communities in the Wairarapa hill country and coastal areas that are not accessible via alternative routes in the event of closures on the main access route. Such routes are therefore critically important and should be protected to mitigate the risk of extended closures. Resilience can be enhanced by targeted strengthening and enhanced emergency preparedness planning which would help reduce the duration of closures.

Based on the resilience assessment, we make the following recommendations:

1 The Wairarapa District Councils and Lifelines Group review and consider the resilience states presented and adopt them for use in emergency response planning.

2 The resilience of the bridges and large culverts be considered to arrive at a holistic understanding of the resilience of the transport network.

3 The relative importance of the routes in the Wairarapa transport network be assessed to facilitate prioritisation of resilience enhancement actions and planning.

4 The resilience assessment be considered to develop resilience enhancement actions, which may comprise emergency response planning to facilitate faster recovery, and where appropriate risk mitigation measures to reduce the potential for closures.

5 The resilience assessment is used to identify critical areas in the region to develop emergency response plans, for use the event of failures in storm and earthquake events that cause closures on the local road network.

6 Risk mitigation prioritisation should be undertaken in conjunction with the development of preventative maintenance priorities for the road network management team (roading engineers and contractors).

7 Consideration be given to understanding the resilience of adjacent transport networks to gain an appreciation of external access that is likely to be available for response and recovery after major events. Given that the resilience of the western part of the Wellington region has been assessed and access through the Remutaka range has poor resilience, it would be prudent to engage with transport authorities to the north (Tararua region) to understand the resilience of access from the north.

8 The Wairarapa Engineering Lifelines Association consider the effect of road access resilience on the resilience of other lifeline utilities.

9 The Network Contractor continues to record all instances of slope failures to build a database of slope performance over the whole network and to monitor the frequency of movement at areas of known instability. A system similar to Waka Kotahi's RAMM database and the use of data collection apps (similar to those developed by WSP) is likely to be appropriate.

10 The indicative volumes of overslip materials presented should be used for general planning purposes only. It should be noted that these volumes are indicative only.

1 Introduction

WSP has been engaged by Masterton District Council on behalf of the three Wairarapa District Councils (Masterton, Carterton and South Wairarapa – 'the Councils') to assess the resilience of the local road network in the Wairarapa. WSP's Offer of Service dated 12 July 2021 (ref: 5-C4397.PP) outlined the proposed methodology and focus of this study.

The aims of the study are:

- Characterisation of the resilience of selected local roads in the Wairarapa for two scenarios:
  - A large local magnitude 8.0 earthquake in the region; and
  - A large storm event.
- Estimate rough order volumes of slip materials that would need to be cleared in each event.

The scope of work excludes state highways, the resilience of which has been assessed previously by WSP (then Opus) for the Waka Kotahi NZ Transport Agency (Opus, 2012). The outputs of the present study can be meshed with the resilience of the state highways, creating a single transport network assessment.

2 Site Description

2.1 Study area

The area of interest for this study is the Wairarapa, within the Wellington Region. The study focuses on a series of priority routes based on the road hierarchy shown in Figure 1, along with other roads highlighted by the Councils.

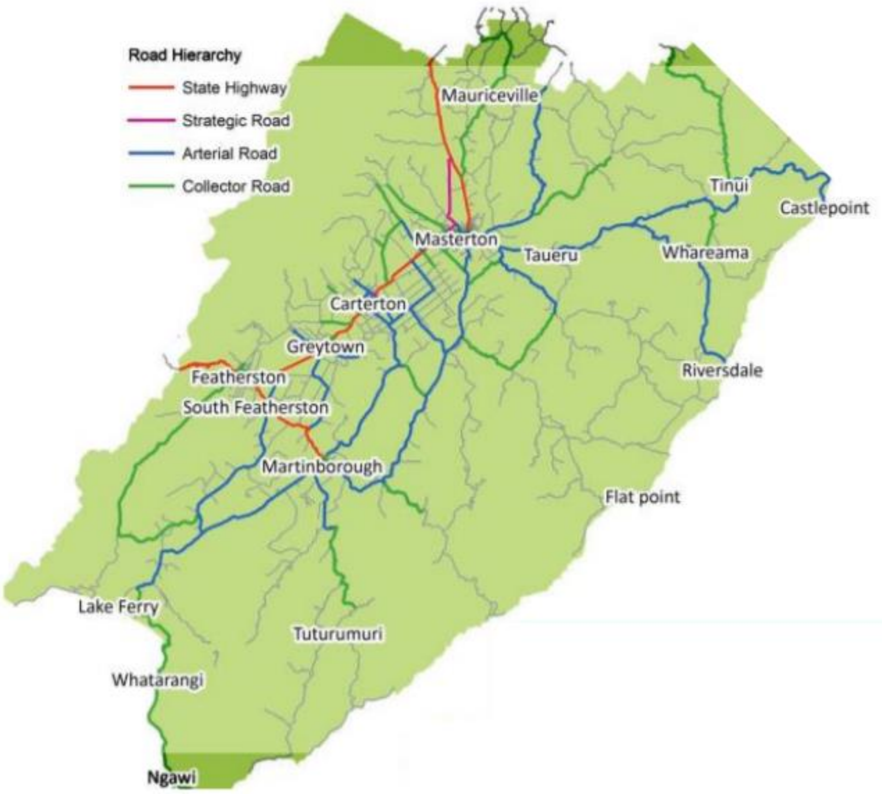

Figure 1: Hierarchy of roads in the Wairarapa region.

The study area and final selection of roads considered in the study are shown in Figure 2, with the District Council boundaries also indicated.

This figure shows that a significant proportion of additional roads were included in the study following a workshop with the Councils on 19 October 2021 (about 12% of additional road lengths were included, with about 30% of additional roads in hill terrain, as these provided critical access routes for remote communities).

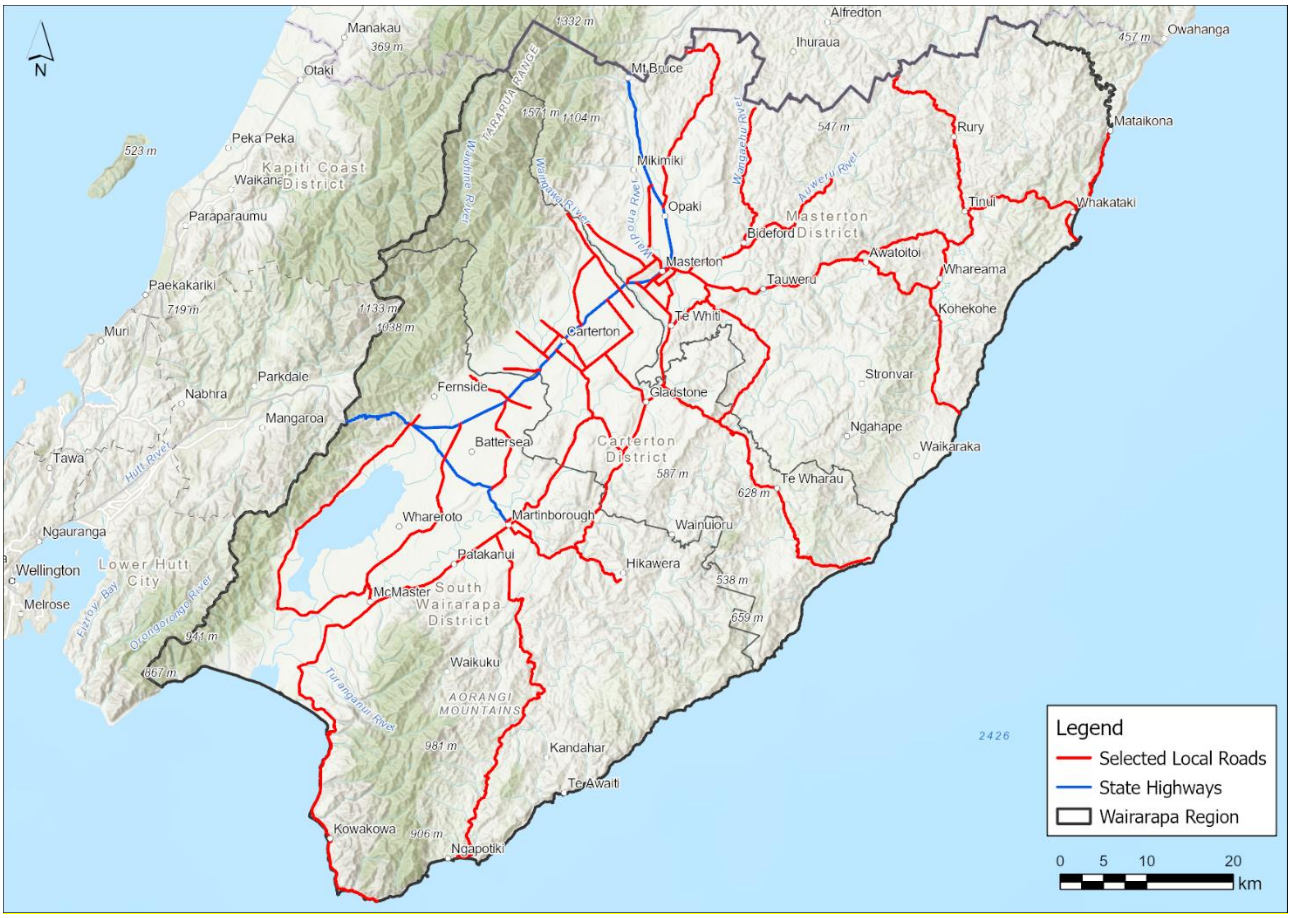

Figure 2: Wairarapa region and selected local roads for assessment.

2.2 Geomorphology

The geomorphology of the study area is highly variable, as indicated by the topographic shading in Figure 2. Broad alluvial plains and terraces are found in the western part of the region, with several large rivers flowing southwest towards Lake Wairarapa and out to the sea at Palliser Bay.

The very steep-sided Remutaka and Tararua Ranges extend along the western boundary of the region. Towards the southern end of the region, more steep-sided hill terrain can be found in the Aorangi Range that extends to the south coast at Cape Palliser.

The eastern part of the region consists of hill terrain with more moderate slopes, dissected by river valleys.

At the east coast, there are some areas of steep slopes and cliffs, and other areas of flat coastal platforms.

2.3 Geology

The geology of the Wairarapa has been mapped at 1:250,000 scale in the GNS QMAP geology maps for the Wellington and Wairarapa areas (Begg & Johnston, 2000; Lee & Begg, 2002). This mapping indicates that the Wairarapa region is underlain by a variety of geological units. A map showing simplified geological units in the region is presented in Figure 3.

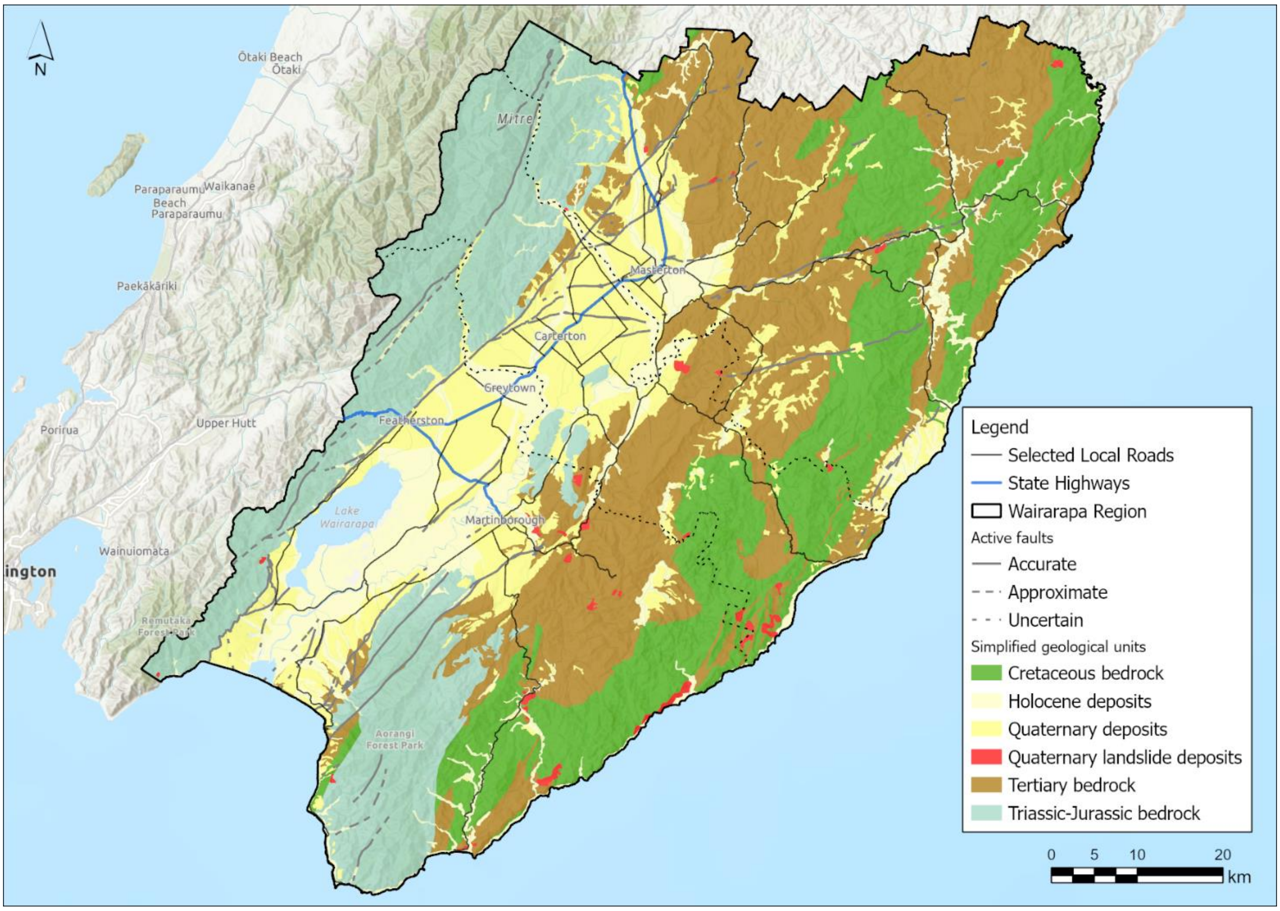

Figure 3: Geological units and active faults in the Wairarapa.
(Geology is simplified from GNS 1:250,000 mapping)

The steep slopes of the Remutaka, Tararua and Aorangi Ranges are generally formed of Triassic-Jurassic age sedimentary rocks, primarily of indurated sandstone and mudstone (commonly known as 'greywacke'). The more moderate slopes found primarily in the eastern hills are generally formed of younger sedimentary rocks of Tertiary and Cretaceous age, primarily sandstone, siltstone and mudstone but also with some areas of limestone. The hillslopes within the Wairarapa are likely to be mantled by variable thicknesses of colluvial soils, fan deposits and scree deposits, which are not significant enough in size to be included in the 1:250,000 scale geological mapping from GNS.

Young alluvial deposits of Quaternary age are found in the river valleys dissecting the areas of hill terrain, and in the broad plains located in the western part of the region. These deposits tend to be gravel-dominated, with finer materials mostly confined to the lower reaches of large rivers in the lower Wairarapa valley. Around Lake Wairarapa, fine-grained swamp deposits can be found. Beach deposits including areas of sand dunes are found at the coastal margins of the region.

The New Zealand Active Faults Database maintained by GNS (https://data.gns.cri.nz/af/) indicates that several active faults are located within the Wairarapa region (Figure 3). The most significant fault mapped is the Wairarapa Fault, which extends NE-SW through the region and separates the Remutaka and Tararua Ranges from the broad Wairarapa plains. The last major rupture of the Wairarapa Fault caused a magnitude (Mw) 8.2 earthquake in 1855, and the fault has a recurrence interval of ~1,200 years (Little, et al., 2009). Several other faults branch off to the east of the Wairarapa Fault, and there are multiple faults located in the Aorangi Range at the southern end of the region. The M_W 7.2 and M_W 6.8 Masterton earthquakes of June and August 1942 did not cause any surface rupture (Downes, et al., 2001), but may have occurred on the Carterton Fault.

2.4 Slope instability

There are several locations in the Wairarapa region where slip-prone hillslopes are present along the local road network. Known areas of slope instability are highlighted in Figure 4. A list of roads with slip-prone sections has been developed from a discussion with Council staff on 19 October 2021, and from a review of available records. Notable records include a Wairarapa Engineering Lifelines Association (WELA) publication on the risk to lifelines from natural hazards (WELA, 2003), the NZ Landslide Database (NZLD) from GNS (https://data.gns.cri.nz/landslides/wms.html), and landslides included in GNS QMAP geological mapping (Begg & Johnston, 2000; Lee & Begg, 2002). Useful records of landslides are also given in reconnaissance reports published following the February 2004 storm (Hancox & Wright, 2005) and June 1942 earthquake (Ongley, 1944).

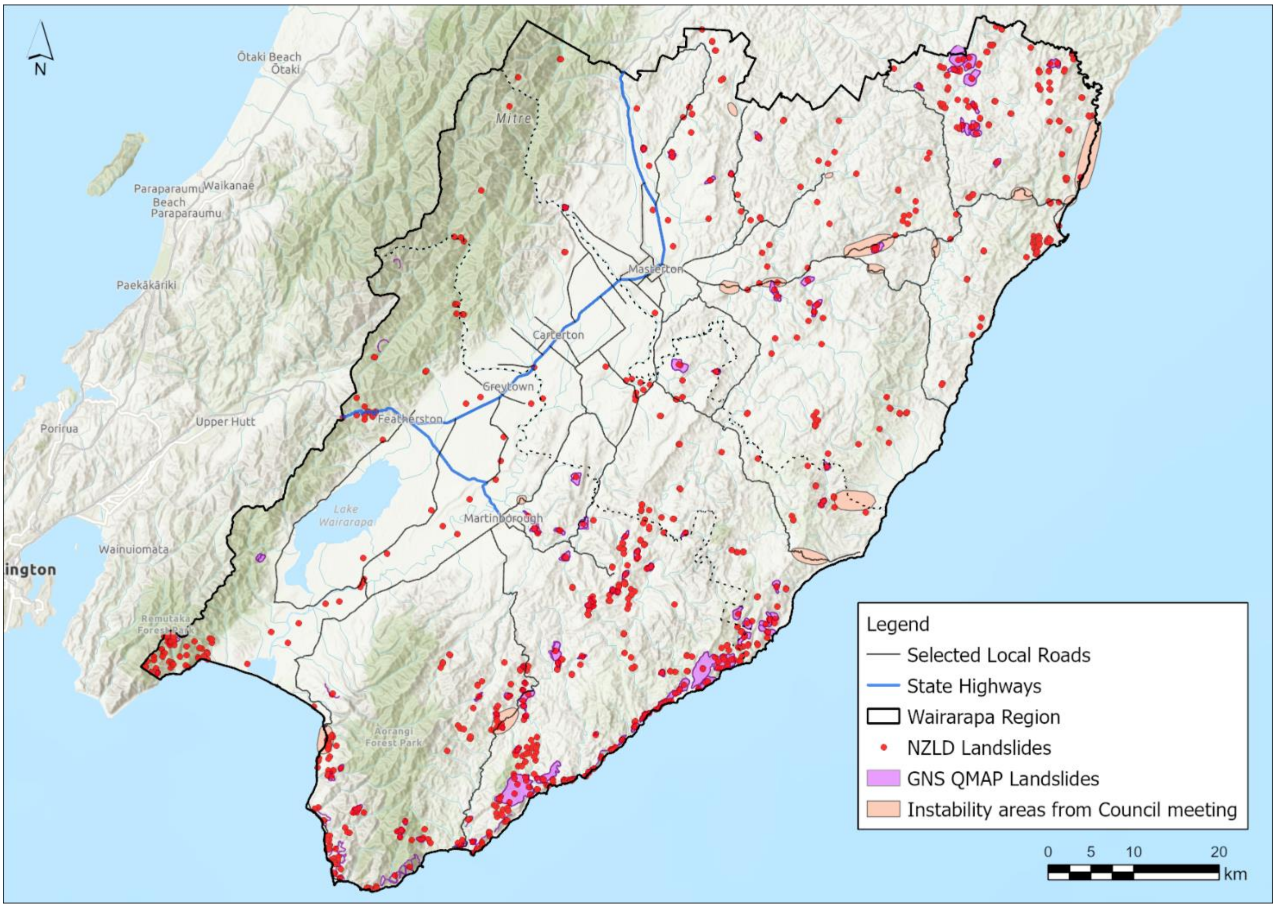

Figure 4: Recorded slope instability in the Wairarapa region.

Roads with known areas of significant instability include:

- Cape Palliser Road (notably at Johnson's Hill and Whatarangi Bluff)
- Mataikona Road
- Te Wharau Road
- Masterton-Castlepoint Road
- White Rock Road
- Blairlogie-Langdale Road (notably at Kerosene Ridge)
- Te Ore Ore-Bideford Road (notably near Hill End)
- Langdale Road

2.5 Flooding

Many of the local roads in the Wairarapa are vulnerable to surface flooding during periods of significant rainfall. Areas with known potential for flooding are highlighted in Figure 5.

A list of roads with known flood-prone sections has been developed from a discussion with Council staff along with reported flood-prone areas from WELA (2003) and other publications. Additionally, a draft model of flood depths for a 100-year return period event has been shared by Greater Wellington Regional Council for use in this study. This draft flood depth model (T+T, 2022) represents an update of flood hazard zones previously published by GWRC (2017).

Roads with known flood-prone sections include:

- Manaia Road
- Paierau Road
- Masterton-Castlepoint Road
- Homewood Road
- Te Ore Ore-Bideford Road
- Opaki-Kaiparoro Road
- Kokotau Road
- Lake Ferry Road
- Kahutara Road

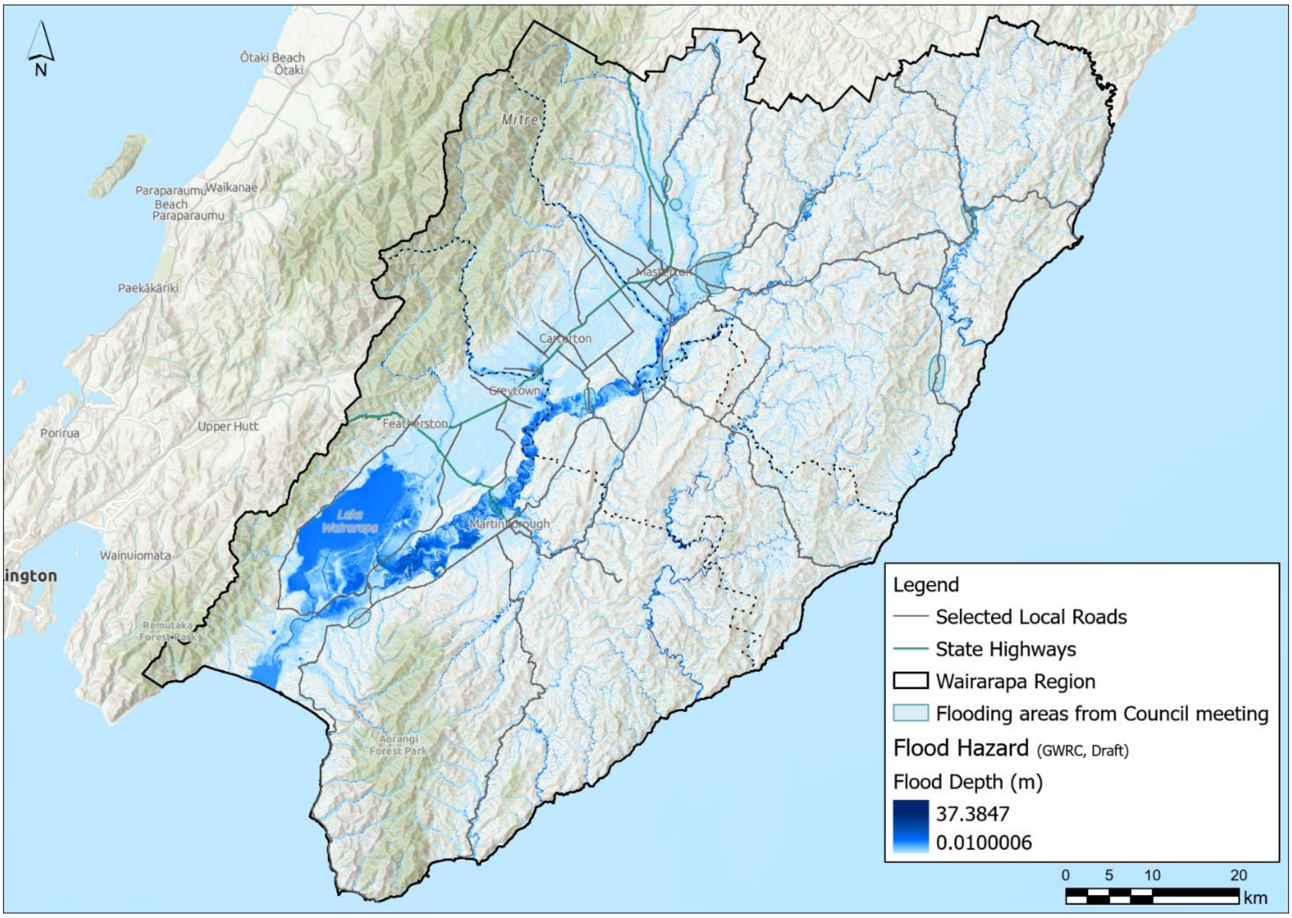

Figure 5: Recorded and potential areas of flooding in the Wairarapa region.

In addition to the above, there might be areas of local flooding due to the rainfall runoff exceeding the capacity of stormwater drainage systems. However, these are likely to be limited in extent and of shorter duration than those shown on the map.

2.6 Liquefaction

Liquefaction susceptibility zones were developed for the Wairarapa by GNS (Dellow, et al., 2018), based on mapped geological units and available borehole data and with reference to historical observations, following an earlier study by WSP (then Works Consultancy Services) for Greater Wellington (Brabhaharan & Jennings, 1993).

Liquefaction susceptibility is classified into zones of Low, Moderate, High, and Very High susceptibility, as shown in Figure 6. The most susceptible areas are generally located in the south-western part of the region around Lake Wairarapa and in coastal areas, where there are significant sand and silt deposits.

Elsewhere in the region, alluvial deposits are typically gravel-dominated, and therefore the susceptibility to liquefaction is lower. However, there are likely to be areas of localised liquefaction along river and stream courses that could affect bridge crossings of these rivers, as highlighted by Brabhaharan & Jennings (1993).

The liquefaction susceptibility zones don't show likely ground damage from liquefaction, which is likely to dominate the impact on the resilience of transport networks. In particular, lateral spreading of liquefied ground adjacent to waterways and water bodies is the consequence of liquefaction likely to cause severe damage to roads. The potential for lateral spreading has been taken into consideration in the assessment of resilience in areas of liquefaction in proximity to water courses or water bodies.

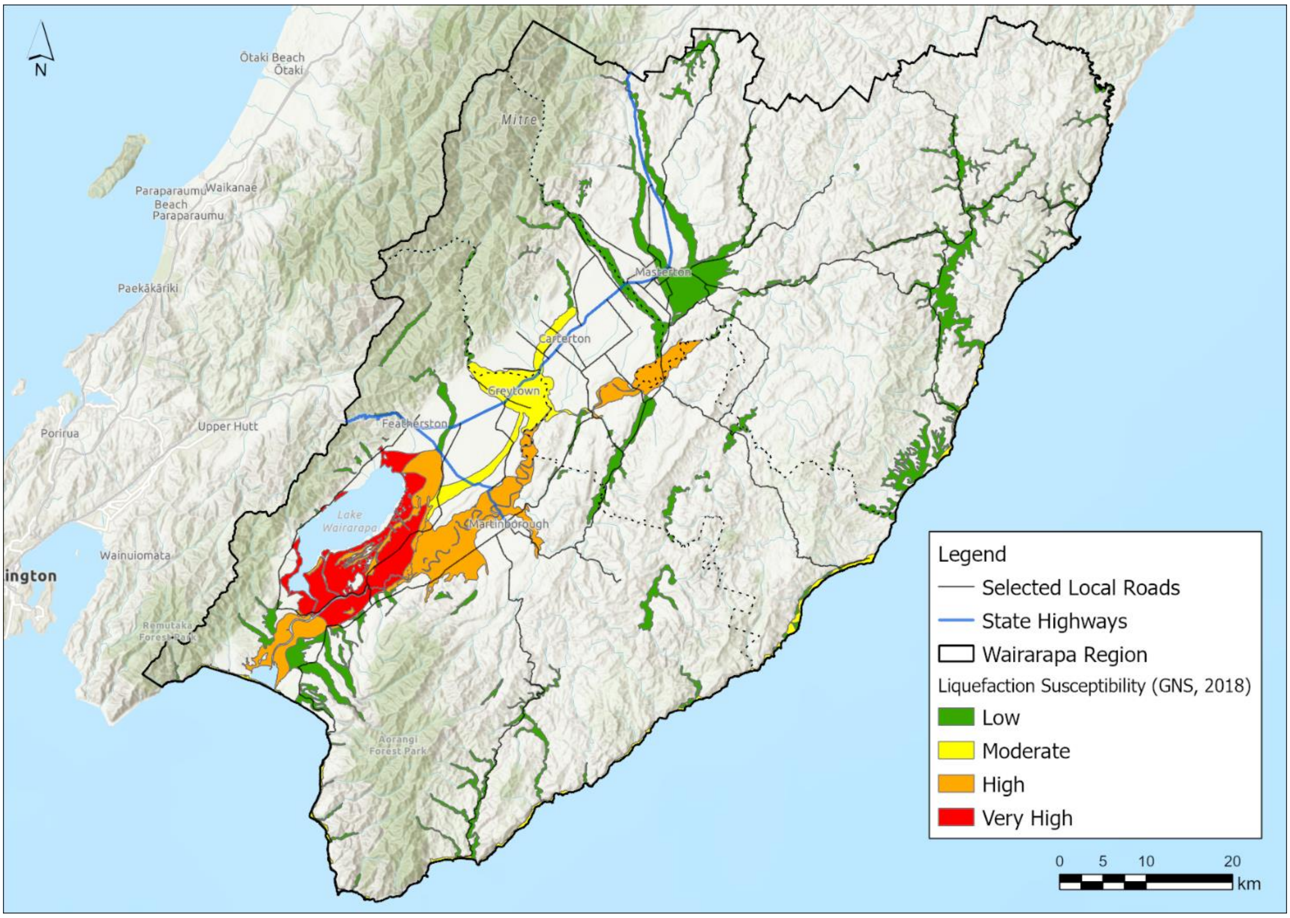

Figure 6: Liquefaction susceptibility in the Wairarapa, from GNS (Dellow, et al., 2018).

3 Resilience Context

3.1 Route Resilience

Knowledge of the performance of the road in natural hazard events is important to understand the impact reduced levels of service would have on the local community, other lifeline utilities, 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 assesses the resilience of the route by considering the extent and duration of a loss of functionality. The priority was to consider the functionality of the routes 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 restore the original usage state after the reduction or loss of access. This is shown conceptually in Figure 7, after Brabhaharan et al. (2006), 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 greater the resilience. The larger the area, the poorer the resilience.

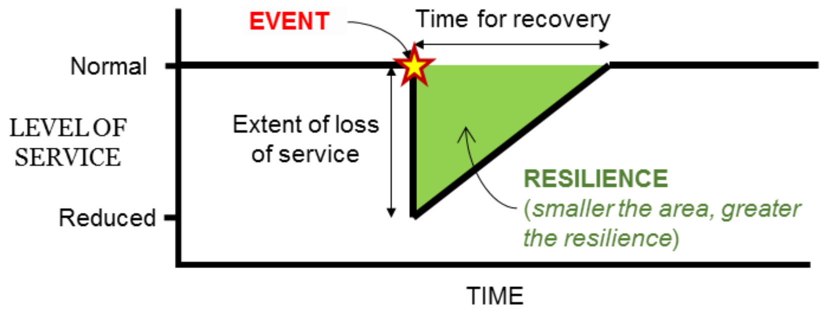

Figure 7: Resilience of route.
(after Brabhaharan et al., 2006)

"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 (Brabhaharan, et al., 2006). These states are summarised in Table 1, with explanation of the states in

Table 2 and

Table 3. The resilience states used in this study align with those previously used by Opus (2012) for the Wellington Region Road resilience study.

Table 1: Summary of resilience states.

Resilience State	Description
Availability state	Availability State indicates the severity of damage to the road and 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 extent of loss of access on that section of the road network after an event.
Outage state	Outage State indicates the duration over which the road will be in a given Availability State. This gives an indication of the duration of loss or reduced access in links along the road network.

Table 2: 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.
6	Closed +	Road closed and unavailable for use and affecting alternate direction carriageway.

Table 3: Outage state.

Level	State	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.

3.2 Network Resilience

The resilience of the transport network will depend on:

a) Route resilience

b) Redundancy

c) Interconnectivity.

The assessment of the resilience of the routes will enable consideration of the transport network as a whole, by considering this alongside redundancy and interconnectivity.

In addition to internal interconnectivity which will determine the ability to use alternate roues if one route is closed, it is also important to consider external interconnectivity, as each region will depend on access from outside the region. In the case of Wairarapa, the western connectivity to the western part of the Wellington region is through State Highway 2 in the Remutaka hill range, which is known to be vulnerable to closures. Therefore, it would be useful to consider connectivity from the north through the Tararua Region.

4 Scope and Methodology

The scope of the study was to assess the resilience states along the selected local roads in the Wairarapa region as discussed in Section 3. The methodology developed for the study comprised:

(a) A desk study, comprising:

- Collection and review of road and terrain information including GIS data.
- Review of the geology of the district.
- Review of aerial photos.

(b) Workshop with Council staff to confirm priority routes, and to discuss the geotechnical issues along these routes and how they affect maintenance and management of the road.

(c) Field mapping, comprising:

- Drive over reconnaissance of the route by WSP staff.

(d) Characterisation of the road network, using a spatial approach, by:

- Characterisation of the roads with the aid of the field mapping, aerial photographs, terrain maps and Google Earth maps.
- Capture of the characterisation of the road network onto a GIS platform.

(e) Assessment of resilience, considering:

- Geology, groundwater, slope angles.
- Erosion, scour and flooding potential.
- Types and condition of retaining walls.
- Potential slope failures.
- Extent of impacts on road access.
- Observations of impacts arising from large storm and earthquake events.

(f) Preparation of maps showing Resilience States, through:

- Assessment of resilience states for the characterisation, using the approach used by Opus (2012) for the Wellington Region state highway and critical local road networks.
- Derivation of resilience states with the aid of GIS, and preparation of maps.

(g) Consideration of the key road resilience issues, through:

- Consideration of the engineering issues arising from slips/erosion damage.
- Consideration of the location, extent and duration of likely areas of closure/loss of service.
- Identification of critical sections of vulnerability for possible mitigation.

(h) Assessment of potential slip volumes that would need to be cleared after a large storm or earthquake event.

(i) Preparation of this report.

5 Road Characterisation

5.1 Potential failure mechanisms

The local roads covered in this study are in areas underlain by a significant number of the different geological and geomorphic units present in the Wairarapa. These different units are associated with varied geotechnical issues.

Previous investigations and reports after past storm and earthquake events, along with our experience of natural hazards in the Wellington Region, have allowed us to develop an understanding of the potential failure mechanisms affecting the Wairarapa local roads.

Storm events in February 2004, March 2005 and July 2006 caused significant landslides in the Wairarapa (Hancox & Wright, 2005; Hancox, et al., 2007). Shallow soil slides and flows with long runout distances were reported to be common, particularly on steep grass-covered slopes in the eastern hills underlain by relatively weak Tertiary sedimentary rocks. Several debris slides and flows also occurred from steep coastal slopes and gullies. Similar widespread landslides occurred in the Wairarapa during the winter of 1977 (Crozier, et al., 1980).

Significant earthquakes affecting the region occurred in 1855 (Mw 8.2 Wairarapa earthquake), 1936 (Mw 7.2 Pahiatua earthquake) and 1942 (Mw 7.2 and Mw 6.8 Masterton earthquakes). Liquefaction and earthquake-induced landslides in the Wairarapa were reported in subsequent scientific papers and in news media from the time of the events.

The key issues affecting the resilience of the selected local roads are as follows:

- Slips from steep natural slopes above the road, particularly in areas of older basement rock such as in the Aorangi Ranges.
- Slips from steep cuttings above the road.
- Shallow landslides with long runout distances, particularly within areas of Tertiary geology in the eastern hill terrain, and in areas of pasture.
- Flooding and debris flow from gullies on slopes above the road.
- Loss of support to roads beside rivers due to scour erosion of natural slopes, sidling fills and retaining walls, particularly when river levels are elevated during or following storm events.
- Loss of support to coastal roads due to erosion of natural slopes, retaining walls and other protective structures, particularly during storm surge events.
- Loss of the whole road width in areas of large active landslides, such as at Johnson's Hill on Cape Palliser Road.

- Liquefaction and lateral spreading of road surfaces and adjacent slopes in areas of susceptible ground during significant earthquake events, such as around Lake Wairarapa and the major rivers on the Wairarapa Plains.

5.2 Framework and approach

The approach we have used is to characterise the damage from large storm and earthquake events and develop resilience states to assess the resilience of the selected priority routes. The selected roads were characterised using a GIS based spatial approach developed by Brabhaharan et al. (2001), using desk-based inspection of terrain maps and hazard maps, supplemented by drive-over mapping of a small sample of the roads to build a general understanding of the typical resilience issues. Review of the road characterisation was completed with the aid of Google Maps Street View.

The following factors formed the basis for characterising the roads, by considering geotechnical issues and hazards and their consequences to the availability of the roads following a large storm or earthquake:

- Slope type (cuttings, embankments, culverts, retaining walls etc)
- Slope angle and height
- Geomorphology of adjacent slopes / catchments
- Geology
- Hydrology / groundwater
- Vegetation
- Location of existing slope stabilisation or retaining features
- Location of drainage features
- Width of any berms / ditches
- Evidence for past instability and observation of road performance in past storm and earthquake events
- Characterisation of likely failure modes and typical runout distances
- Consideration of existing flood modelling and liquefaction hazard zones for the region.

Information relating to these factors was collected during a desktop appraisal of available records. Physiographic information was derived from a DEM generated using data from a 2013 LiDAR survey commissioned by GWRC. Road network information, including the centreline data used in the assessment, was provided by the Councils.

5.3 Flat terrain road characterisation

The characterisation of roads in flat parts region was based primarily on existing flood modelling and liquefaction susceptibility zones. A draft flood model prepared by T+T (2022) has been shared by GWRC, while liquefaction susceptibility zones have been defined by GNS (Dellow, et al., 2018).

5.3.1 Flooding

Areas with the potential flooding include flat, low-lying land around the large rivers in the Wairarapa Plains, including the Ruamahanga, Waiohine and Waipoua Rivers, along with the areas around Lake Wairarapa. Additionally, localised flooding can occur in river valleys within the eastern hills and the Aorangi Ranges, which can affect roads in these locations. Mapped areas with the potential for flooding are shown in Figure 5.

A draft model shared by GWRC for use in this assessment shows flooding depths across the Wairarapa. The GWRC flood model represents a 1% annual exceedance probability (AEP), or a 1 in 100-year average recurrence interval (ARI). This matches the storm event scenario return period of approximately 100 years considered in this assessment.

All sections of the selected roads that are located within areas shown to be flooded in the 1% AEP event in the GWRC flood model are expected to have a reduced availability in the storm event scenario. We have used the modelled flood depths to defines two levels of flood severity, with the deeper flood depths on the road surface expected to fully close the road and have a longer associated outage, while shallower flood depths are expected to create difficult driving conditions without causing a full road closure. The threshold between the two levels of flood severity we have applied is set at 0.4 m flood depth. This value is chosen on the basis that a 4WD vehicle can still pass while flood depths are up to 0.4 m, but at greater flood depths the road is considered impassable for most vehicles.

The known areas of flooding mapped from discussion with Council staff and from available records were used as a reference layer along with the GWRC flood model, to ensure all areas of known and expected (modelled) flooding were captured in our characterisation.

5.3.2 Liquefaction

Liquefaction susceptibility zones were developed for the Wairarapa by GNS (Dellow, et al., 2018), based on mapped geological units and available borehole data and with reference to historical observations. Liquefaction susceptibility is classified into zones of Low, Moderate, High, and Very High susceptibility, as shown in Figure 6. Areas of Moderate, High and Very High susceptibility are expected to experience consequential liquefaction at Modified Mercalli (MM) shaking intensities of MM8 and greater, meaning damage to infrastructure is anticipated. Areas of Low liquefaction susceptibility, comprising primarily alluvial gravel deposits, are expected to suffer minor liquefaction damage only during the most extreme (MM10) earthquake shaking.

Historical records suggest that shaking intensities in previous local earthquakes affecting the Wairarapa were MM9-10 in the M_W 8.2 1855 earthquake (Dellow, et al., 2018) and MM8-9 in the M_W 7.2 June 1942 earthquake (Downes, et al., 2001). For the local magnitude 8.0 earthquake scenario considered in this study, we have classified areas of the road network located within Low liquefaction susceptibility zones as experiencing negligible liquefaction damage. Sections of the road network located within Moderate, High and Very High liquefaction susceptibility zones are expected to experience consequential liquefaction, and roads within these zones are characterised to reflect the damage anticipated considering the potential for consequent ground damage as discussed below.

As noted in Section 2.6, ground damage from liquefaction is a better determinant of likely road damage than liquefaction susceptibility alone. Ground damage could be subsidence of the ground and ejection of sand and silt, and in areas near water courses or water bodies, lateral spreading of the ground towards these water courses. Lateral spreading would cause greater damage and loss of access along transport routes. Unfortunately, the 2018 GNS study does not consider ground damage and lateral spreading.

The 1993 Wellington Region liquefaction study by Works Consultancy Services (now part of WSP) considered ground damage and lateral spreading from liquefaction (Brabhaharan & Jennings, 1993). The areas classified as susceptible to liquefaction in the GNS study were compared to the 1993 study and the locations of water courses and water bodies, and the road resilience was classified on a similar basis to the western part of the Wellington Region. Roads in areas of moderate to high liquefaction and within 100 m of the water bodies were assessed to be prone to damage due to lateral spreading arising as a consequence of liquefaction.

5.4 Hill terrain road characterisation

Roads within Wairarapa hill country were characterised using a desk-based inspection of terrain data, geological mapping, aerial imagery, and Google Maps Street View. This information was supplemented by drive-over reconnaissance of a small sample of the road network and concurrent work carried out by WSP for the South Wairarapa District Council on some coastal cliffs near Cape Palliser Road. Areas of known slope instability were highlighted from available records collected during the desk study stage, and from discussion with Council staff. Slope instability in the region is highlighted in Figure 4. These slip-prone areas were incorporated into the hill terrain road characterisation.

The draft flood model shared by GWRC shows flooding depths across some of the roads in the hill terrain (shown in Figure 5). Some of the roads that are exposed to overslips and/or underslips are also located within areas shown to be flooded in the 1% AEP draft model provided by GWRC. The effects of slope instability and flooding on the roads is assessed in combination for the storm event scenario. Roads in areas that are prone to both flooding and slips may in some cases be assigned a high availability state, due to presence of flood waters on the road (which may recede after a few days), as well as a high outage state, due to the occurrence of overslips or underslips which remove access to part of the road width. Sections of road where this situation is realised have been highlighted on the resilience maps presented.

5.5 Maps

The resilience state maps are presented as A3 maps at 1:100,000 scale in Appendix A, B, C and D. The road characterisation mapping was generally carried out at about 1:5,000 scale, and thus the GIS data enables specific areas of the maps to be viewed at larger scales than shown.

6 Resilience Assessment

6.1 Event scenarios

The information collected prior to and during the road characterisation allow for a qualitative assessment of the road form and the resilience and security of the route. This requires the consideration of the size / return period of the earthquake and storm events of interest, an assessment of the effects of instability and flooding on the availability of access along the route, and an assessment of the potential duration of outages.

To develop performance states to assess the resilience of the road, the following natural hazard scenarios were adopted:

- A large local earthquake (with a magnitude of about 8.0).
- A large storm event (with a return period of about 100 years).

The resilience states were developed for each of the natural hazard scenarios and used for mapping the resilience of the selected local roads.

6.2 Resilience Assessment Approach

The resilience of selected local roads in the Wairarapa region has been assessed by consideration of the extent and duration of a loss of functionality in the aftermath of a large storm and a large earthquake. The resilience of these roads was characterised using Availability and Outage states based on the concept of resilience developed for road networks, based on research by WSP (then Opus). The resilience states used in this study align with those previously used by Opus (2012) for the Wellington Region Road resilience study, meaning the results of this assessment are comparable to the rest of the Wellington Region and the state highways in the Wairarapa area.

The resilience maps developed in this study highlight the vulnerability of the Wairarapa local road network to numerous closures in large storm and earthquake events, due to slips, flooding and liquefaction. The key issues affecting roads in different parts of the region are discussed below.

6.3 Eastern hills

Local roads in the eastern hill terrain of the Wairarapa are expected to be closed in several places following a large storm or earthquake event, due to a variety of landslides and flooding.

Where roads traverse these hillsides, slips from natural and cut slopes are common. Slumping of slopes below the road is also a risk, particularly where the road surface is constructed on sidling fills and/or is supported by inadequate retaining structures. These slips are often shallow soil slides and flows with long runout distances and are particularly common in areas of weaker Tertiary bedrock and steep, grass-covered slopes.

The local roads are vulnerable to debris flows and flooding from gullies adjacent to the road, particularly where there are steep slopes in weak materials further upstream in these gullies. Debris flows and flooding would be significant enough to block the full road width in places.

Local roads running through valleys within the eastern hills are vulnerable to flooding from adjacent watercourses during storms, which may close the road for a few hours in most cases but potentially up to a few days in some areas. Scour erosion of slopes below the road may also occur when river levels are elevated, potentially resulting in the loss of one or both lanes in some cases, depending on the height of the slope below the road. Erosion and failure of slopes below the road could also occur due to blockage or inadequate capacity of water table drains or culverts leading to overland flow over the road and onto slopes below.

6.4 Ranges

Like in the eastern hills, local roads within the steep ranges of the Wairarapa (e.g. the Aorangi Ranges) are expected to be closed in several places due to slips and flooding. Steep, high natural hillslopes are common in these ranges, and roads that traverse across or run along the base of these slopes are vulnerable to slips and rock fall from above, particularly where cuttings have been made during the formation of the road.

Debris slides and flows may occur from gullies and large slopes adjacent to or set back from the road. Such landslides may have long runout distances and can block the full road width in places. Debris flows from gullies in steep terrain are also a possibility, especially during or following heavy rainfall.

Where roads are situated adjacent to rivers and streams, scour erosion of slopes below the road can result in dropouts that may cause the loss of one or both lanes. This may also result from overland flow due to inadequate capacity or blockage of culverts and water table drains as discussed above. The road may also be subject to flooding in places when the river level is elevated.

6.5 Wairarapa Plains

Roads situated in the broad Wairarapa Plains are generally located in relatively flat areas, on floodplains or old river terraces. For roads in close proximity to one or more of the large rivers flowing across the plains, and in the areas around Lake Wairarapa, flooding is very likely to occur during and following a large storm event or periods of extended wet weather. Such flooding may close full roads for hours to few days before flood waters recede.

Based on the geology of the Wairarapa Plains, roads in this area are also vulnerable to liquefaction and lateral spreading, which may cause damage ranging from minor cracking to significant settlement and horizontal displacements. The swamp areas around Lake Wairarapa are particularly vulnerable, with significant liquefaction damage expected here.

Broad drainage channels traverse the plains, and in places fill embankments have been constructed to support the road across these channels. It is possible that damage to the road could occur if these embankments are damaged by scour erosion during storms, or by liquefaction-induced slumping during earthquakes.

To a lesser degree, some section of the local roads in the plains may be vulnerable to minor slips from slopes above the road, primarily where cuttings have been made as part of the construction of the road. Such slips are generally not expected to have a significant impact on the road in terms of availability or outage duration.

6.6 Coastal areas

Several of the selected local roads considered in this study have sections located in coastal areas, as these roads serve the small communities located along the south and east coasts. In places, these roads are vulnerable to coastal flooding during storm surge events, which may include debris being washed onto the road.

Some of these coastal roads are also vulnerable to erosion of slopes below the road, as well as damage to retaining and erosion mitigation structure such as rip rap. Damage of this sort previously occurred on Cape Palliser Road during a storm surge event in June 2013, where the road was closed due to a dropout at Kupe's Sail, and past of the road was lost at Te Kopi just prior to the Pūtangirua Pinnacles access road.

Steep coastal escarpments are common where the Wairarapa hill terrain meets the ocean, and roads passing along or adjacent to these slopes are vulnerable to large landslides that may cause long road closures. Notable locations where the road is vulnerable include Johnson's Hill and Whatarangi Bluff on Cape Palliser Road, and along Mataikona Road.

Roads serving these coastal communities are often particularly critical routes due to the lack of viable alternative roads connecting the coastal areas to the rest of the region.

6.7 Other potential issues

As well as the key issues discussed above, there are other issues which have previously affected local roads in the Wairarapa, and that may occur during a large storm or earthquake event.

As well as significant flooding from rivers and Lake Wairarapa, it is also possible that other areas of localised surface flooding could occur. Some of these areas may not be captured in our characterisation. For example, insufficient or damaged drainage infrastructure around the road could contribute to surface flooding in places. Flooding has also occurred in the past due to large landslides dams created along rivers during storm events, as occurred on Te Ore Ore-Bideford Road in 1991 (WELA, 2003) and on Kaiwhata Road in 2019 and 2020 (RNZ, 2020).

Bridges in the region are vulnerable to damage during large storm and earthquake events. There is potential for bridges to be damage or washed away during increased river flow after heavy rainfall, particularly if abutments suffer scour damage or there is significant debris in the river. Bridge approach embankments may be vulnerable to liquefaction and slumping during earthquake events, which could render some bridges impassable by vehicles. Bridges have not been considered in this study.

6.8 Impact of climate change

The road characterisation and resilience assessment of the selected local roads has been undertaken based on existing data and past observations from storms and earthquakes. Climate change is likely to result in more frequent extreme weather events, and this is likely to result in more frequent closures on the local road network. Coastal areas may be badly affected by more frequent and severe storm surges. Also, the time taken for flood waters to subside in the lower Wairarapa valley may increase as sea levels continue to rise, potentially increasing outage durations for roads in affected areas.

7 Indicative Volumes of Overslip Materials

Indicative volumes of slip materials that may need to be cleared from the selected local roads after the large storm and earthquake scenarios assessed in this study have been assessed by considering the various road categories vulnerable to overslips, and then derived using the spatial GIS platform. Volumes are provided for each district in the Wairarapa in the table below (Table 4). Ranges of the volume of materials expected are given to represent the uncertainties involved in these estimates. The quantities provided represent solid volumes only and are rough order indicative quantities. The volumes are also calculated based on an assumption of uniform rainfall intensity or earthquake shaking across the entire Wairarapa region, which is unlikely to happen, except in an extreme scenario.

In assessing the slip volumes, consideration was given to records of historical storms in the Wairarapa, particularly the February 2004 storm. Slip volumes presented for the earthquake scenario take into consideration landslides observed in the 2016 Kaikōura earthquake and a resilience characterisation of roads along the Kaikōura coastal section of State Highway 1 undertaken previously by Opus (2001) (now WSP). The experience of the project team from the 2010-2011 Canterbury earthquakes and the 2008 Wenchuan earthquake in China, along with knowledge of the failure characteristics of slopes in the Wairarapa region, were also used.

On narrow roads in the Wairarapa hill terrain, the amount of overslip materials that will accumulate on the road will be limited by the narrow width of the road, as runout will extend the debris deposition beyond the width of the road and will run down the slopes below the road. We have presented two sets of indicative volumes, one set representing the approximate volumes of material produced by overslip failures, and the second set representing the approximate volumes of material that may remain in place on the road platform.

Table 4: Indicative volumes of overslip materials in the Wairarapa.

Area	Rough order volume of possible overslip materials ('000s m^3)			
	Failure volume		On-road volume	
	Storm	Earthquake	Storm	Earthquake
Masterton District	60 to 400	80 to 550	30 to 220	40 to 350
Carterton District	10 to 100	20 to 100	5 to 50	10 to 50
South Wairarapa District	70 to 450	120 to 750	40 to 280	60 to 450
TOTAL – Wairarapa region	150 to 950	220 to 1,400	75 to 550	110 to 850

NOTE:

1. Volumes reported are solid volumes only. Cartage needs to consider bulking of materials.
2. Uniform ground shaking / rainfall across the region assumed in assessing volumes.

The total volume of overslip materials expected in a large earthquake is likely to be greater than in a large storm. Based on observations from previous significant storms and earthquakes, and with reference to records of storms and earthquakes in the Wairarapa specifically, it is anticipated that the proportion of slopes that fail in a large storm will be smaller than in a large earthquake, because intense rainfall associated with storms tend to be concentrated in smaller areas. It is also expected that the size of slips on comparable slopes will generally be larger in an earthquake compared with a storm, particularly for modified slopes such as roadside cuttings. These expected differences are reflected in the total volumes presented for the earthquake and storm scenarios.

The actual quantities of slip materials will depend on the local soil and rock conditions along the routes, the characteristics of the particular storm or earthquake event, and the antecedent season / weather conditions prior to the vent, as well as aftershock sequence after an earthquake and rainfall following the event.

The volume of overslip material will typically increase after it has detached from the slope. This process is referred to as 'bulking'. It is necessary to consider the bulking factor of the materials to facilitate planning of emergency response and maintenance resources for debris clearance following slips occurring in earthquakes or storms. Bulking factors are generally larger for stronger rock (bulking factor of about 50 to >65%), which will tend to break into blocky debris during a slip, compared to softer rock (about 40 to 55%) and soils (about 5 to 20%), which are more likely to break apart easily (Entwisle, et al., 2015). Bulking can be exacerbated by the presence of water in slips involving groundwater to surface runoff.

Roads are also vulnerable to under slips, due to collapse of un-engineered retaining walls and fills, often loose side cast fill from early construction of roads, and erosion due to uncontrolled surface runoff or due to blockage or inadequate capacity of culverts. In many cases the damage from under slips will result in much longer outages than the overslips, and restrict access to overslip sites, and therefore the slip estimate values given in this section should be read in conjunction with the availability and outage state maps in the consideration of appropriate emergency response priorities for restoring access.

The indicative volumes of overslip materials presented should be used for general planning purposes only. Additional investigations could be completed at key sites or on specific routes to refine these indicative volumes.

8 Resilience Enhancement

8.1 Approaches to Enhance Resilience

Resilience can be enhanced by reducing the reduction in service or loss of access, reducing the time for recovery of access, or a combination of the two as shown in Figure 8, i.e., reduce the resilience risk from the green triangle to the blue triangle (Brabhaharan, 2020).

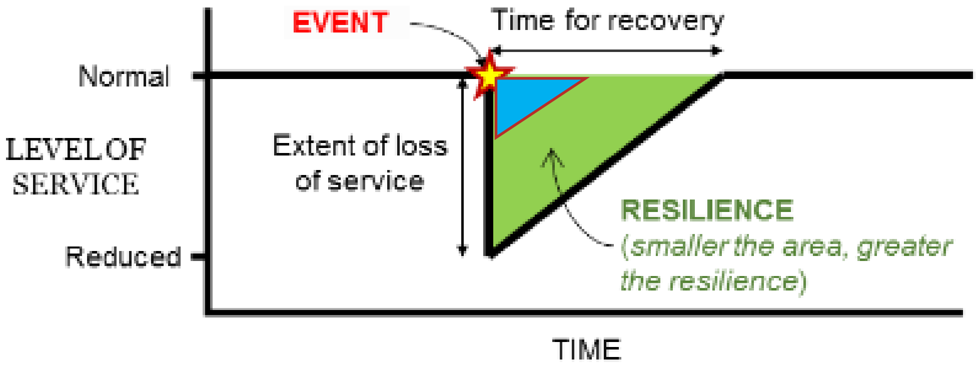

Figure 8: Enhancement of resilience.

It would therefore be prudent to give priority to protecting risk areas that are either critical for the functionality of the socio-economy or difficult or time consuming to restore, for example areas vulnerable to underslips or damage to retaining walls below the road, as shown in Figure 9. On the other hand, slips onto the road from slopes above may cause full road closures but are generally more straightforward to clear unless they involve very large slips in slopes of considerable height. Mitigation can target damage limitation where it is easily repairable, and plan to restore access quickly. Where the importance of access (and safety) is low, damage can be accepted, and plans put in place to repair after the event.

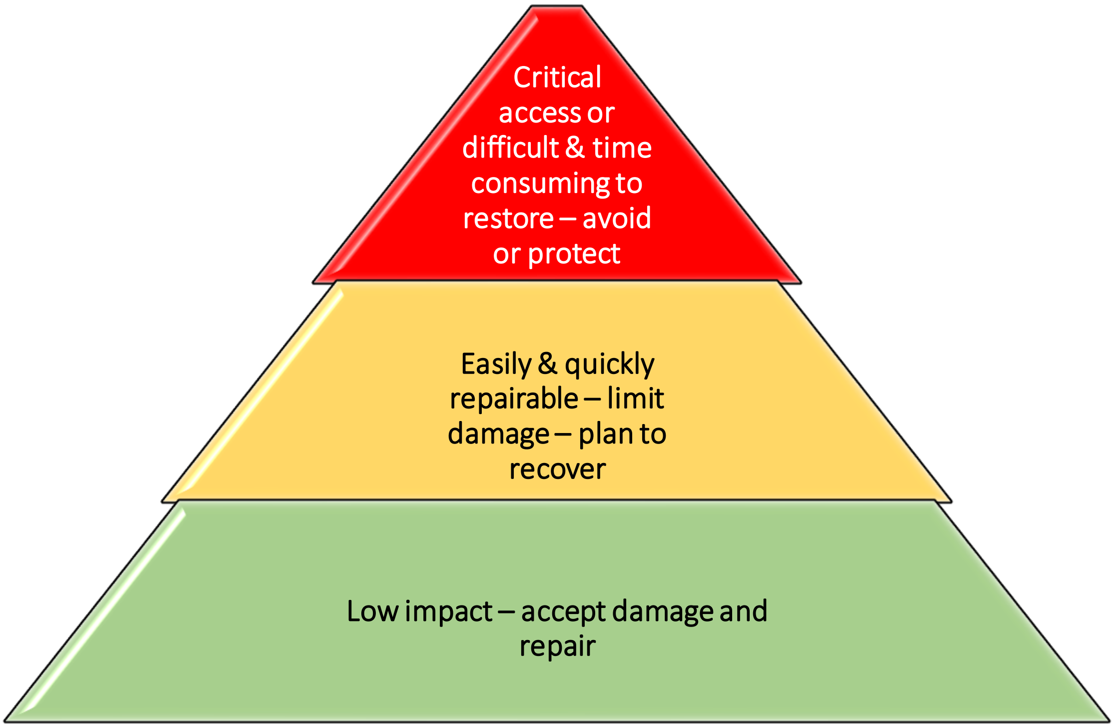

Figure 9: Resilience enhancement prioritisation strategy.

8.2 Application to Wairarapa Road Network

It should be noted that because of the extent of hill country in the Wairarapa, and of the size of some of the slopes, a large proportion of the roads in the hilly terrain cannot be practically mitigated to enhance route resilience in large earthquake and storm events.

Similarly, it is not practical to mitigate the risk of flooding to all vulnerable areas of the road network. Although vulnerabilities on some sections of the road network can be mitigated through interventions to reduce the frequency of closures, there would remain the residual risk of closure from time to time. Such closures can be expected to increase in frequency due to climate change.

Another approach to enhance resilience is to have redundancy in the road network, in the form of viable alternative routes or connectivity between existing routes. In many parts of the Wairarapa, particularly for small, isolated communities, there are few or no alternative routes, increasing the importance of protecting the existing routes. It is also possible that even in places with several alternative routes, all roads could suffer damage in large storm and earthquake events, simply due to the nature of the terrain in the Wairarapa.

8.3 Emergency Response Planning

Given the low traffic volumes and routes with no alternatives in the Wairarapa as well as the large slopes and flood plains, emergency response planning will be a significant measure that would be part of the mix to enhance resilience.

A systematic approach to planning for emergency management would facilitate early recovery of access along routes and hence enhance the resilience of access for communities. This may involve understanding the available resources and strategic and distributed location of resources to enable remediation work to begin quickly and from different locations after an event. This would also need to consider provision of fuel supplies for earthmoving plant.

8.4 Prioritisation

Understanding the importance of the different routes in the road network will enable prioritisation of the resilience management measures by understanding the criticality of these resilience risks. For example, the road networks in the Wellington region were prioritised based on their importance considering traffic use, public transport use, access for emergency services and lifelines facilities and availability of alternate routes, for example Opus (2000; 2009; 2014). This enabled the criticality of the resilience risks to be assessed and development of a prioritised list of resilience management measures (WSP Opus, 2018).

It is recommended that the importance of the road routes in the transport network in the Wairarapa is also assessed in a similar manner.

9 Recommendations

The following recommendations are made for consideration by the Councils, based on the transport network resilience study:

1. The Wairarapa District Councils and Lifelines Group review and consider the resilience states presented and adopt them for use in emergency response planning.
2. The resilience of the bridges and large culverts be considered to arrive at a holistic understanding of the resilience of the transport network.
3. The relative importance of the routes in the Wairarapa transport network be assessed to facilitate prioritisation of resilience enhancement actions and planning.
4. The resilience assessment should be used to identify critical sites where road or lane closures may persist for long periods and prioritise these sites for risk mitigation. This prioritisation should be in terms of the route importance, as noted above. It is noted that physical mitigation of all sites would be virtually impossible, or very expensive at best, and resilience mitigation should include emergency response planning.
5. Risk mitigation prioritisation should be undertaken in conjunction with the development of preventative maintenance priorities for the road network management team (roading engineers and contractors).
6. The resilience assessment is used to identify critical areas in the region to develop emergency response plans, for use the event of failures in storm and earthquake events that cause closures on the local road network.
7. Consideration be given to understanding the resilience of adjacent transport networks to understand external access for response and recovery after major events. Given that the resilience of the western part of the Wellington region has been assessed and access through the Remutaka range has poor resilience, it would be prudent to engage with transport authorities to the north (Tararua region) to understand the resilience of access from the north.
8. The Wairarapa Engineering Lifelines Association consider the effect of road access resilience on the resilience of other lifeline utilities.
9. The Network Contractor continues to record all instances of slope failures to build a database of slope performance over the whole route and to monitor the frequency of movement at areas of known instability. The RAMM database in conjunction with collector apps such as those developed by WSP is likely to be appropriate.
10. The indicative volumes of overslip materials presented should be used for general planning purposes only. Additional investigations could be completed at key sites or on specific routes if there is a need to better understand the indicative volumes.

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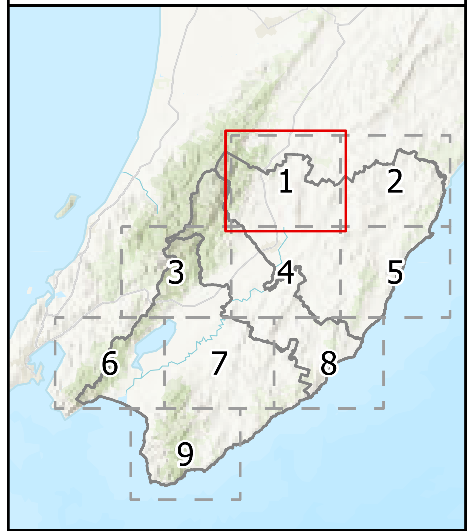
Appendix A
Storm Availability Maps



Storm Availability State

- Full
- Poor
- Single Lane
- Difficult
- Closed
- Other roads

Scale:
1:110,000
0 2.5 5 Km

Title:
Wairarapa Resilience Study

Project:
Wairarapa Resilience Study

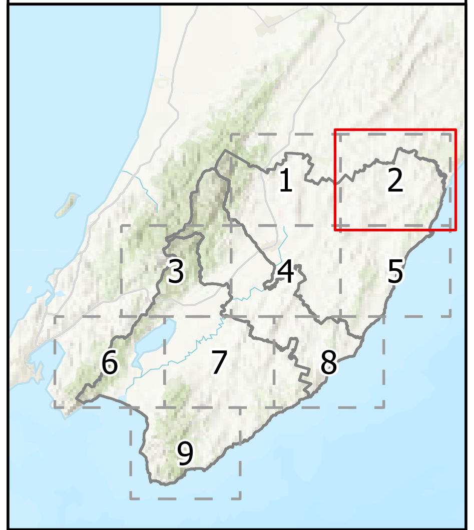
Prepared For:
MASTERTON DISTRICT COUNCIL
CARTERTON DISTRICT COUNCIL
SOUTH WAIRARAPA DISTRICT COUNCIL Kia Reretahi Tātau

Prepared By:
wsp

Date:	*Project No:*	*Figure:*
April 2022	5-C4397.00	A1 of A9

Storm Availability State

- Full
- Poor
- Single Lane
- Difficult
- Closed
- Other roads



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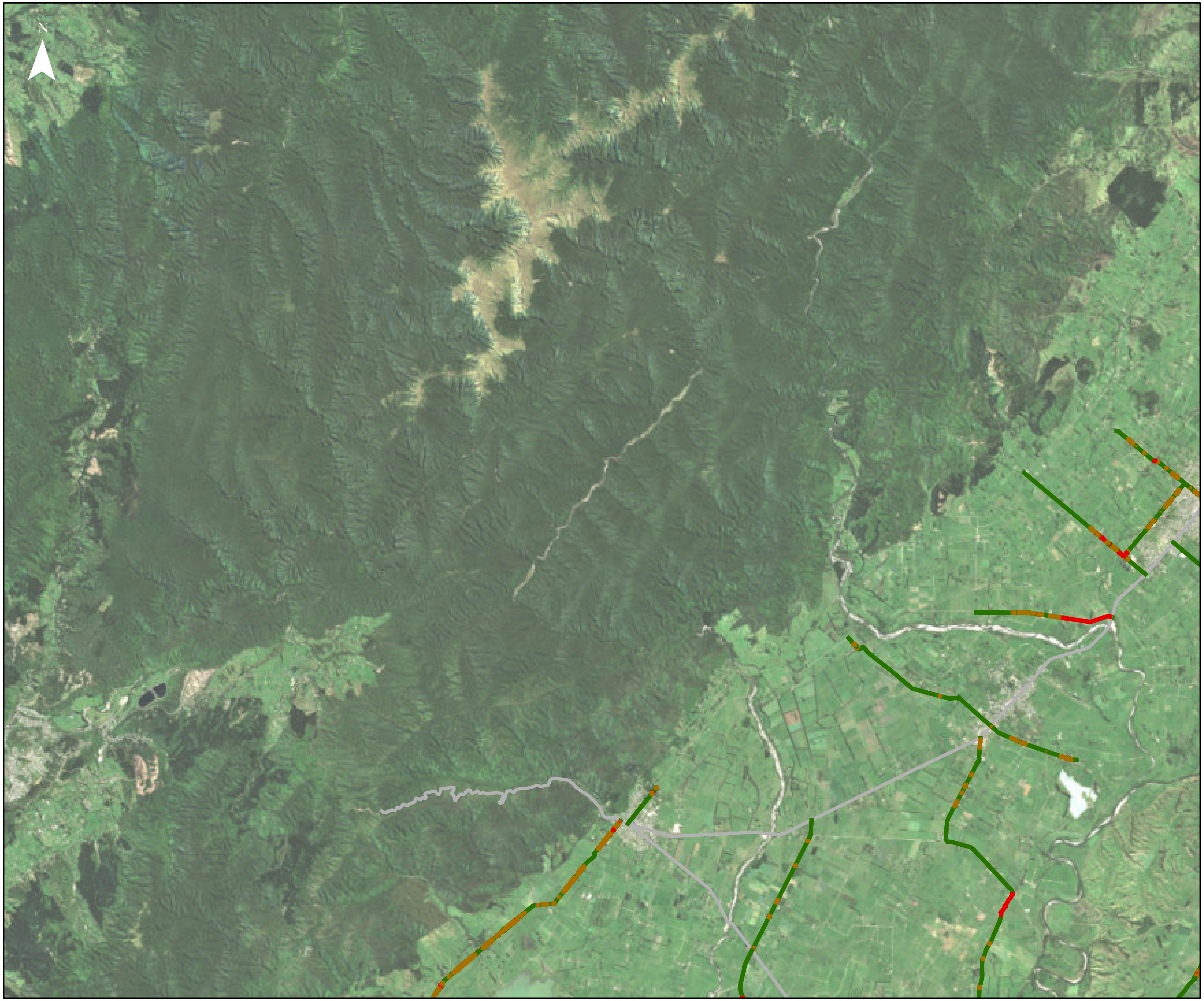
Title:
Wairarapa Resilience Study

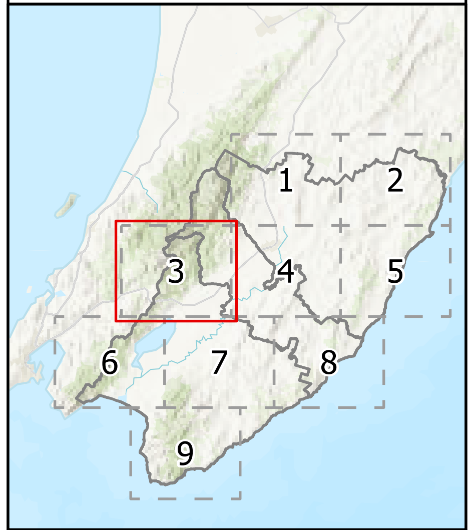
Project:
Wairarapa Resilience Study

Prepared For:
Masterton District Council
Carterton District Council
South Wairarapa District Council Kia Reretahi Tātau

Prepared By:
wsp

Date:	Project No:	Figure:
April 2022	5-C4397.00	A2 of A9





Storm Availability State

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- Poor
- Single Lane
- Difficult
- Closed
- Other roads

Scale:
1:110,000
0 2.5 5 Km

Title:
Wairarapa Resilience Study

Project:
Wairarapa Resilience Study

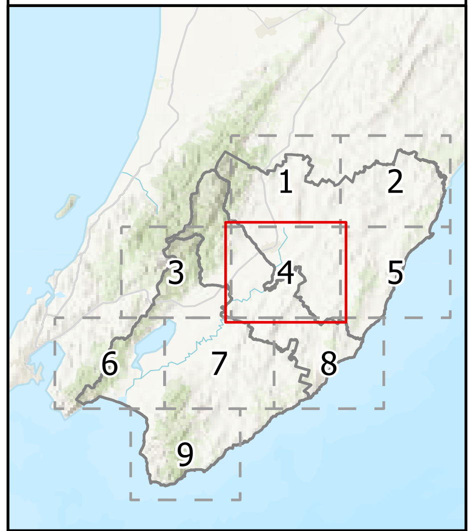
Prepared For:
MASTERTON DISTRICT COUNCIL
CARTERTON DISTRICT COUNCIL
SOUTH WAIRARAPA DISTRICT COUNCIL
Kia Reretahi Tātau

Prepared By:
wsp

Date:	*Project No:*	*Figure:*
April 2022	5-C4397.00	A3 of A9

Storm Availability State

- Full
- Poor
- Single Lane
- Difficult
- Closed
- Other roads



Scale:
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Title:
Wairarapa Resilience Study

Project:
Wairarapa Resilience Study

Prepared For:
MASTERTON DISTRICT COUNCIL
CARTERTON DISTRICT COUNCIL
SOUTH WAIRARAPA DISTRICT COUNCIL Kia Reretahi Tātau

Prepared By: wsp

Date:	*Project No:*	*Figure:*
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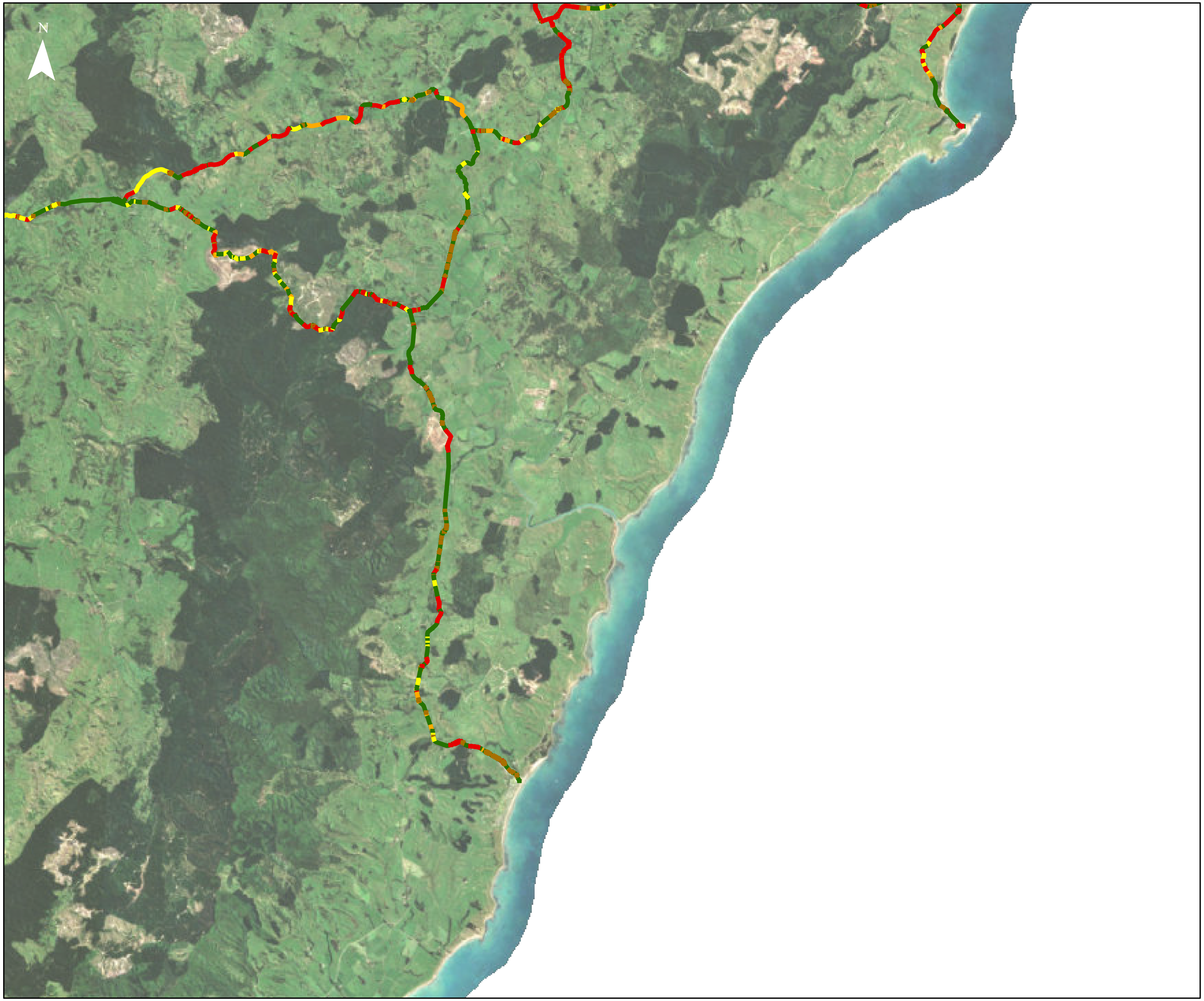
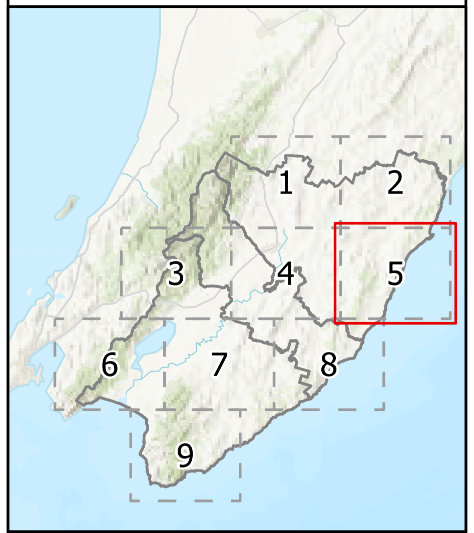


Storm Availability State

- Full
- Poor
- Single Lane
- Difficult
- Closed
- Other roads



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Title:
Wairarapa Resilience Study

Project:
Wairarapa Resilience Study

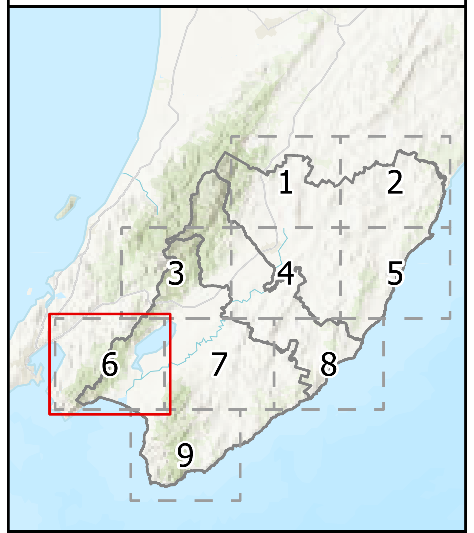
Prepared For:
MASTERTON DISTRICT COUNCIL
CARTERTON DISTRICT COUNCIL
SOUTH WAIRARAPA DISTRICT COUNCIL
Kia Reretahi Tātau

Prepared By:
wsp

Date:	*Project No:*	*Figure:*
April 2022	5-C4397.00	A5 of A9

Storm Availability State

- Full
- Poor
- Single Lane
- Difficult
- Closed
- Other roads



Scale:
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Title:
Wairarapa Resilience Study

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Wairarapa Resilience Study

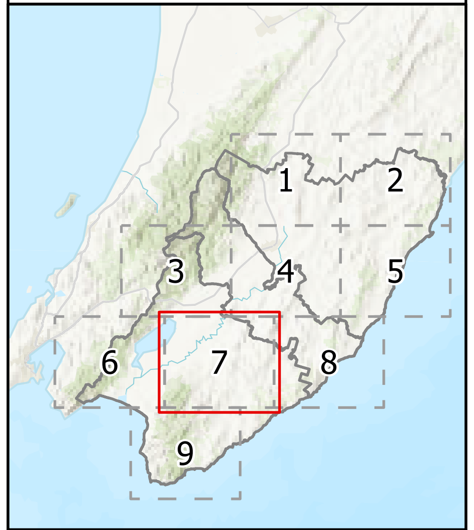
Prepared For:
CARTERTON DISTRICT COUNCIL
MASTERTON DISTRICT COUNCIL
SOUTH WAIRARAPA DISTRICT COUNCIL
Kia Reretahi Tātau

Prepared By:
wsp

Date:	*Project No:*	*Figure:*
April 2022	5-C4397.00	A6 of A9

Storm Availability State

- Full
- Poor
- Single Lane
- Difficult
- Closed
- Other roads



Scale:
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0 2.5 5 Km

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Wairarapa Resilience Study

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Wairarapa Resilience Study

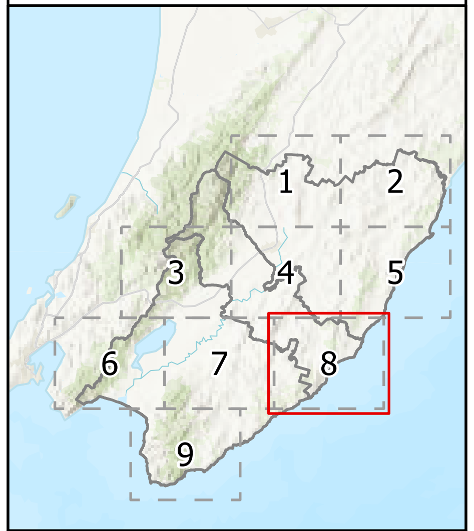
Prepared For:
MASTERTON DISTRICT COUNCIL
CARTERTON DISTRICT COUNCIL
SOUTH WAIRARAPA DISTRICT COUNCIL
Kia Reretahi Tātau

Prepared By:
wsp

Date:	*Project No:*	*Figure:*
April 2022	5-C4397.00	A7 of A9

Storm Availability State

- Full
- Poor
- Single Lane
- Difficult
- Closed
- Other roads



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Title:
Wairarapa Resilience Study

Project:
Wairarapa Resilience Study

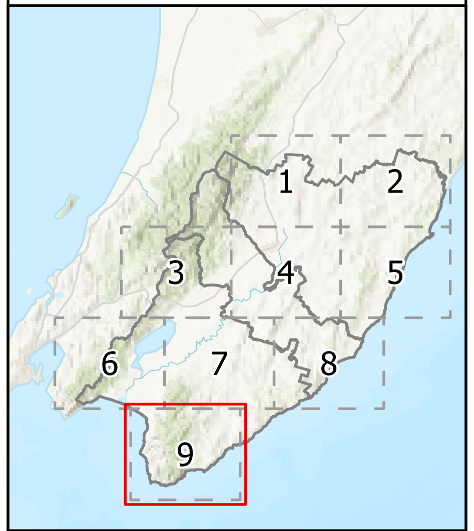
Prepared For:
MASTERTON DISTRICT COUNCIL
CARTERTON DISTRICT COUNCIL
SOUTH WAIRARAPA DISTRICT COUNCIL
Kia Reretahi Tātau

Prepared By:
wsp

Date:	*Project No:*	*Figure:*
April 2022	5-C4397.00	A8 of A9

Storm Availability State

- Full
- Poor
- Single Lane
- Difficult
- Closed
- Other roads



Scale:
1:110,000
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Title:
Wairarapa Resilience Study

Project:
Wairarapa Resilience Study

Prepared For:
MASTERTON DISTRICT COUNCIL
CARTERTON DISTRICT COUNCIL
SOUTH WAIRARAPA DISTRICT COUNCIL
Kia Reretahi Tātau

Prepared By:
wsp

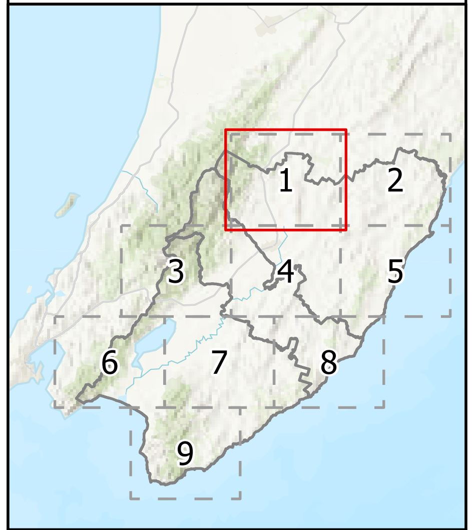
Date:	*Project No:*	*Figure:*
April 2022	5-C4397.00	A9 of A9

Appendix B
Storm Outage Maps

Storm Outage State

- Open (no closure)
- Minor (up to 3 days)
- Moderate (3 days to 2 weeks)
- Severe (2 weeks to 3 months)
- Long term (>3 months)
- Other Roads
- Areas where outage may relate to single closure

Note:
The high outage state may relate to single lane closures rather than full lane closures



Scale:
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Title:
Wairarapa Resilience Study

Project:
Wairarapa Resilience Study

Prepared For:
MASTERTON DISTRICT COUNCIL
CARTERTON DISTRICT COUNCIL
SOUTH WAIRARAPA DISTRICT COUNCIL
Kia Reretahi Tātau

Prepared By:
wsp

Date:	Project No:	Figure:
April 2022	5-C4397.00	B1 of B9

Storm Outage State

- Open (no closure)
- Minor (up to 3 days)
- Moderate (3 days to 2 weeks)
- Severe (2 weeks to 3 months)
- Long term (>3 months)
- Other Roads
- Areas where outage may relate to single closure

Note:
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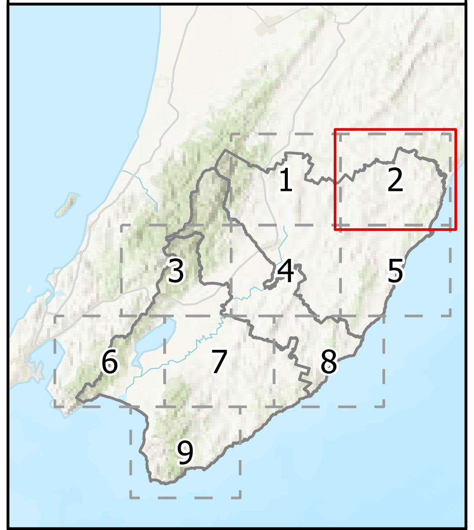

Scale:
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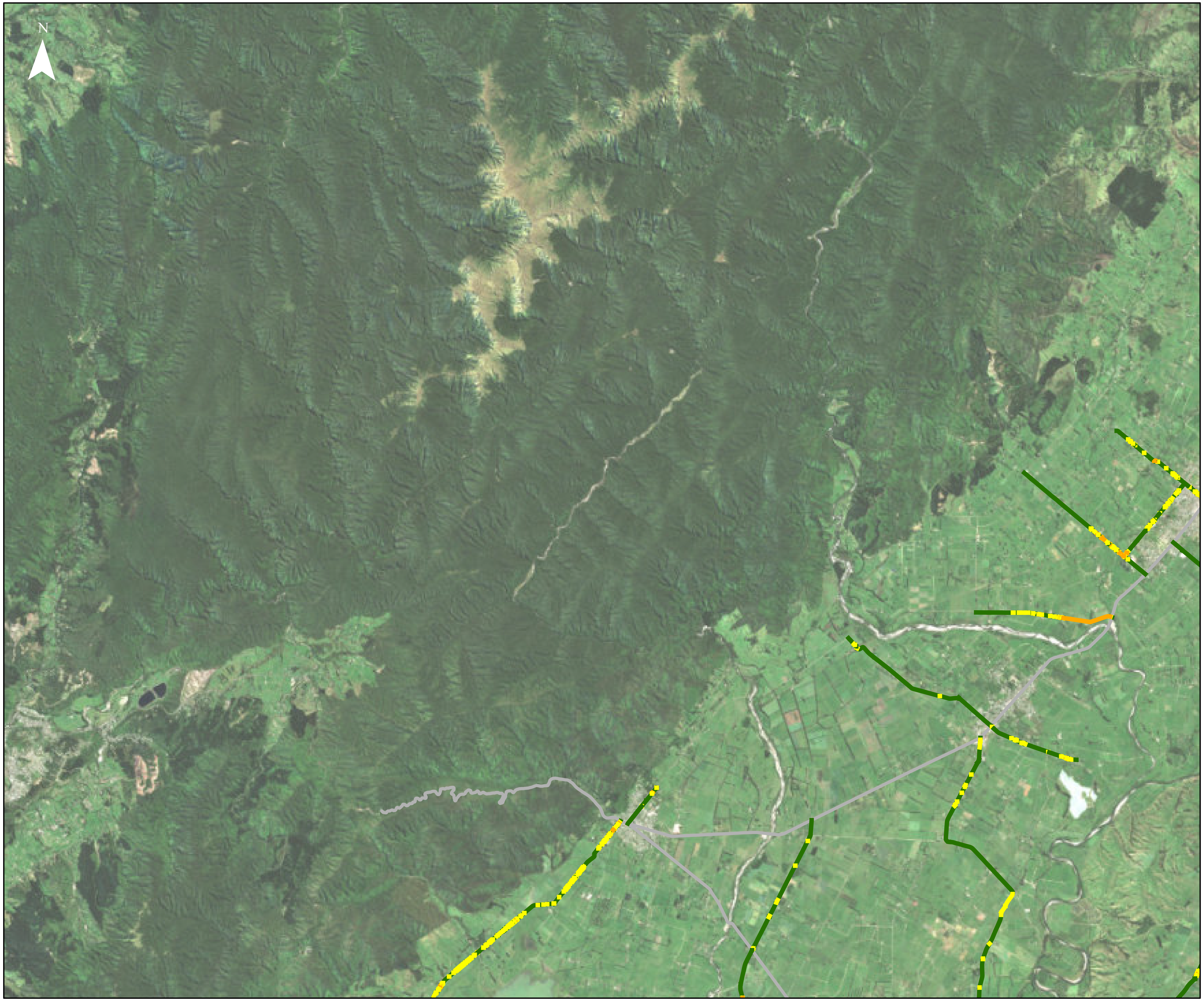
Title:
Wairarapa Resilience Study

Project:
Wairarapa Resilience Study

Prepared For:
MASTERTON DISTRICT COUNCIL
CARTERTON DISTRICT COUNCIL
SOUTH WAIRARAPA DISTRICT COUNCIL *Kia Reretahi Tātau*

Prepared By:
wsp

Date:	*Project No:*	*Figure:*
April 2022	5-C4397.00	B2 of B9



Storm Outage State

- Open (no closure)
- Minor (up to 3 days)
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- Severe (2 weeks to 3 months)
- Long term (>3 months)
- Other Roads
- Areas where outage may relate to single closure

Note:
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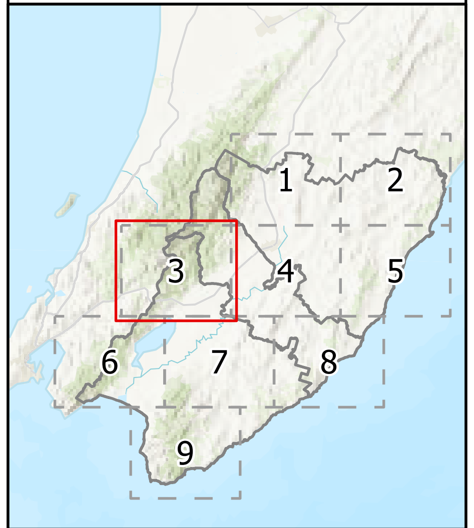

Scale:
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Title:
Wairarapa Resilience Study

Project:
Wairarapa Resilience Study

Prepared For:
MASTERTON DISTRICT COUNCIL
CARTERTON DISTRICT COUNCIL
SOUTH WAIRARAPA DISTRICT COUNCIL *Kia Reretahi Tātau*

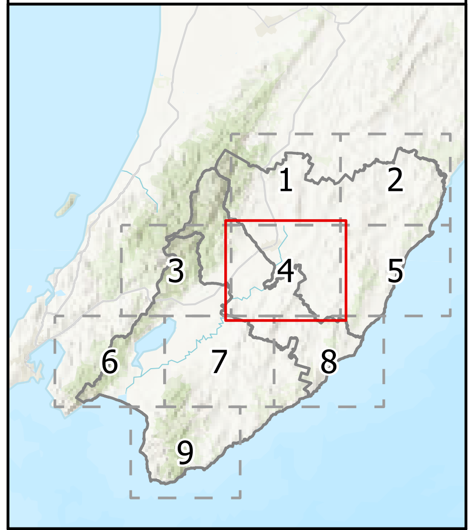
Prepared By:
wsp

Date:	*Project No:*	*Figure:*
April 2022	5-C4397.00	B3 of B9

Storm Outage State

- Open (no closure)
- Minor (up to 3 days)
- Moderate (3 days to 2 weeks)
- Severe (2 weeks to 3 months)
- Long term (>3 months)
- Other Roads
- Areas where outage may relate to single closure

Note:
The high outage state may relate to single lane closures rather than full lane closures



Scale:
1:110,000
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Title:
Wairarapa Resilience Study

Project:
Wairarapa Resilience Study

Prepared For:

MASTERTON DISTRICT COUNCIL

CARTERTON DISTRICT COUNCIL

SOUTH WAIRARAPA DISTRICT COUNCIL
Kia Reretahi Tātau

Prepared By:

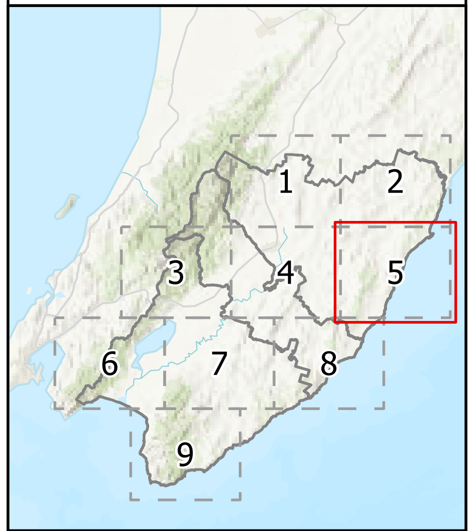
WSP

Date:	*Project No:*	*Figure:*
April 2022	5-C4397.00	B4 of B9

Storm Outage State

- Open (no closure)
- Minor (up to 3 days)
- Moderate (3 days to 2 weeks)
- Severe (2 weeks to 3 months)
- Long term (>3 months)
- Other Roads
- Areas where outage may relate to single closure

Note:
The high outage state may relate to single lane closures rather than full lane closures



Scale:
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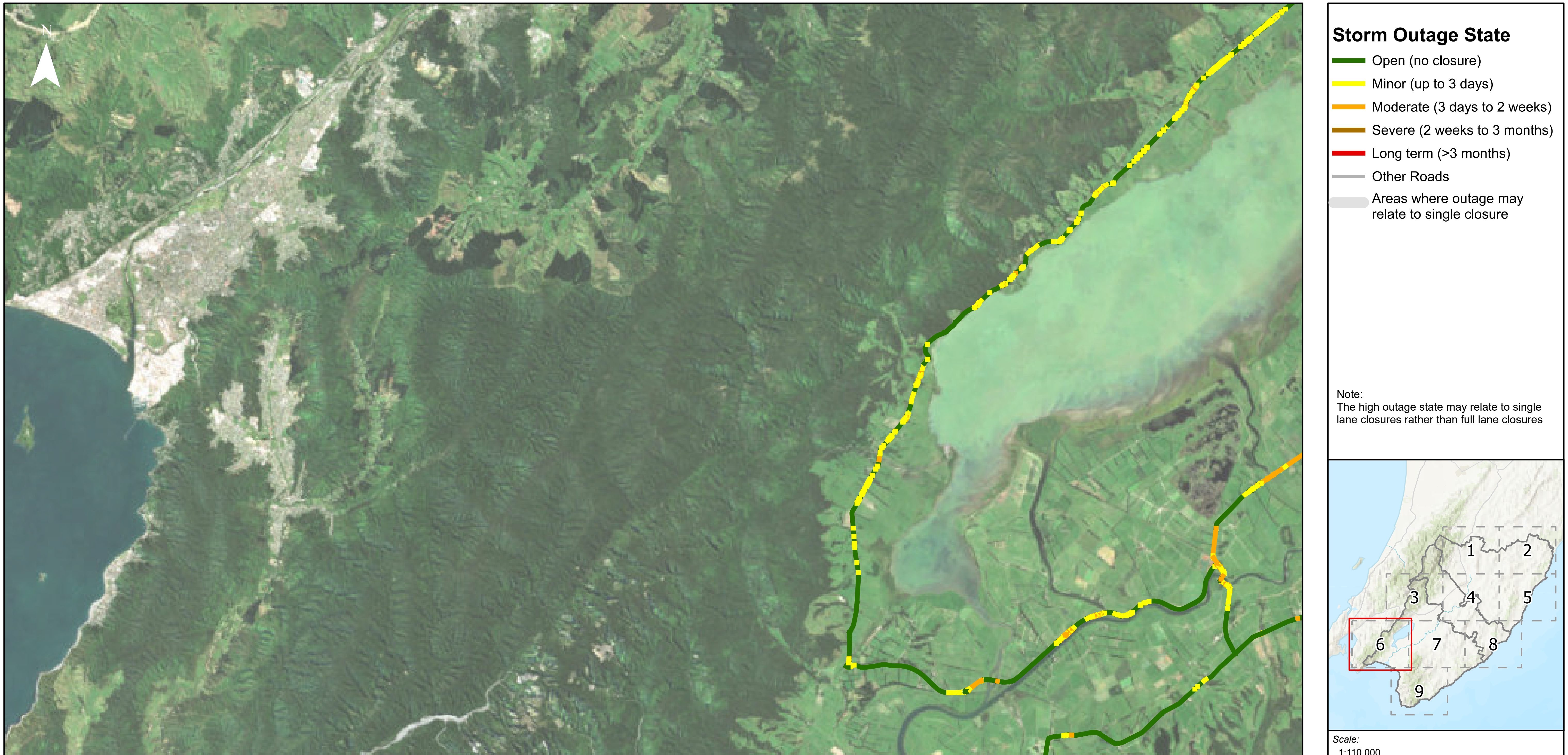
Title:
Wairarapa Resilience Study

Project:
Wairarapa Resilience Study

Prepared For:
Masterton District Council
Carterton District Council
South Wairarapa District Council

Prepared By:
WSP

Date:	*Project No:*	*Figure:*
April 2022	5-C4397.00	B5 of B9



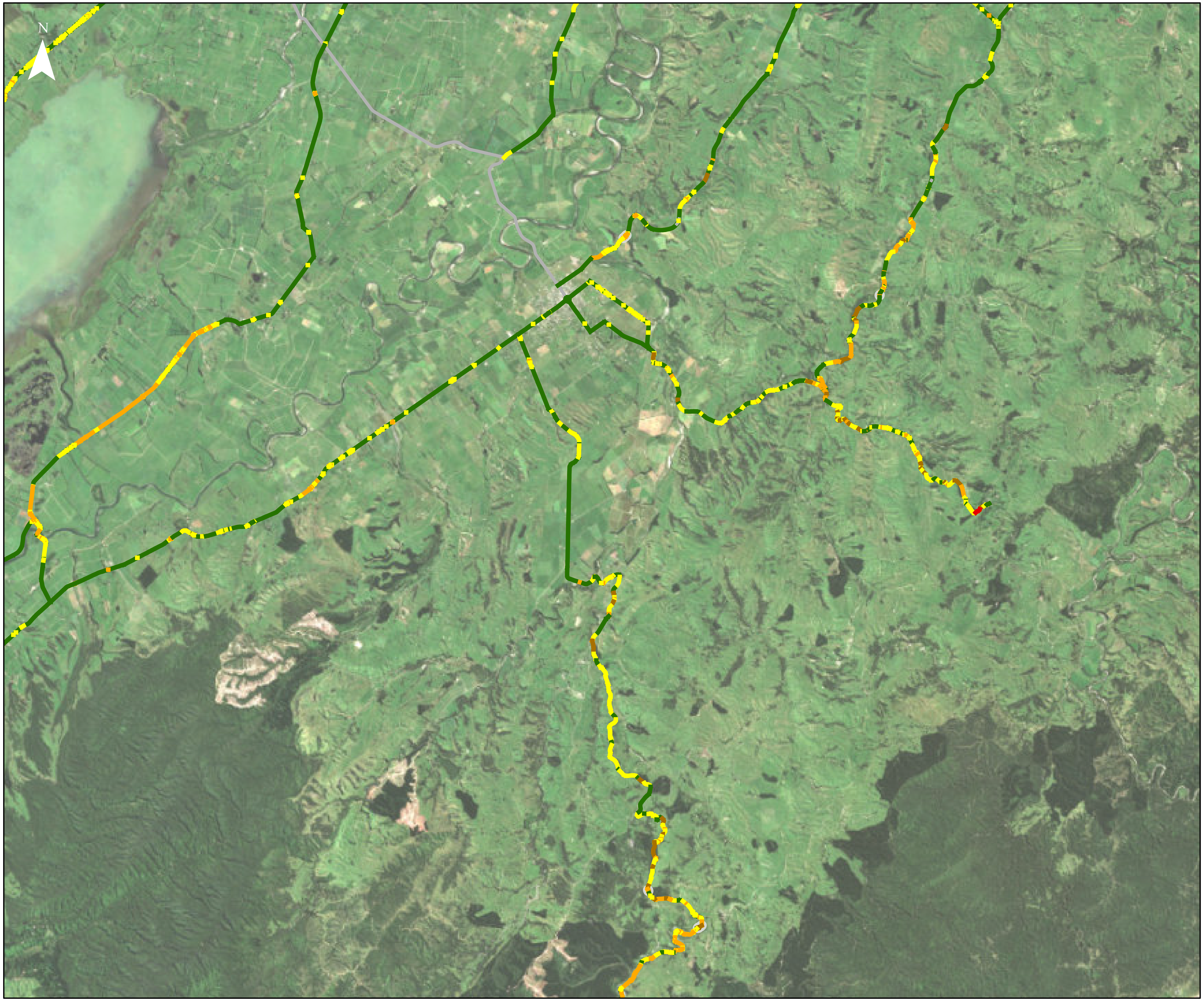
Title:
Wairarapa Resilience Study

Project:
Wairarapa Resilience Study

Prepared For:

Prepared By:

Date:	*Project No:*	*Figure:*
April 2022	5-C4397.00	B6 of B9



Storm Outage State

- Open (no closure)
- Minor (up to 3 days)
- Moderate (3 days to 2 weeks)
- Severe (2 weeks to 3 months)
- Long term (>3 months)
- Other Roads
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Note:
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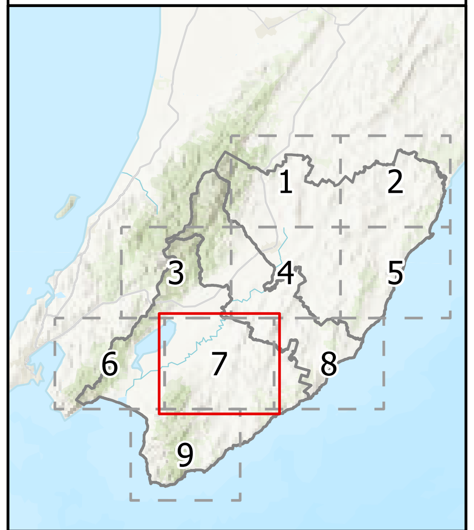

Scale:
1:110,000
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Title:
Wairarapa Resilience Study

Project:
Wairarapa Resilience Study

Prepared For:
MASTERTON DISTRICT COUNCIL
CARTERTON DISTRICT COUNCIL
SOUTH WAIRARAPA DISTRICT COUNCIL Kia Reretahi Tātau

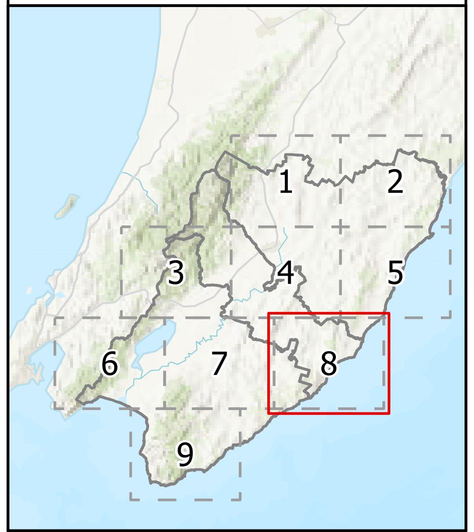
Prepared By:
wsp

Date:	*Project No:*	*Figure:*
April 2022	5-C4397.00	B7 of B9

Storm Outage State

- Open (no closure)
- Minor (up to 3 days)
- Moderate (3 days to 2 weeks)
- Severe (2 weeks to 3 months)
- Long term (>3 months)
- Other Roads
- Areas where outage may relate to single closure

Note:
The high outage state may relate to single lane closures rather than full lane closures



Scale:
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Title:
Wairarapa Resilience Study

Project:
Wairarapa Resilience Study

Prepared For:
MASTERTON DISTRICT COUNCIL
CARTERTON DISTRICT COUNCIL
SOUTH WAIRARAPA DISTRICT COUNCIL Kia Reretahi Tātau

Prepared By:
wsp

Date:	*Project No:*	*Figure:*
April 2022	5-C4397.00	B8 of B9

Storm Outage State

- Open (no closure)
- Minor (up to 3 days)
- Moderate (3 days to 2 weeks)
- Severe (2 weeks to 3 months)
- Long term (>3 months)
- Other Roads
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Note:
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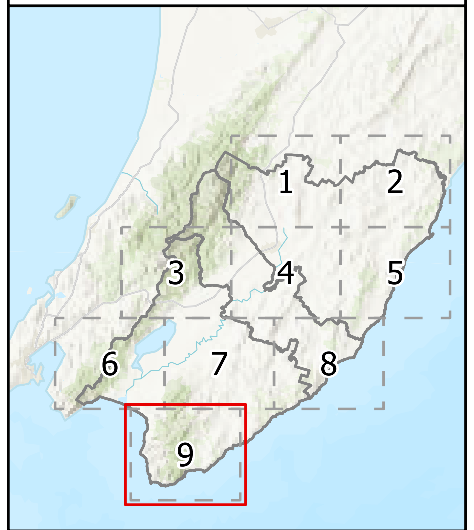

Scale:
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Title:
Wairarapa Resilience Study

Project:
Wairarapa Resilience Study

Prepared For:
MASTERTON DISTRICT COUNCIL
CARTERTON DISTRICT COUNCIL
SOUTH WAIRARAPA DISTRICT COUNCIL Kia Reretahi Tātau

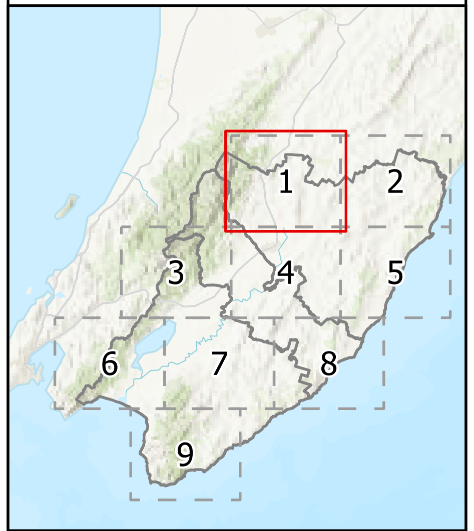
Prepared By:
wsp

Date:	*Project No:*	*Figure:*
April 2022	5-C4397.00	B9 of B9

Appendix C
Earthquake Availability Maps

Earthquake Availability State

- Full
- Poor
- Single Lane
- Difficult
- Closed
- Other roads



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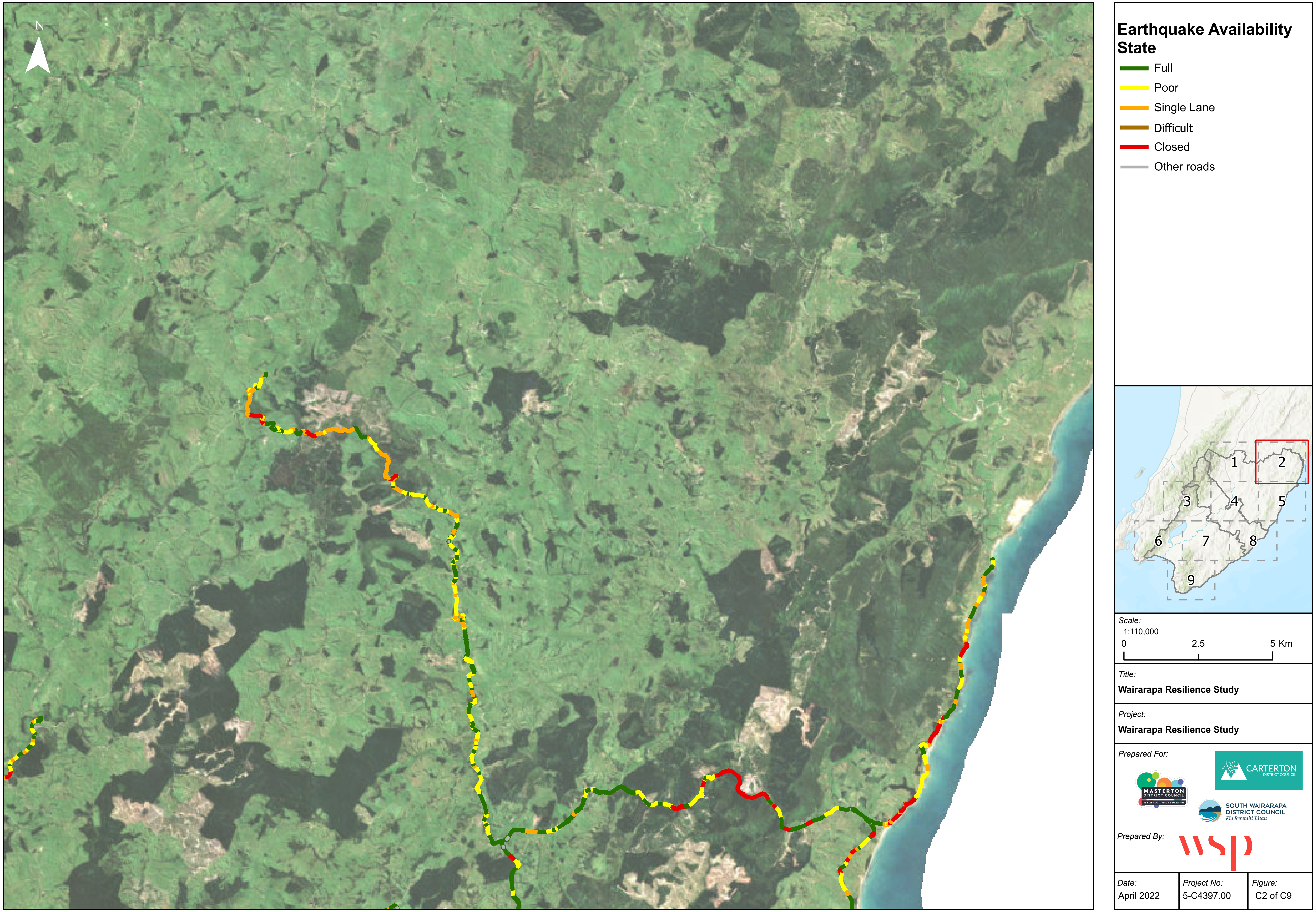
Title:
Wairarapa Resilience Study

Project:
Wairarapa Resilience Study

Prepared For:
CARTERTON DISTRICT COUNCIL
MASTERTON DISTRICT COUNCIL
SOUTH WAIRARAPA DISTRICT COUNCIL
Kia Reretahi Tātau

Prepared By:
wsp

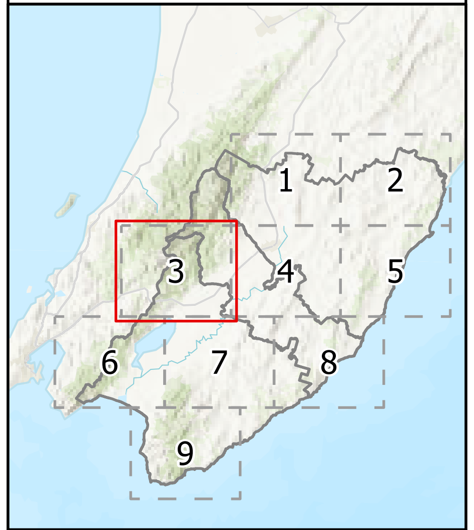
Date:	*Project No:*	*Figure:*
April 2022	5-C4397.00	C1 of C9



N
Earthquake Availability State
Full
Poor
Single Lane
Difficult
Closed
Other roads
1
2
3
4
5
6
7
8
9
Scale:
1:110,000
0
2.5
5 Km
Title:
Wairarapa Resilience Study
Project:
Wairarapa Resilience Study
Prepared For:
CARTERTON DISTRICT COUNCIL
MASTERTON DISTRICT COUNCIL
SOUTH WAIRARAPA DISTRICT COUNCIL
Kia Reretahi Tātau
Prepared By:
wsp
Date:
April 2022
Project No:
5-C4397.00
Figure:
C2 of C9

Earthquake Availability State

- Full
- Poor
- Single Lane
- Difficult
- Closed
- Other roads



Scale:
1:110,000
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Title:
Wairarapa Resilience Study

Project:
Wairarapa Resilience Study

Prepared For:
MASTERTON DISTRICT COUNCIL
CARTERTON DISTRICT COUNCIL
SOUTH WAIRARAPA DISTRICT COUNCIL Kia Reretahi Tātau

Prepared By:
wsp

Date:	Project No:	Figure:
April 2022	5-C4397.00	C3 of C9

Earthquake Availability State

- Full
- Poor
- Single Lane
- Difficult
- Closed
- Other roads

Scale: 1:110,000

0 2.5 5 Km

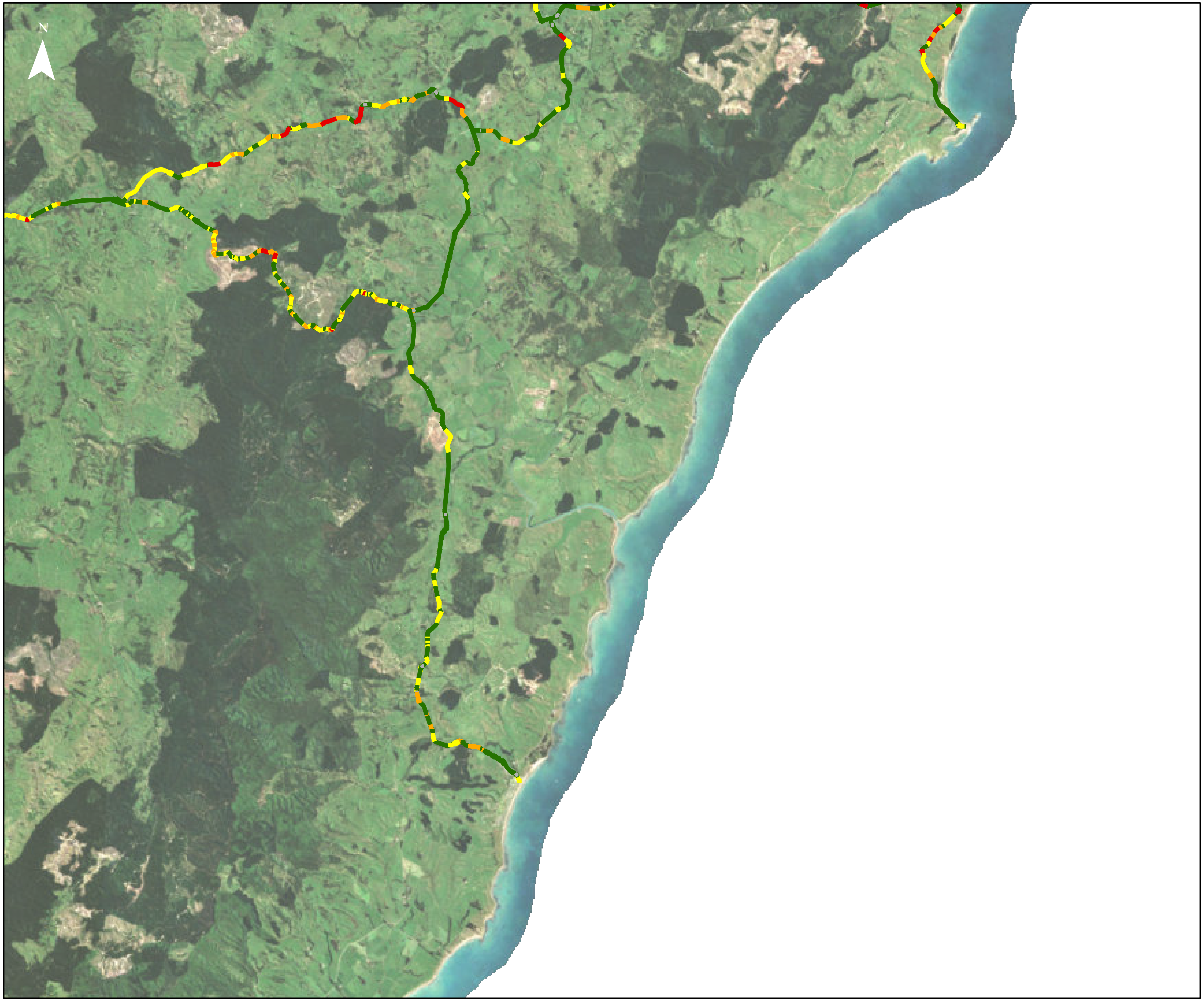
Title: **Wairarapa Resilience Study**

Project: **Wairarapa Resilience Study**

Prepared For: Masterton District Council; Carterton District Council; South Wairarapa District Council

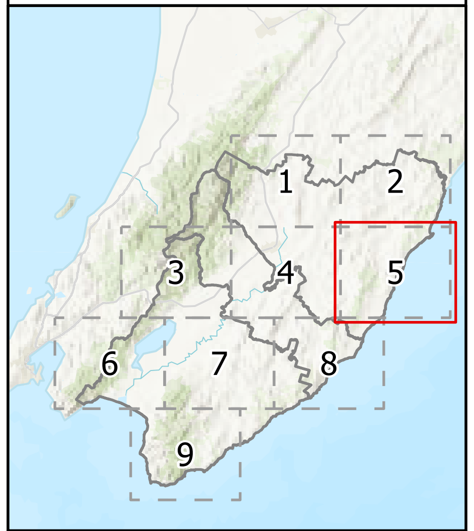
Prepared By: WSP

Date:	Project No:	Figure:
April 2022	5-C4397.00	C4 of C9



Earthquake Availability State

- Full
- Poor
- Single Lane
- Difficult
- Closed
- Other roads



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0 2.5 5 Km

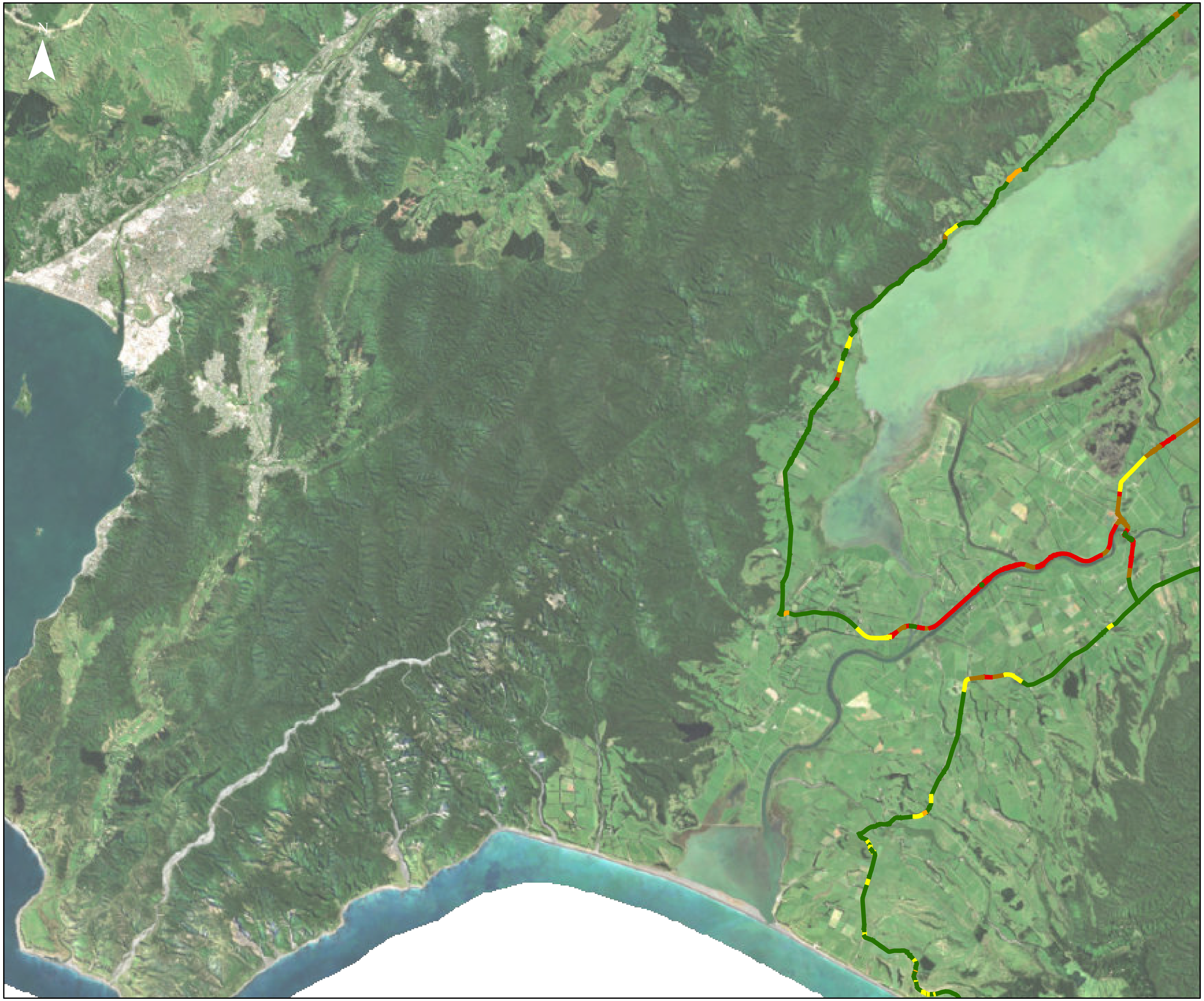
Title:
Wairarapa Resilience Study

Project:
Wairarapa Resilience Study

Prepared For:
MASTERTON DISTRICT COUNCIL
CARTERTON DISTRICT COUNCIL
SOUTH WAIRARAPA DISTRICT COUNCIL
Kia Reretahi Tātau

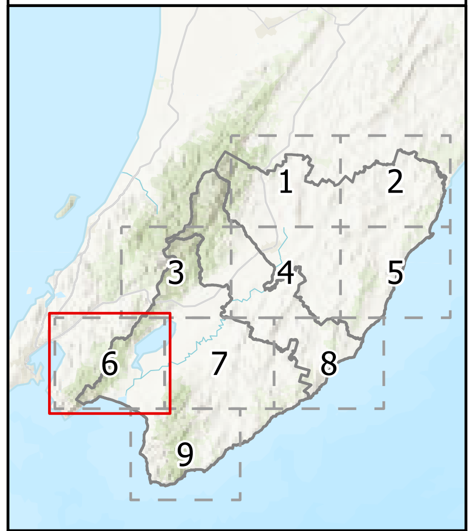
Prepared By:
WSP

Date:	*Project No:*	*Figure:*
April 2022	5-C4397.00	C5 of C9



Earthquake Availability State

- Full
- Poor
- Single Lane
- Difficult
- Closed
- Other roads



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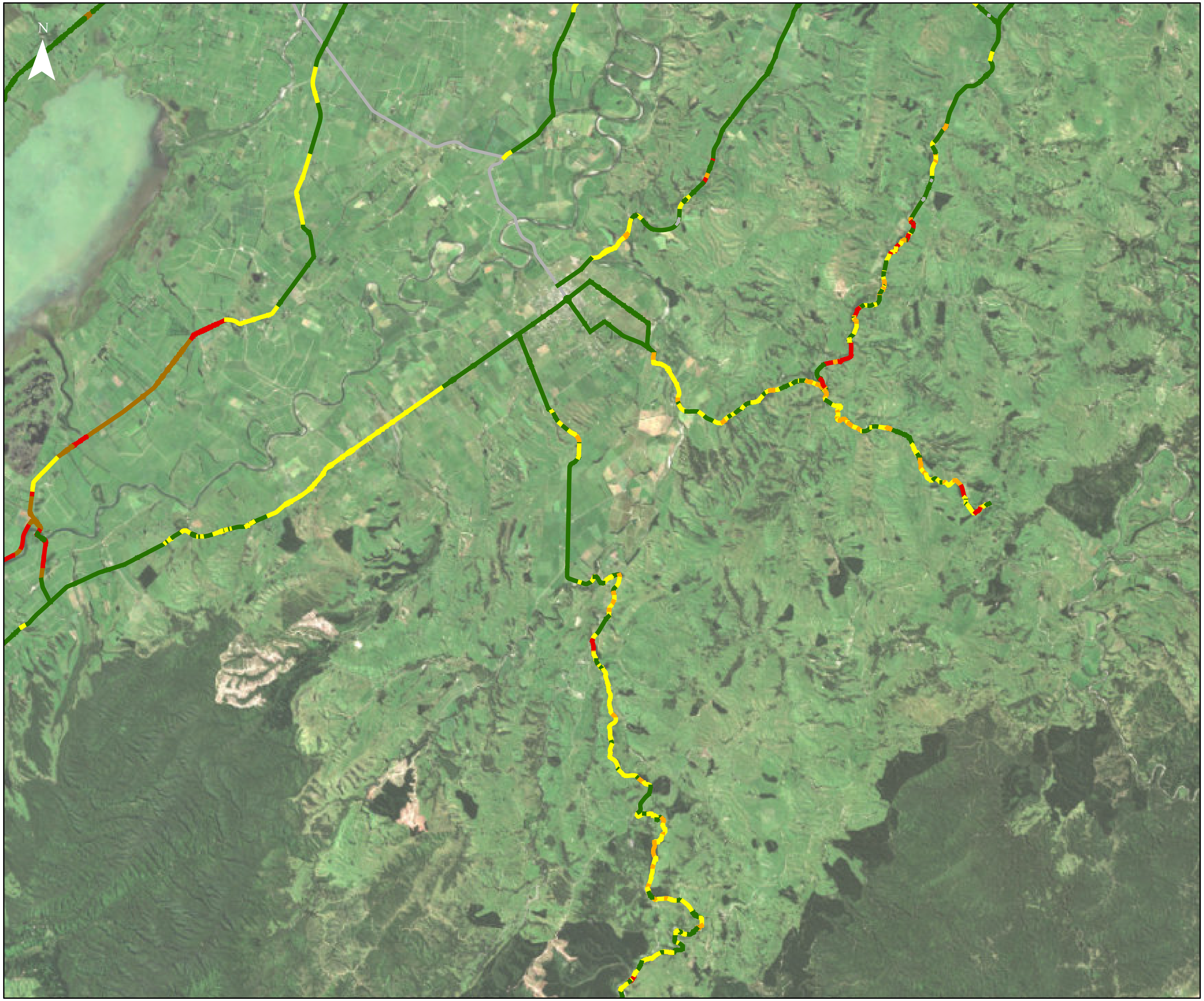
Title:
Wairarapa Resilience Study

Project:
Wairarapa Resilience Study

Prepared For:

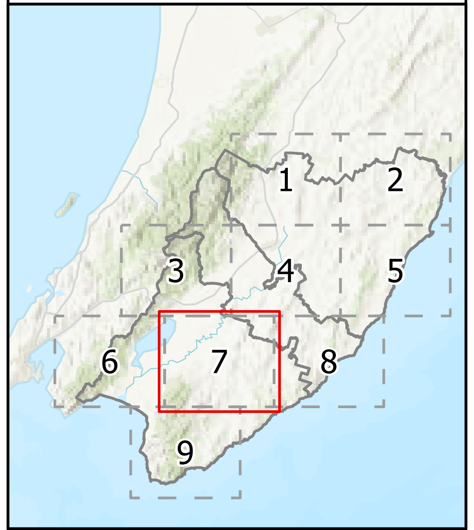
Prepared By:

Date:	*Project No:*	*Figure:*
April 2022	5-C4397.00	C6 of C9



Earthquake Availability State

- Full
- Poor
- Single Lane
- Difficult
- Closed
- Other roads



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Title:
Wairarapa Resilience Study

Project:
Wairarapa Resilience Study

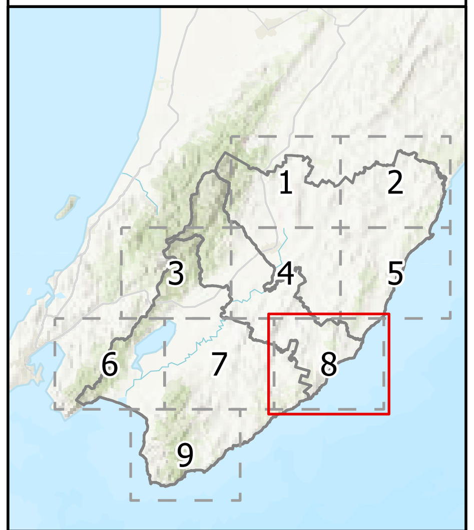
Prepared For:

Prepared By:

Date:	*Project No:*	*Figure:*
April 2022	5-C4397.00	C7 of C9

Earthquake Availability State

- Full
- Poor
- Single Lane
- Difficult
- Closed
- Other roads



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Title:
Wairarapa Resilience Study

Project:
Wairarapa Resilience Study

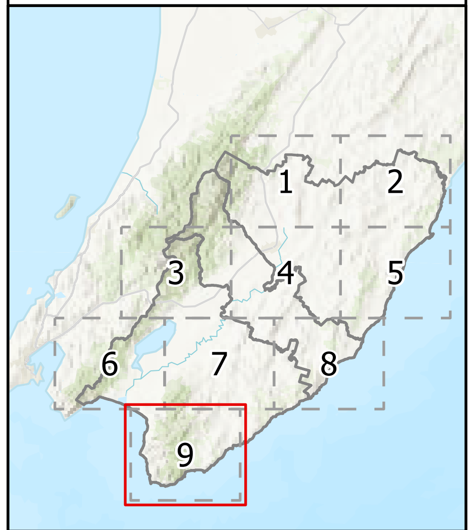
Prepared For:
MASTERTON DISTRICT COUNCIL
CARTERTON DISTRICT COUNCIL
SOUTH WAIRARAPA DISTRICT COUNCIL
Kia Reretahi Tātau

Prepared By:
wsp

Date:	*Project No:*	*Figure:*
April 2022	5-C4397.00	C8 of C9

Earthquake Availability State

- Full
- Poor
- Single Lane
- Difficult
- Closed
- Other roads



Scale:
1:110,000
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Title:
Wairarapa Resilience Study

Project:
Wairarapa Resilience Study

Prepared For:
CARTERTON DISTRICT COUNCIL
MASTERTON DISTRICT COUNCIL
SOUTH WAIRARAPA DISTRICT COUNCIL
Kia Reretahi Tātau

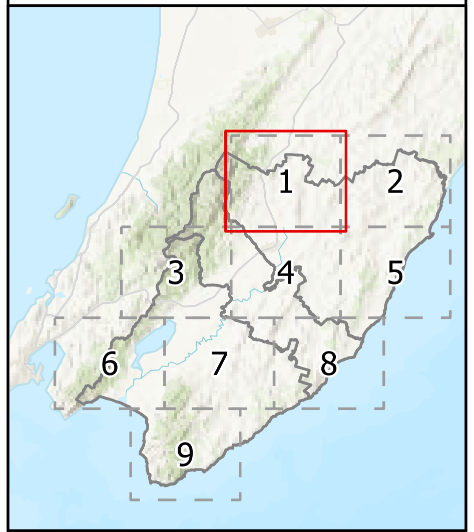
Prepared By:
wsp

Date:	*Project No:*	*Figure:*
April 2022	5-C4397.00	C9 of C9

Appendix D
Earthquake Outage Maps

Earthquake Outage State

- Open (no closure)
- Minor (up to 3 days)
- Moderate (3 days to 2 weeks)
- Severe (2 weeks to 3 months)
- Long term (>3 months)
- Other Roads



Scale:
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Title:
Wairarapa Resilience Study

Project:
Wairarapa Resilience Study

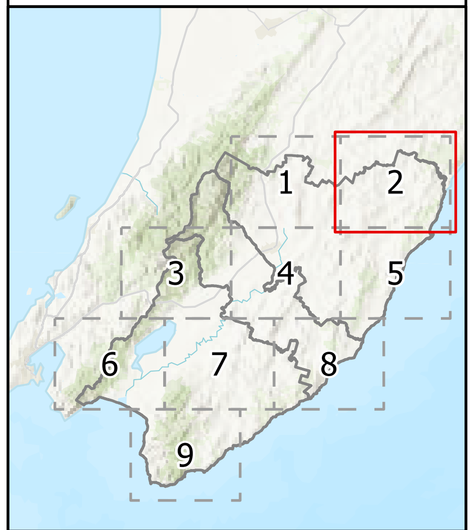
Prepared For:
MASTERTON DISTRICT COUNCIL
CARTERTON DISTRICT COUNCIL
SOUTH WAIRARAPA DISTRICT COUNCIL *Kia Reretahi Tātau*

Prepared By:
WSP

Date:	Project No:	Figure:
April 2022	5-C4397.00	D1 of D9

Earthquake Outage State

- Open (no closure)
- Minor (up to 3 days)
- Moderate (3 days to 2 weeks)
- Severe (2 weeks to 3 months)
- Long term (>3 months)
- Other Roads



Scale:
1:110,000
0 2.5 5 Km

Title:
Wairarapa Resilience Study

Project:
Wairarapa Resilience Study

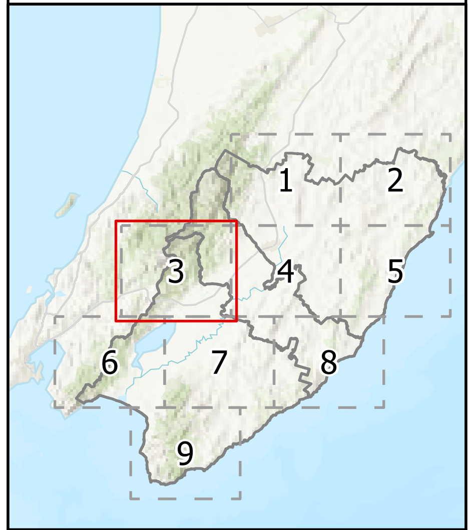
Prepared For:
MASTERTON DISTRICT COUNCIL
CARTERTON DISTRICT COUNCIL
SOUTH WAIRARAPA DISTRICT COUNCIL
Kia Reretahi Tātau

Prepared By:
wsp

Date:	*Project No:*	*Figure:*
April 2022	5-C4397.00	D2 of D9

Earthquake Outage State

- Open (no closure)
- Minor (up to 3 days)
- Moderate (3 days to 2 weeks)
- Severe (2 weeks to 3 months)
- Long term (>3 months)
- Other Roads



Scale:
1:110,000
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Title:
Wairarapa Resilience Study

Project:
Wairarapa Resilience Study

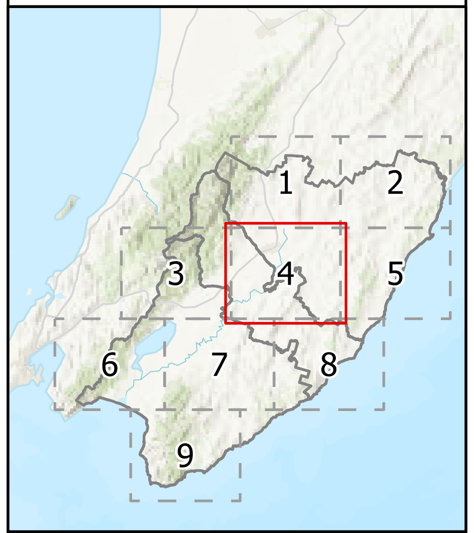
Prepared For:

Prepared By:

Date:	*Project No:*	*Figure:*
April 2022	5-C4397.00	D3 of D9

Earthquake Outage State

- Open (no closure)
- Minor (up to 3 days)
- Moderate (3 days to 2 weeks)
- Severe (2 weeks to 3 months)
- Long term (>3 months)
- Other Roads



Scale:
1:110,000
0 2.5 5 Km

Title:
Wairarapa Resilience Study

Project:
Wairarapa Resilience Study

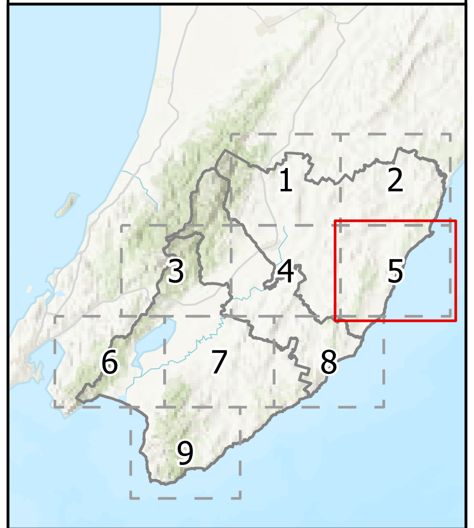
Prepared For:
MASTERTON DISTRICT COUNCIL
CARTERTON DISTRICT COUNCIL
SOUTH WAIRARAPA DISTRICT COUNCIL
Kia Reretahi Tātau

Prepared By:
wsp

Date:	*Project No:*	*Figure:*
April 2022	5-C4397.00	D4 of D9

Earthquake Outage State

- Open (no closure)
- Minor (up to 3 days)
- Moderate (3 days to 2 weeks)
- Severe (2 weeks to 3 months)
- Long term (>3 months)
- Other Roads



Scale:
1:110,000
0 2.5 5 Km

Title:
Wairarapa Resilience Study

Project:
Wairarapa Resilience Study

Prepared For:

MASTERTON DISTRICT COUNCIL

CARTERTON DISTRICT COUNCIL

SOUTH WAIRARAPA DISTRICT COUNCIL
Kia Reretahi Tātau

Prepared By:

wsp

Date:	*Project No:*	*Figure:*
April 2022	5-C4397.00	D5 of D9

Earthquake Outage State

- Open (no closure)
- Minor (up to 3 days)
- Moderate (3 days to 2 weeks)
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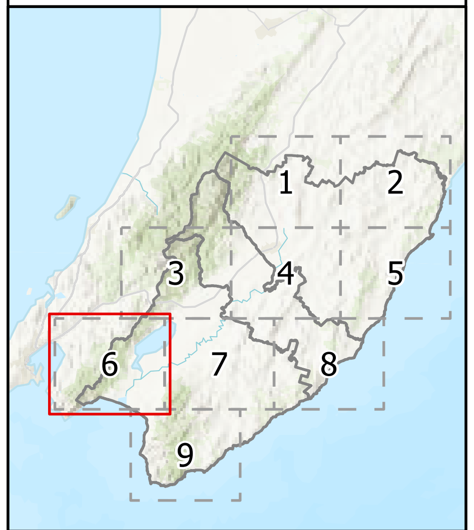


Scale:
1:110,000
0 2.5 5 Km

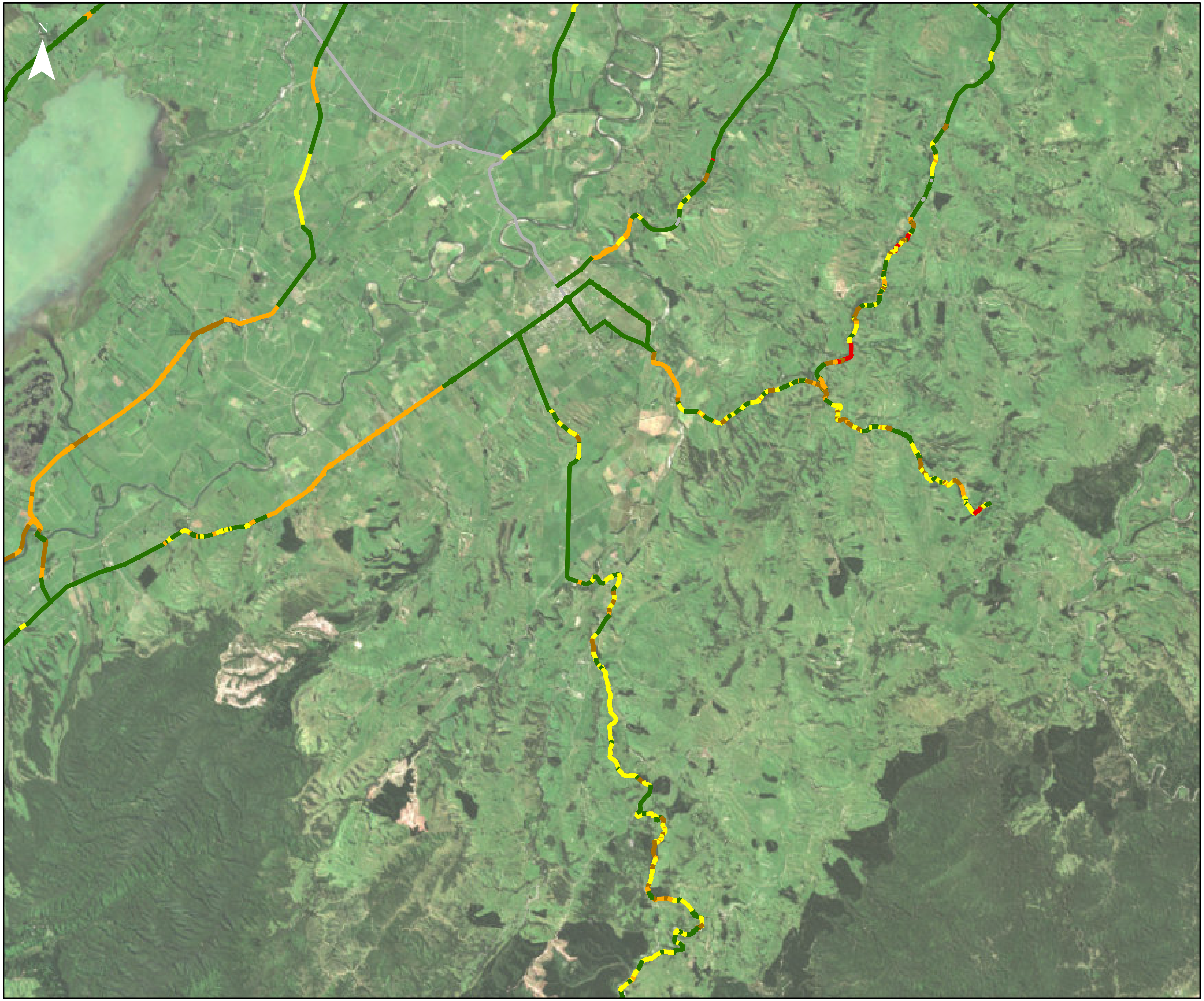
Title:
Wairarapa Resilience Study

Project:
Wairarapa Resilience Study

Prepared For:
MASTERTON DISTRICT COUNCIL
CARTERTON DISTRICT COUNCIL
SOUTH WAIRARAPA DISTRICT COUNCIL
Kia Reretahi Tātau

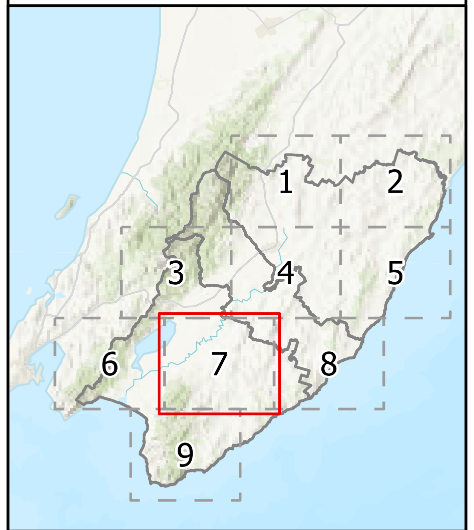
Prepared By:
wsp

Date:	*Project No:*	*Figure:*
April 2022	5-C4397.00	D6 of D9



Earthquake Outage State

- Open (no closure)
- Minor (up to 3 days)
- Moderate (3 days to 2 weeks)
- Severe (2 weeks to 3 months)
- Long term (>3 months)
- Other Roads



Scale:
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0 2.5 5 Km

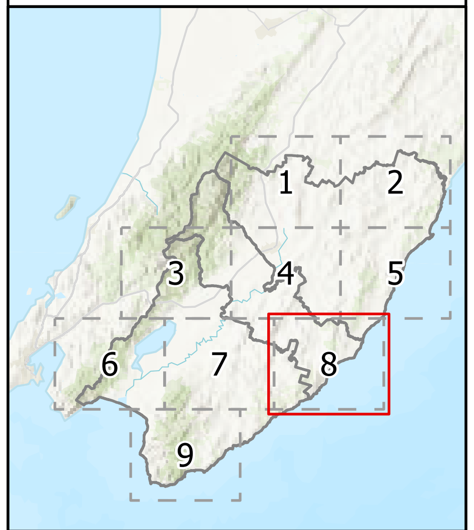
Title:
Wairarapa Resilience Study

Project:
Wairarapa Resilience Study

Prepared For:
MASTERTON DISTRICT COUNCIL
CARTERTON DISTRICT COUNCIL
SOUTH WAIRARAPA DISTRICT COUNCIL Kia Reretahi Tātau

Prepared By: wsp

Date:	Project No:	Figure:
April 2022	5-C4397.00	D7 of D9



Earthquake Outage State

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Scale:
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0 2.5 5 Km

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wsp

Date:	*Project No:*	*Figure:*
April 2022	5-C4397.00	D8 of D9

Earthquake Outage State

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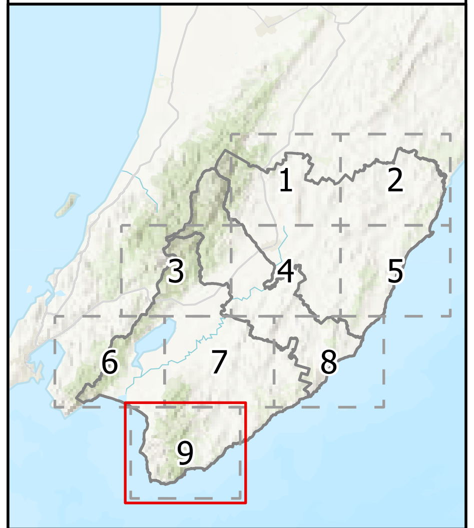

Scale:
1:110,000
0 2.5 5 Km

Title:
Wairarapa Resilience Study

Project:
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Prepared For:
MASTERTON DISTRICT COUNCIL
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SOUTH WAIRARAPA DISTRICT COUNCIL
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wsp

Date:	*Project No:*	*Figure:*
April 2022	5-C4397.00	D9 of D9

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