Canterbury AF8 Risk Profiles

Alpine Fault Magnitude 8 (AF8) Science Summary for Canterbury

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Disclaimer: Section 5 of this report consist of data compiled from various peer-reviewed and non-peer-reviewed studies by the AF8 Science Team for the Canterbury CDEM Group. It is for the sole purpose of providing some context to the Canterbury CDEM Group in their preparations for AF8 planning under the SAFER framework. There has been no attempt to describe the methodologies used in its creation, or the robustness or otherwise of the compiled data. The compilers of this report note that there is likely an appetite to use this data for other purposes, however, many of these models have a number of limitations. Potential use of these data (even with good intentions) for other purposes could lead to incorrect or inappropriate analysis and subsequent decision making. Therefore, the compilers of this report request that the AF8 Science Team is consulted with regards to any potential usage of the science/data presented herein, so as that they can provide assistance and/or guidance.

For any enquiries about this data or subsequent use for any other purpose, please contact Prof Tom Wilson, University of Canterbury (thomas.wilson@canterbury.ac.nz) and James Thompson Canterbury CDEM Group (James.Thompson@cdemcanterbury.govt.nz).

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1. Introduction

This report provides a summary of previous and ongoing scientific research projects related to an Alpine Fault Mw 8.0 (AF8) earthquake event in the Canterbury region. Project AF8 (which stands for “Alpine Fault Magnitude 8) is a three-year programme of scientific modelling, response planning and community engagement designed to address an associated knowledge gap. It is a partnership of all the Civil Defence and Emergency Management (CDEM) Groups in the South Island, funded by the Government through the National Emergency Management Agency’s (NEMA), formerly the Ministry of Civil Defence & Emergency Management’s (MCDEM), Resilience Fund. It involves scientists from six universities and Crown Research Institutes, emergency services, lifelines, iwi, health authorities and many other partner agencies. The project is managed by Emergency Management Southland.

As part of the AF8 programme, the regional CDEM groups are required to produce a regional AF8 response and recovery plan. To aid in this planning, Canterbury Civil Defence and Emergency Management Group have approached the AF8 science team and requested a compilation which summarises and curates relevant and available AF8 research, specifically for the Canterbury region.

Therefore, this report is a compendium of AF8 hazard, impact and risk science studies, with a specific focus on the Canterbury region. It presents a curated summary of relevant research projects, which are typically either international-peer reviewed journal articles or internally peer-reviewed scientific reports. It does not include any new science, except where explicitly stated. Inclusion criteria of studies was determined by relevance and availability.

Many of the studies that inform and make up the AF8 science have been undertaken at a national scale (e.g. Orchiston et al., 2018), so some work has been undertaken within this report to focus outputs for the Canterbury region – specifically on Territorial Authority (TA) basis.

The report is structured as follows:

- Section 1: Introduction;
- Section 2: Summarises a range of recent scientific research specific to, or inclusive of, an Alpine Fault earthquake event impacting the Canterbury region;
- Section 3: A brief overview of potential information gaps;
- Section 4: Summary of ongoing research projects;
- Section 5: Relevant hazard, exposure, impact and risk data and science is mapped and discussed for each of Canterbury’s Territorial Authorities;
- Section 6: Brief summary of the report.

2. Research Summaries

This section provides succinct summaries of each piece of science and/or data relevant to AF8 hazards/exposure/impacts/risk in the Canterbury region and available to the compilers of this report. The studies are broadly ordered in terms of relevance, with the key initial AF8 studies presented first (Sections 2.1 and 2.2) followed by hazard-based studies (Sections 2.4 – 2.10) and impact/loss/risk-based studies (Sections 2.11 – 2.22).

2.1. Design and development of realistic exercise scenarios: a case study of the 2013 Civil Defence Exercise Te Ripahapa - (Robinson et al., 2014)

This study develops a deterministic, credible AF8 hazard and impact scenario for a specific Civil Defence and Emergency Management exercise (Te Ripahapa). It considers hazards, casualties and infrastructure impacts.

2.1.1. Hazards

The scenario is based on a Mw8.0 Alpine Fault rupture with a central hypocentre and considers four aftershocks > Mw5.5 in the 18 hours proceeding (Figure 1). The scenario also considers liquefaction, landsliding, landslide dams (Waimakariri) and debris flows (Aoraki/Mt Cook), (Figure 2).

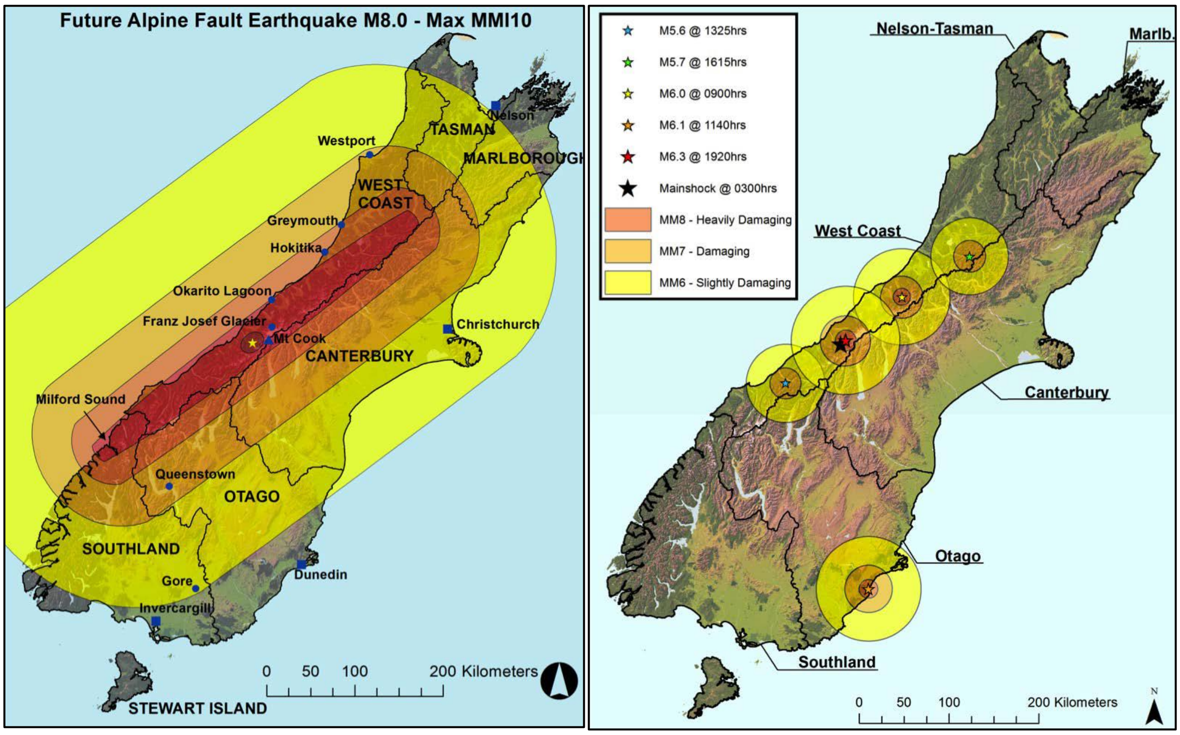

Figure 1: a) Damaging isoseismals for the 29th May 0300hrs M8.0 Alpine fault main event earthquake, b) Aftershock map showing the location of the major (>M5.5) aftershocks during the exercise (Robinson et al., 2014). The shaking model is superseded by (Robinson et al., 2016a).

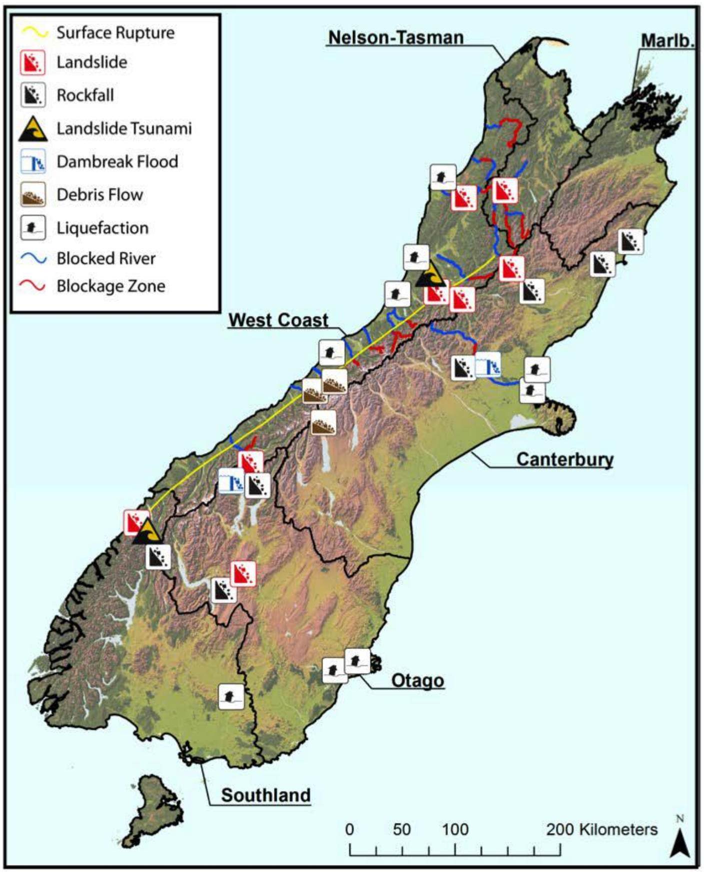

Figure 2: Location of geomorphic hazards resulting from an M8 Alpine Fault earthquake (Robinson et al., 2014).

2.1.2. Casualties

This study estimates that total fatalities resulting from building collapse due to high-intensity shaking are 34 for Canterbury. Total injuries in Canterbury during this scenario are 376. Table 1 details the total numbers of injuries and fatalities by each district; Figure 3 a & b respectively show the distribution of these across the South Island.

Table 1: Fatalities and injuries by district (Robinson et al., 2014).

District	Fatalities	Injuries
Kaikōura District	0	0
Hurunui District	7	180
Waimakariri District	5	136
Christchurch City	0	0
Selwyn District	7	167
Ashburton District	5	119
Timaru District	0	9
Mackenzie District	8	210
Waimate District	0	0
Total	32	821

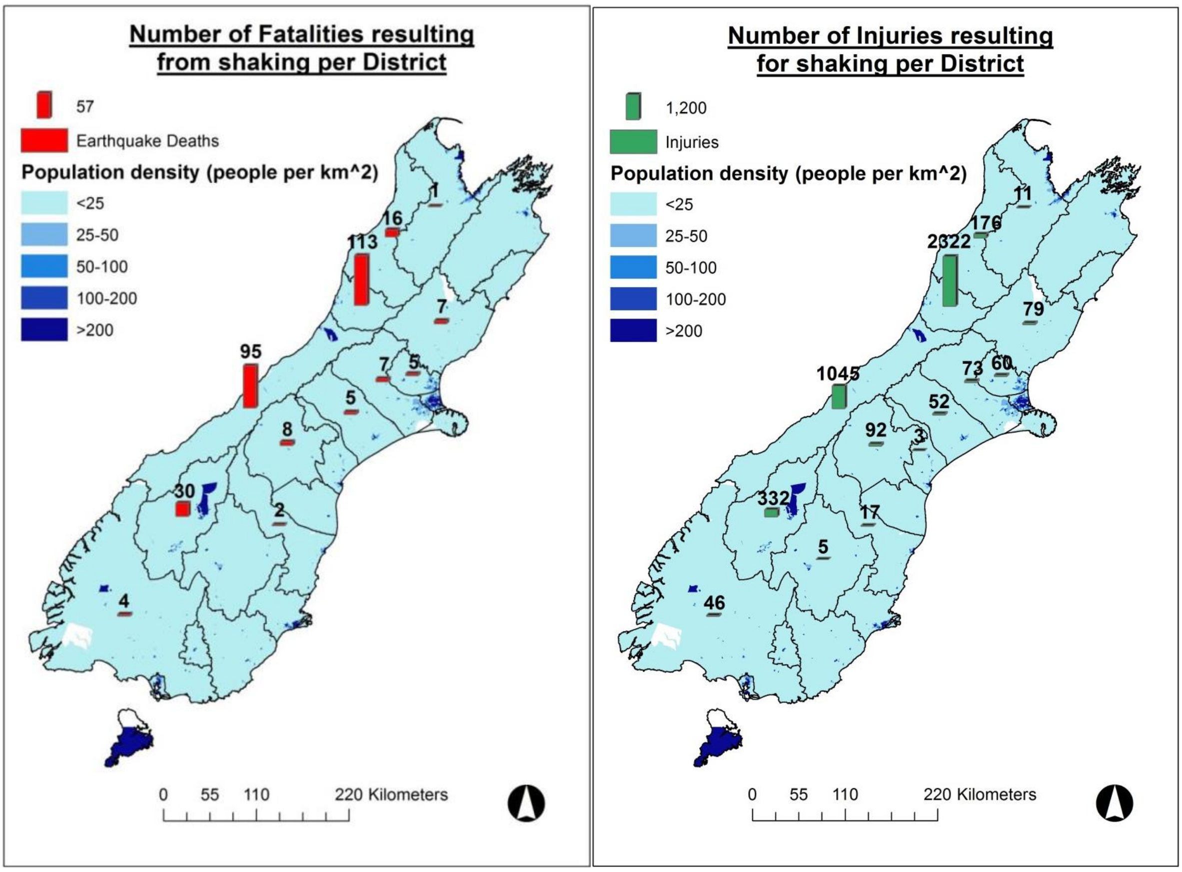

Figure 3: a) The total number of fatalities per district generated by building collapse due to high intensity shaking and landslide/rockfall induced tsunami, b) the total number of injuries per district generated by building damage due to high-intensity shaking and landslide/rockfall induced tsunami (Robinson et al., 2014).

2.1.3. Impacts

This deterministic study considers impacts to the transport, power, and telecommunications networks as well as analysing the anticipated extent of damage to buildings. The State Highway network is extensively damaged, in particular the Alpine passes, (Lewis and Arthur's) restricting access from Canterbury to the West Coast. Mt Cook Village is also without road access and only limited access is available to the surrounding areas (*Figure 4)*.

The rail network is similarly affected with no access through Arthur's Pass (*Figure 5*). Further landslides and rockfalls in the Waimakariri Gorge and throughout Arthur's Pass have damaged and blocked the line. There is no access along the Midland Line between Springfield in Selwyn District. Access between Christchurch and Springfield is still possible as the line and bridges here survive relatively intact (*Figure 5*). The Main North Line (Picton to Christchurch via Blenheim and Kaikōura): Most of this line is unaffected, but the same rockfalls that partially block SH1 north and south of Kaikōura render the Main North Railway line completely impassable. Rockfalls have significantly damaged the line and block isolated sections and tunnels along the route. There is no access along the Main North Line between Goose Bay in Kaikōura District and Mirza in Marlborough District. The rest of the line remains passable and open. Christchurch International Airport is undamaged following the main earthquake. Most of the airfields within the Southern Alps are severely damaged in the initial earthquake (*Figure 5*).

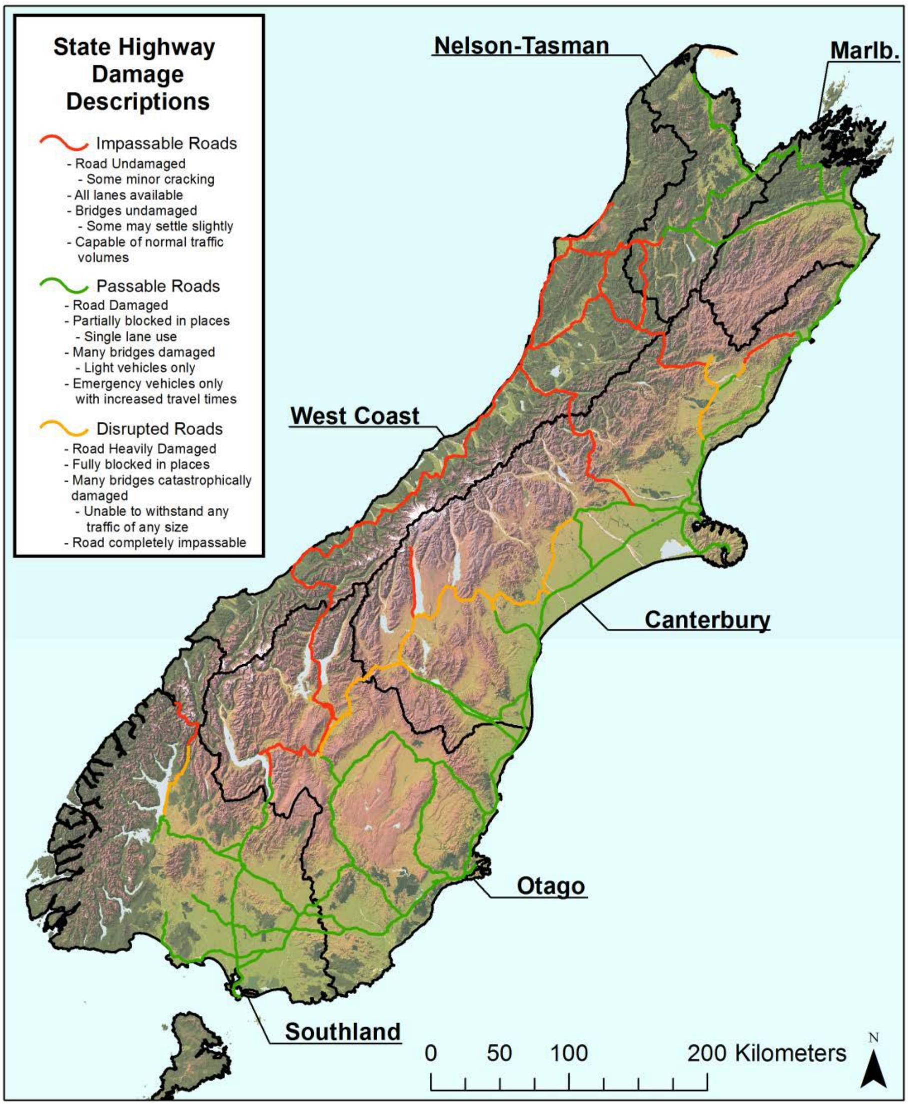

Figure 4: Condition of State Highway network following an M8 Alpine Fault earthquake.

During this event power generators are expected to shut down, specifically: Kumara, Coleridge, Tekapo A, Tekapo B, Ohau A, Ohau B, Ohau C and Benmore. Power is immediately lost to the entire southland region for at least 5 hours. Arthur's Pass remains without power for several days, possibly weeks. The rest of Canterbury can be restored in stages throughout the first day *(Table 2)*. This event is expected to leave the West Coast without power for an extended period *(Figure 6).*

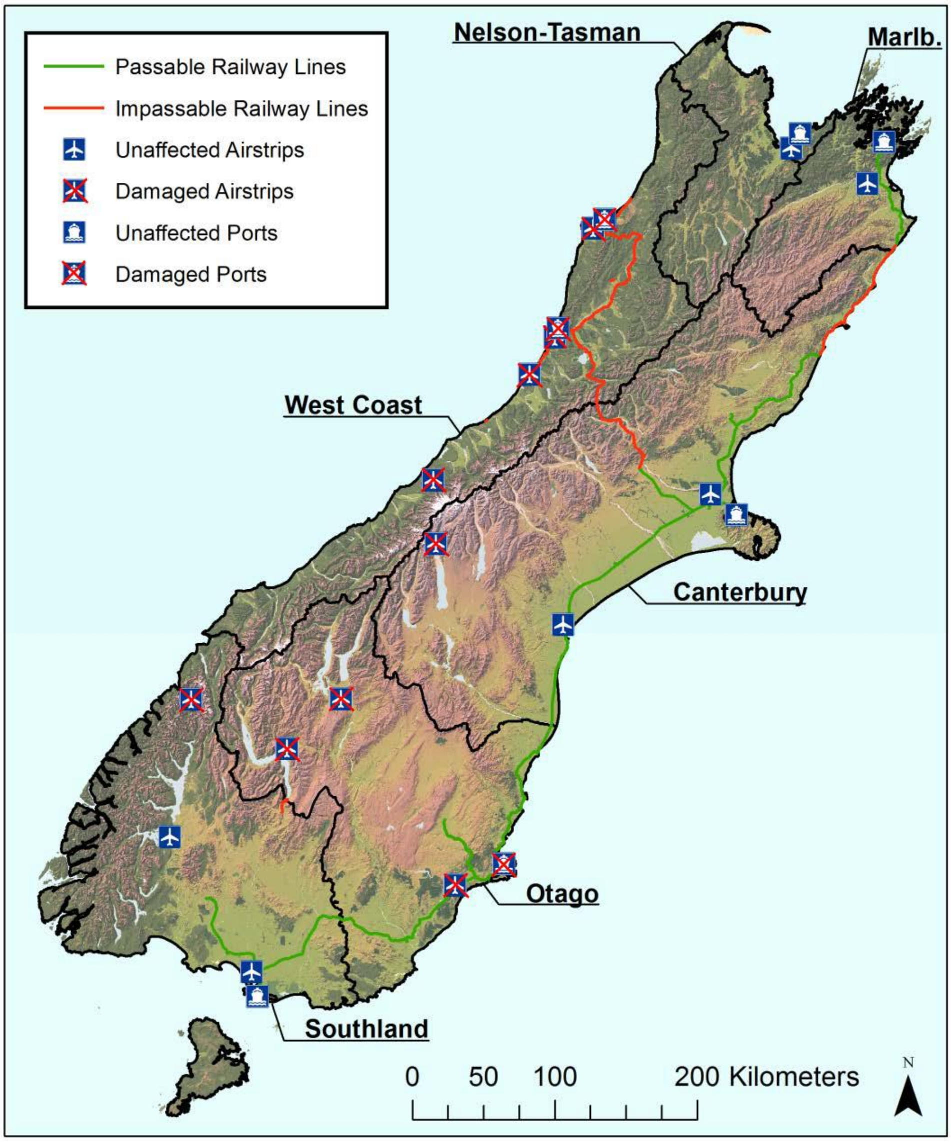

Figure 5: Condition of the railway network, critical ports, and airports/airfields following an M8 Alpine Fault Earthquake.

The telecommunications network is heavily damaged. In the foothills of the Southern Alps, internet and landline connections survive but are unreliable and cut out randomly. All of Canterbury is affected by losses in mobile telephone reception. Generally, this lasts for short periods, reoccurring due to aftershocks and the reinstatement of power. There is no internet or telephone connection for any of the communities within Arthur's Pass and internet and telephone connection is lost between Glentanner and Mt Cook Village. South of Glentanner, internet and landline connections may remain intact but they are likely to be disrupted and are unreliable. Backup power generators at telecommunication assets across the South Island can provide temporary service, where the longevity of these systems is estimated in *Figure 7*.

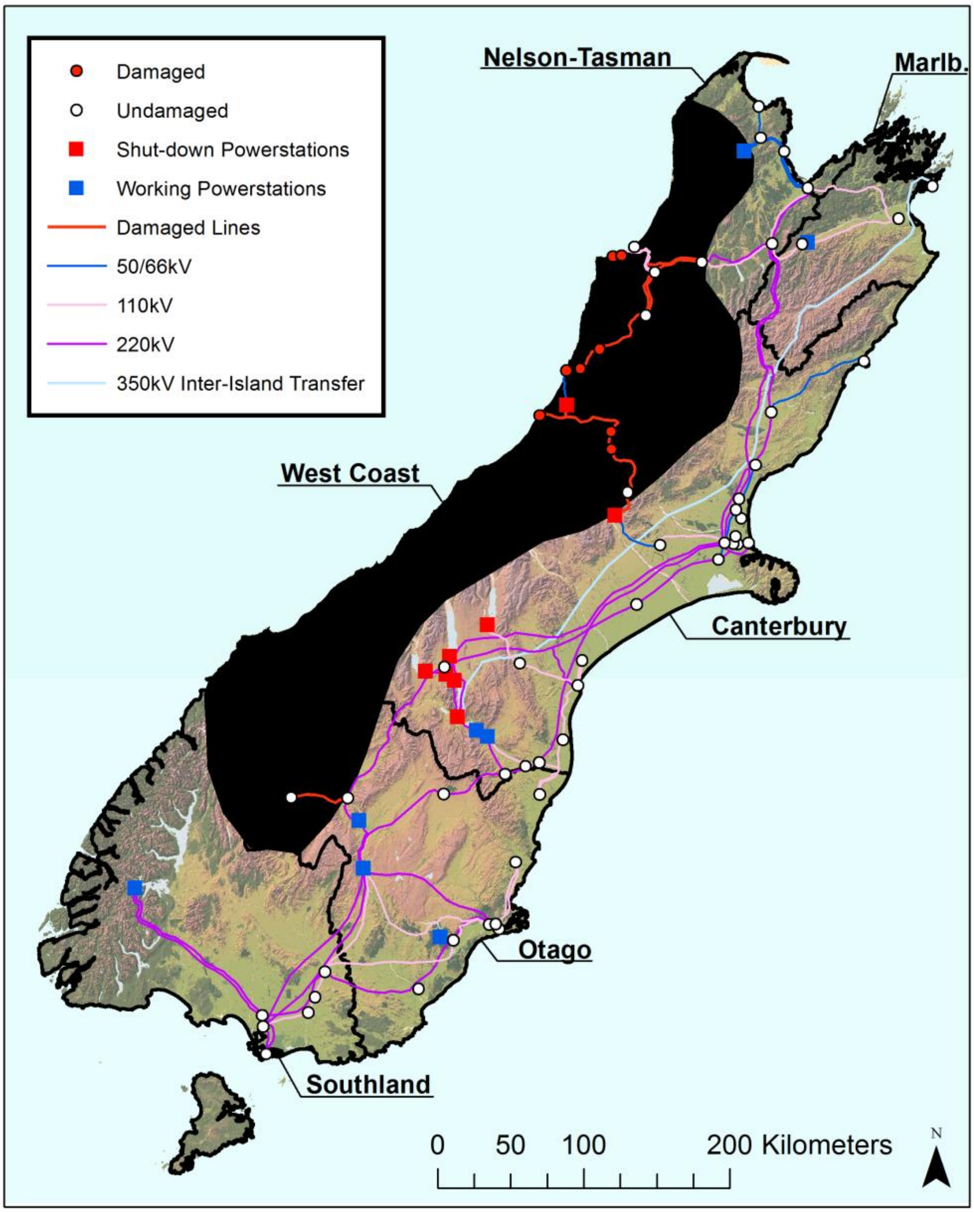

Figure 6: Shutdown and working power stations, damaged substations, damaged transmission lines and long-term power outage region (black).

Table 2: Timings for power returning to key locations in Canterbury.

Location	Est. Power Outage
Twizel	6.5 hrs
Timaru	6.75 hrs
Christchurch	7.5 hrs
Kaikōura	8.25 hrs

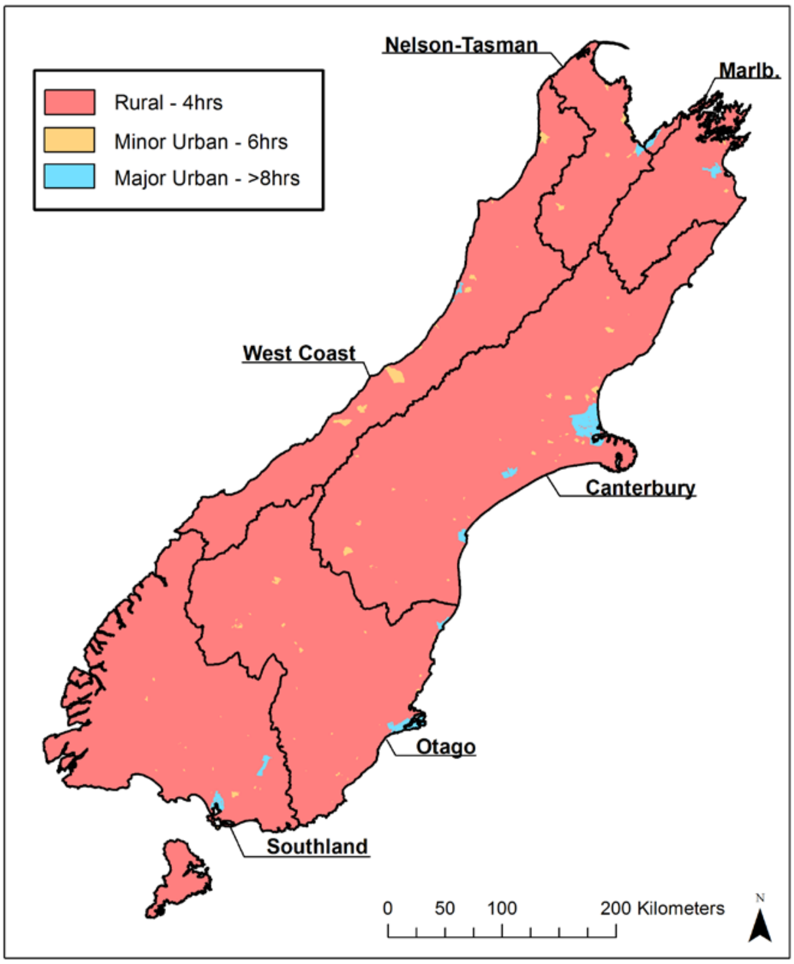

Figure 7: Estimated longevity of backup generators for mobile telephone reception in the event of Island-wide power loss.

2.2. Multiple infrastructure failures and restoration estimates from an Alpine Fault earthquake: Capturing modelling information for MERIT - (Robinson et al., 2016a)

This study builds on Robinson et al. (2014) by enhancing hazard models and refining impact scenario through expert elicitation. The deterministic impact assessment is used to conduct a time-stamped restoration model for infrastructure networks, which was designed to input a wider economic model. The hazard model used for this study builds on Robinson et al., (2014) with a key addition being long-range aftershock estimates (*Table 3*). Functionality states are used for infrastructure impacts as summarised in (*Table 4*).

Table 3: STEP model aftershock rate from generic parameters in different magnitude and time intervals.

Magnitude	0–90 days	0–365 days	365–730 days
M5+	380	428	23
M6+	35	40	2
M7+	3	4	0.2

Table 4: Functionality state descriptions for each of the critical infrastructure networks designed by the corresponding network providers. [a]The values for each functionality do not represent network capacities (i.e. 0.5 does not equal 50% capacity), these are illustrative only. [b] Only bridges experiencing MMI7 or higher were considered vulnerable to damage requiring restoration. [c] New Zealand Transport Agency (NZTA) suggested there was little benefit in restoring these bridges to double lane sections without restrictions, and noted that many of these bridges are already (i.e. pre-earthquake) single lane with speed and weight restrictions corresponding to the 0.6 functionality state herein (Robinson et al., 2016a).

Network/Infrastructure	Functionality State[a]
State Highways (NZTA)	
Bridges[b, c]	0 – No Access
	0.2 – No public access Emergency/Construction/Military vehicles only, single lane, one vehicle at a time, 10 km/hr speed restriction, 3.5 tonnes maximum weight restriction
	0.4 – Single lane access for all light (<3.5 tonnes) vehicles, 10 km/hr speed restriction
	0.6 – Single lane access for all mid-weight (<6 tonnes) vehicles, 10 km/hr speed restriction
Roads	0 – No Access
	0.25 – No public access, Emergency/Construction/Military vehicles only
	0.5 – Single lane access for all light (<3.5 tonnes) vehicles, 30 km/hr speed restrictions
	0.75 – Double lane access for all mid-weight (<6 tonnes) vehicles, 60 km/hr speed restrictions
	1 – Full access, no restrictions (100 km/hr)
Railways (KiwiRail)	
Rails/Bridges	0 – No Access
	1 – Full Access
HEP Transmission (Transpower)	
Steel towers/Wooden Poles	0 – No Transmission
	1 – Full Transmission
Wastewater	
Piped systems	0 – No service
	1 – Full service
Water	
Piped systems	0 – No service
	1 – Full service
Storm Water	
Piped systems	0 – No service
	1 – Full service

The following sections summarise the impact modelling results. Time-stamped functionality level results are presented for a range of time slices (T=x) in the number of days since the initial earthquake. A detailed explanation of the simulated restoration strategy can be found in the aforementioned report (Robinson et al., 2016a).

For roads, the initial modelled functionality state is used to define an impedance value with respect to increased travel times (*Table 5*).

Table 5: Impedance values added to functionality states between F=0 and F=1 for various infrastructure networks. These values are added to the initial (i.e. pre-earthquake) network connectivity when traversed (Robinson et al., 2016a).

Infrastructure	Functionality State	Impedance Value
State Highway Bridges and Surface Rupture points	0.2	4 minutes
	0.4	3 minutes
	0.6	2 minutes
State Highway landslide sections	0.25	x4
	0.5	x3
	0.75	x2

2.2.1. Timestamped road loss of service (LOS)

2.2.1.1. T=0 days

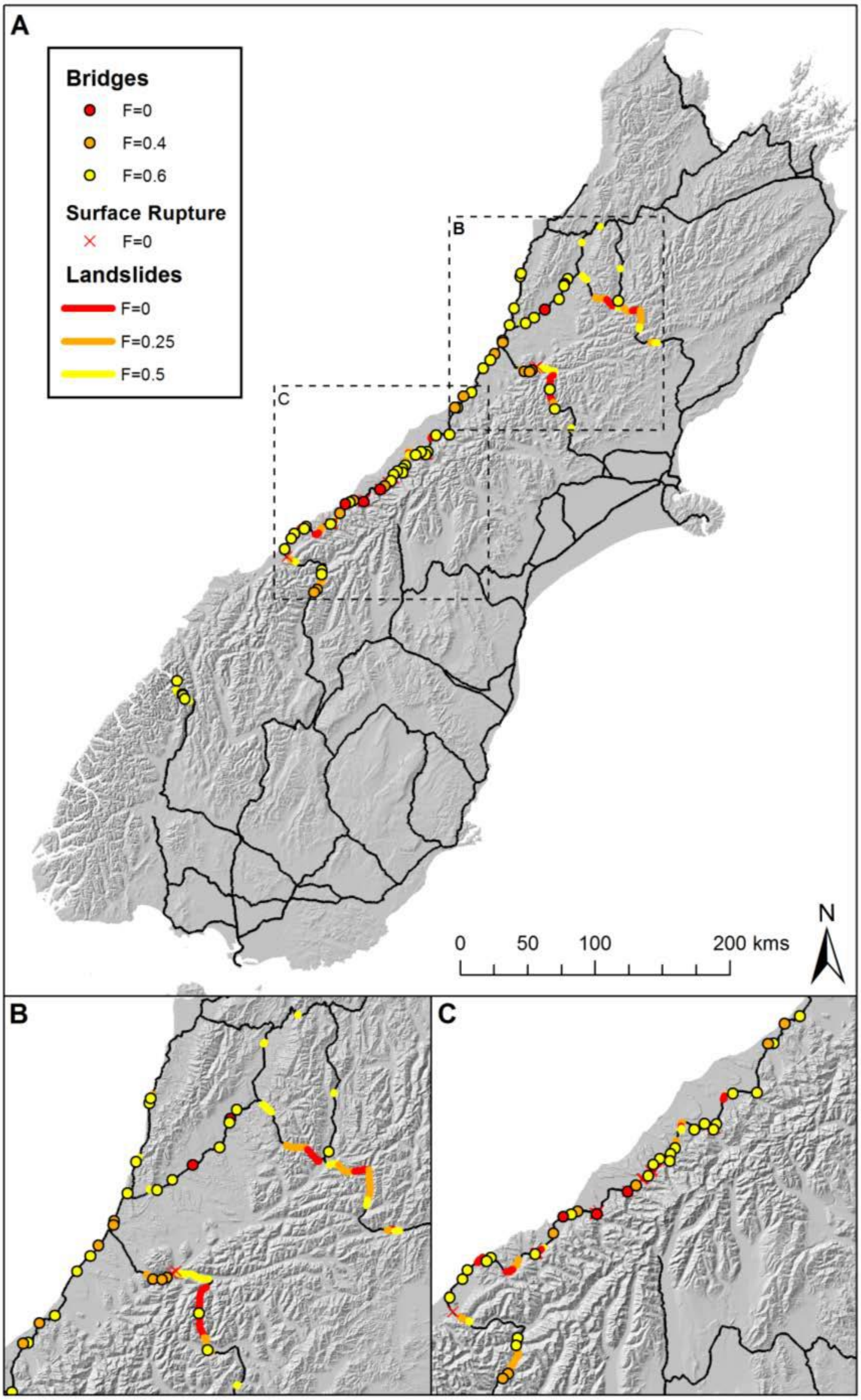

Figure 8: Landslide, surface rupture, and bridge losses on the State Highway network immediately after an Alpine Fault earthquake (T=0). Only bridges experiencing MMI7+ shaking have been evaluated (Robinson et al., 2016a).

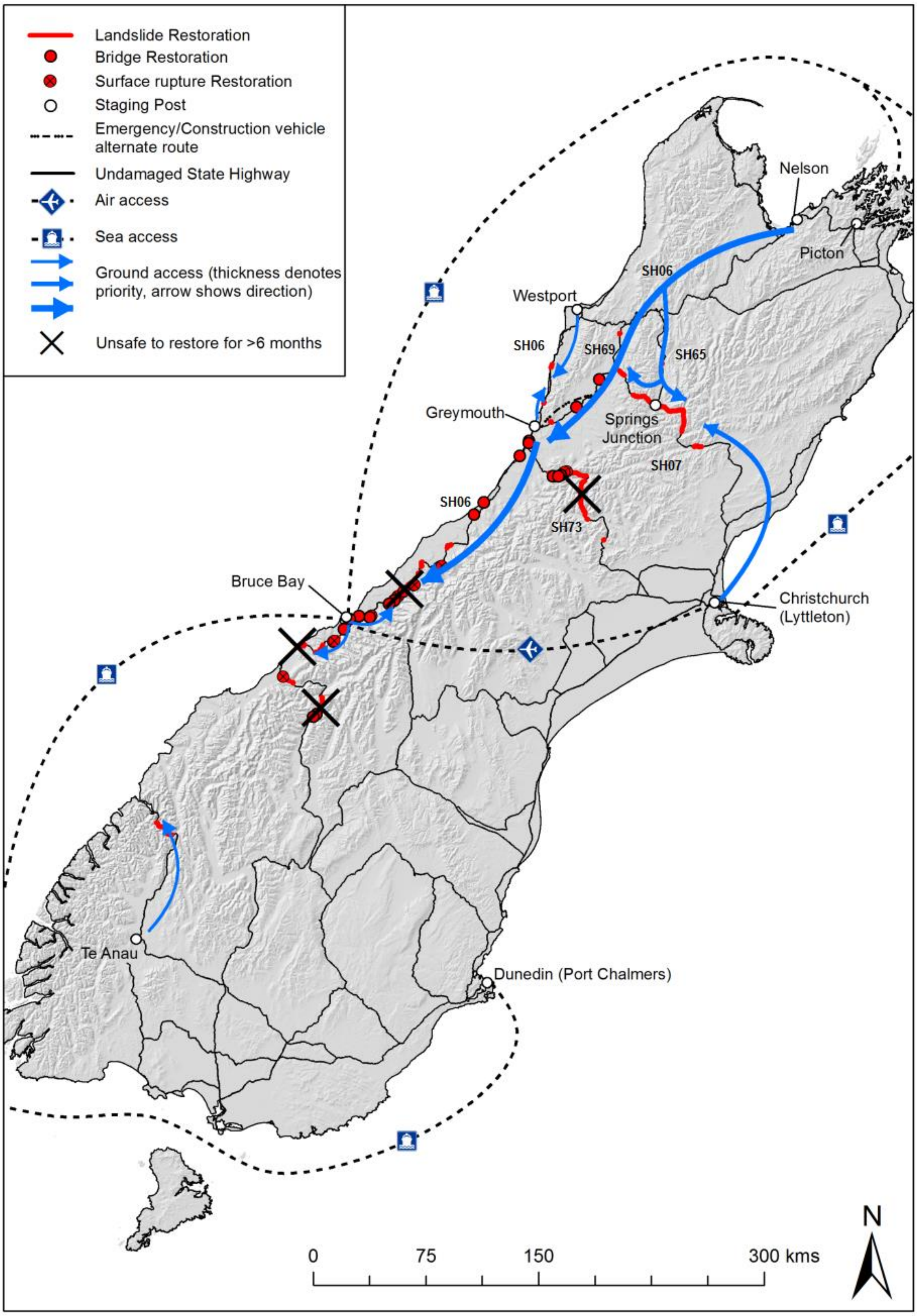

Figure 9: Restoration strategy for the State Highway network following an Alpine Fault earthquake.

Table 6: Change in travel time, in minutes, between key South Island nodes, including Canterbury, at T=0 compared to pre-earthquake for various vehicle types. Black boxes show inaccessible routes (Robinson et al., 2016a).

Emergency/Construction/Military Vehicles													
	Dunedin	Franz Josef	Greymouth	Haast	Hokitika	Invercargill	Milford Sound	Aoraki/Mt Cook	Nelson	Picton	Queenstown	Reefton	Westport
Christchurch	0		292		340	0		0	67	0	0	150	140
Dunedin			292		340	0		0	67	0	0	150	140
Franz Josef													
Greymouth					16	438		292	30	30	439	78	16
Haast													
Hokitika						520		358	46	46	521	94	32
Invercargill								0	128	0	0	296	286
Milford Sound													
Aoraki/Mt Cook									67	0	0	150	140
Nelson										0	129	0	0
Picton											0	0	0
Queenstown												297	287
Reefton													0

Table 7: Change in travel time, in minutes, between key South Island nodes, including Canterbury, at T=0 compared to pre-earthquake for vehicles under 3.5 tonnes. Black boxes show inaccessible routes (Robinson et al., 2016a).

Vehicles up to 3.5 tonnes													
	Dunedin	Franz Josef	Greymouth	Haast	Hokitika	Invercargill	Milford Sound	Aoraki/Mt Cook	Nelson	Picton	Queenstown	Reefton	Westport
Christchurch	0					0		0	67	0	0	150	140
Dunedin						0		0	67	0	0	150	140
Franz Josef													
Greymouth					11								
Haast													
Hokitika													
Invercargill								0	128	0	0	296	286
Milford Sound													
Aoraki/Mt Cook									67	0	0	150	140
Nelson										0	129	0	0
Picton											0	0	0
Queenstown												297	287
Reefton													0

Table 8: Change in travel time, in minutes, between key South Island nodes, including Canterbury, at T=0 compared to pre-earthquake for vehicles 3.5 – 6 tonnes. Black boxes show inaccessible routes (Robinson et al., 2016a).

Vehicles between 3.5 and 6 tonnes	Dunedin	Franz Josef	Greymouth	Haast	Hokitika	Invercargill	Milford Sound	Aoraki/Mt Cook	Nelson	Picton	Queenstown	Reefton	Westport
Christchurch	0					0		0	67	0	0		
Dunedin						0		0	67	0	0		
Franz Josef													
Greymouth													
Haast													
Hokitika													
Invercargill								0	128	0	0		
Milford Sound													
Aoraki/Mt Cook									67	0	0		
Nelson										0	129		
Picton											0		
Queenstown													
Reefton													

2.2.1.2. T=3 days

Three days after the disaster, most progress has been made on clearing minor landslide/rockfall disruptions and the accessible sections of highway experiencing surface rupture. Fords are put in place at damaged bridges, providing F=0.6 access (Table 5).

Table 9: Change in travel time, in minutes, between key South Island nodes, including Canterbury, at T=3 compared to pre-earthquake for various vehicle types. Black boxes show inaccessible routes, while yellow boxes show decreased travel times compared to T=0 (Robinson et al., 2016a).

Emergency/Construction/Military Vehicles	Dunedin	Franz Josef	Greymouth	Haast	Hokitika	Invercargill	Milford Sound	Aoraki/Mt Cook	Nelson	Picton	Queenstown	Reefton	Westport
Christchurch	0	386	286		334	0		0	67	0	0	150	140
Dunedin		515	286		334	0		0	67	0	0	150	140
Franz Josef			68		52	750		588	92	92	751	92	84
Greymouth					16	432		286	24	24	433	24	16
Haast													
Hokitika						514		352	40	40	515	40	32
Invercargill								0	128	0	0	296	286
Milford Sound													
Aoraki/Mt Cook									67	0	0	150	140
Nelson										0	129	0	0
Picton											0	0	0
Queenstown												297	287
Reefton													0

Table 10: Change in travel time, in minutes, between key South Island nodes, including Canterbury, at T=3 compared to pre-earthquake vehicles under 3.5 tonnes. Black boxes show inaccessible routes, yellow boxes show decreased travel times compared to T=0 (Robinson et al., 2016a).

Vehicles up to 3.5 tonnes													
	Dunedin	Franz Josef	Greymouth	Haast	Hokitika	Invercargill	Milford Sound	Aoraki/Mt Cook	Nelson	Picton	Queenstown	Reefton	Westport
Christchurch	0		284		327	0		0	67	0	0	150	140
Dunedin			284		327	0		0	67	0	0	150	140
Franz Josef													
Greymouth					11	430		284	22	22	431	70	8
Haast													
Hokitika						507		345	33	33	508	81	19
Invercargill								0	128	0	0	296	286
Milford Sound													
Aoraki/Mt Cook									67	0	0	150	140
Nelson										0	129	0	0
Picton											0	0	0
Queenstown												297	287
Reefton													0

Table 11: Change in travel time, in minutes, between key South Island nodes, including Canterbury, at T=3 compared to pre-earthquake vehicles 3.5 – 6 tonnes. Black boxes show inaccessible routes, yellow boxes show decreased travel times compared to T=0 (Robinson et al., 2016a).

Vehicles between 3.5 and 6 tonnes													
	Dunedin	Franz Josef	Greymouth	Haast	Hokitika	Invercargill	Milford Sound	Aoraki/Mt Cook	Nelson	Picton	Queenstown	Reefton	Westport
Christchurch	0					0		0	67	0	0	150	140
Dunedin						0		0	67	0	0	150	140
Franz Josef													
Greymouth													
Haast													
Hokitika													
Invercargill								0	128	0	0	296	286
Milford Sound													
Aoraki/Mt Cook									67	0	0	150	140
Nelson										0	129	0	0
Picton											0	0	0
Queenstown												297	287
Reefton													0

2.2.1.3. T=14 days

Table 12: Change in travel time, in minutes, between key South Island nodes, including Canterbury, at T=14 compared to pre-earthquake various vehicle types. Black boxes show inaccessible routes, yellow boxes show decreased travel times compared to T=0 (Robinson et al., 2016a).

Emergency/Construction/Military Vehicles													
	Dunedin	Franz Josef	Greymouth	Haast	Hokitika	Invercargill	Milford Sound	Aoraki/Mt Cook	Nelson	Picton	Queenstown	Reefton	Westport
Christchurch	0	348	277		320	0	8	0	67	0	0	150	140
Dunedin		477	277		320	0	8	0	67	0	0	150	140
Franz Josef			39		28	712	721	550	54	54	713	54	47
Greymouth					11	423	432	277	15	15	424	15	8
Haast													
Hokitika						500	509	338	26	26	501	26	19
Invercargill							8	0	128	0	0	296	286
Milford Sound								8	137	8	8	305	295
Aoraki/Mt Cook									67	0	0	150	140
Nelson										0	129	0	0
Picton											0	0	0
Queenstown												297	287
Reefton													0

Table 13: Change in travel time, in minutes, between key South Island nodes, including Canterbury, at T=14 compared to pre-earthquake vehicles under 3.5 tonnes. Black boxes show inaccessible routes, yellow boxes show decreased travel times compared to T=0 (Robinson et al., 2016a).

Vehicles up to 3.5 tonnes													
	Dunedin	Franz Josef	Greymouth	Haast	Hokitika	Invercargill	Milford Sound	Aoraki/Mt Cook	Nelson	Picton	Queenstown	Reefton	Westport
Christchurch	0	348	277		320	0		0	67	0	0	150	140
Dunedin		477	277		320	0		0	67	0	0	150	140
Franz Josef			39		28	712		550	54	54	713	54	47
Greymouth					11	423		277	15	15	424	15	8
Haast													
Hokitika						500		338	26	26	501	26	19
Invercargill								0	128	0	0	296	286
Milford Sound													
Aoraki/Mt Cook									67	0	0	150	140
Nelson										0	129	0	0
Picton											0	0	0
Queenstown												297	287
Reefton													0

Table 14: Change in travel time, in minutes, between key South Island nodes, including Canterbury, at T=14 compared to pre-earthquake vehicles 3.5 – 6 tonnes. Black boxes show inaccessible routes, yellow boxes show decreased travel times compared to T=0 (Robinson et al., 2016a).

Vehicles between 3.5 and 6 tonnes	Dunedin	Franz Josef	Greymouth	Haast	Hokitika	Invercargill	Milford Sound	Aoraki/Mt Cook	Nelson	Picton	Queenstown	Reefton	Westport
Christchurch	0		284			0		0	67	0	0	150	140
Dunedin			284			0		0	67	0	0	150	140
Franz Josef													
Greymouth						430		284	22	22	431	70	8
Haast													
Hokitika													
Invercargill								0	128	0	0	296	286
Milford Sound													
Aoraki/Mt Cook									67	0	0	150	140
Nelson										0	129	0	0
Picton											0	0	0
Queenstown												297	287
Reefton													0

2.2.1.4. T= 30 days

Table 15: Change in travel time, in minutes, between key South Island nodes, including Canterbury, at T=30 compared to pre-earthquake for various vehicle types. Black boxes show inaccessible routes, yellow boxes show decreased travel times compared to T=0 (Robinson et al., 2016a).

Emergency/Construction/Military Vehicles	Dunedin	Franz Josef	Greymouth	Haast	Hokitika	Invercargill	Milford Sound	Aoraki/Mt Cook	Nelson	Picton	Queenstown	Reefton	Westport
Christchurch	0	217	150		191	0	8	0	2	0	0	23	13
Dunedin		346	150		191	0	8	0	2	0	0	23	13
Franz Josef			35		26	581	590	419	50	50	582	50	43
Greymouth					9	296	305	150	15	15	297	15	8
Haast													
Hokitika						371	380	209	24	24	372	24	17
Invercargill							8	0	63	0	0	169	159
Milford Sound								8	72	8	8	178	168
Aoraki/Mt Cook									2	0	0	23	13
Nelson										0	64	0	0
Picton											0	0	0
Queenstown												170	160
Reefton													0

Table 16: Change in travel time, in minutes, between key South Island nodes, including Canterbury, at T= 30 compared to pre-earthquake vehicles under 3.5 tonnes. Black boxes show inaccessible routes, yellow boxes show decreased travel times compared to T=0 (Robinson et al., 2016a).

Vehicles up to 3.5 tonnes	Dunedin	Franz Josef	Greymouth	Haast	Hokitika	Invercargill	Milford Sound	Aoraki/Mt Cook	Nelson	Picton	Queenstown	Reefton	Westport
Christchurch	0	217	150		191	0	8	0	2	0	0	23	13
Dunedin		346	150		191	0	8	0	2	0	0	23	13
Franz Josef			35		26	581	590	419	50	50	582	50	43
Greymouth					9	296	305	150	15	15	297	15	8
Haast													
Hokitika						371	380	209	24	24	372	24	17
Invercargill							8	0	63	0	0	169	159
Milford Sound								8	72	8	8	178	168
Aoraki/Mt Cook									2	0	0	23	13
Nelson										0	64	0	0
Picton											0	0	0
Queenstown												170	160
Reefton													0

Table 17: Change in travel time, in minutes, between key South Island nodes, including Canterbury, at T= 30 compared to pre-earthquake vehicles 3.5 – 6 tonnes. Black boxes show inaccessible routes, yellow boxes show decreased travel times compared to T=0 (Robinson et al., 2016a).

Vehicles between 3.5 and 6 tonnes	Dunedin	Franz Josef	Greymouth	Haast	Hokitika	Invercargill	Milford Sound	Aoraki/Mt Cook	Nelson	Picton	Queenstown	Reefton	Westport
Christchurch	0		284			0		0	67	0	0	150	140
Dunedin			284			0		0	67	0	0	150	140
Franz Josef					26								
Greymouth						430		284	22	22	431	70	8
Haast													
Hokitika													
Invercargill								0	128	0	0	296	286
Milford Sound													
Aoraki/Mt Cook									67	0	0	150	140
Nelson										0	129	0	0
Picton											0	0	0
Queenstown												297	287
Reefton													0

2.2.1.5. T= 90 days

By 90 days after the earthquake, all restoration other than the sections too dangerous to access has been completed. It will be at least another 90 days before these sections will be considered safe enough for restoration to be considered (i.e. T=180 days). Landslide restorations in Lewis Pass (SH7) and on SH94 are completed, returning all sections to pre-earthquake functionality.

Table 18: Change in travel time, in minutes, between key South Island nodes, including Canterbury, at T= 90 compared to pre-earthquake various vehicle types, including public vehicles. Black boxes show inaccessible routes, yellow boxes show decreased travel times compared to T=0 (Robinson et al., 2016a).

Emergency/Construction/Military and Public Vehicles <3.5 tonnes													
	Dunedin	Franz Josef	Greymouth	Haast	Hokitika	Invercargill	Milford Sound	Aoraki/Mt Cook	Nelson	Picton	Queenstown	Reefton	Westport
Christchurch	0	215	149		189	0	8	0	2	0	0	23	13
Dunedin		344	149		189	0	8	0	2	0	0	23	13
Franz Josef			34		26	579	588	417	48	48	580	48	42
Greymouth					8	295	304	149	14	14	296	14	8
Haast													
Hokitika						369	378	207	22	22	370	22	16
Invercargill							8	0	63	0	0	169	159
Milford Sound								8	72	8	8	178	168
Aoraki/Mt Cook									2	0	0	23	13
Nelson										0	64	0	0
Picton											0	0	0
Queenstown												170	160
Reefton													0

Table 19: Change in travel time, in minutes, between key South Island nodes, including Canterbury, at T= 90 compared to pre-earthquake vehicles 3.5 – 6 tonnes. Black boxes show inaccessible routes, yellow boxes show decreased travel times compared to T=0 (Robinson et al., 2016a).

Vehicles between 3.5 and 6 tonnes													
	Dunedin	Franz Josef	Greymouth	Haast	Hokitika	Invercargill	Milford Sound	Aoraki/Mt Cook	Nelson	Picton	Queenstown	Reefton	Westport
Christchurch	0	215	149		189	0	8	0	2	0	0	23	13
Dunedin		344	149		189	0	8	0	2	0	0	23	13
Franz Josef			34		26	579	588	417	48	48	580	48	42
Greymouth					8	295	304	149	14	14	296	14	8
Haast													
Hokitika						369	378	207	22	22	370	22	16
Invercargill							8	0	63	0	0	169	159
Milford Sound								8	72	8	8	178	168
Aoraki/Mt Cook									2	0	0	23	13
Nelson										0	64	0	0
Picton											0	0	0
Queenstown												170	160
Reefton													0

2.2.2. Aftershock Road impacts

Recovery would be hampered by additional damage which would limit the ability of repair crews to work from Picton (in particular) south. The impacted roads are presented in Table 20 and Figure 10.

Table 20: Total of potentially damaging aftershocks (Mw5-Mw8) by State Highway (Robinson et al., 2016a).

Highway	Number of earthquakes expected
SH6	59.35
SH73	11.23
SH65	8.00
SH7	6.86
SH63	5.49
SH94	1.26
SH80	0.16

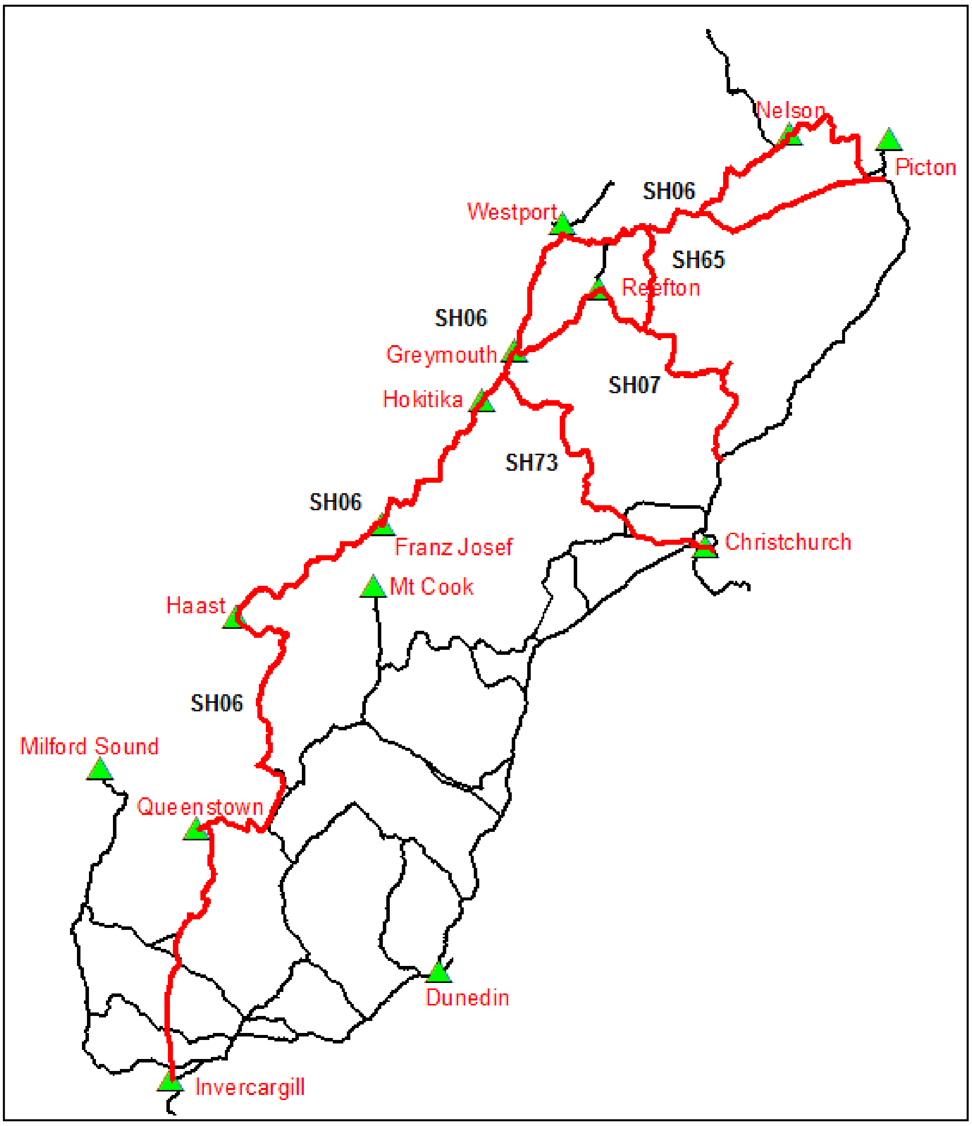

Figure 10: State highways most impacted by aftershocks (Robinson et al., 2016a).

2.2.3. Time-stamped Rail LOS

2.2.3.1. T=0 days

The primary losses to the network are from landsliding. All bridges on the network perform well, with none sustaining any disruption inducing damage. Nevertheless, all bridges require inspection following the earthquake to confirm this before trains can use them. Consequently, on the day of the earthquake, all rail bridges are closed prior to precautionary inspections. Landslides primarily affect the Midland Line where it passes through the Southern Alps (*Figure 11*) at:

- Cass;
- Waimakariri River to Otira Tunnel (southern portal);
- Otira Tunnel (northern portal) to Otira Township;
- Otira Township to Taramakau River;
- Taramakau River;
- Lake Poerua; and
- Lake Brunner.

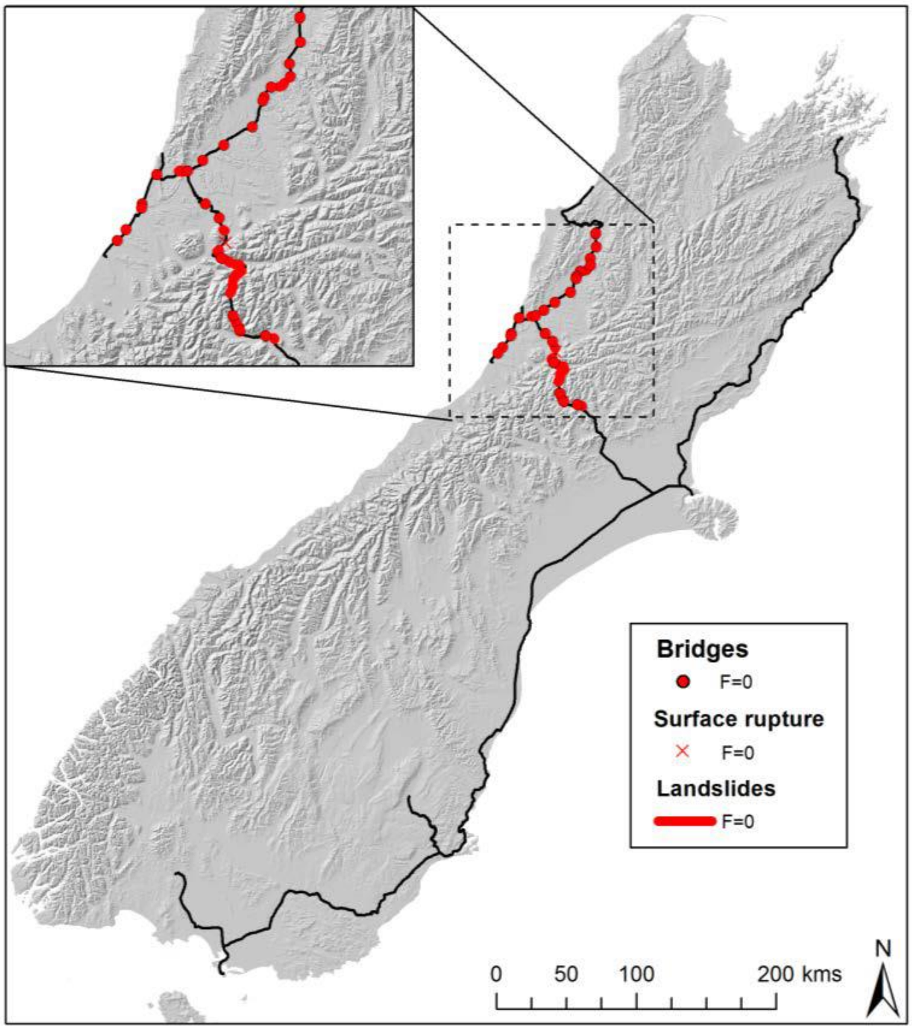

Figure 11: Landslide, surface rupture, and bridge losses to the South Island Rail network immediately after an Alpine Fault earthquake (T=0). Only bridges experiencing MMI7+ shaking have been evaluated (Robinson et al., 2016a).

Travel along both the Main North and Main South Lines are possible, connecting the major east coast towns and ports, however, both inter- and intra-regional travel west of Christchurch is disrupted (*Table 21*).

Table 21: Change in accessibility for nodes on the rail network at T=0. Black boxes show inaccessible routes (Robinson et al., 2016a).

	Dunedin	Greymouth	Hokitika	Invercargill	Picton	Reefton	Westport
Christchurch	✓			✓	✓		
	Dunedin			✓	✓		
		Greymouth					
			Hokitika				
				Invercargill	✓		
					Picton		
						Reefton	

2.2.3.2. T=3 days

Three days after the earthquake the small landslides/rockfalls at Cass are remediated on the Midland Line, allowing the first access to the blockages between the Waimakariri and Mingha Rivers. Just three days after the earthquake, the Midland Line is the only line still requiring restoration.

2.2.3.3. T=25 days

Further restoration is not completed on the Midland Line until 25 days after the earthquake. At this time the landslides between the Waimakariri and Mingha Rivers are cleared, as are the landslides along the Taramakau River, allowing the first access to both portals of the Otira Tunnel. The scale of landslides around the tunnel portals however is much larger than the landslide cleared to date and requires substantial restoration work to fully complete the network restoration. Consequently, there is no change to the network connectivity.

2.2.3.4. T=100 days

Further notable progress is not made until 100 days after the earthquake when the landslides blocking the southern portal of the Otira Tunnel are cleared. This allows rail access between the major east coast cities and Arthur's Pass township for the first time since the earthquake. Nevertheless, the most severe blockages at the northern portal near Otira still require remediation, restricting rail connections between the east and west coasts.

2.2.3.5. T=186 days

Almost six months after the earthquake, the final landslide blockages on the Midland Line at the northern portal of the Otira Tunnel are finally cleared. These are the last remaining restoration works on the rail network, restoring the connection between the east and west coasts and returning the network connectivity to pre-earthquake levels. Normal rail services can now be resumed for the first time since the earthquake.

2.2.4. Aftershock Impacts to Rail

Concentrating on the first 90 days after the main event, the Midland Line would possibly be impacted by 4 or 5 damaging aftershocks and a similar number of lesser events disrupting due to safety inspections. It is possible that these events could add a month to the restoration times for the Midland Line resulting in a total time to restoration of about 9 months.

2.2.5. Time-stamped HEP Transmission LOS

2.2.5.1. T=0 days

During the Canterbury earthquake sequence, steel pylons and wooden pole supports were observed to perform well despite experiencing strong ground shaking (Giovinazzi et al., 2011). Consequently, ground shaking is considered unlikely to cause significant losses to the HEP Transmission network. Losses therefore primarily result from landslides. In Arthur's Pass region, 26 steel pylons carrying 60 kV cables are damaged as a result *(Figure 12).*

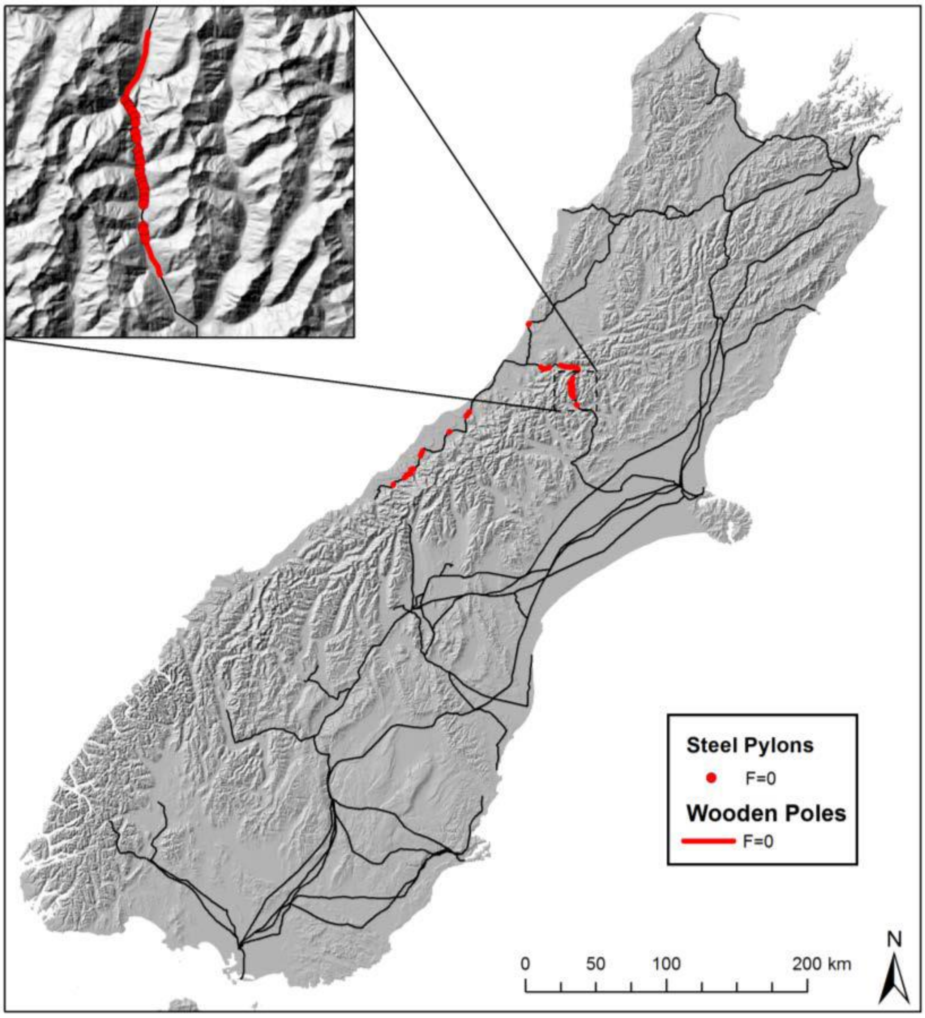

Figure 12: Landslide losses to the HEP Transmission network immediately following an Alpine Fault earthquake (T=0). Ground shaking and surface rupture were considered not to cause significant losses (Robinson et al., 2016a).

Table 22: Locations with and without electrical power due to HEP Transmission network losses immediately following an Alpine Fault earthquake (T=0), (Robinson et al., 2016a).

Location	Electricity Available?
Christchurch	✓
Dunedin	✓
Franz Josef	X
Greymouth	X
Hokitika	X
Invercargill	✓
Aoraki/Mt Cook	✓
Nelson	✓
Picton	✓
Queenstown	✓
Reefton	✓
Westport	✓

The loss of the 60 kV lines through Arthur's Pass only presents a local issue.

It is estimated that repair time for each wooden pole is six hours compared to a steel pylon, which takes two days. Transpower have up to 30 spare steel pylons in storage at all times. As this is not less than the number of pylons lost (26), restoration would therefore not be disrupted by a lack of initial replacement stock in this scenario.

2.2.5.2. T=80 days

All wooden pole supports on the west coast are restored. At this stage, it is still likely to be unsafe for teams to attempt restoration in Arthur's Pass for at least a further ~100 days (~3.5 months). Consequently, restoration of the HEP Transmission network ceases and given the limited electrical load carried by the line through Arthur's Pass, decision-makers may decide not to restore the network here.

2.2.6. Aftershock Impacts to Electrical Transmission

The aftershock modelling indicates that the 50/60kV network will possibly be impacted by 23 or 24 damaging (Mw5+, within 5km) aftershocks in the first 90 days following the main shock. No substations or power stations are expected to be directly impacted.

2.2.7. Time-stamped 3-waters LOS

The only Canterbury town included in this study is Aoraki/Mt Cook Village, which experiences up to MMI9 shaking in this scenario. The proceeding tables summarise impacts and outage times for the 3-water networks.

Table 23: Supporting infrastructure component impacts and restoration for Aoraki/Mt Cook Village 3-waters (Robinson et al., 2016a). Note: Storm water damage is assumed to align with Sewer damage.

	Water treatment	Pumps	Storage	Sewage treatment
Damage	Complete	Extensive	Extensive	Complete
Restoration times	2.5 days	20 days	2 days	2.5 days

Table 24: Impacts and total restoration for Aoraki/Mt Cook Village 3-waters including pipes and supporting infrastructure (Robinson et al., 2016a). Note: Storm water damage is assumed to align with Sewer damage.

	Water	Sewers	Stormwater
Pipe Breaks	2	4	-
Total Restoration times (including support infrastructure)	16	16	16

2.3. Coseismic landsliding estimates for an Alpine Fault earthquake and the consequences for erosion of the Southern Alps, New Zealand - (Robinson et al., 2016b)

This paper presents first-order estimates of the scale and effects of coseismic landsliding resulting from an AF8 event. The study surmises that an AF8 event could produce ~50,000±20,000 landslides at average densities of 2

– 9 landslides/km^2 in the area of most intense landsliding *(Figure 13)*. Between 50% and 90% are expected to occur in a 7000 km2 zone between the fault and the main divide of the Southern Alps *(Figure 14).*

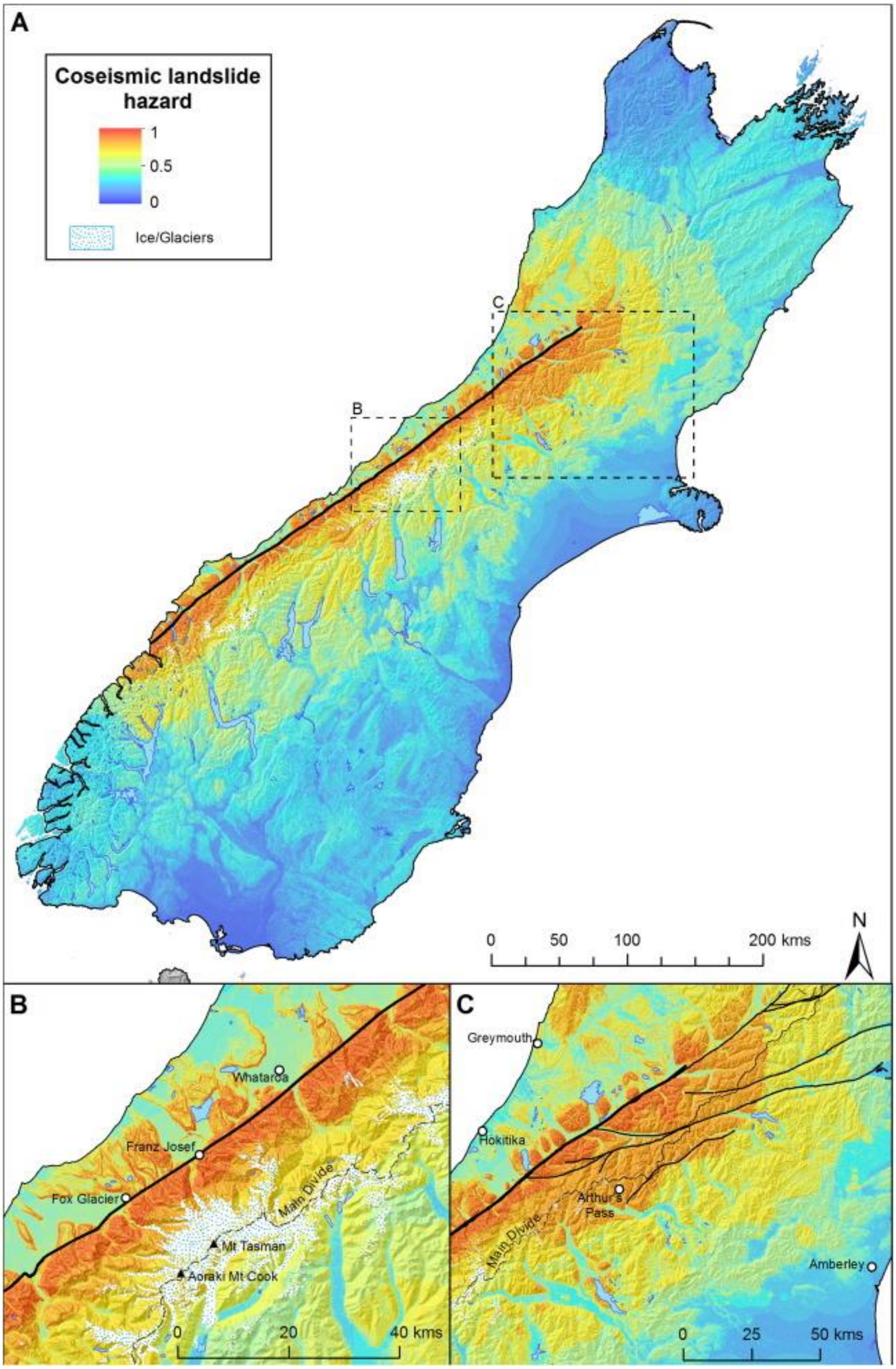

Figure 13: Coseismic landslide hazard resulting from AF8 scenario for A) the entire South Island; B) the central Southern Alps; and C) the northern Southern Alps. Major mapped faults are shown in black (Robinson et al., 2016b).

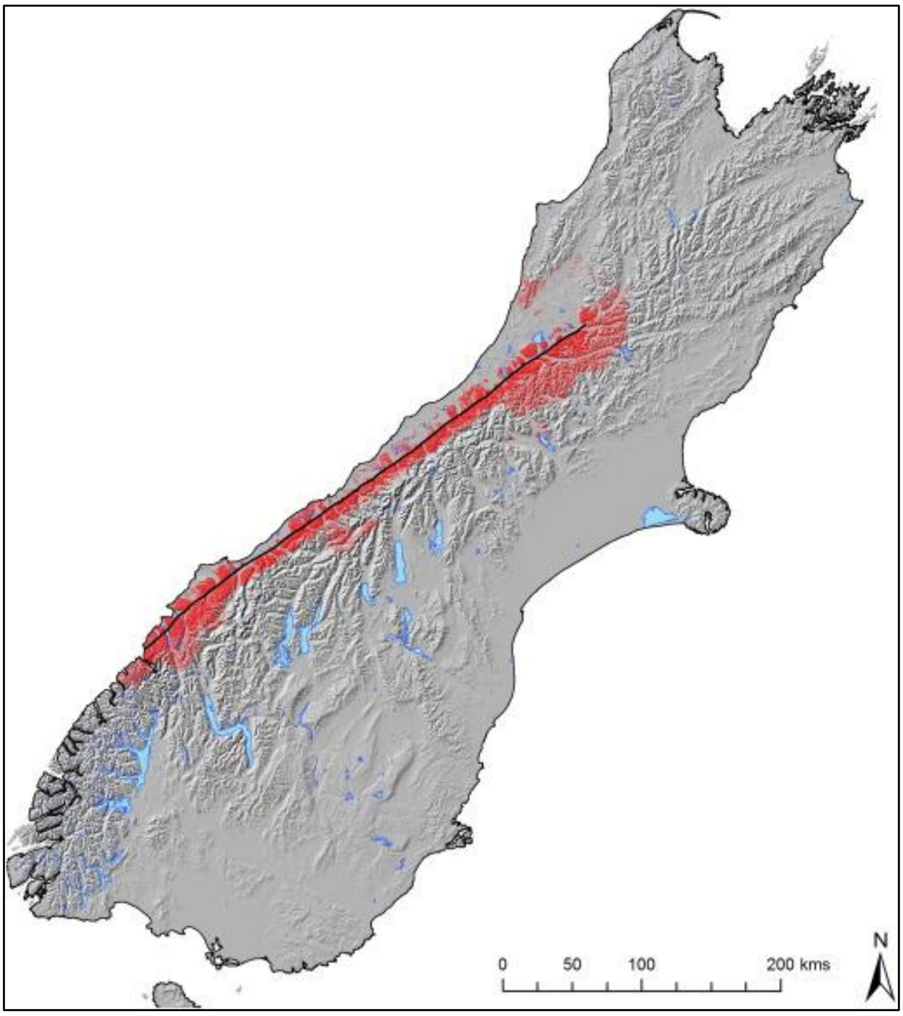

Figure 14: Spatial extent of the highest 20% of modelled coseismic landslide hazard for an Mw 8.0 Alpine Fault earthquake. This region is anticipated to experience 50–90% of the total landslides (Robinson et al., 2016b).

Total landslide volume is estimated to be 0.81 + 0.87/0.55 km3. In major northern and southern river catchments, total landslide volume is equivalent to up to a century of present-day aseismic denudation measured from suspended sediment yields. This suggests that earthquakes occurring at century-timescales are a major driver of erosion in these regions. In the central Southern Alps, coseismic denudation is equivalent to less than a decade of aseismic denudation, suggesting precipitation and uplift dominate denudation processes. Nevertheless, the estimated scale of coseismic landsliding is considered to be a substantial hazard throughout the entire Southern Alps, including Canterbury, and is likely to present a substantial issue for post-earthquake response and recovery.

2.4. Ground motion simulations of great earthquakes on the Alpine Fault: effect of hypocentre location and comparison with empirical modelling - (Bradley et al., 2017)

This paper simulates ground motion intensity in peak ground velocity (PGV) for AF8 scenarios. The simulations utilise the latest understanding of wave propagation physics, kinematic earthquake rupture descriptions and the three-dimensional nature of the Earth's crust. The effect of hypocentre location is explicitly considered, which lead to significant differences in ground motion over North Canterbury in particular *(Figure 15).* Rupture directivity and basin-generated surface waves are also considered, which have a significant increase in PGV from past modelling for Canterbury. The simulations performed in this paper have been adopted, as one possible ground motion prediction, in the 'Project AF8'. The notably higher simulated amplitudes than those from empirical predictions are noted in the paper as a potential cause for a re-examination of regional impact assessments for major Alpine Fault earthquakes (many of the subsequent projects summarised in this report are based off).

Figure 16 illustrates the expected MMI in the South Island for the AF8 scenarios. The Southern hypocentre scenario *(Figure 15c and 16c)* is the most widely adopted Project AF8 scenario for regional CDEM group response and recovery planning as it represents a worst-case AF8 scenario for New Zealand as a whole. In Canterbury, it represents the worst-case AF8 scenario for the northern TA's in particular (Selwyn, Christchurch and Waimakariri, and especially Hurunui and Kaikōura)

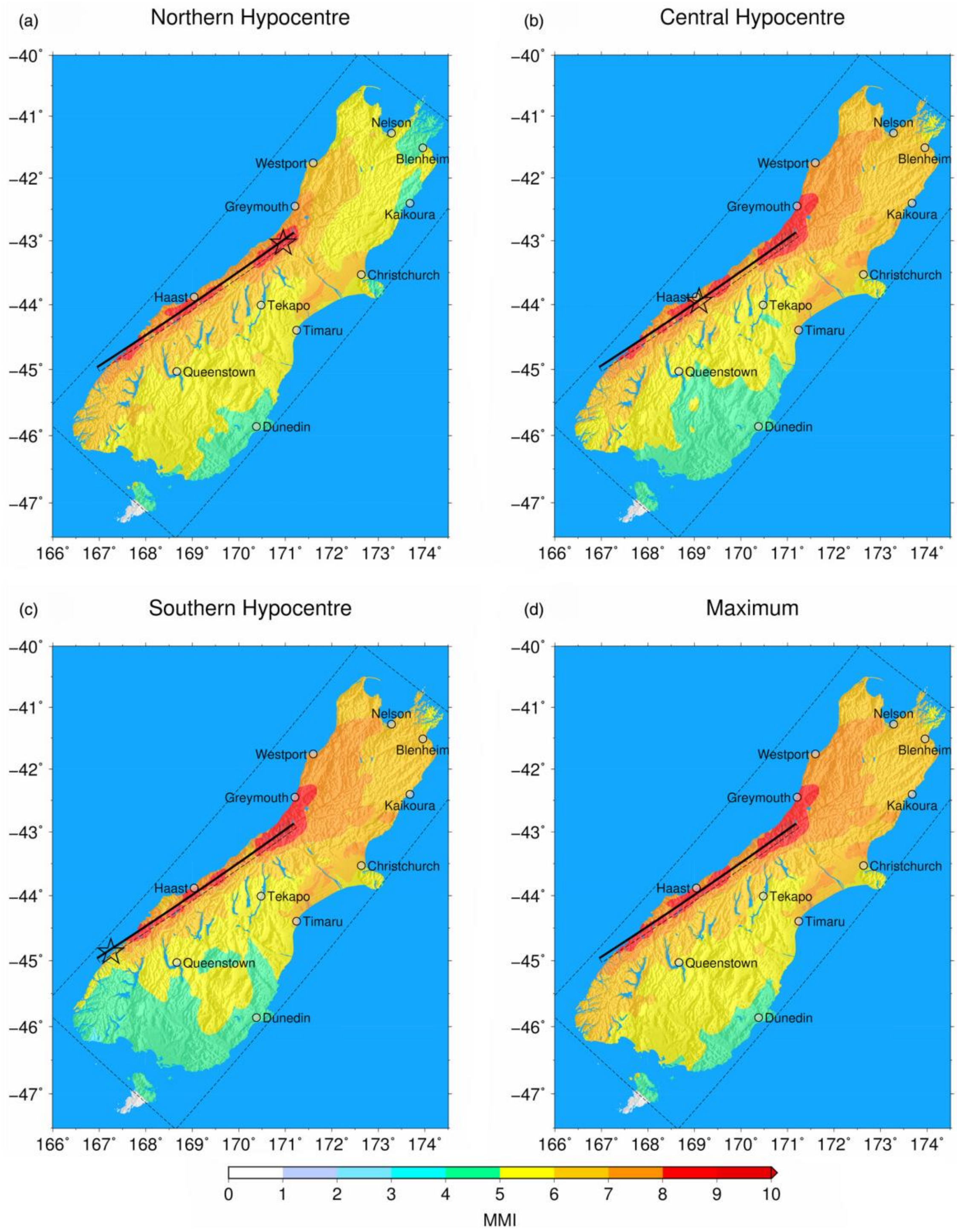

Figure 15: Estimated Modified Mercalli Intensity (MMI) over the South Island based on the PGV–MMI correlation of Worden et al. (2012) for: (a) Northern; (b) Central; (c) Southern hypocentres; (d) the maximum MMI over the South Island from the three hypocentre scenarios (Bradley et al., 2017).

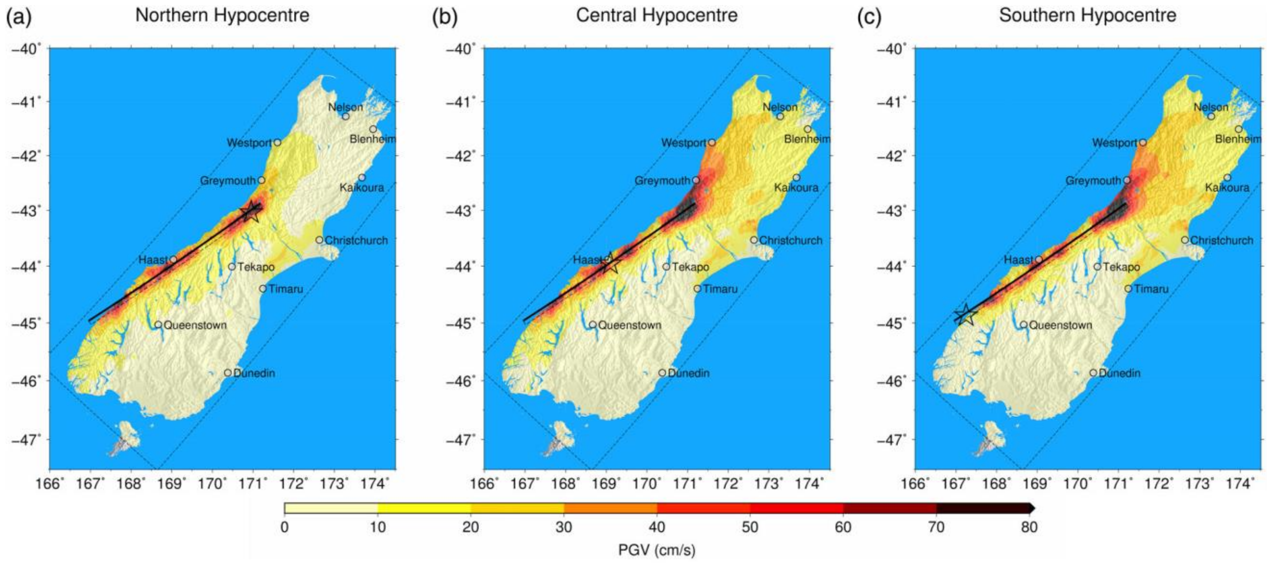

Figure 16: Spatial distribution of peak ground velocity (PGV) over the South Island for the three rupture scenarios considered. The effect of hypocentre location on the directivity and directivity–basin coupling is most prominent in the Canterbury region and northern South Island (Bradley et al., 2017).

2.5. Aftershock scenarios following a M8.2 Alpine fault earthquake - (Christopherson, A., William, R., Berryman, 2017)

This scientific research letter, and associated spatial dataset, is the result of a request from the University of Canterbury to GNS Science on potential aftershock sequences for a major Alpine Fault earthquake. For this, comparable international aftershock sequences (the 2001 Mw7.8 Kokoxili earthquake and the 2002 Mw7.9 Denali earthquake) are applied to a Mw8.2 Alpine Fault earthquake. The research letter (Christopherson, A., William, R., Berryman, 2017) recommends scenario 3 *(Figure 17c)* as the most appropriate for response and recovery planning. It was derived from the Denali earthquake and includes a Mw7.0 aftershock on the Hope Fault about 11 days after the main shock.

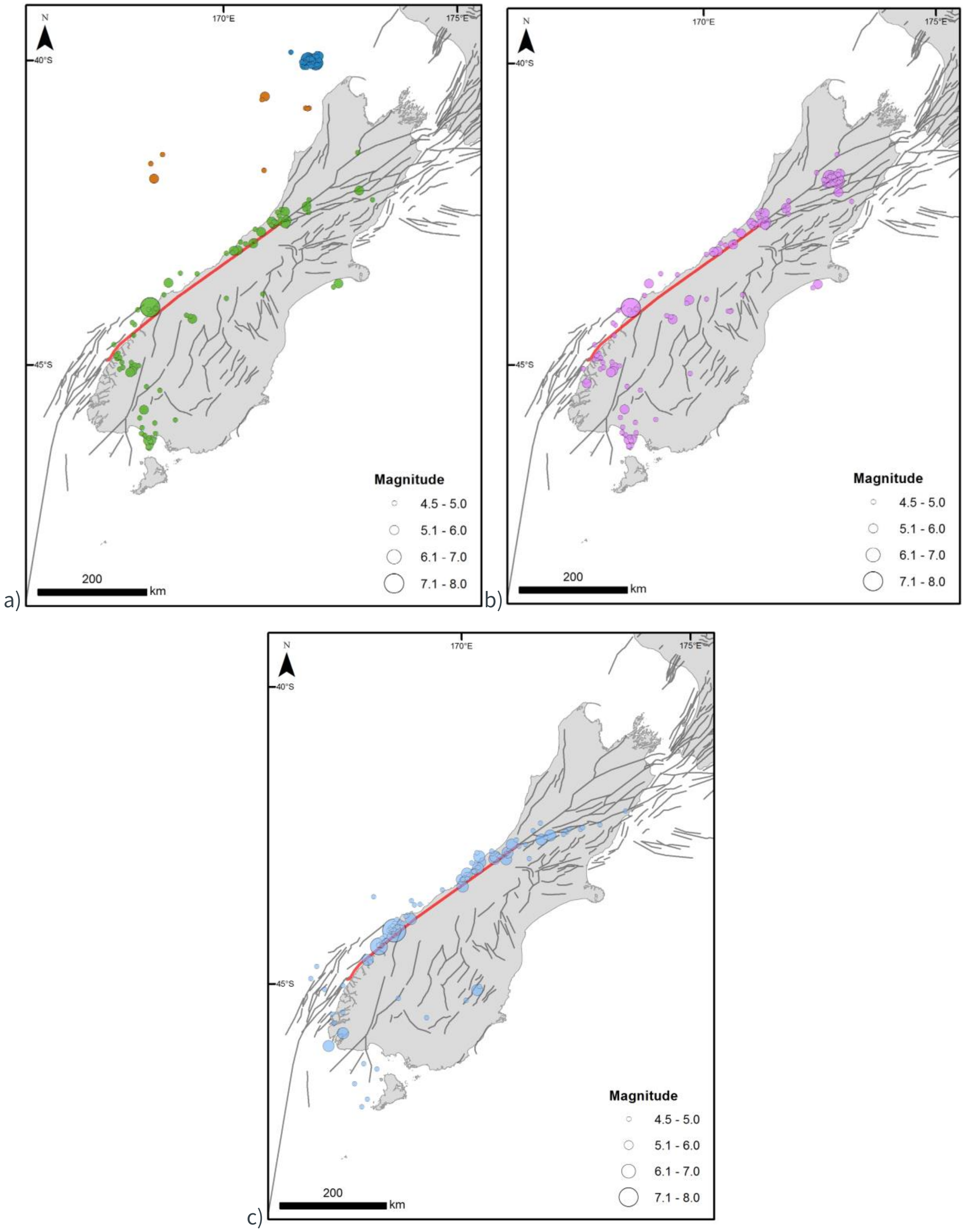

Figure 17: a) The Kokoxili earthquake sequence moved to the Alpine Fault. The blue and brown cluster on the left-hand side here moved separately (b) to the south-west segment of the Awatere fault and into Otago, respectively. The magnitudes are the original magnitudes, which were later shifted upwards by 0.4 units to reflect the larger main shock of the Alpine Fault scenario. C) The locations of the Denali earthquake sequence transferred to the Alpine Fault. The magnitudes are the original magnitudes, which were later shifted upwards by 0.3 units to reflect the larger main shock of the Alpine Fault.

2.6. AF8 Liquefaction and Landslide Susceptibility Models – (QuakeCoRE Summer Internship outputs)

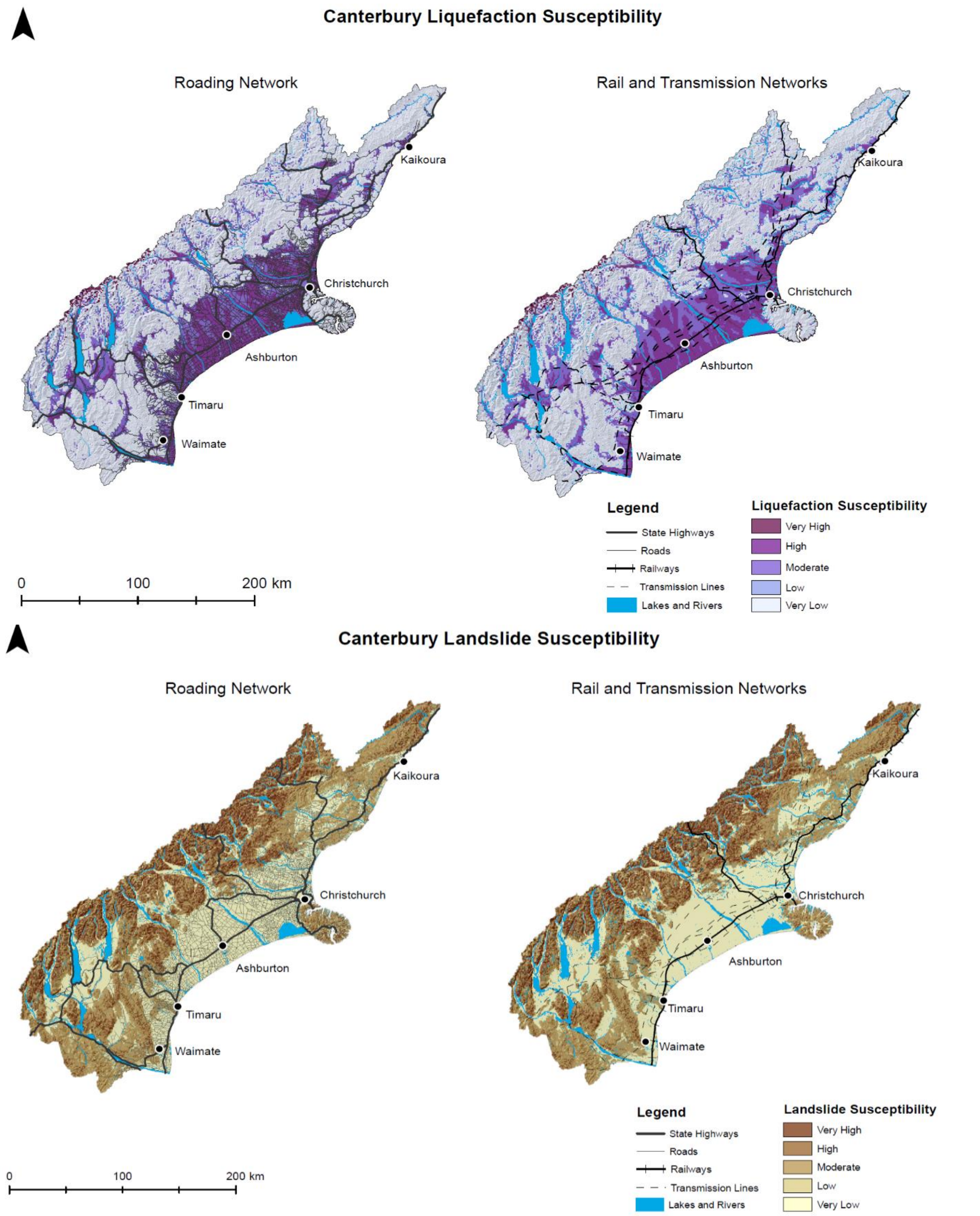

Figure 18: Modelled liquefaction (top) and landslide (bottom) susceptibility for the South Island conducted by QuakeCore Interns.

A group of students conducting a summer internship for QuakeCoRE have modelled liquefaction and landslide susceptibility (Figure using existing global hazard models (Zhu et al., 2017; Nowicki Jessee et al., 2018). The landslide model does not supersede the work done by Robinson et al., (2016), which provides a landslide probability for the specific AF8 scenario. This work provides a susceptibility rating that is not inclusive of earthquake seismicity but does provide an indication of the areas prone to these hazards during an AF8. The susceptibility maps are based on soil composition, water table and not determined by earthquake data. The resulting maps are presented in *Figure 18* and presented in more detail in Section 4 for each TA in Canterbury.

2.7. Tsunami and Seiche Hazard Scoping Study for Lakes Tekapo, Pukaki, Ohau, Alexandrina and Ruataniwha (Clark et al., 2015)

This study estimates potential tsunami and seiche sources for lakes Tekapo, Alexandrina, Pūkaki, Ruataniwha and Ōhau. The following text and figures summarise the key findings of this study

There are active faults crossing the beds of lakes Ruataniwha, Alexandrina and Tekapo. There are also potentially additional active faults beneath lakes Tekapo and Pūkaki. Rupture of lake bed faults will displace the water volume above the fault and almost certainly generate a tsunami. The most hazardous scenario, in terms of fault rupture-generated tsunami, is rupture of the Ostler Fault which could produce wave heights of at least 3 m in Lake Ruataniwha. Rupture of the Irishman Creek Fault Zone could produce wave heights of at least 2 m on Lake Alexandrina. Rupture of an extension of the Irishman Creek Fault Zone into Lake Tekapo could produce maximum wave heights of ~2 m on Lake Tekapo. Rupture of a possible extension of the Coal River faults into Lake Tekapo could produce maximum wave heights of ~3 m *(Clark et al., 2015)*.

Seiches can be triggered by coseismic displacement of the lake bed, or by seismic waves. Lakes Tekapo, Alexandrina, Pūkaki, Ruataniwha and Ōhau could potentially be prone to seiche generated by both mechanisms. There are no well-established relationships between amount of coseismic displacement, ground shaking or seismic wave properties and seiche generation, so the size of potential seiche waves cannot be estimated. Recent moderate to large distant earthquakes do not appear to have generated seiches on lakes Tekapo, Alexandrina, Pūkaki, Ruataniwha and Ōhau perhaps suggesting they are not prone to seiching but we cannot estimate the impact of an Alpine Fault earthquake or local earthquake *(Clark et al., 2015)*.

Landslides directly into lakes can displace sufficient volumes of water to produce tsunami. Parts of the margins of lakes Ōhau, Pūkaki and Tekapo have very steep slopes which, if subject to failure, could produce landslides capable of creating tsunami waves within the lake.

There are 3 potential landslide source areas around Lake Ōhau, future landslides from these areas could produce tsunami waves with run-up heights of 0.5 – 25 m. There is one large potential landslide sources area around Lake Pūkaki, future landslides from this area could produce tsunami waves with run-up heights of 0.5 – 25 m. There are four potential landslide sources areas around Lake Tekapo, future landslides from these area could produce tsunami waves with run-up heights of 0.5 – 25 m. Whilst such events would undoubtedly have significant impacts, the size of the potential landslide source areas and the volume of material that would enter the lake is subject to considerable uncertainty, and further field based study would be required to improve understanding of the stability of the steep slopes surrounding the lakes and the potential landslide source areas that have been identified.

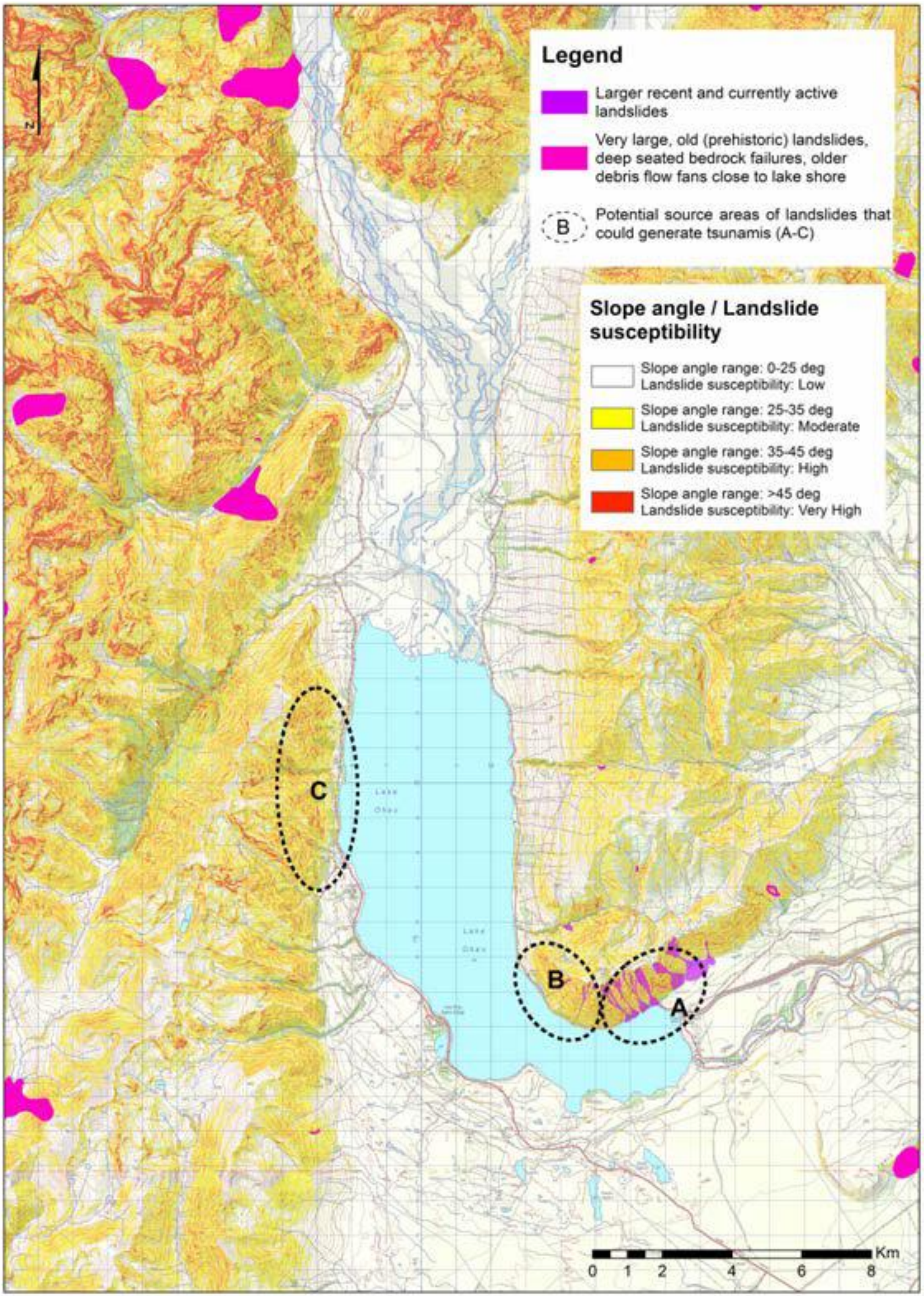

Figure 19: Slope angle and landslide susceptibility map of Lake Ōhau showing existing landslides and potential future landslide source areas (A to C) (Clark et al., 2015).

Delta collapse can potentially generate tsunami (depending on the speed and amount of mass movement). Lakes Ōhau, Pūkaki and Tekapo all have sizeable deltas that, in the event of rapid collapse, may trigger tsunami. The main delta slopes of Lake Pūkaki is directly in line with the southern shore of Lake Pūkaki. The main delta to Lake Ōhau is in line with the southwestern shore of Lake Ōhau. Seismic lines in Lake Tekapo suggest geological evidence of past submarine slumping. At this stage we cannot estimate the size of delta-collapse triggered tsunami but it should be considered a potential hazard in lakes Ōhau, Pūkaki and Tekapo.

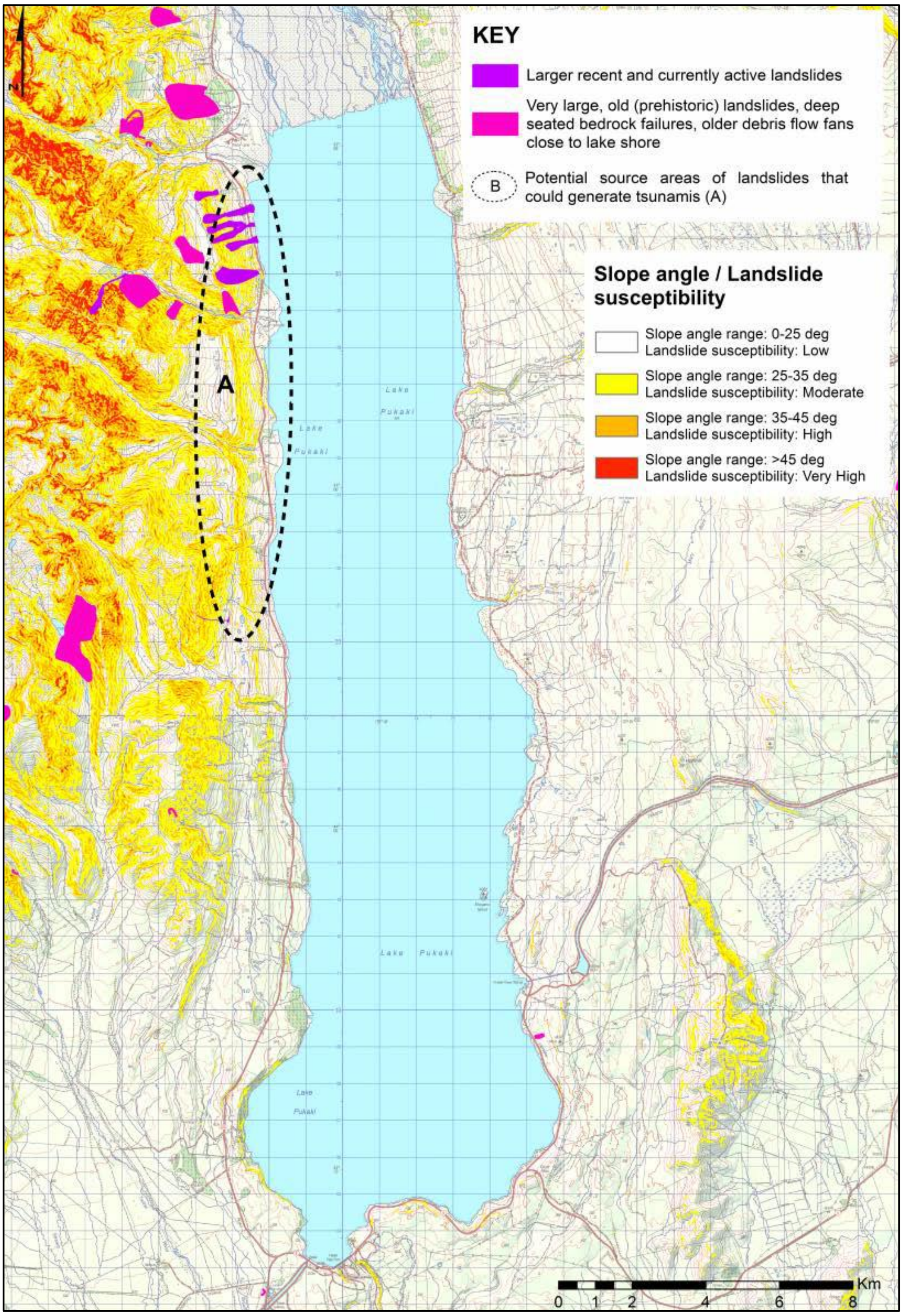

Figure 20: Slope angle and landslide susceptibility map of Lake Pūkaki showing existing mapped landslides and potential future landslide source areas (A).

The assessment of potential tsunami and seiche sources on lakes Tekapo, Alexandrina, Pūkaki, Ruataniwha and Ōhau shows there are a number of mechanisms by which tsunami and seiches could be generated on all these lakes. Some lakes are more exposed to certain tsunami- and seiche-generating mechanisms than others due to local geological structures and topography. Approximate and preliminary estimates of tsunami wave heights could be made for fault rupture- and landslide- generated tsunami. However, insufficient data exists to make estimates of wave heights for seiches and delta collapse-generated tsunami. This study has not included tsunami modelling, but this, along with collection of some additional data, may allow more precise estimates of tsunami wave heights and inundation zones to be estimated.

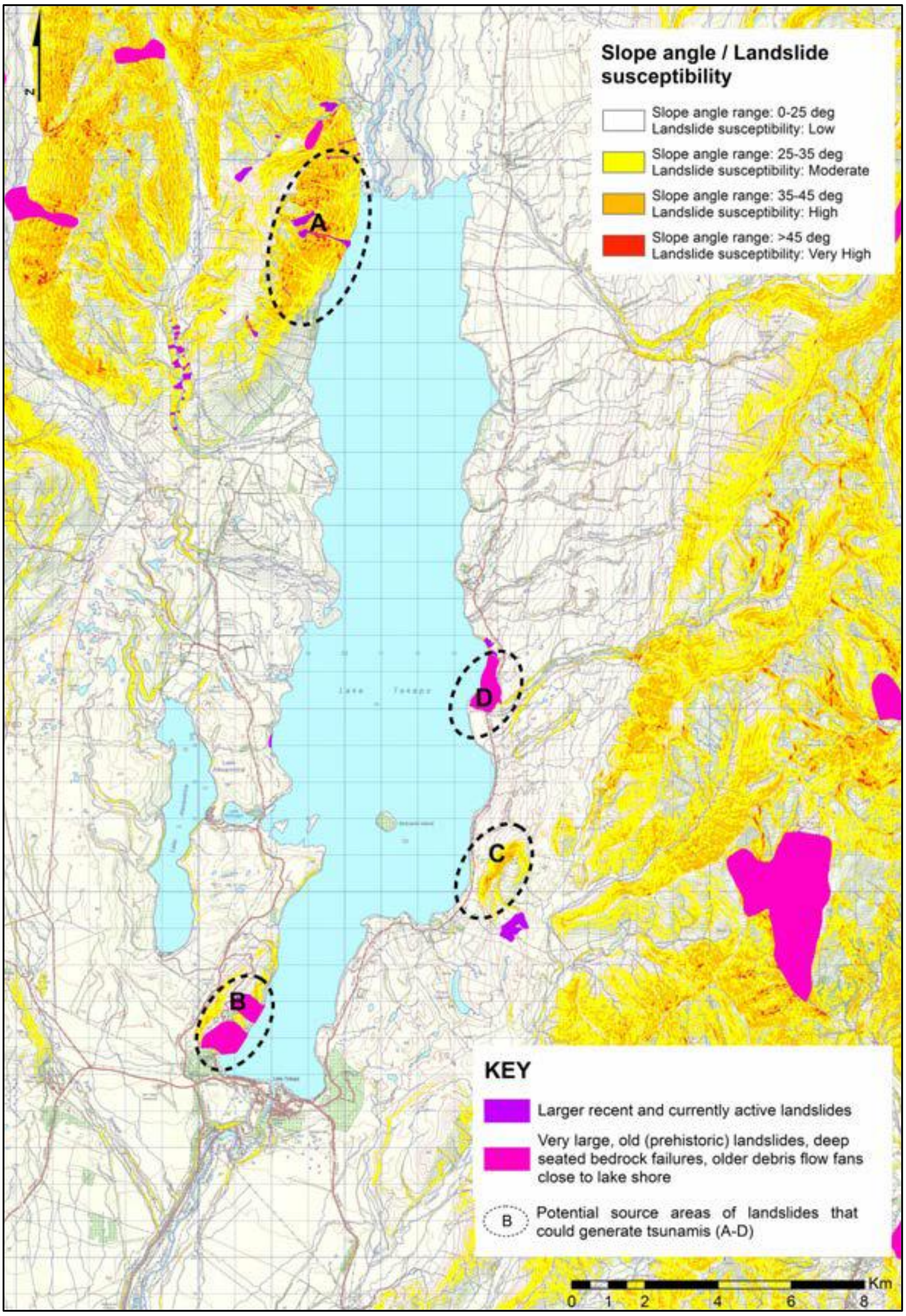

Figure 21: Slope angle and landslide susceptibility map of areas around lakes Tekapo and Alexandrina showing existing mapped landslides and potential future landslide source areas (A-D).

Coseismic tilting of the lakes would probably generate seiches but the size of such waves cannot be estimated without numerical modelling. Several local faults and regional seismic sources, such as the Alpine Fault and Puysegur subduction zone, could generate significant ground shaking at the lakes of this study. The relationship between ground shaking levels and seiche generation is poorly understood. Recent moderate to large distant earthquakes did not appear to generate seiches on lakes Tekapo, Alexandrina, Pūkaki, Ruataniwha and Ōhau, perhaps suggesting they are not prone to seiching but we cannot estimate the impact of an Alpine Fault earthquake or local earthquake.

Lakes Tekapo, Alexandrina, Pūkaki, Ruataniwha and Ōhau are located in an area with a known history of very large landslides. Parts of the margins of lakes Ōhau, Pūkaki and Tekapo have very steep slopes which, if subject to failure, could produce landslides capable of creating tsunami waves within the lake. A preliminary landslide susceptibility assessment, based on slope angle data, was carried out for each lake which identified potential landslide sources areas; the tsunami generating potential of example landslides at these sites was estimated based on landslide size, slope height and steepness, and location on the lakeshore.

The deltas present at some parts of the margins of lakes Ōhau, Pūkaki and Tekapo have been mapped. If there were to be a rapid underwater slumping of one or more of these deltas following an earthquake or large storm, this would rapidly displace an equivalent volume of water and potentially generate a tsunami. Seismic lines in Lake Tekapo show areas of disturbed reflectors interpreted as mass movement or turbidite deposits, indicating there has potentially been submarine slumping in the past in this lake. In the absence of high resolution seismic and bathymetric data, the volume of delta material that may potentially collapse cannot be estimated, nor can the size of a potential tsunami. (Clark et al., 2015).

Table 25: Summary of landslide volumes and estimated maximum run-up heights of waves generated by hypothetical potential landslides into lakes Tekapo, Pūkaki, Ōhau.

Example Landslide Area[1]	Estimated[2] Landslide volume (m^3)	Possible max wave run-up height (m)	Other potential geological hazards at sites of interest and explanatory comments
Lake Ohau			
A1	100,000 – 1,000,000	10-25 m	
A2	100,000 – 500,000	~5–10 m	
A3	100,00 – 500,000	~5–10 m	
B1	1,000-1,000,000	0.5-25 m	
B2	10,000 – 1,000,000	0.5-25 m	
C	10,000 – 1,000,000	1-25 m	
Lake Pukaki			
A	250,000 – 1,000,000	10-25 m	Direct landslide hazard also
Lake Tekapo			
A1	10,000 – 500,000	1-3 m	
A2	10,000 – 500,000	1-3 m	
A3	10,000 – 500,000	1-3 m	
B1	700,000 – 1,000,000	10-25 m	
B2	500,000 - 1,000,000	10-25 m	
C	1,000 – 100,000	0.5-3	
D	100,000 – 2,000,000	10-25 m	

2.8. Seiche Effects in Lake Tekapo, New Zealand, in a Mw8.2 Alpine Fault Earthquake (Wang et al., 2020)

This study couples an earthquake ground motion model and a tsunami simulation model to investigate water oscillations and seiche potential in Lake Tekapo, New Zealand, in an Mw8.2 Alpine Fault earthquake. The results *(Figure 23)* reveal that the lake water oscillations can reach 4.0 m in the lake's southern arm, about 1.0 m in front of the Lake Tekapo township, and about 1.5–2.5 m above normal lake level along many parts of the lakeshore. The dynamically triggered waves in the lake are much larger, and thus, pose much bigger threat to the lake area than the tsunami amplitude estimated from static vertical coseismic displacements, the conventional mechanism for tsunami generation. This stresses that dynamic effects need to be considered in tsunami hazard assessment and mitigation in seiche-prone areas such as bays, harbours and inland lakes, especially for strike-slip dominant sources (Wang et al., 2020).

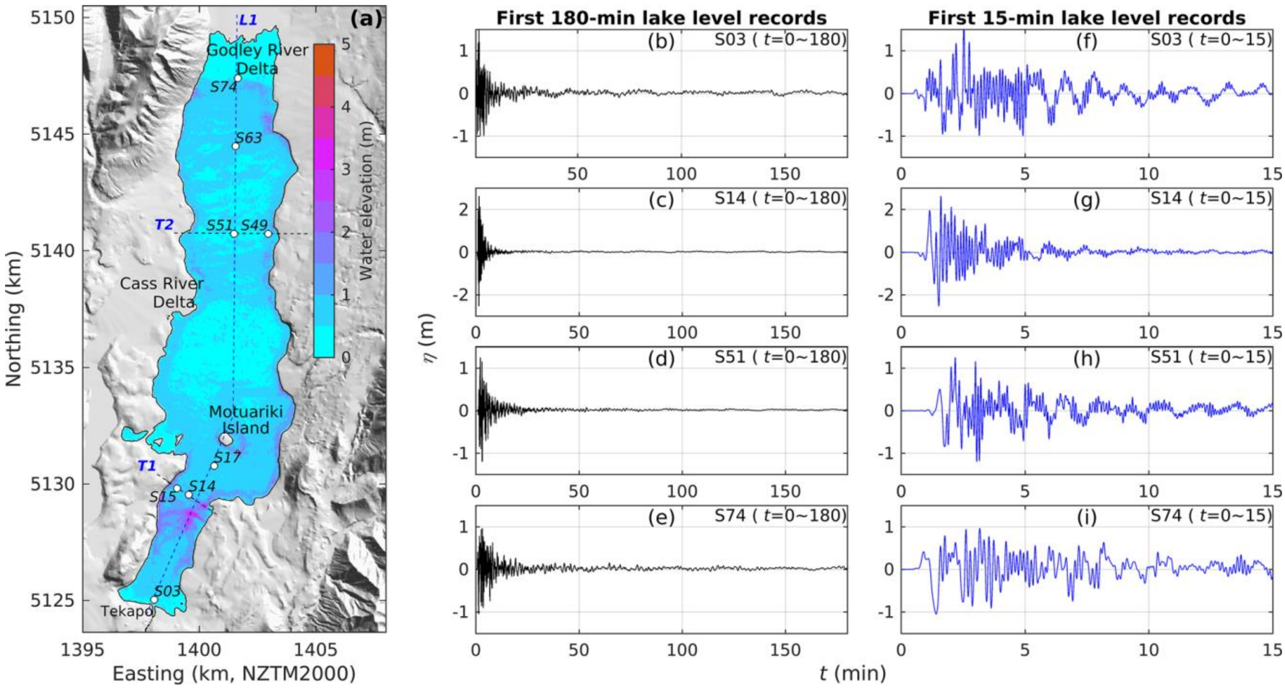

Figure 22: a) Spatial distribution of modelled maximum water elevation in Lake Tekapo. Colour scale indicates water elevation in metres above normal (Wang et al., 2020).

2.9. Tsunami hazard from lacustrine mass wasting in Lake Tekapo, New Zealand (Mountjoy et al., 2018)

This study presents the first high-resolution bathymetric mapping of Lake Tekapo, making it the first completely mapped lake in New Zealand. It should be noted that inundation, if any, would not be of good quality due to the authors acknowledging the poor topographical data available at the time of modelling. The bathymetric and sedimentary data reveal a dynamic lake-bed geomorphology with active delta systems and widespread mass failures, characterized by a range of scales and failure styles. This study demonstrates that even the relatively small landslides (<0.05 km3) observed to have occurred in the past could generate multi-metre-high waves along the populated southern lake shoreline. Wave heights at the southern shore where the township of Tekapo occurs could be as large as 5 m following full collapse of the Cass Delta, and potentially larger with concurrent failures at multiple locations during a strong earthquake. This study builds on previous work by Wang et al., (2020) by conducting scenario-based tsunami modelling for New Zealand lakes, and it demonstrates that there is a considerable landslide-tsunami hazard in Tekapo. The most recent landslides identified are inferred to be earthquake triggered as they occur at the same stratigraphic interval. These coseismic landslides are much more widespread than previously known, and this study demonstrates that concurrent slope failure can cause significant wave amplification. The follow-up to this study will involve the use of dated sediment records, in combination with landslide frequency estimates from seismic reflection data, to gain some insight into the timing of events. This will then be used to develop a probabilistic tsunami hazard model that can feed through into an inundation and risk model for the township of Tekapo and the hydroelectric power generation infrastructure.

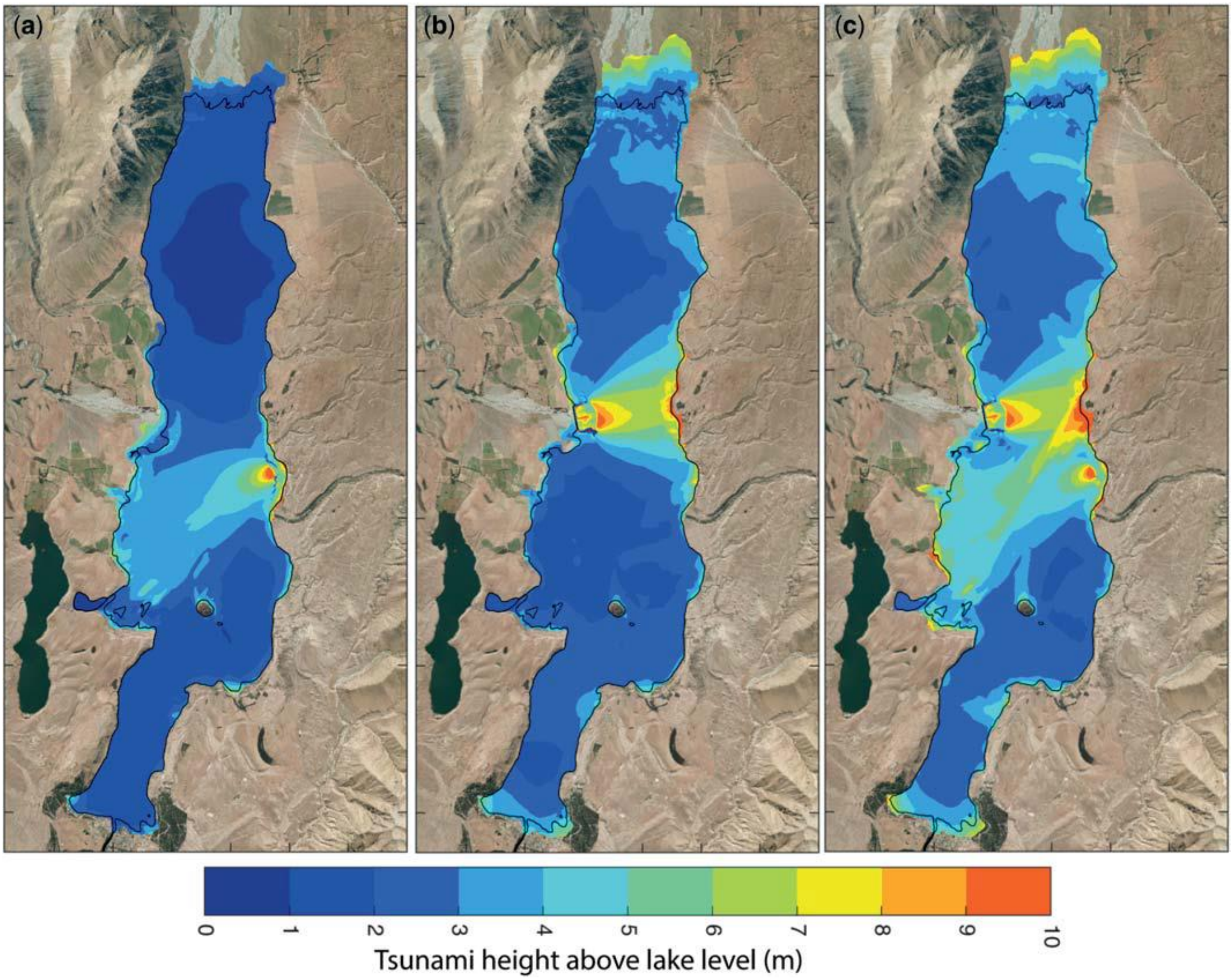

Figure 23: Scenario modelling results for (a) validation scenario V01; (b) validation scenario V02 and (c) combined modelling result for both scenarios occurring simultaneously (Mountjoy et al., 2018).

2.10. Secondary Hazard Risks Expert Panel Summary - (AF8 Science Team, 2018)

This scenario-based summary of Alpine Fault hazard risks was produced using a co-creation approach between Alpine Fault hazard scientists and CDEM Group Managers at two workshops in 2018. It presents the professional, expert opinions of those present on the day. These views are based on the south to north AF8 Scenario, which presents only one of many possible outcomes of a future Alpine Fault earthquake. There are many modelled uncertainties and additional factors that will affect what happens in reality, including time of day/night, and time of year. This summary document is intended for use ONLY in South Island CDEM Groups planning and can therefore only be made available upon request. It is not suitable for use beyond this without further development and consultation with the Expert Panel.

AF8 ALPINE FAULT MAGNITUDE 8

Secondary Hazard Risks Expert Panel Summary

October 2018

Expert Panel: CDEM Group Managers and Alpine Fault hazard scientists.

A suite of potential secondary hazard risks associated with the AF8 Scenario to provide some credible options for South Island CDEM Group planning, including:

- → General risks
- → Location specific risks

These hazard risk scenarios have been assigned a probability to communicate the Expert Panel's best estimate of their likelihood.

>80%	Very likely
50%-79%	Likely
15%-49%	Unlikely
<14%	Very Unlikely

Disclaimer: This scenario-based summary of Alpine Fault hazard risks was produced using a co-creation approach between Alpine Fault hazard scientists and CDEM Group Managers at two workshops in 2018. It presents the professional, expert opinions of those present on the day. These views are based on the south to north AF8 Scenario, which presents only one of many possible outcomes of a future Alpine Fault earthquake. There are many modelled uncertainities and additional factors that will affect what happens in reality, including time of day/night, and time of year.

This summary document is intended **for use ONLY in South Island CDEM Group planning**. It is not suitable for use beyond this without further development and consultation with the Expert Panel.

For more information, please contact: info@af8.org.nz

Figure 24: Title page (for reference) of the Secondary Hazard Risks Expert Panel Summary (AF8 Science Team, 2018).

2.11. Project AF8 Impact Scenarios – (Project AF8 Science Team, ~ 2017)

A piece of unpublished work by the Project AF8 Science Team developed time-stamped models for South Island infrastructure lifelines impacted by an AF8 event. This work is underpinned by (Robinson et al., 2016a) and expert elicitation during a roadshow of workshops from across the South Island Civil Defence and Emergency Management Groups. The proceeding figures display the estimated damage and service disruptions, respectively for 3- (72 hours) and 7-day time slices, respectively. These results are mapped at TA scale in Section 4. Electricity networks are excluded from this summary due to inconsistencies with more recent studies (refer to section 2.12, (Davies, 2019)). Note that the underlying continuation of seismic and coseismic hazards is considered in this study, leading to an increase in some network damage, and a decreased level of service, at 7 days compared with 72 hours.

2.11.1. 72 hours

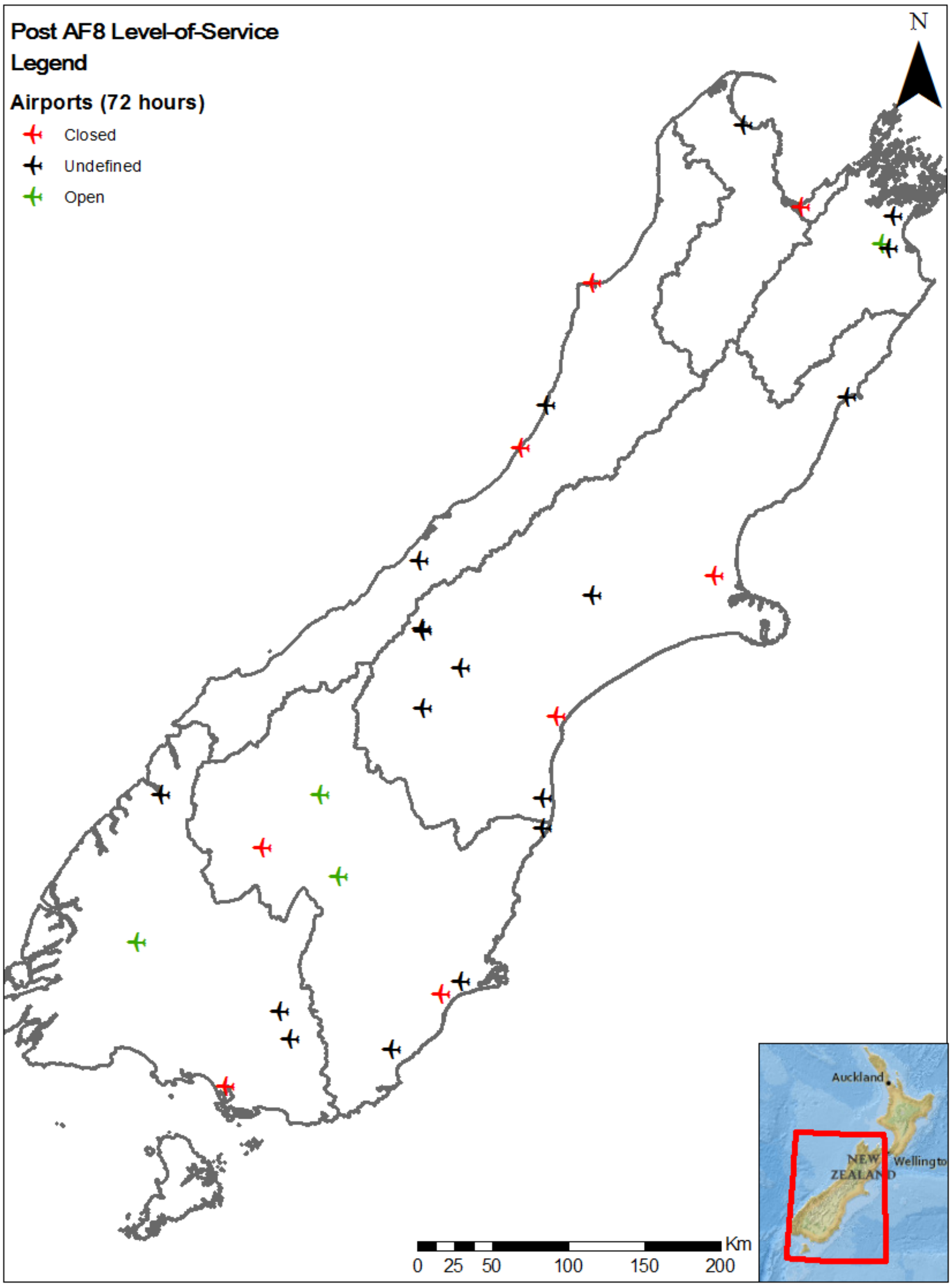

Figure 25: Airport functionality level within 72 hours of AF8 event.

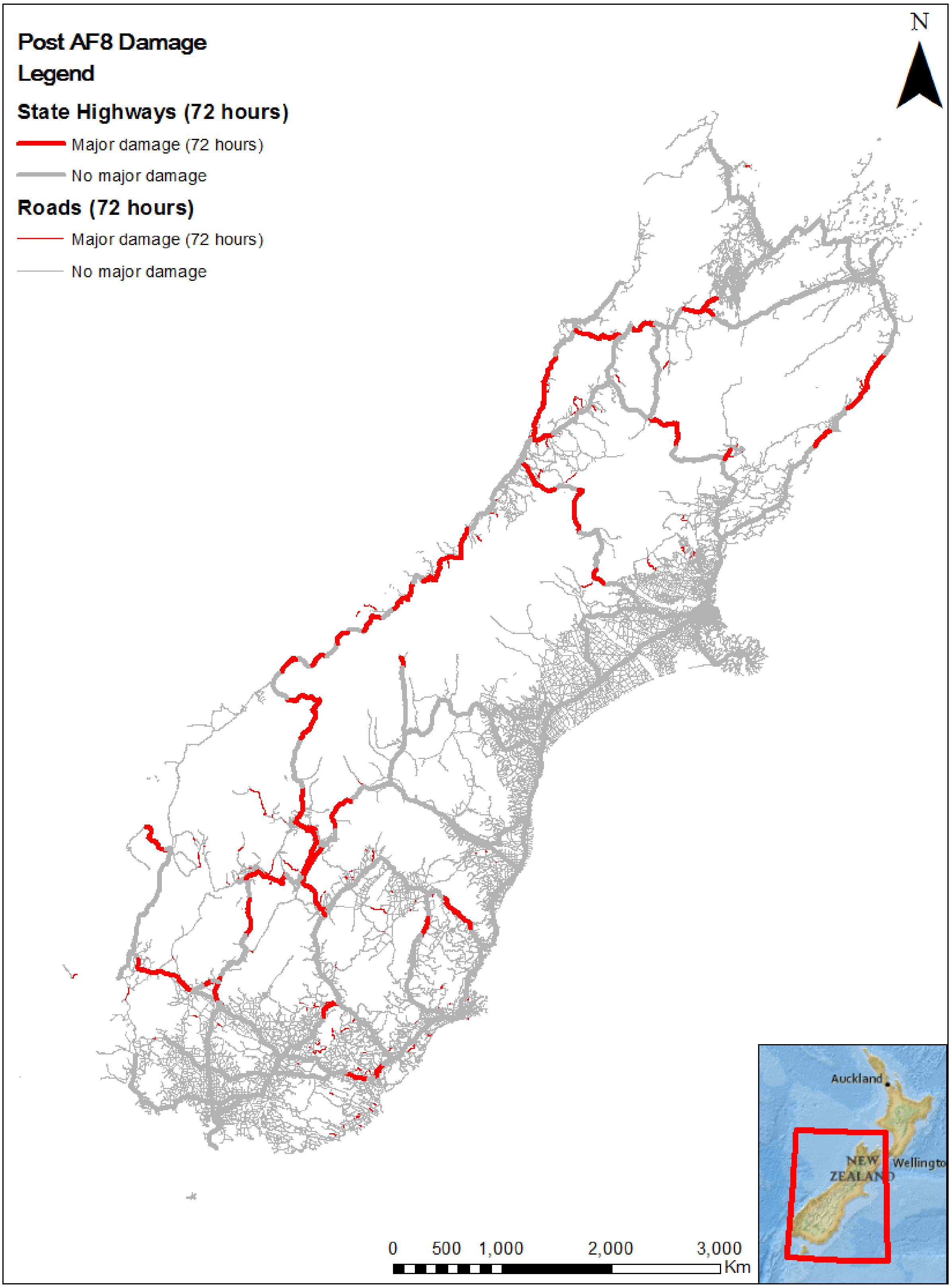

Figure 26: Road damage levels within 72 hours of an AF8 event.

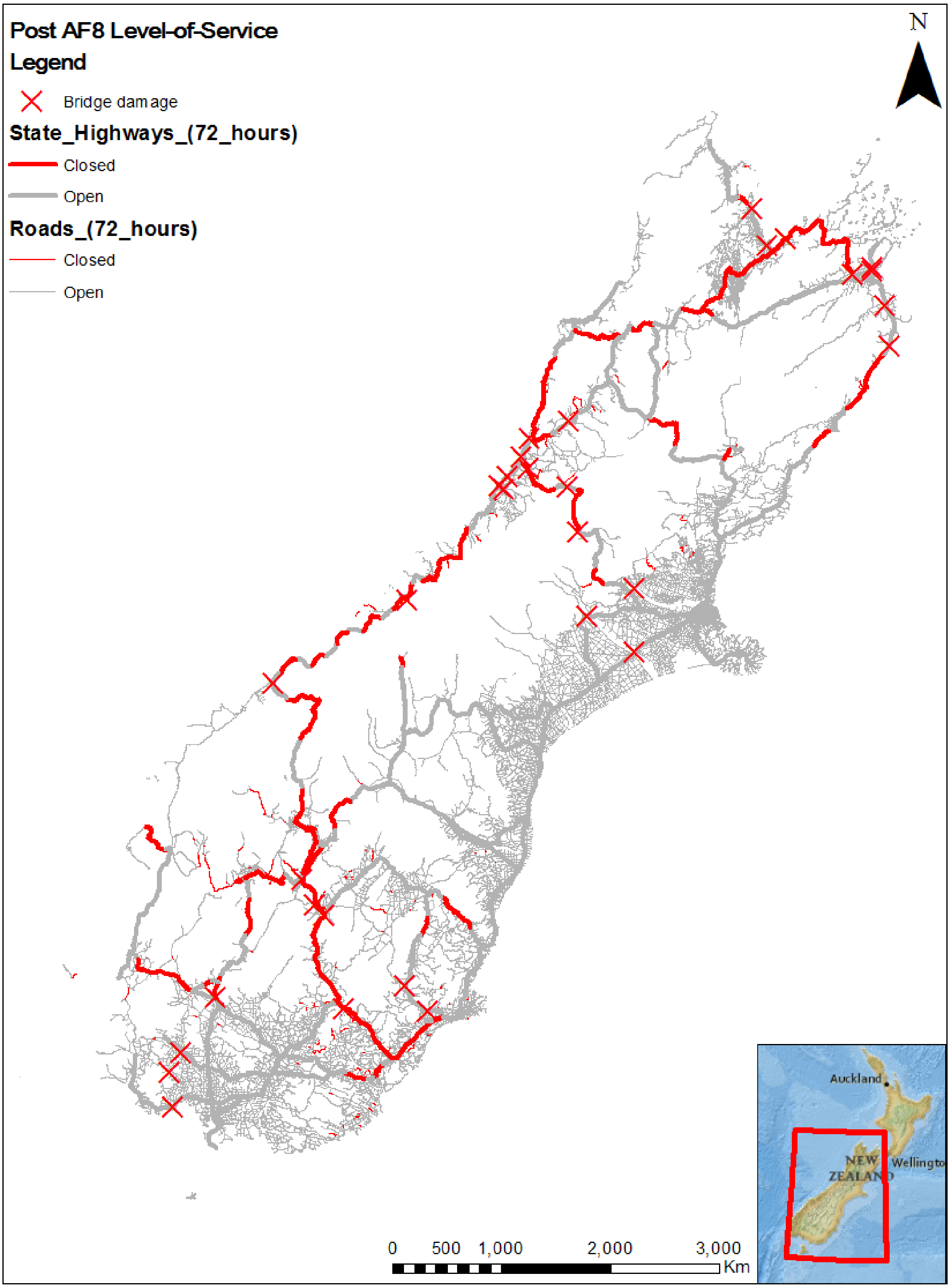

Figure 27: Road service levels within 72 hours of an AF8 event.

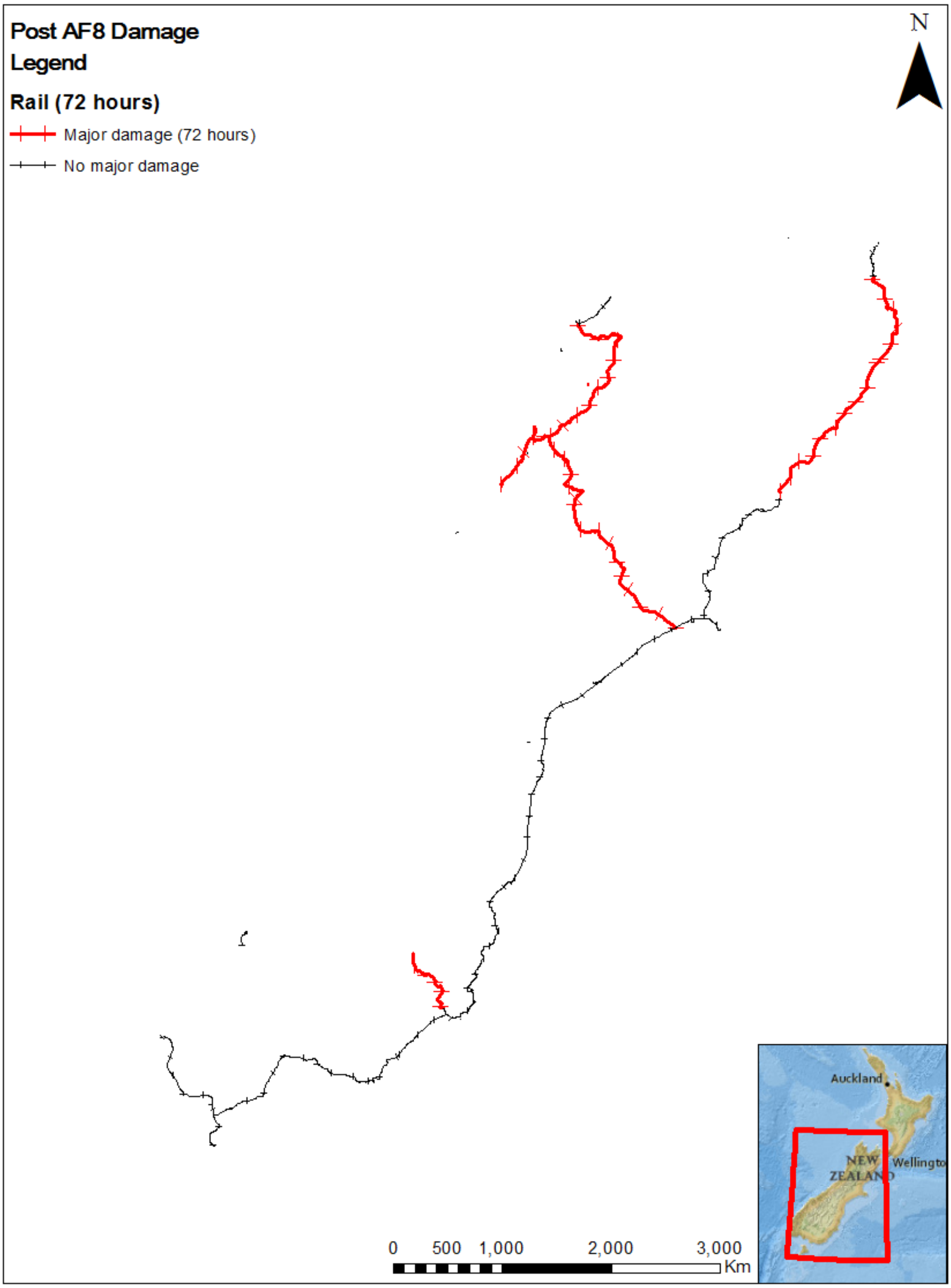

Figure 28: Rail damage levels within 72 hours of an AF8 event.

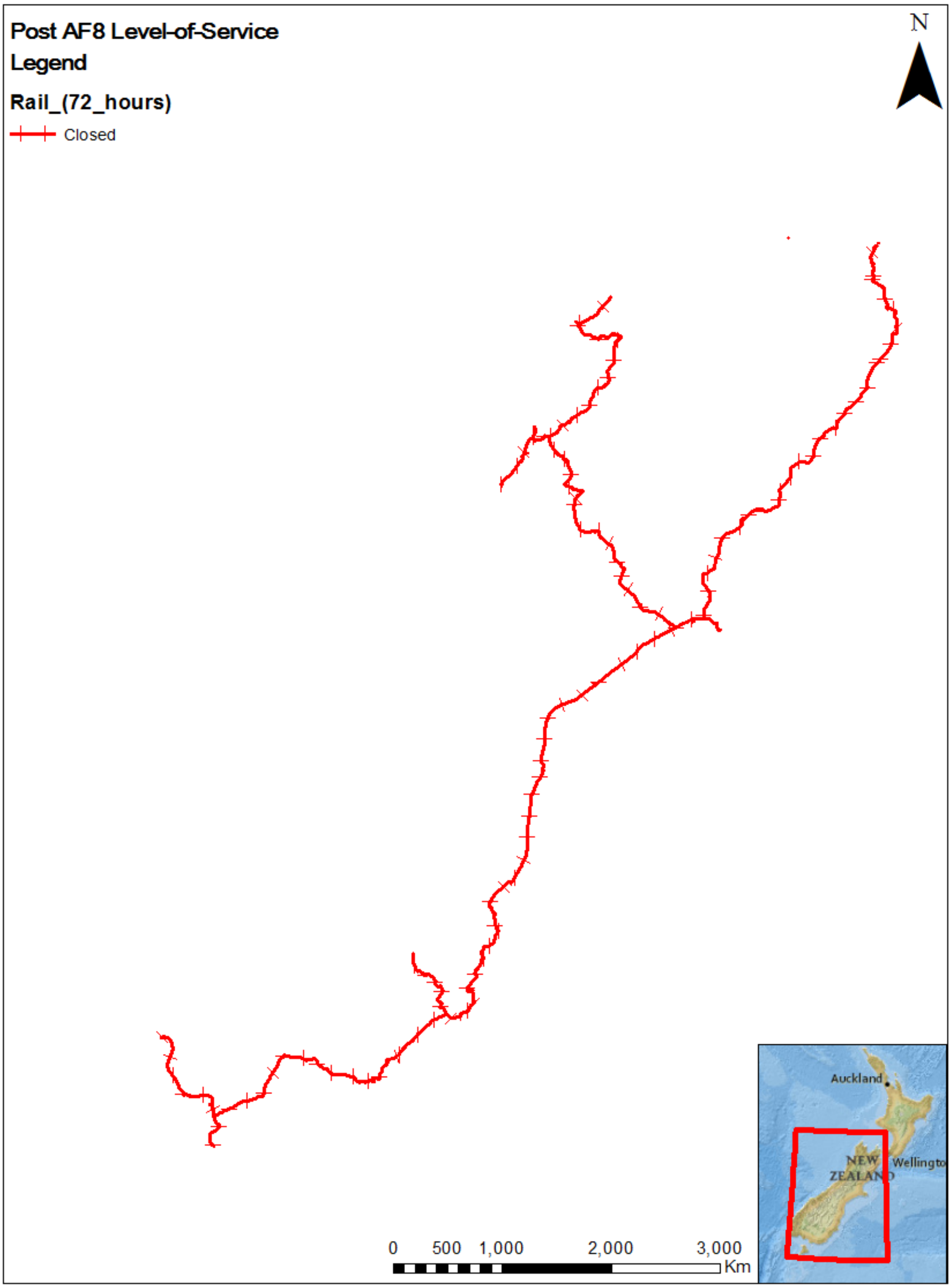

Figure 29: Rail service levels within 72 hours of an AF8 event.

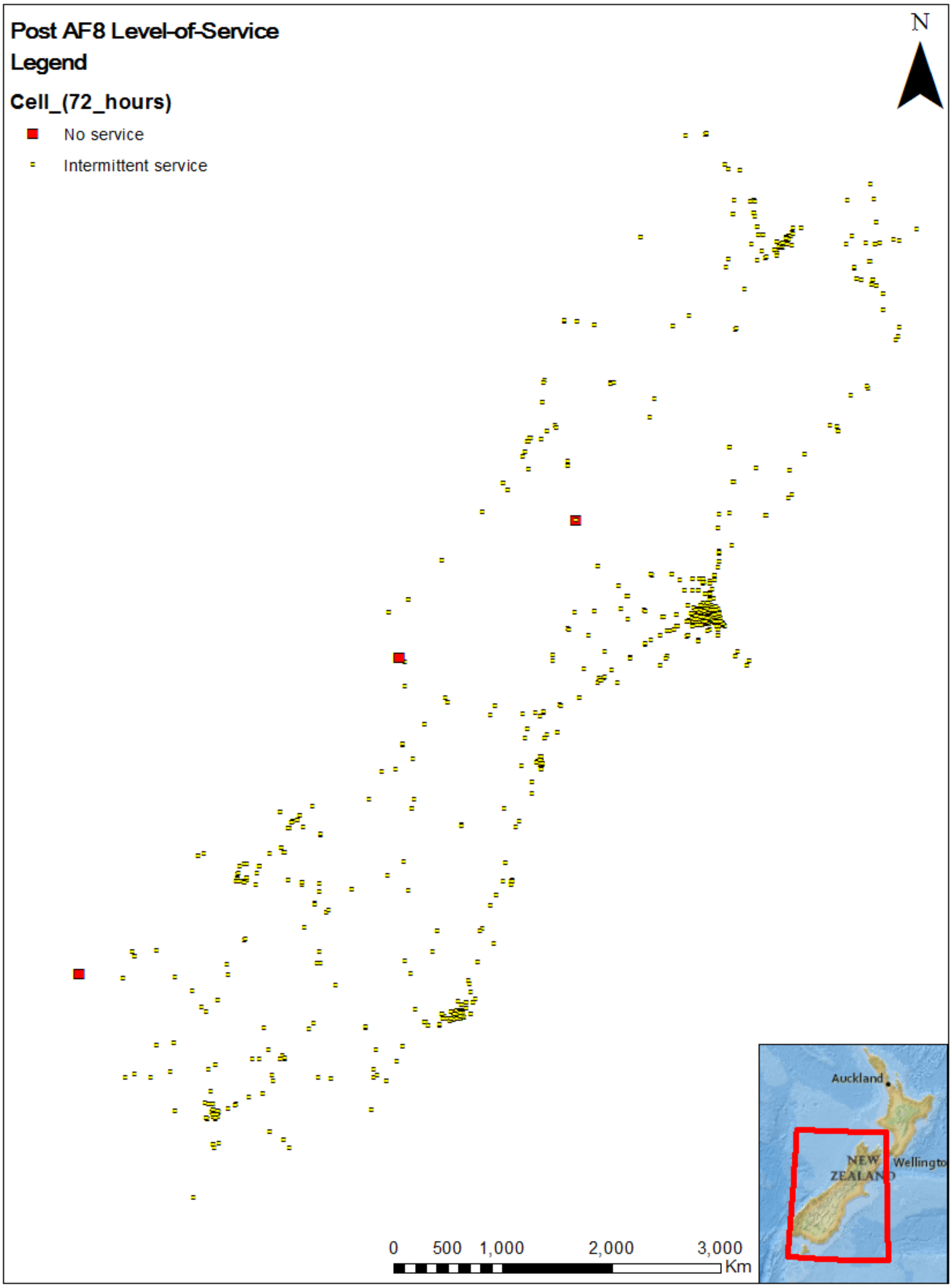

Figure 30: Telecommunication component damage levels within 72 hours of an AF8 event.

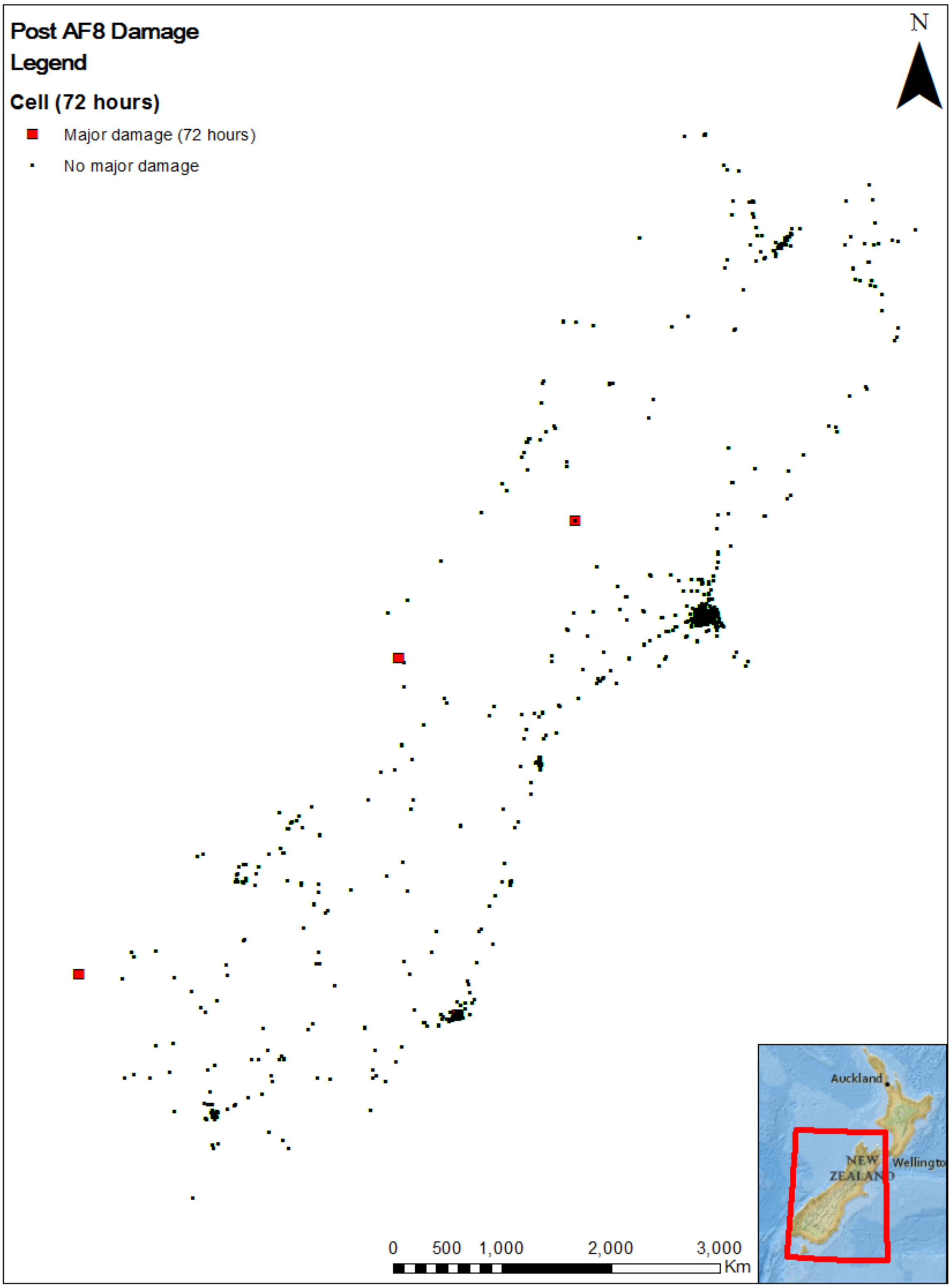

Figure 31: Telecommunication component service levels within 72 hours of an AF8 event.

2.11.2. 7 Days

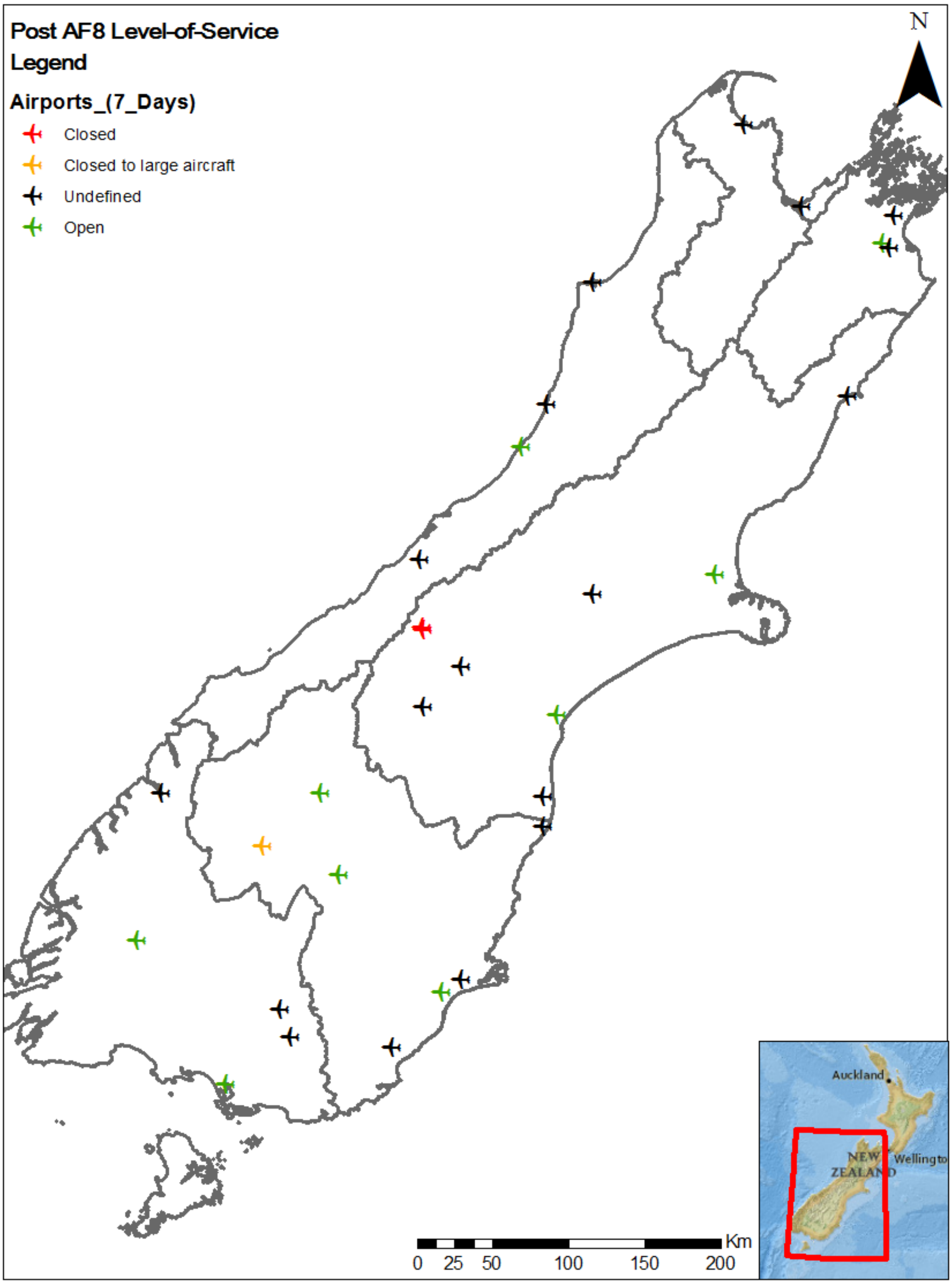

Figure 32: Airport service levels within 7 days of an AF8 event.

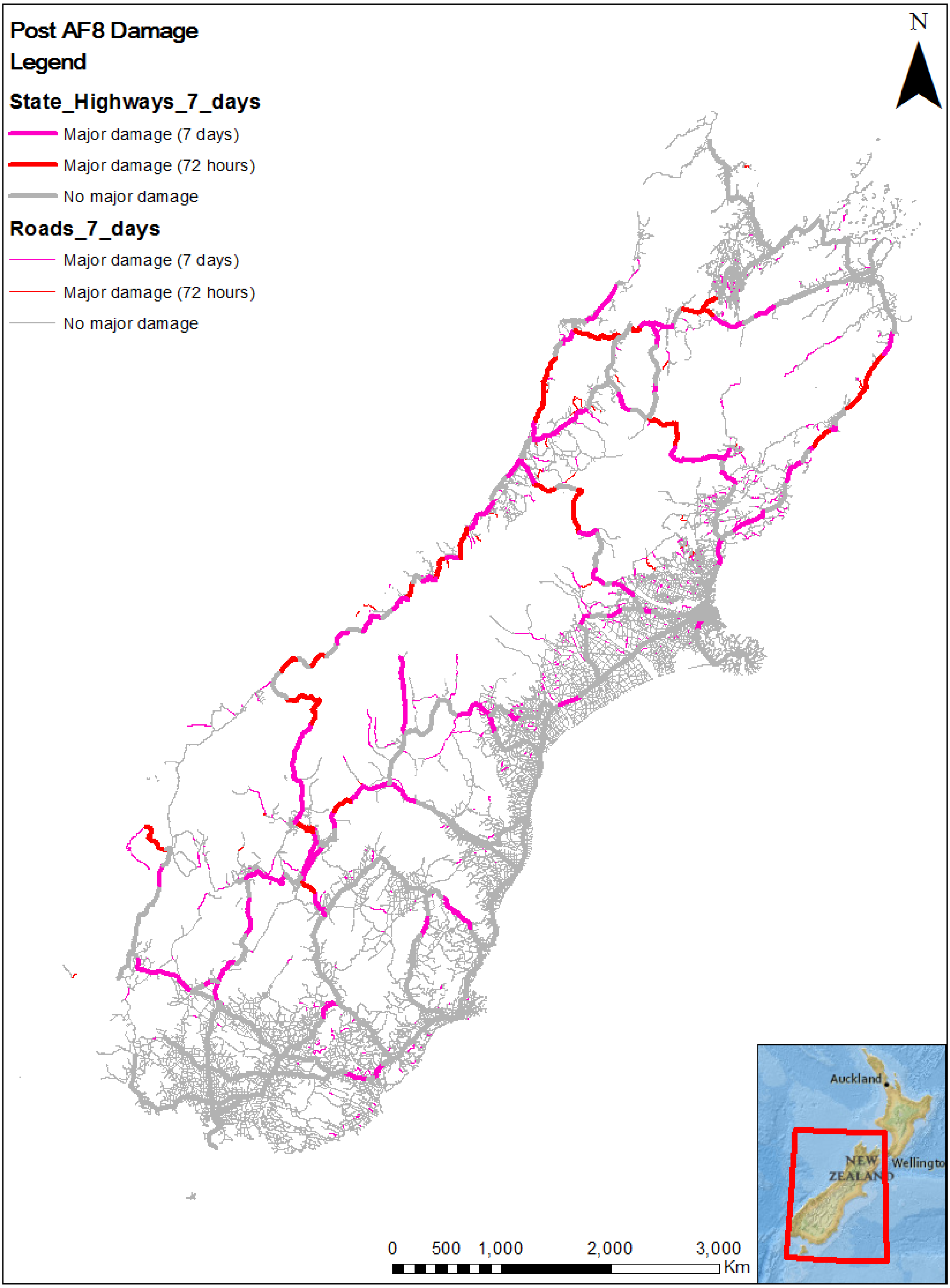

Figure 33: Road damage levels within 7 days of AF8 event. Note that the underlying continuation of seismic and coseismic hazards are considered in this study, leading to an increase in damage to roads at 7 days compared with 72 hours.

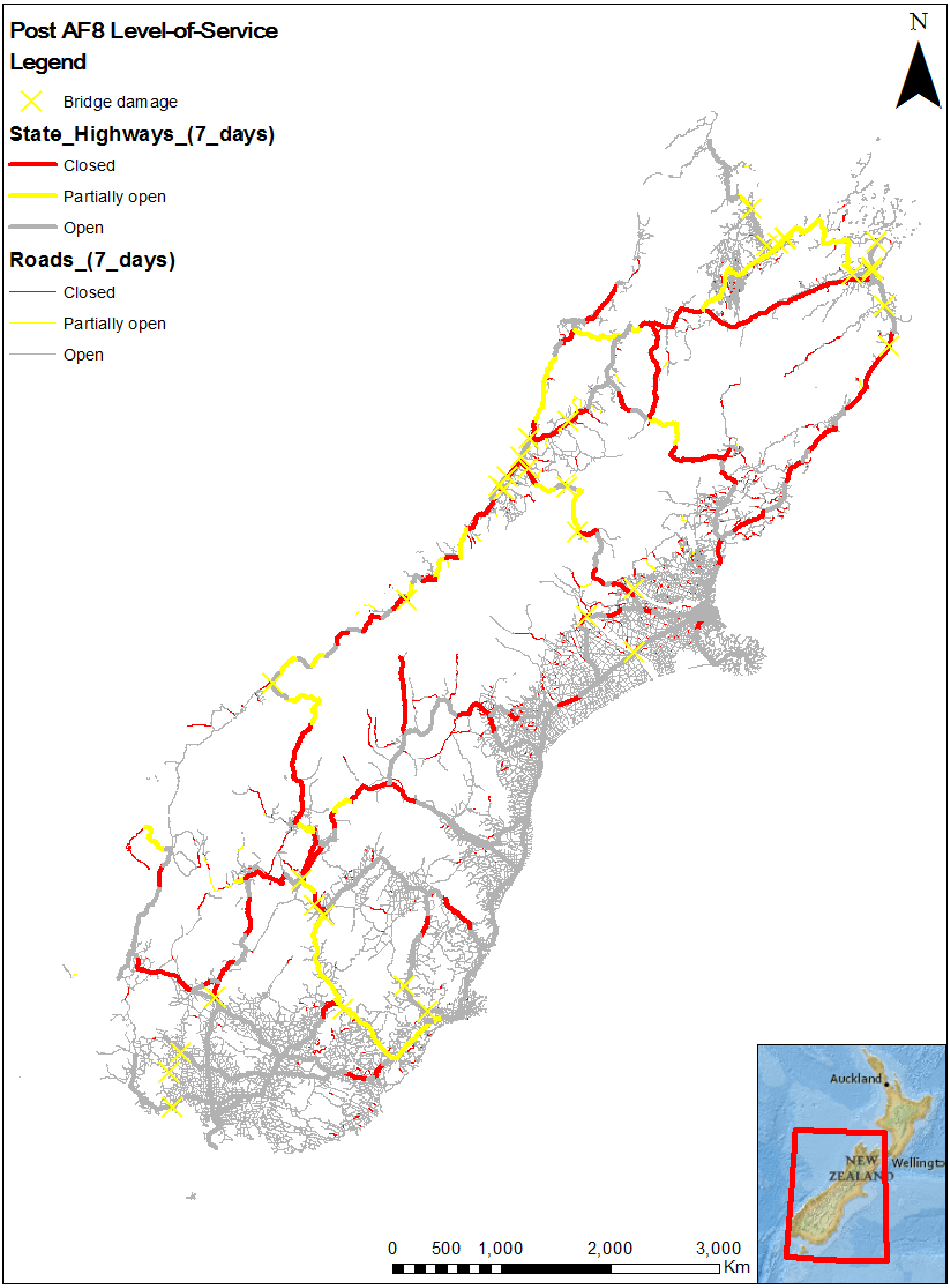

Figure 34: Road service levels within 7 days of AF8 event. Note that the underlying continuation of seismic and coseismic hazards are considered in this study, leading to an increase in damage to roads, and a decreased level of service, at 7 days compared with 72 hours.

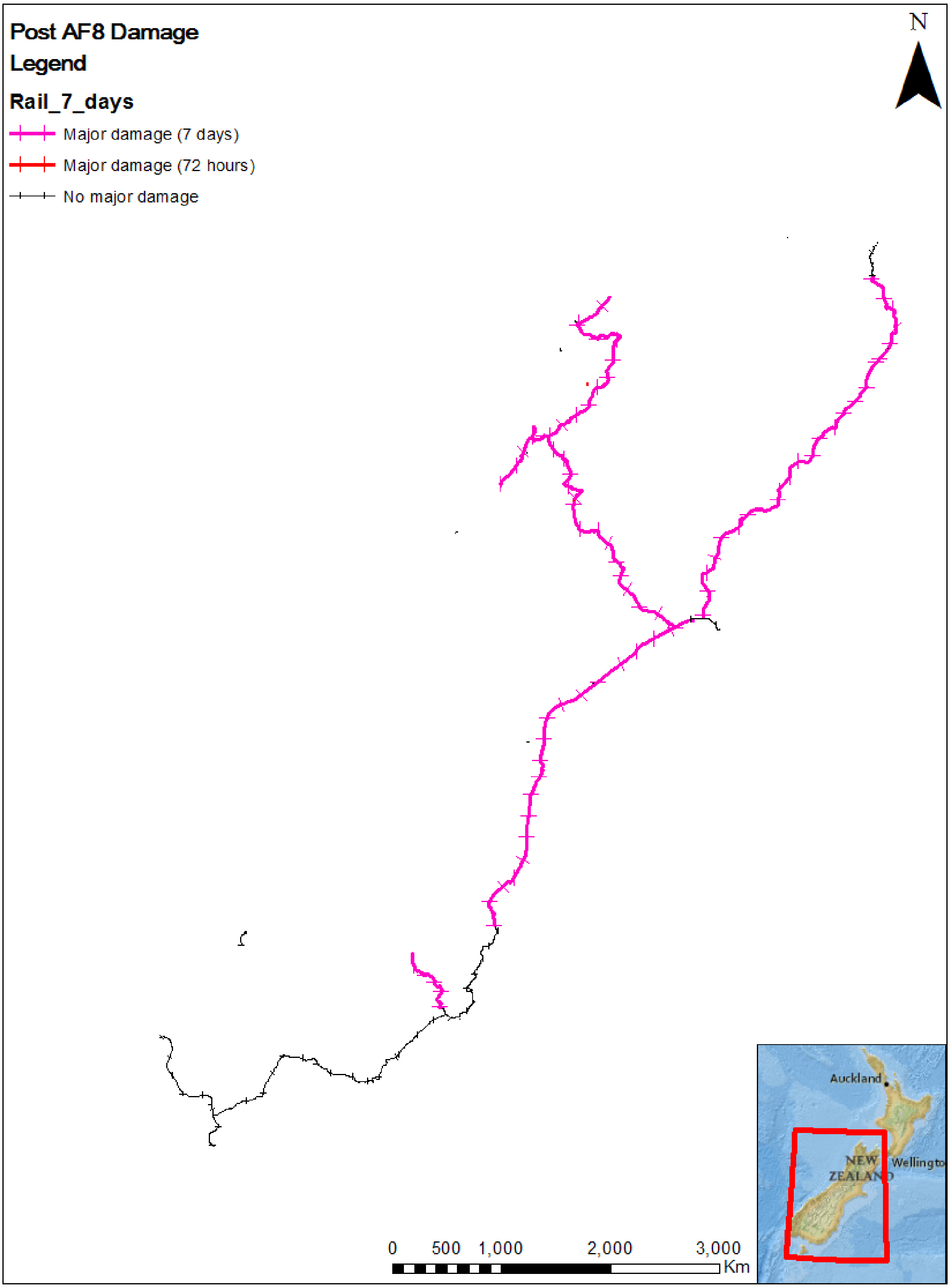

Figure 35: Rail damage levels within 7 days of AF8 event. Note that the underlying continuation of seismic and coseismic hazards are considered in this study, leading to an increase in damage to rail at 7 days compared with 72 hours.

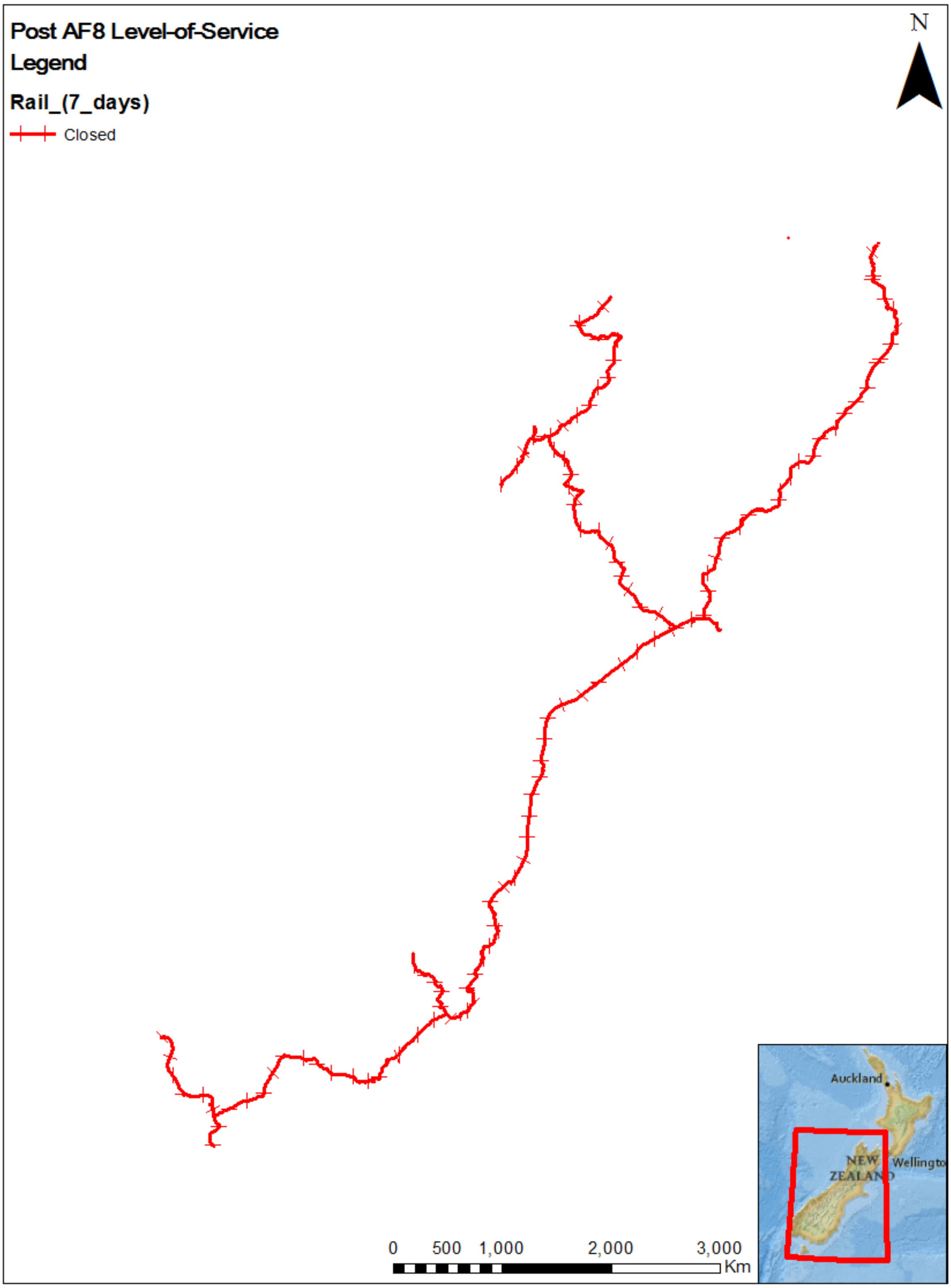

Figure 36: Rail service levels within 7 days of AF8 event.

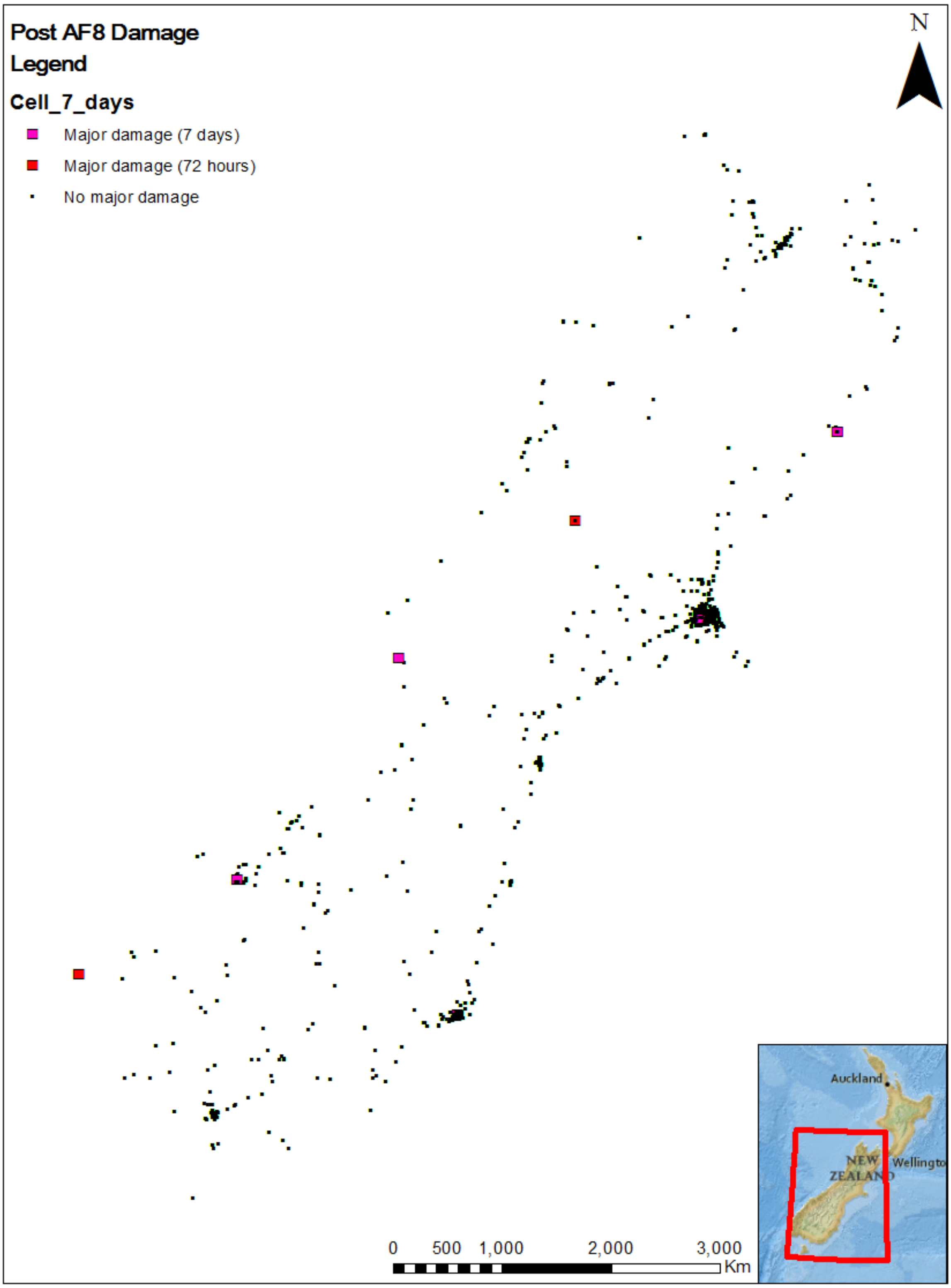

Figure 37: Telecommunication component damage levels within 7 days of an AF8 event. Note that the underlying continuation of seismic and coseismic hazards are considered in this study, leading to an increase in network damage at 7 days compared with 72 hours.

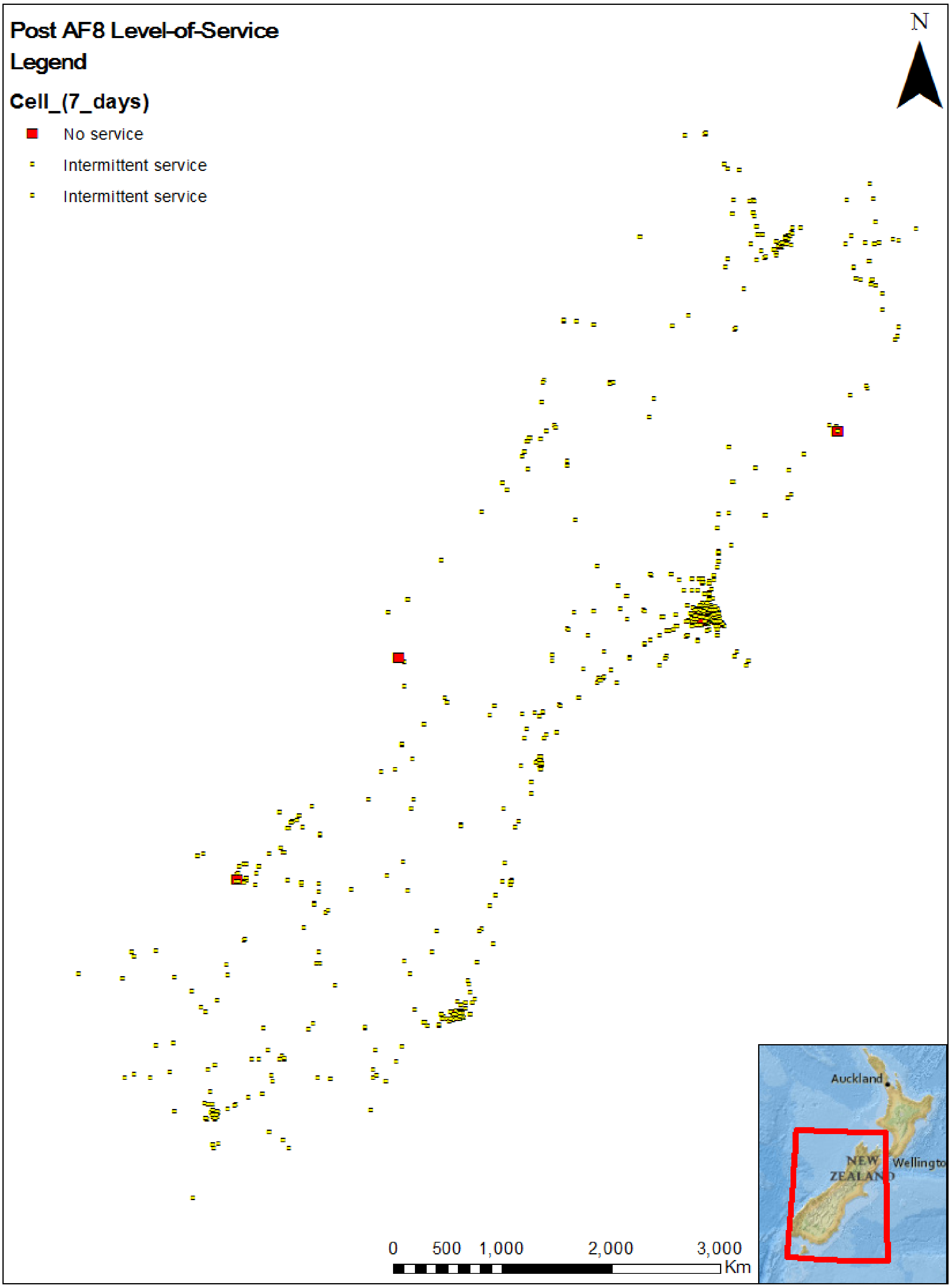

Figure 38: Telecommunication component service levels within 7 days of an AF8 event. Note that the underlying continuation of seismic and coseismic hazards are considered in this study, leading to an increase in network damage, and a decreased level of service, at 7 days compared with 72 hours.

2.12. Increasing the disaster resilience of remote communities through scenario co-creation (AF8+) - (Davies, 2019)

This PhD thesis develops a scenario-based participatory approach that produced network outages over time, for a deterministic AF8 scenario. This body of work, now coined the "AF8+" scenario, was co-created and used to enable discussion and collaboration within workshops. It was designed to provide an example of an extreme earthquake for response and recovery planning in the South Island of New Zealand, with a primary focus on the West Coast and specifically Franz Josef township. The work does, however, still consider Canterbury in detail. The AF8+ scenario was compiled using the best scientific knowledge currently available (Orchiston et al., 2016). Recovery strategies and service levels were estimated in workshops for this AF8+ scenario only. Utilising the AF8+ earthquake scenario, this study simulates hazard exposure, asset failure and recovery of interdependent critical infrastructure networks. The temporal impact results of this study are summarised in the maps presented below.

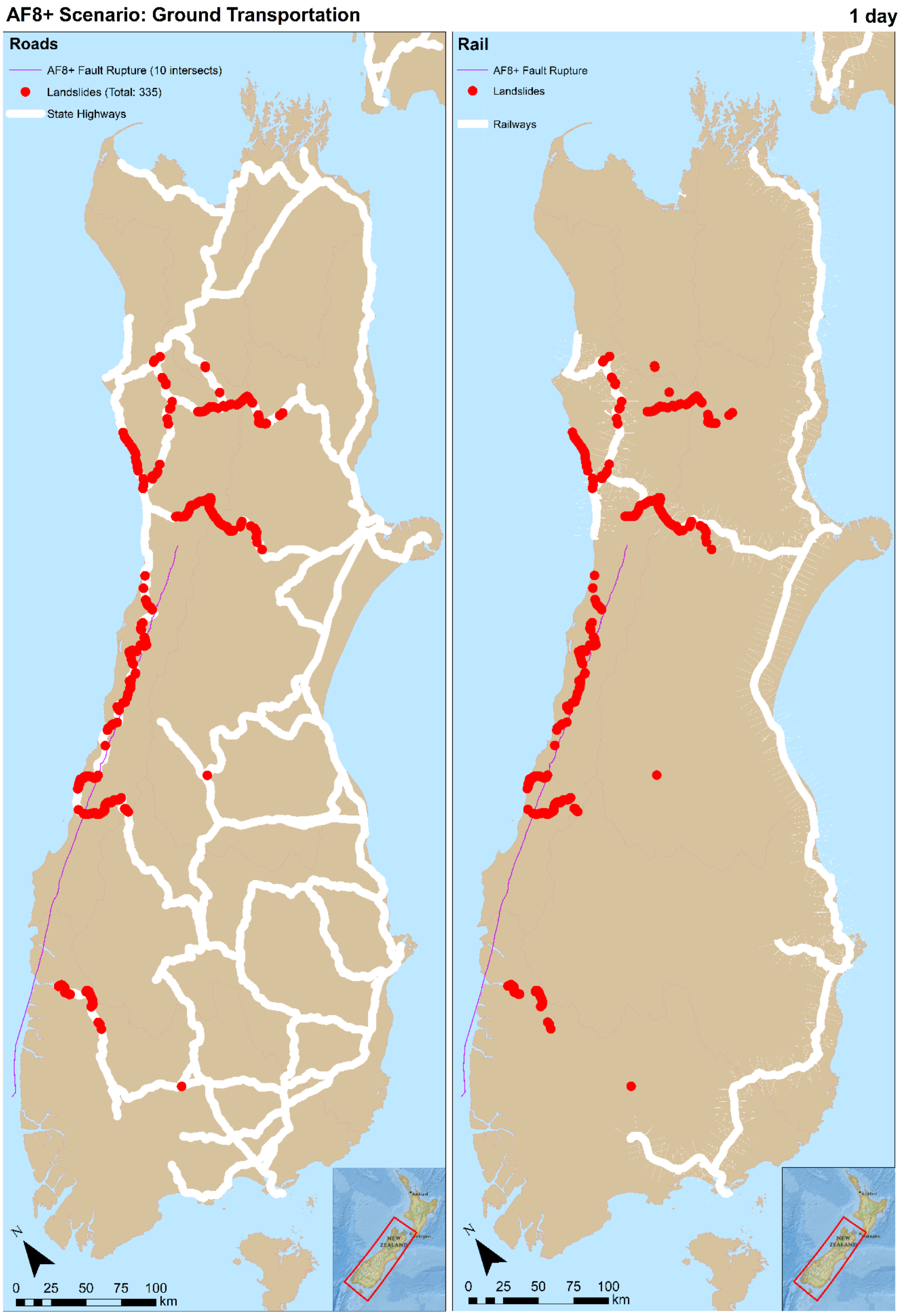

Figure 39: The AF8+ hazard map for State Highways and rail lines (T = 1 day), (Davies, 2019).

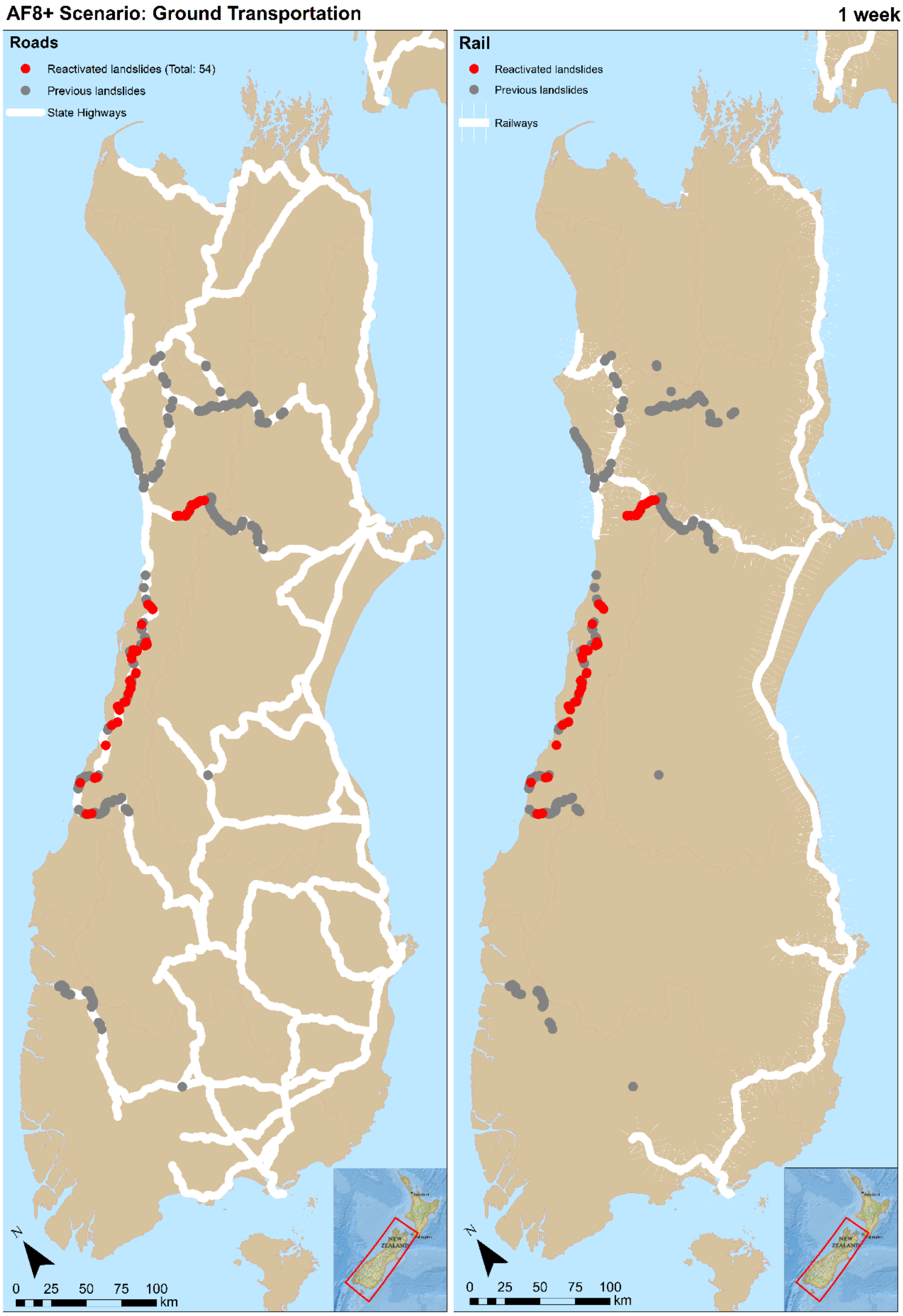

Figure 40: The AF8+ hazard map for State Highways and rail lines (T = 1 week) (Davies, 2019).

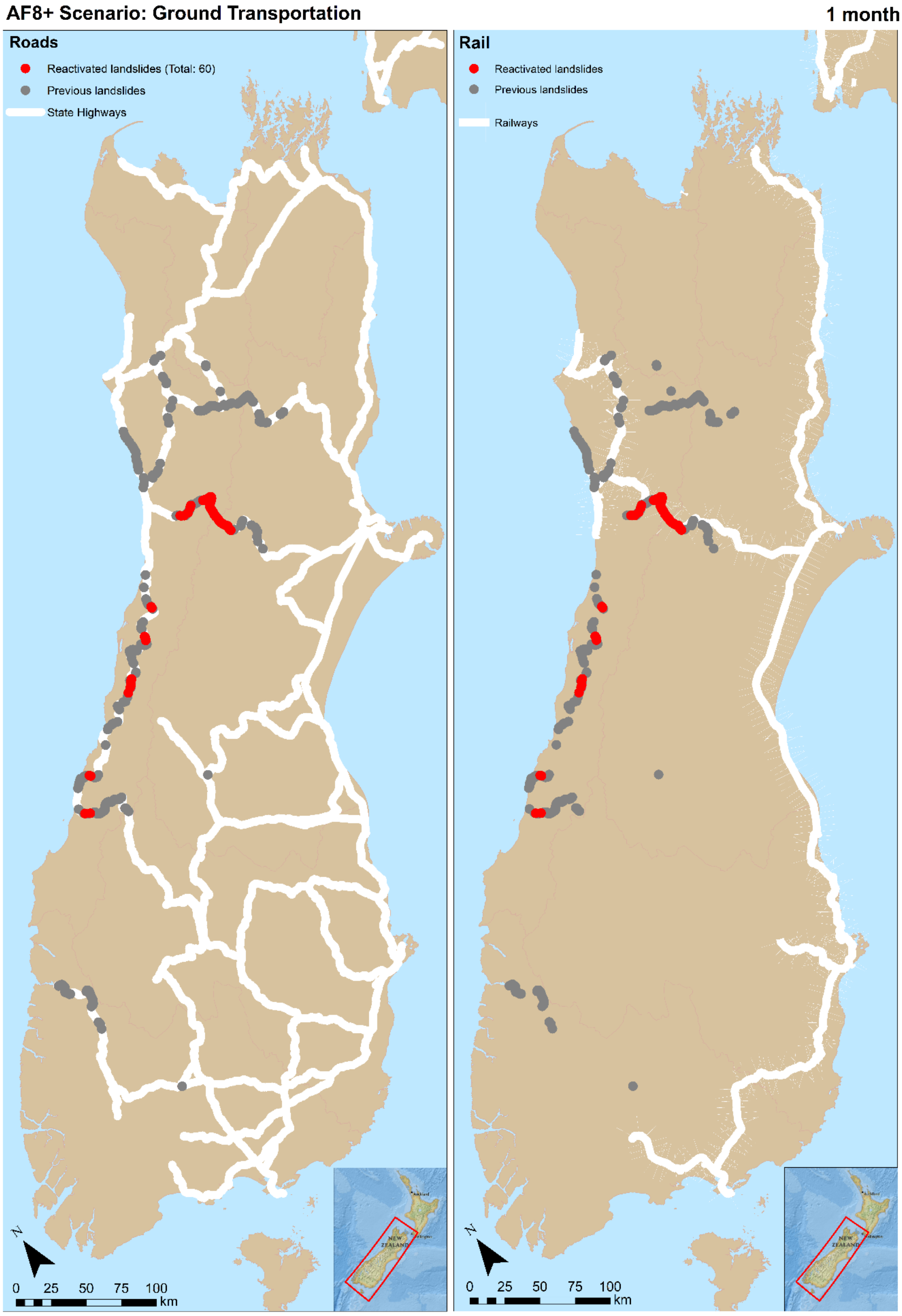

Figure 41: The AF8+ hazard map for State Highways and rail lines (T = 1 month) (Davies, 2019).

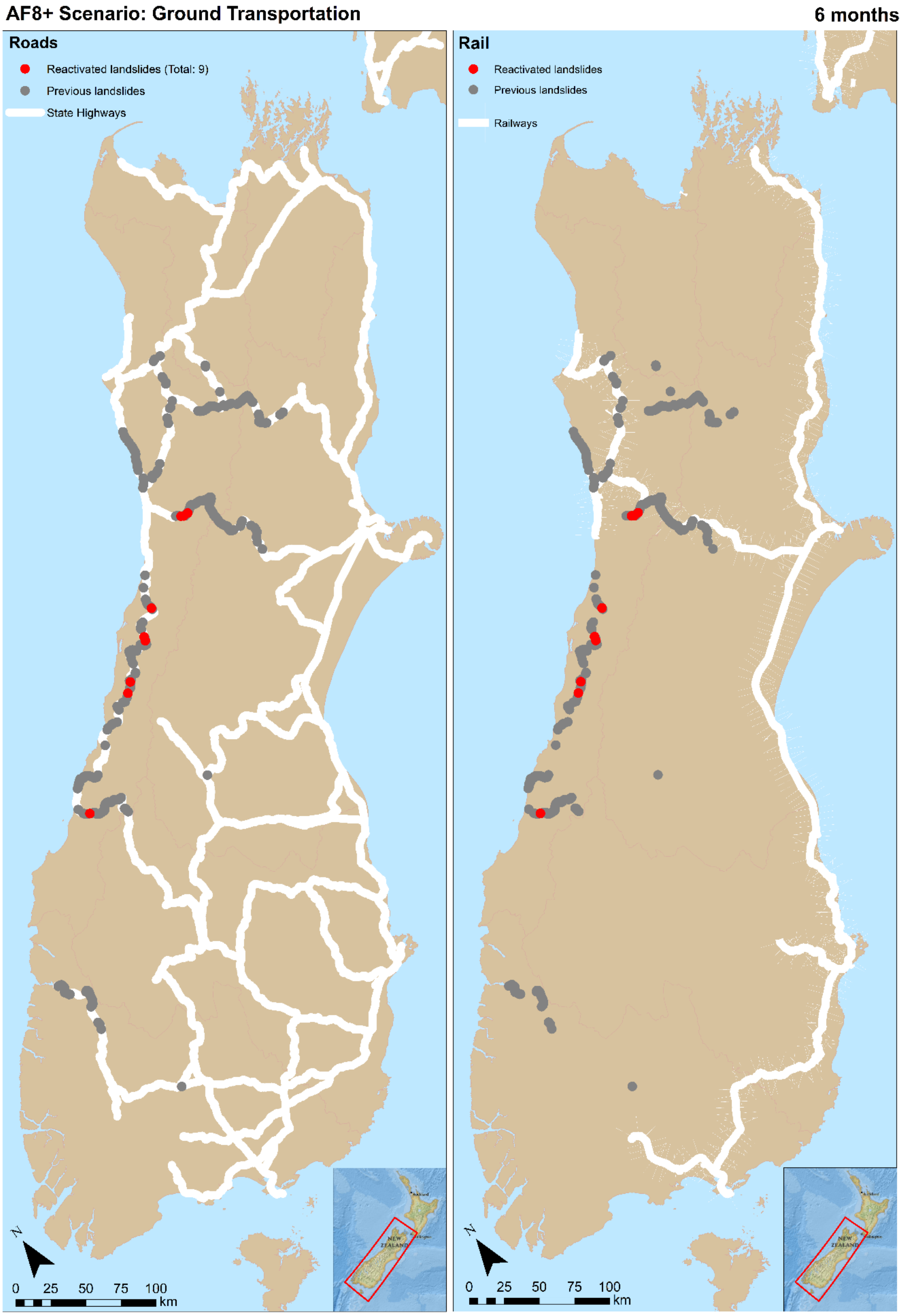

Figure 42: The AF8+ hazard map for State Highways and rail lines (T = 6 months) (Davies, 2019).

Figure 43: The AF8+ hazard map for State Highways and rail lines (T = 1 year) note Davies (2019) presents this data forecast out to 10 years, this was not included in the current report as the impacts beyond 1 year are outside of the Canterbury region (Davies, 2019).

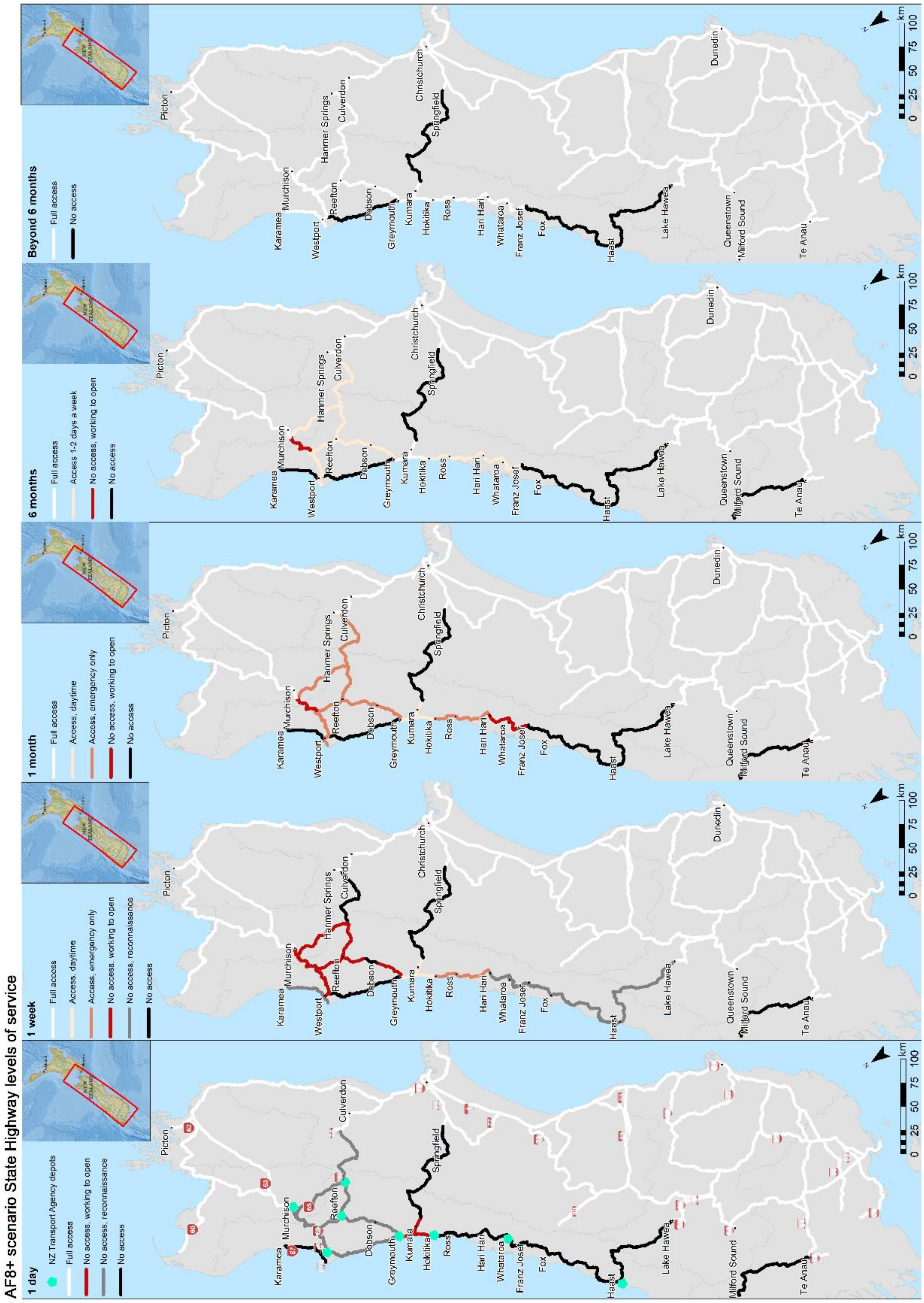

Figure 44: The co-created AF8+ impact maps for South Island state highways' service levels (Davies, 2019).

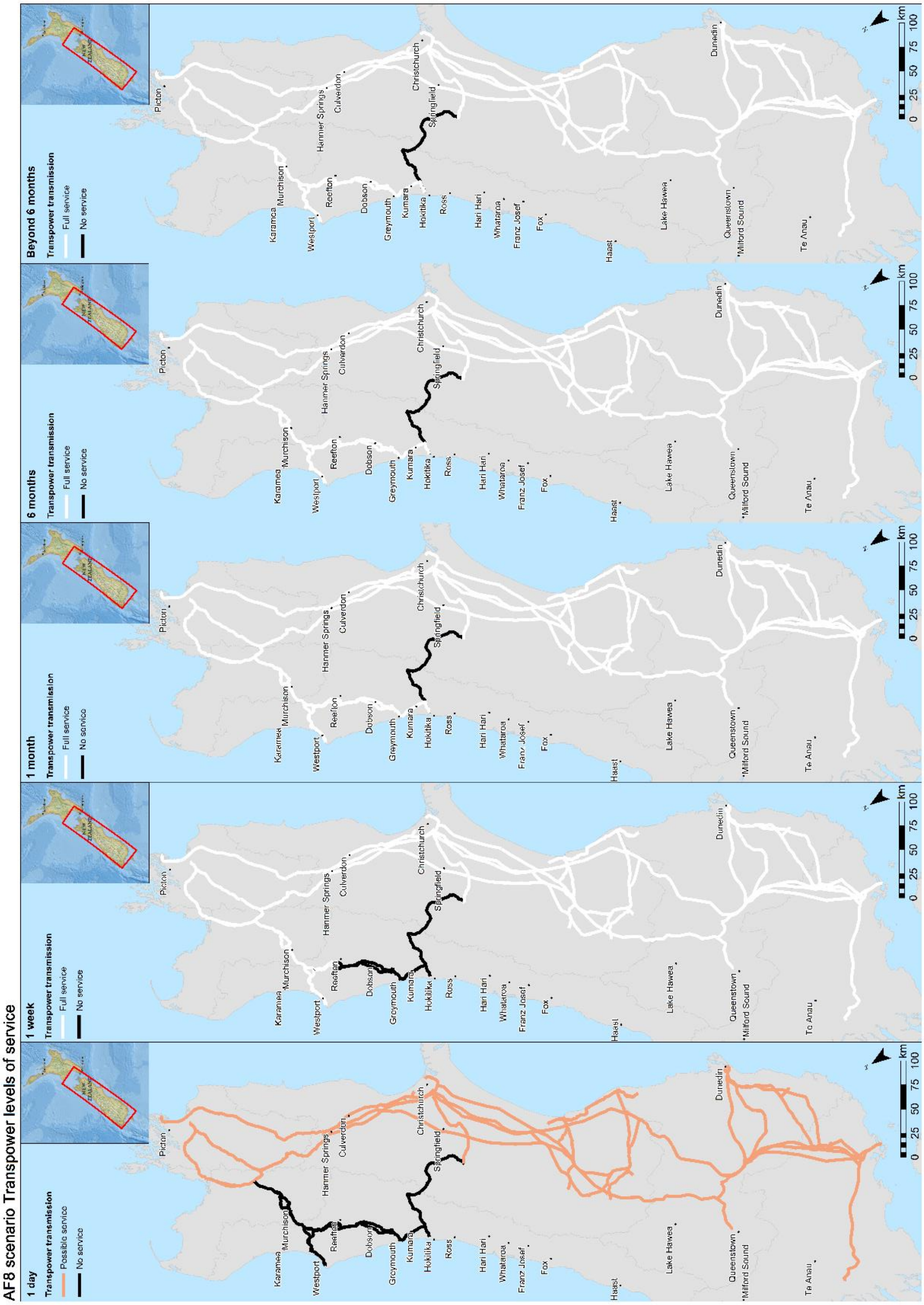

Figure 45: The co-created AF8+ impact maps for South Island electricity transmission service levels (Davies, 2019).

South Island rail network outages were also established in this study but are not shown because it was expected that there would be no rail service on the East-West line, including the West Coast, west of Springfield for several years.

2.13. Vulnerability of New Zealand Ports to Natural Hazards - (Ragued et al., 2012)

This study is not AF8 specific, however, it does provide a systematic hazard assessment for the major ports in Canterbury which can provide an indication of their performance for an AF8 event. Note that there are no supporting maps for this study.

Evidence from previous earthquakes indicates that significant damage at ports occurs as a result of liquefaction in the ground backing the berthing structures. This is often due to the presence of saturated cohesionless soils which are the most susceptible to liquefaction. Furthermore, it is common for ports to be situated on non-engineered reclaimed land thus increasing their vulnerability to ground failure. Consequently, understanding the reclamation history of a port is important in reviewing its vulnerability to seismic hazards. In New Zealand, all the ports are located on reclaimed land of varying age and quality. The majority of the reclamations immediately backing the wharves have been constructed after the 1950s. However, in several cities, the land outside of the port was reclaimed in the 1800s and early 1900s and consequently is predicted to be of poor quality considering the rudimentary construction techniques used to reclaim the land. Major ports in the South Island may be affected (Nelson, Marlborough, Timaru, Otago, Lyttelton). And Lyttelton Port (Christchurch) and PrimePort (Timaru) are among those where damage is expected, with shaking > MM7 (Ragued et al., 2012).

2.14. Transportation impact assessment following a potential Alpine fault earthquake in New Zealand. - (Aghababaei et al., 2020)

This work is underpinned by the work of (Davies, 2019) and focuses on changes in travel times due to AF8 transportation impacts. It is based around travel times to districts on the West coast, but also provides an indication of travel disruption in Canterbury.

To estimate the performance of the road network impacted by an AF8 earthquake scenario, this research developed a generalizable methodology to simulate post-disaster transportation impacts on a large regional road network. This includes the base model development and model calibration, as well as validation in a post-disaster situation. Post-disaster corridor and district trip analyses were undertaken using the outputs of the dynamic assignment, including; mean travel time, total travel time, total travelled distance, and flow. The outputs from this model will provide emergency response and transportation organisations with critical information regarding the performance of the network following an AF8 event.

The results of this service disruption assessment are presented in *Figure 46* and the proceeding tables.

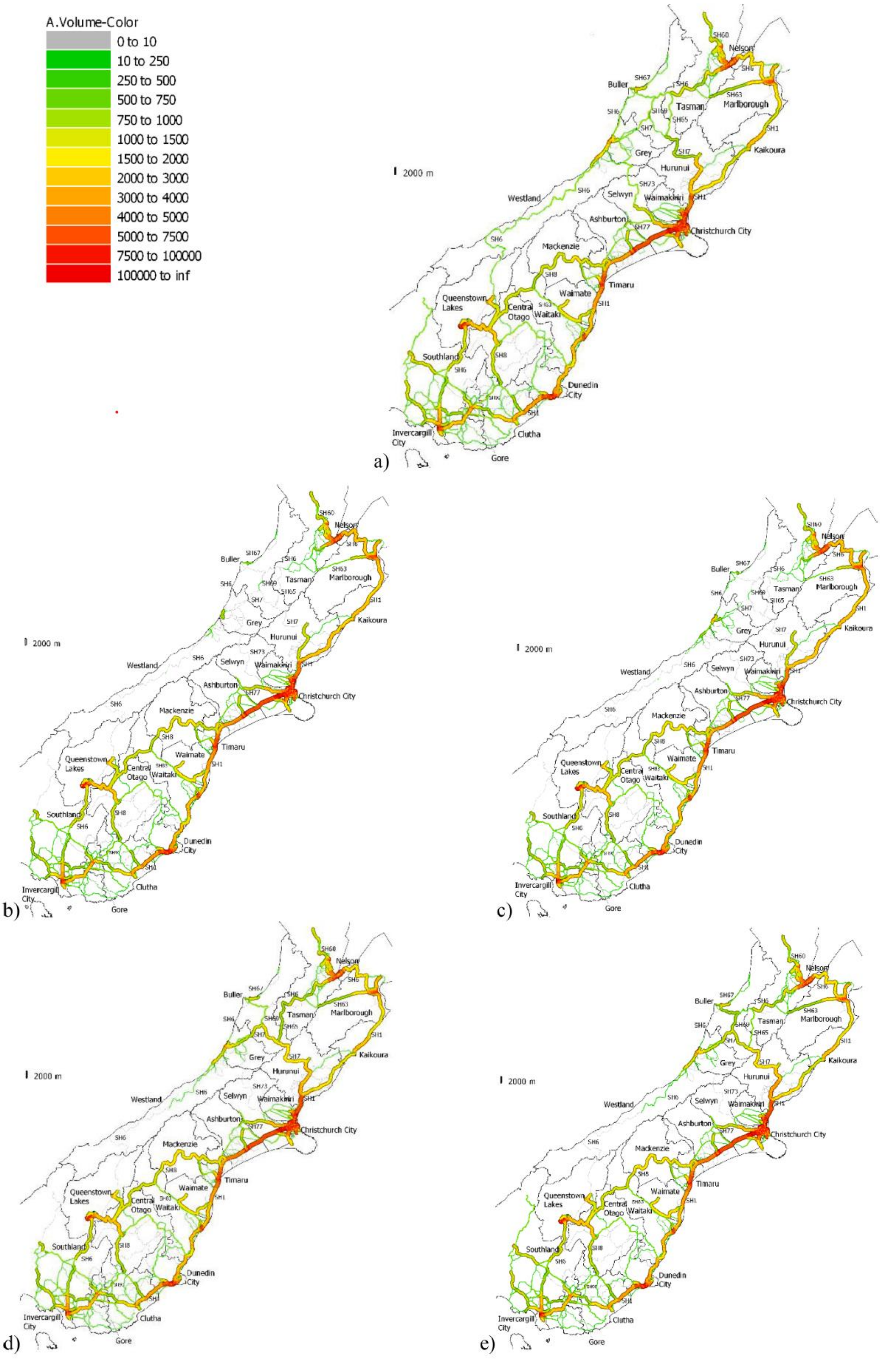

Figure 46: Daily Traffic Count Data (a) BAU, (b) One Day after, (c) One Week after, (d) Six Months after, and (e) Beyond Six Months after AF8 (Aghababaei et al., 2020).

Table 26: Traffic flow and travel time variation from Buller District, comparing four scenarios (Aghababaei et al., 2020).

Districts/Scenarios	BAU TT (min)	Average Travel Time (TT) Variation (min)				BAU Trips (#)	Eliminated Trips (#)			
		Day1	Week1	Month6	Month6 +		Day1	Week1	Month6	Month6 +
Buller	12	−6 (−49%)	−5 (−45%)	−2 (−17%)	−1 (−5%)	4,267	−1622	−1622	−231	−64
Westland	149	Blocked	−53 (−36%)	4 (3%)	19 (13%)	319	−319	−302	−119	−61
Christchurch	253	Blocked	Blocked	−6 (−2%)	8 (3%)	308	−308	−308	−72	−15
Grey	81	Blocked	−19 (−24%)	14 (17%)	38 (46%)	216	−216	−210	−90	−44
Marlborough	238	Blocked	Blocked	64 (27%)	(0%)	145	−145	−145	−35	−4
Queenstown	433	Blocked	Blocked	122 (28%)	142 (33%)	70	−70	−70	−39	−26
Nelson	208	Blocked	Blocked	53 (26%)	−1 (0%)	46	−46	−46	−22	−8
Tasman	206	Blocked	Blocked	48 (23%)	1 (0%)	24	−24	−24	−9	−2
Selwyn	256	Blocked	Blocked	9 (3%)	37 (14%)	23	−23	−23	−9	−3
Waimakariri	211	Blocked	Blocked	−23 (−11%)	6 (3%)	15	−15	−15	−5	0
Ashburton	286	Blocked	Blocked	23 (8%)	54 (19%)	12	−12	−12	−10	−5
Hurunui	150	Blocked	Blocked	2 (2%)	2 (2%)	5	−5	−5	0	0
Timaru	312	Blocked	Blocked	24 (8%)	28 (9%)	4	−4	−4	−2	−2
Dunedin	502	Blocked	Blocked	Blocked	79 (16%)	4	−4	−4	−4	−2
Otago	452	Blocked	Blocked	80 (18%)	80 (18%)	7	−7	−7	−5	−5
Invercargill	595	Blocked	Blocked	13 (2%)	26 (4%)	2	−2	−2	−1	−1
Mackenzie	359	Blocked	Blocked	38 (11%)	43 (12%)	2	−2	−2	0	0
Total	–	–	–	–	–	5,469	−2824	−2801	−653	−242

Table 27: Traffic flow and travel time variation from Westland District, comparing four scenarios (Aghababaei et al., 2020).

Districts/Scenarios	BAU TT (min)	Average Travel Time (TT) Variation (min)				BAU Trips (#)	Eliminated Trips (#)			
		Day1	Week1	Month6	Month6 +		Day1	Week1	Month6	Month6 +
Westland	16	−4 (−26%)	−4 (−24%)	−3 (−16%)	−3 (−16%)	1,785	−159	−74	−33	−33
Grey	57	−11 (−19%)	−20 (−35%)	−10 (−18%)	−10 (−18%)	692	−686	−93	−34	−34
Buller	144	Blocked	−54 (−38%)	6 (4%)	25 (17%)	294	−294	−287	−124	−65
Christchurch	217	Blocked	Blocked	89 (41%)	89 (41%)	201	−201	−201	−27	−27
Marlborough	306	Blocked	Blocked	28 (9%)	−1 (0%)	72	−72	−72	−3	−1
Queenstown	244	Blocked	Blocked	415 (170%)	420 (172%)	44	−44	−44	−32	−31
Nelson	304	Blocked	Blocked	18 (6%)	−12 (−4%)	32	−32	−32	−3	−3
Selwyn	199	Blocked	Blocked	125 (63%)	124 (62%)	21	−21	−21	−5	−5
Tasman	236	Blocked	Blocked	9 (4%)	−4 (−2%)	19	−19	−19	−1	0
Hurunui	293	Blocked	Blocked	5 (3%)	6 (3%)	16	−16	−16	0	0
Waimakariri	218	Blocked	Blocked	76 (35%)	77 (36%)	15	−15	−15	0	0
Southland	435	Blocked	Blocked	338 (78%)	343 (79%)	10	−10	−10	−7	−7
Mackenzie	329	Blocked	Blocked	184 (56%)	187 (57%)	8	−8	−8	−1	−1
Waitaki	380	Blocked	Blocked	207 (54%)	199 (52%)	5	−5	−5	−2	−2
Otago	237	Blocked	Blocked	Blocked	Blocked	3	−3	−3	−3	−3
Kaikoura	270	Blocked	Blocked	11 (4%)	19 (7%)	2	−2	−2	0	0
Ashburton	235	Blocked	Blocked	194 (83%)	201 (85%)	2	−2	−2	−1	−1
Dunedin	431	Blocked	Blocked	212 (49%)	217 (50%)	1	−1	−1	0	0
Total	–	–	–	–	–	3,223	−1,591	−906	−277	−214

Table 28: Traffic flow and travel time variation from Grey District, comparing four scenarios (Aghababaei et al., 2020).

Districts/Scenarios	BAU TT (min)	Average Travel Time (TT) Variation (min)				BAU Trips (#)	Eliminated Trips (#)			
		Day1	Week1	Month6	Month6 +		Day1	Week1	Month6	Month6 +
Grey	9	−2 (−21%)	0 (1%)	0 (2%)	0 (0%)	11,211	−4221	−2	0	−1
Westland	57	−24 (−42%)	−18 (−32%)	−8 (−15%)	−8 (−14%)	668	−659	−92	−27	−27
Christchurch	198	Blocked	Blocked	68 (35%)	68 (34%)	296	−296	−296	−12	−12
Buller	80	Blocked	−23 (−29%)	21 (26%)	42 (52%)	213	−213	−210	−96	−51
Queenstown	378	Blocked	Blocked	204 (54%)	204 (54%)	103	−103	−103	−33	−29
Marlborough	267	Blocked	Blocked	31 (12%)	2 (1%)	77	−77	−77	−1	0
Hurunui	161	Blocked	Blocked	6 (4%)	5 (3%)	35	−35	−35	0	0
Nelson	217	Blocked	Blocked	33 (15%)	1 (1%)	29	−29	−29	0	0
Selwyn	153	Blocked	Blocked	145 (94%)	145 (94%)	22	−22	−22	−2	−2
Tasman	182	Blocked	Blocked	30 (16%)	3 (1%)	12	−12	−12	0	0
Timaru	265	Blocked	Blocked	91 (34%)	91 (35%)	7	−7	−7	0	0
Waimakariri	185	Blocked	Blocked	55 (30%)	55 (30%)	7	−7	−7	0	0
Kaikoura	235	Blocked	Blocked	12 (5%)	12 (5%)	5	−5	−5	0	0
Southland	638	Blocked	Blocked	Blocked	166 (26%)	2	−2	−2	−2	0
Mackenzie	348	Blocked	Blocked	106 (30%)	119 (34%)	2	−2	−2	0	0
Total	–	–	–	–	–	12,689	−5690	−901	−173	−122

Table 29: Eliminated heavy vehicle trips from three most impacted districts comparing four scenarios (Aghababaei et al., 2020).

Table 5
Eliminated Heavy Vehicle Trips from Three Most Impacted Districts Comparing Four Scenarios.

Districts	BAU Trips (#)	Eliminated Trips (#)			
		Day1	Week1	Month6	Month6 +
Buller	287	− 202 (− 70%)	− 184 (− 64%)	− 48 (− 17%)	− 13 (− 5%)
Grey	384	− 330 (− 86%)	− 157 (− 41%)	− 21 (− 5%)	− 17 (− 4%)
Westland	238	− 192 (− 81%)	− 113 (− 47%)	− 25 (− 11%)	− 24 (− 10%)

2.15. New Zealand Critical Lifelines Infrastructure National Vulnerability Assessment - (New Zealand Lifelines Council, 2020)

The New Zealand Lifelines Council has documented some relevant comments on infrastructure lifeline exposure, susceptibility and potential/likely impacts from various AF8 research projects and expert judgement from regional lifelines groups in their 2020 report (New Zealand Lifelines Council, 2020). The relevant parts of this report (i.e. for an AF8 event in Canterbury) are summarised below. The report also provides excellent context to the general vulnerabilities in each of the critical infrastructure networks.

2.15.1. Road

The report notes that for an AF8 event, roads and bridges are likely to be damaged and seriously obstructed in the areas of the most severe shaking. Large parts of the South Island normally accessed through alpine passes or steep-sided valleys nearer to the Alpine Fault will be inaccessible by road, potentially for weeks to months. The SH 1 Kaikōura Corridor (road and rail in a narrow corridor) is particularly vulnerable to slips from rainfall and earthquakes. SH6, 7 & 73 provide the only links to the West Coast and damage to one, or all of these is highly likely in a major earthquake event, potentially isolating the West Coast from Canterbury (and other regions) completely. The Lyttelton Tunnel (Christchurch) and access roads are susceptible to coseismic landslide impacts. Figure 47 displays the critical transportation assets for the South Island.

2.15.2. Rail

The Kaikōura Corridor in the South Island is included as one of three nationally significant pieces of the rail network. A disruption to the rail tracks north of Christchurch would result in goods being sent by road inland – which itself is then reliant on the road network status. Within two weeks following the 2016 Kaikōura earthquake, KiwiRail entered into coastal shipping freight market with a NZ Connect Service to quickly move domestic freight from Auckland to Christchurch and reduce reliance on trucks. Rail vulnerabilities are similar to those discussed in the Roads section.

2.15.3. Port

The scenario most likely to affect several ports is a rupture in the northern section of the Alpine Fault with Lyttelton Port and PrimePort expected to experience MMI intensities of VII.

2.15.4. Airport

Auckland and Christchurch are the only two hubs for international USAR assistance. Kaikōura Aerodrome became critical infrastructure following the 2016 Kaikōura earthquake for moving supplies and evacuating people – sites of similar post-event significance should be identified for a wider scenario. Hokitika, Greymouth, Westport, Manapōuri, Milford, Queenstown, Wānaka, Glentanner, Mt Cook, Twizel and Tekapo Airports may be compromised in an AF8 event (and most other airports in the South Island will need to be inspected before operation) making those that are operational post-event even more critical.

Figure 47: Critical South Island transport assets, including Road criticality levels.

2.15.5. Electricity

In an AF8 event, electricity throughout the South Island will be affected with blackouts likely within at least 150 km of the Alpine Fault and intermittent supply in areas considerably distant. The supply to the North Island may be affected. Most hydro generation plants will shut down with some damage expected. Many substations will be heavily damaged. Landslide dams can form and then fail, creating risks to downstream facilities.

The national grid passes through areas vulnerable to all New Zealand's major natural hazards. The majority of the South Island's generation sources have proximity to the Alpine Fault. Most transmission lines span lattice steel towers which are robust and not expected to incur damage from seismic or flood activity unless there is major ground rupture or landslip at the foundation. Furthermore, as noted earlier, most of the network can be supplied from more than one line (though sometimes the second circuit is on the same tower). However, there are several places where space is constrained and towers are being replaced by pole structures, although these are not specified in the report.

The smaller distribution networks are a combination of overhead lines and underground cables – the former tend to be more resilient to seismic activity and faults are relatively easy to find whilst underground cables are more resilient to wind/flood risk but can break with seismic movement and take more time to repair. Some are older and less resilient to ground movements. Transmission substations are subject to high design standards and are likely to survive an earthquake or at least be repairable, though distribution substations are more variable. Hydro generation is potentially vulnerable to the impact of earthquake shaking on lake sediment and water turbidity which has the potential to close generation plants. Further information on these resilience issues will be sourced as part of Stage 2 (New Zealand Lifelines Council, 2020).

2.15.6. Telecommunications

The 2016 Kaikōura earthquake caused significant damage to the eastern core fibre route used by Chorus, Spark and Vodafone. Kaikōura was effectively isolated from outside communications and the failure put a lot of pressure on the one remaining South Island fibre link to the west. The only intact fibre link in the Kaikōura area was offshore - the Vodafone 'Aqualink' cable, which provides express capacity from Christchurch to Wellington. As a result of collaboration between the three parties, the Aqualink was able to be modified to provide service into Kaikōura and restore some diversity in the core network. So, these will likely again be susceptible to coseismic hazard impacts during and after an AF8 event.

As a network, the sector is most vulnerable to power outage. The main exchanges and cell sites have battery and diesel generators on-site and all sites have battery backup which will operate from anywhere between a couple of hours and several days depending on factors such as traffic and battery age. In a major, prolonged power outage, fuel and access for re-fuelling become critical. Even with the main telecommunications networks operating on backup power, many homes rely on power for phone and internet. Land displacement snaps fibres and damages bridges carrying cables. Another risk that surfaced in Christchurch, and more recently in Wellington following the 2016 Kaikōura earthquake, was the vulnerability of the building stock housing telco equipment.

The major transmission sites are illustrated in *Figure 48*. Loss of these sites could impact transmission capability, to large areas and regions. For this reason, Kordia has invested significantly in resiliency by way of geographical and technological diversity (fibre and Radio) into these sites and centres. Kordia's sites, network and power backup systems are managed to a very high standard of resilience.

Most sites are unmanned and are monitored from the Network Operations Centre, located in Avalon, which is a 24/7 operation. The facility is duplicated in Auckland for redundancy. Kordia provides a managed environment (watertight, ventilated, and powered) with associated towers for others to locate their transmission equipment such as Police, Airways, Ambulance, Transpower, Vodafone, Spark cellular, 2 Degrees and the Maritime Services Authority. As such, many of their sites are critical to several other critical telecommunications providers (New Zealand Lifelines Council, 2020). Standard networks will be damaged with remaining networks overwhelmed by increased telecommunications traffic. In-ground infrastructure is likely to be severely damaged. Electricity outages will have knock-on impacts on telecommunications services.

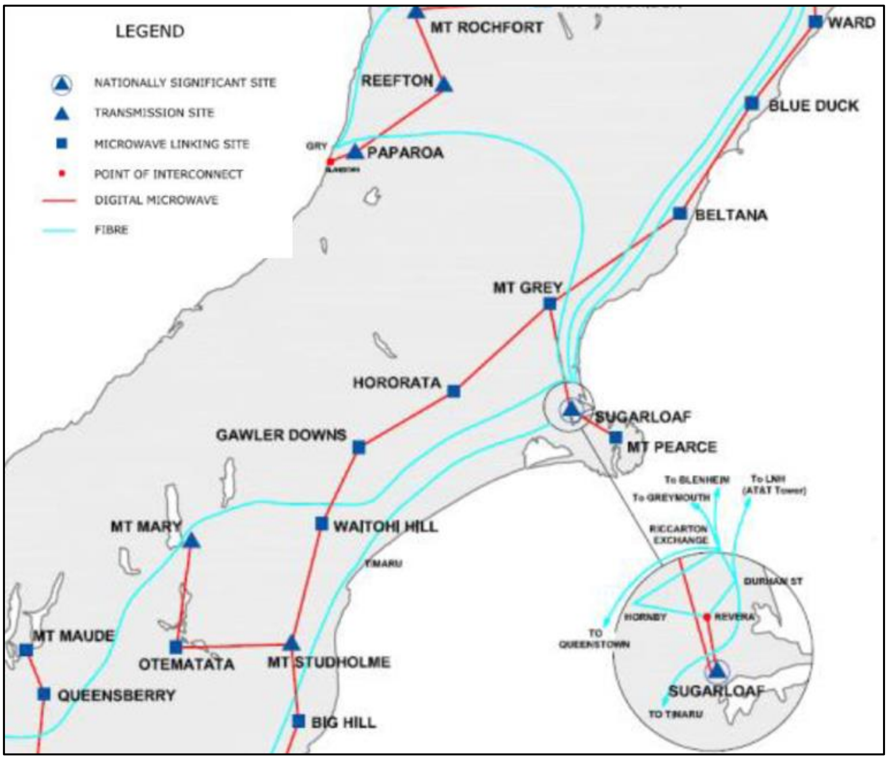

Figure 48: Kordia's central South Island Transmission Network

2.15.7. Fuel

The availability of suitable trucks, drivers and a functional road network to distribute fuel is the key constraint, not the ability to divert fuel to alternative ports. Lyttelton Port is important for the whole South Island - the next largest terminal is a third the size, further south, both Dunedin and Invercargill terminals would be critical supply points following a major earthquake as road and rail links will likely be compromised. Lyttelton to Woolston Pipeline; as with the gas transmission network, this oil pipeline is designed to withstand seismic events but is at risk from major land movement. Regular inspections, testing, spares and contingency planning are all undertaken to mitigate the risk of failure and facilitate a quick restoration if failure does occur.

Fuel distribution in New Zealand is highly road dependent, in fact, some regions, such as the West Coast of the South Island, are totally dependent on trucked fuel. For these areas, isolation by road essentially means loss of fuel supply into that area until the logistics to enable air or sea transport can be put in place. Fuel is stored for supply at retail outlets supplied by the four oil companies (Mobil, BP, Gull, and Z). Some of these are oil company-owned and managed, some independently owned and managed. The re-fuelling rates vary and it is impossible to give a definitive view on the amount of storage held at these sites, though it is typically in the range of 'days' during normal levels of use.

The key vulnerability in the retail outlet network is the dependence on electricity to pump fuel. Only a few stations in New Zealand have on-site standby generation, though some new fuel stations are increasingly being built with 'plug in' generator capability. Regional and local fuel plans are being developed that both highlight and seek to address this key resilience issue.

Many farms and industries also have diesel storage, though there is no national picture of such stockholdings and there is some anecdotal information that on-site storage facilities are reducing due to the high installation and maintenance costs. Further collection of information on fuel storage in New Zealand is intended in (New Zealand Lifelines Council, 2020).

2.15.8. Hotspots

In Canterbury, the New Zealand Lifelines Council identifies The Lyttelton Tunnel and Kaikōura Coast corridor – (state highway, railway, core telecommunications cables) as key infrastructure hotspots.

2.16. Disaster Waste Management Project Proposal – (Environment Canterbury, ~2019)

Environment Canterbury, Waikato Regional Council and Bay of Plenty Regional Council have committed in-kind time to continue a DWM programme, and seek further funding from the MCDEM/NEMA Resilience Fund to achieve the following objectives:

- To incorporate feedback and recommendations from recent workshops on the tool's functionality.
- To seek and incorporate feedback from Civil Defence Emergency Management staff on data management.
- To seek feedback regarding a waste generation timeline during events, and prioritisation of waste streams into the tool. This relates to the response and recovery phases and will require undertaking some research.
- To determine and finalise the data requirements to form minimum data sets to be integrated into the tool.
- Fully integrate the workbook and online component into a single tool. Promote the tool to CDEM groups and waste staff nationally.

No specific information has been found on Environment Canterbury's DWM plan during the collation of this data summary report, however we assume it exists.

2.17. RiskScape Building Impact, Habitability and Casualty Modelling for the AF8 Project - (Horspool et al., 2018)

A confidential draft report is available (upon request to the AF8 Science Team) for building impacts, casualties and habitability estimation for an AF8 event. The results of this work are aggregated into CDEM aggregation zones and can therefore only provide a broad indication of specific results per Territorial Authority. It should be noted that this research has a high degree of uncertainty and the results were not fit for AF8 purposes due to inherent limitations in the base model, which required large assumptions and scaling of international data and models to the New Zealand context, among other things.

This report provides an estimate of potential impacts to communities in the South Island from a Mw7.9 Alpine Fault earthquake. The impact to buildings (damage and habitability) and people (injuries and fatalities) is estimated using the RiskScape multi-hazard impact tool developed by GNS Science and NIWA with inputs from the project AF8 research team. The impact modelling includes uncertainty in the various scenario components by considering a suite of possible earthquake rupture scenarios (south, central and north earthquake initiation), seasonal population distributions (February and June), and diurnal population variations (day and night time) as well as uncertainty in the estimates of damage and casualty states (10 randomised model runs). By including this uncertainty, 120 different impact scenarios were generated. Results are presented as maps and tables and include communication of the average impact across all scenarios as well as the minimum and maximums for different geographic regions divided on CDEM boundaries. By presenting a range of estimated impacts, it is expected that this will allow users of the impact information to understand the considerable variability in impact that is possible in future natural hazard scenarios and to plan accordingly.

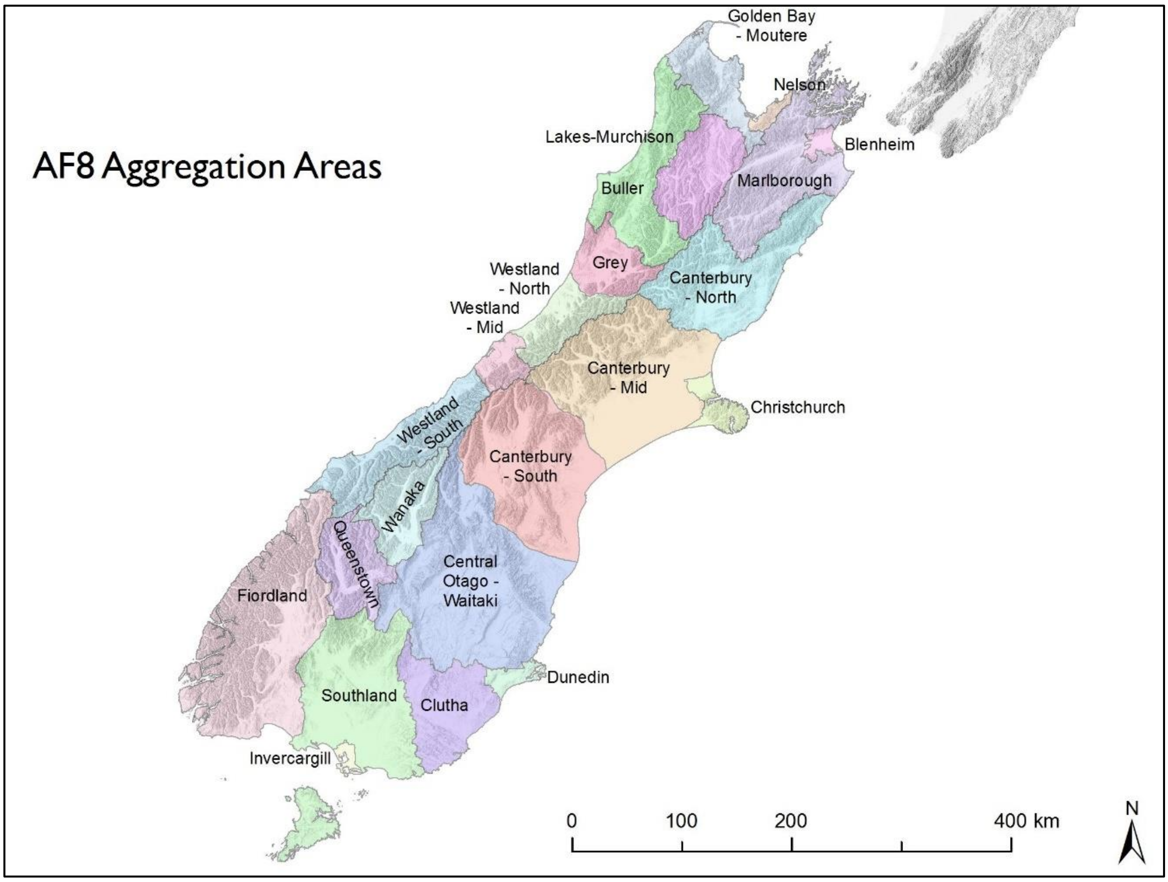

Figure 49: Aggregation areas used for reporting. The aggregation units are designed to fit cleanly within CDEM region boundaries.

2.17.1. Building Damage

Christchurch and Mid-Canterbury areas are amongst only three of the areas containing the highest number of damaged buildings in the South Island. South Canterbury is identified as being in the five highest areas in the South Island.

The results of this modelling have indicated building damage from an Alpine fault rupture will be widespread. Between 10 and 500 damaged buildings are estimated in North Canterbury.

These results are also reflected in the individual scenario results. In a central February day situation, Christchurch contains the highest number of severely damaged buildings (>100). Christchurch and Mid-Canterbury aggregation areas contain high numbers of damaged buildings in this situation while southern and northern aggregation areas contain the least number of damaged buildings.

2.17.2. Human Casualties

The modelled number of moderate injuries, severe injuries and fatalities during February, June, day and night situations are averaged across central northern and southern Alpine Fault ruptures.

The highest numbers of human casualties occur on a February night situation and Mid-Canterbury has the highest numbers in Canterbury.

Modelled results indicate a high number of injuries and fatalities in Christchurch and Mid-Canterbury regardless of whether it is February, June, day or night.

The modelled human casualties during a Central Alpine Fault scenario, on a February day, are highest in Christchurch for fatalities, serious injuries and moderate injuries.

2.17.3. Habitability and Displacement

Within this confidential report, habitability and displacement results are not confidential. These results are presented below and adapted for a Canterbury specific focus. Based on the modelling of Scheele et al. (2020).

Table 30: Number of affected residents per aggregation area.

CDEM Area	Aggregation Area	Displaced	Compromised liveability	Minor disruption	No disruption
Canterbury	Christchurch	0	352	3638	337494
	Canterbury - North	0	37	503	10137
	Canterbury - Mid	3	493	6278	123233
	Canterbury - South	0	144	1871	53557
Total		**3**	**1026**	**12290**	**524421**

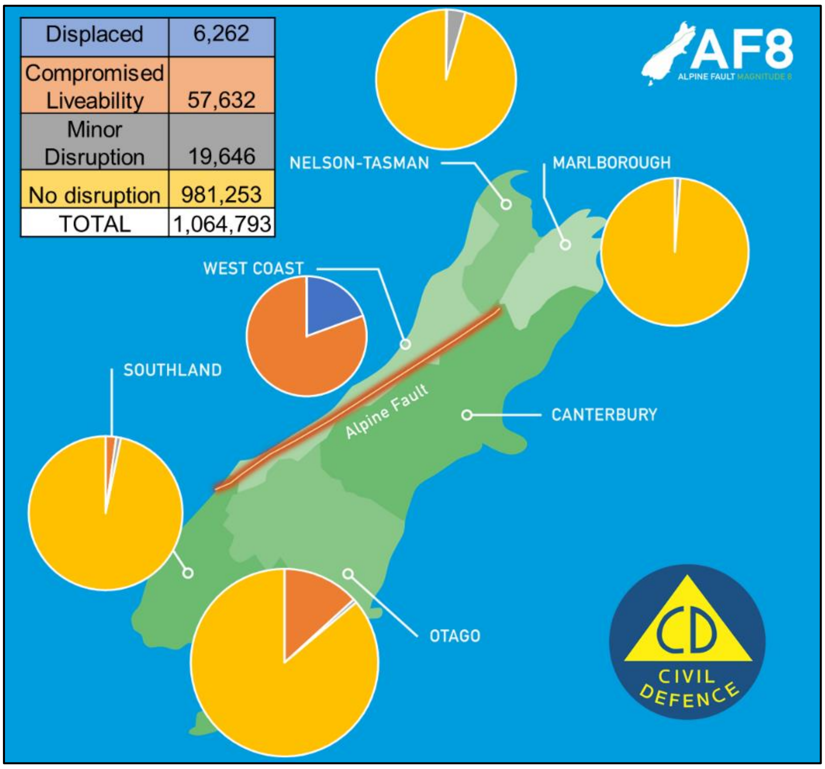

Figure 50: Habitability estimates following AF8 event Data sourced from: (Horspool et al., 2018).

Table 31: Number of affected tourists per aggregation area, for February (peak season) and June (off season).

CDEM Area	Aggregation Area	Feb: Displaced	June: Displaced	Feb: Minor disruption	June: Minor disruption	Feb: No disruption	June: No disruption
Canterbury	Christchurch	16	9	220	118	9904	5353
	Canterbury - North	0	0	32	17	2150	1163
	Canterbury - Mid	0	0	171	85	1339	725
	Canterbury - South	51	27	59	31	4006	2036
Total		**67**	**36**	**482**	**251**	**17399**	**9277**

2.18. Infrastructure Failure Propagations and Recovery Strategies From an Alpine Fault Earthquake Scenario - (Zorn et al., 2018)

This publication also links in with the work presented in (Davies, 2019). Utilising the core Project AF8 earthquake scenario (Bradley et al., 2017), hazard exposure, impacts, and recovery of interdependent critical infrastructure networks are assessed, namely: energy (electricity, petroleum), transportation (road, air, ferry, rail), water & waste (water supply, wastewater, solid waste), and telecommunications sectors (wired, wireless). Asset failures are simulated across each individual network, based on; shaking intensities, exposure to coseismic hazards (slips, landslides, and major rock falls), and estimated component fragilities, which have been further refined and validated through expert elicitation, via workshops coordinated with regional infrastructure stakeholders. Network disruptions are propagated across an interdependent network framework to quantify and delineate the spatial reach of failures (*Figure 51*). By incorporating recovery strategies, temporal changes in service levels are quantified to offer insights into expected interdependent network performance and the possible disconnection of communities from the nationally connected networks, otherwise not apparent when studying each infrastructure in isolation.

Many infrastructure recovery trajectories correlate closely to electricity network function, as presented in *Figure 52*a. While electricity providers advise the potential for “islanding” of electricity within the West Coast region within 180 days, if the national grid is unable to be reconnected, some locations within the West Coast region may remain without, or with intermittent, electricity supplies. Regardless of location, in this scenario (or any similar), infrastructures dependent on electricity within the West Coast region should continue to consider potentially widespread use of back-up electricity sources to aid initial recovery.

This dependence on electricity is also reflected in *Figure 52*b, where the majority of user disruptions, across the presented time frame, can be attributed to indirect failures – predominantly disconnections in electricity supply. At t = 0, direct damages (combined across all infrastructures) accounts for 40% of the cumulative user disruptions with 60% externally initiated. With redundant electricity supplies, the proportion of indirect electricity-initiated disruptions would be expected to decrease (particularly for the mobile and wired telecommunications sectors which represent a combined ~2 million potential user disruptions at peak) and/or be reassigned as indirectly-initiated disruptions, due to reduced road, water supply, or petroleum access, amongst others. Explicitly incorporating redundancies and their attributes/dependencies into the modelling framework (battery life/generator refuelling requirements/road access/supervision etc.) would be a valuable extension to work and should be incorporated as data for this becomes available.

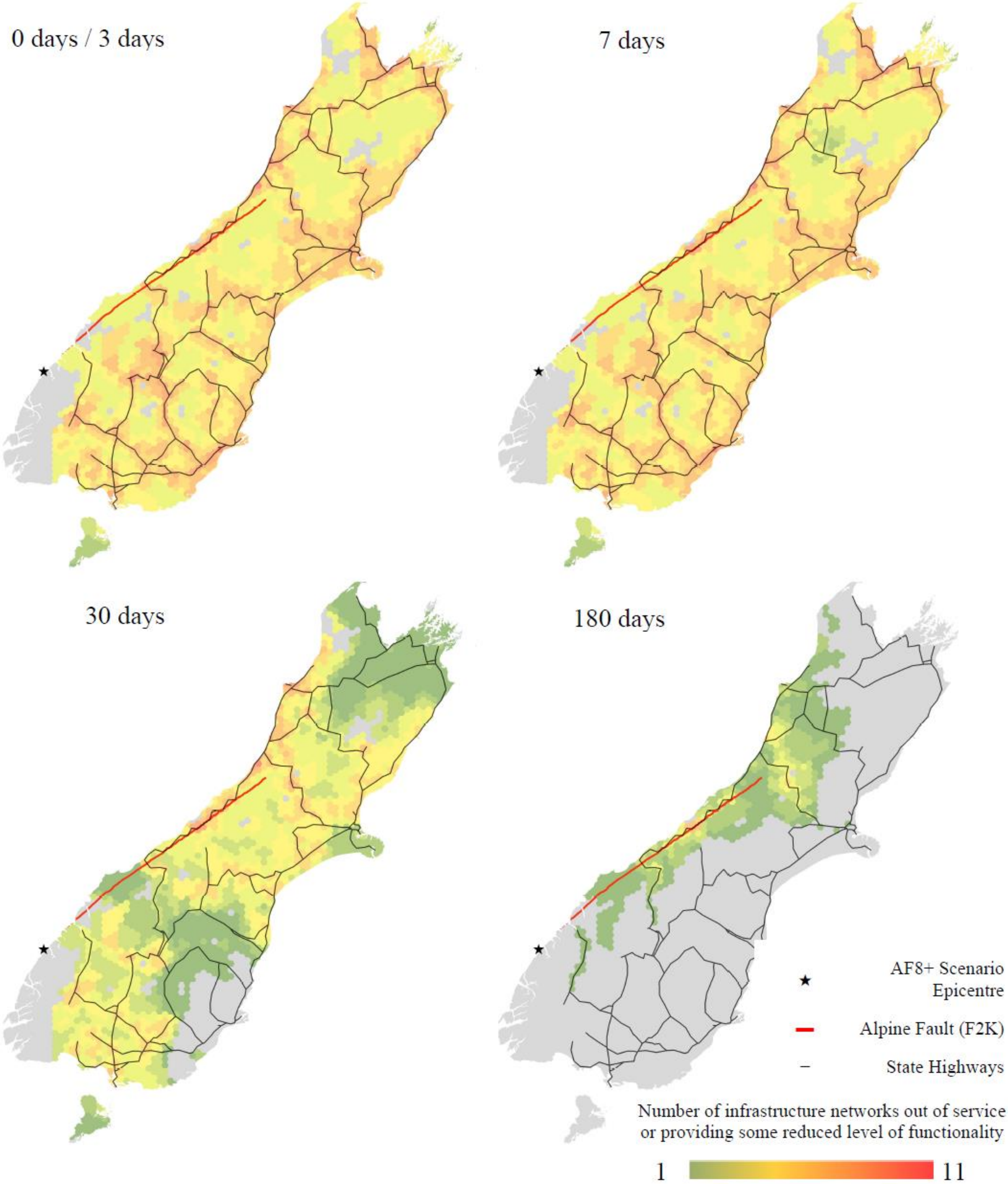

Figure 51: Spatial extents and number of infrastructure disruptions across the South Island. Darker (red) cells indicate a higher proportion of disrupted infrastructure services (either full disruption, or some reduced level of functionality/reliability compared to pre-event services) with greyed out cells representing normal pre-event functionality (or areas without any permanent residents and hence losses in infrastructure service) (Davies, 2019).

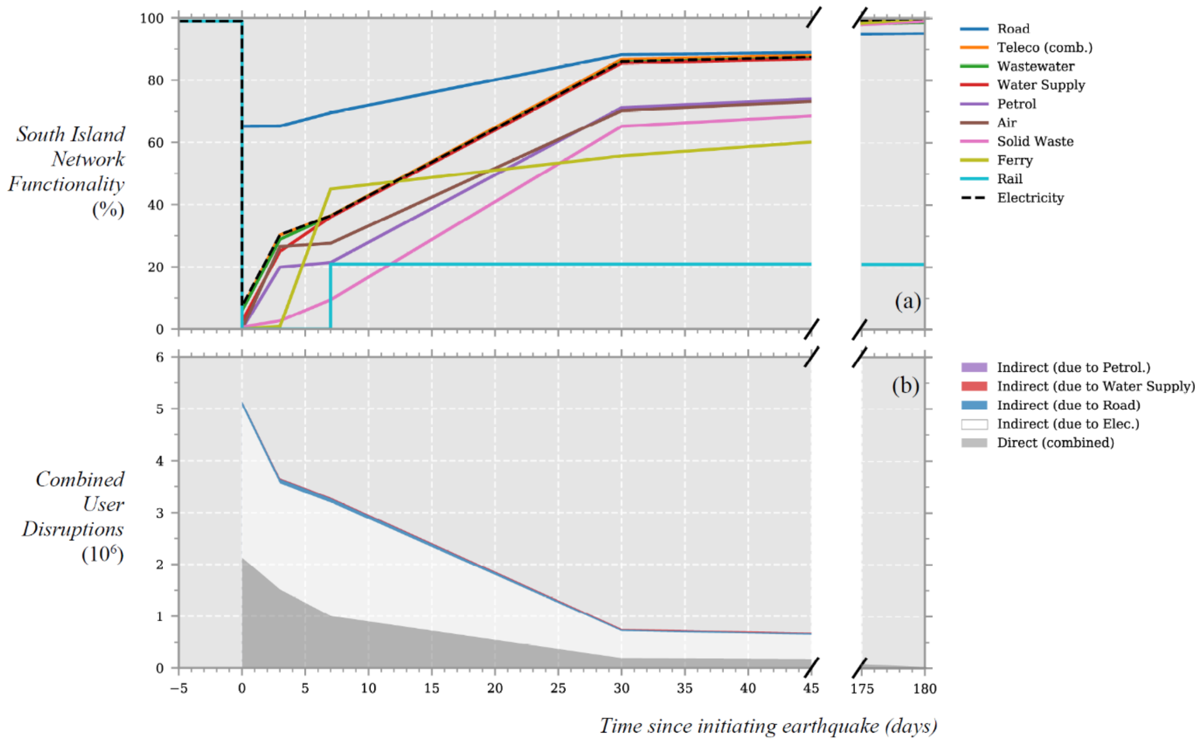

Figure 52: (a) Infrastructure network functionality for the South Island of New Zealand in terms of users disrupted (or passenger-kilometres restored for State Highways) and (b) the attribution of disruptions to direct or indirect causes (via interdependencies) combined across networks. A selection of Wellington (ferry/air) and South Island bound transport passengers (air) are also included.

2.19. Waka Kotahi State Highway resilience story maps - (NZTA, 2020)

Although not an AF8 specific study, Waka Kotahi NZTA (New Zealand Transport Agency) have identified seismic risk and disruption levels for highways and bridges across their network, for a 1:100 ARI earthquake (e.g. *Figure 53*).

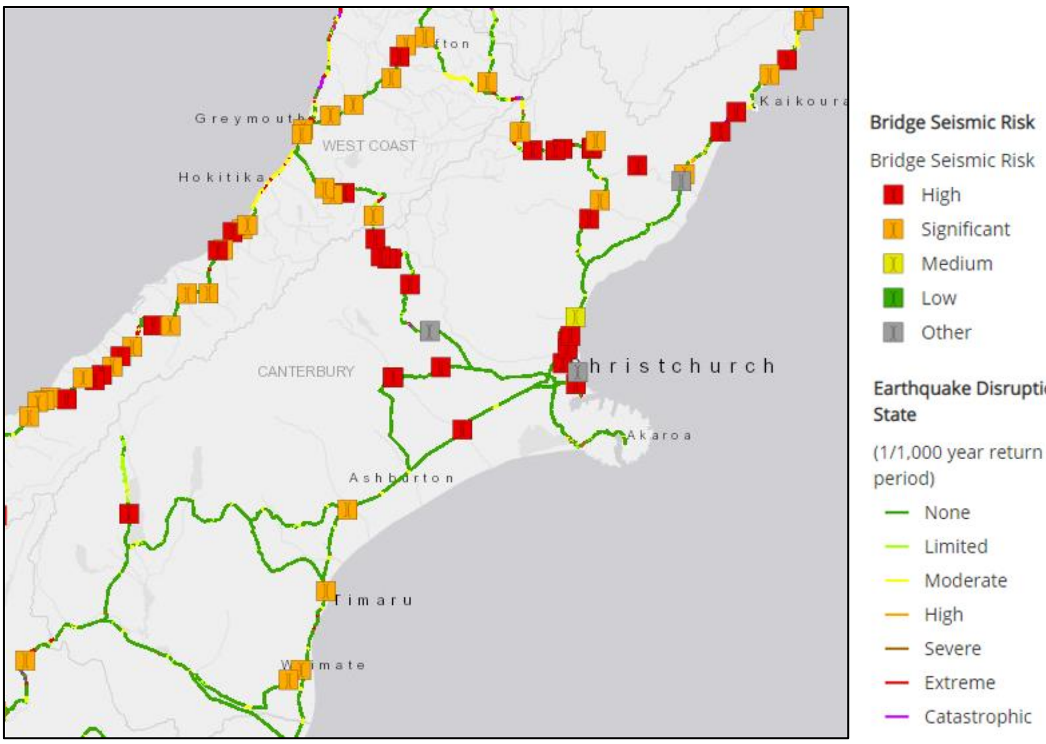

Figure 53: Screen shot from the Waka Kotahi State Highway resilience story maps (https://nzta.maps.arcgis.com/apps/MapSeries/index.html?appid=5a6163ead34e4fdab638e4a0d6282bd2).

2.20. Geospatial Hazard Assessment for Infrastructure Networks – (Amelia Lin, University of Auckland PhD Candidate, in draft)

This study uses the same modelling methods for susceptibility as with the QuakeCoRE Student Internship work (Section 2.6), but takes it a step further by modelling hazard (landslide and liquefaction) probability and linking this to the asset data for roads and rail (Liquefaction model source: (Zhu et al., 2017), Landslide model source: (Nowicki Jessee et al., 2018)). The relevant spatial data includes, for the State Highway and general road network and rail, the landslide and liquefaction probability and spatial extent for an Alpine Fault Mw8.0 earthquake with the epicentre in the north, centre and south. An example for the South Island is presented in *Figure 54* for a South to North rupture. A series of maps for each hazard and asset are presented in Section 4.4 for each TA.

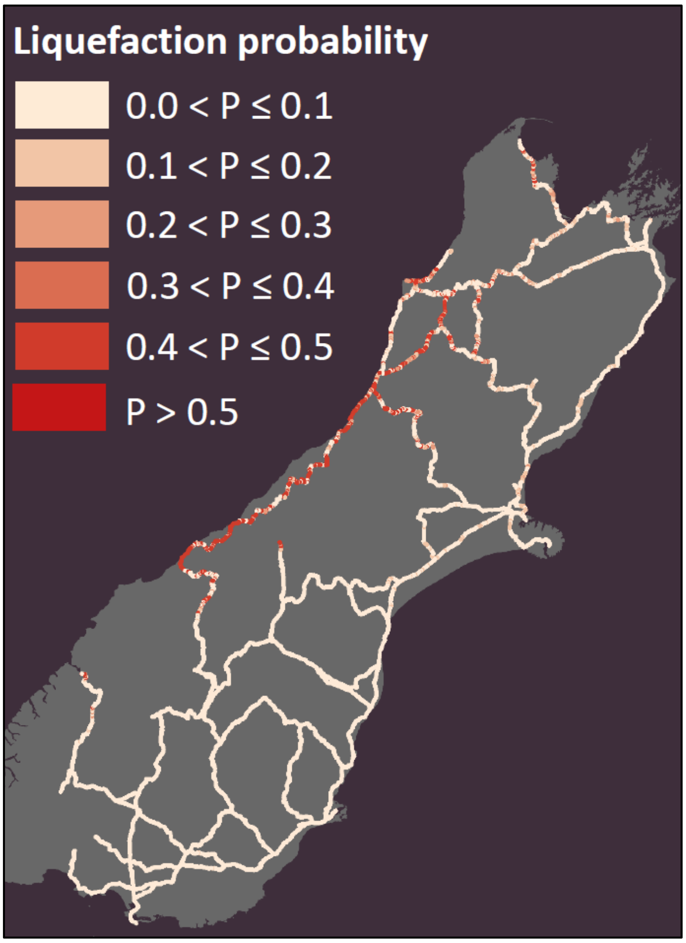

Figure 54: Liquefaction probability for national roads calculated from liquefaction susceptibility and peak ground velocity for an AF8 South – North rupture scenario.

2.21. Register of earthquake-prone buildings (EPB Register) - (Building Performance, 2021)

The EPB Register provides information about buildings that territorial authorities (TAs) have determined to be earthquake prone. Information about these buildings are made available online once an EPB notice has been issued and the TA has recorded this information in the register (https://epbr.building.govt.nz/)

An example of EQP building density is presented in *Figure 55*. For the present report, we have exported the street address for each EPB and geocoded it to determine its location for a subsequent exposure assessment. The results of this novel exposure assessment are presented in Section 4.4 for each TA.

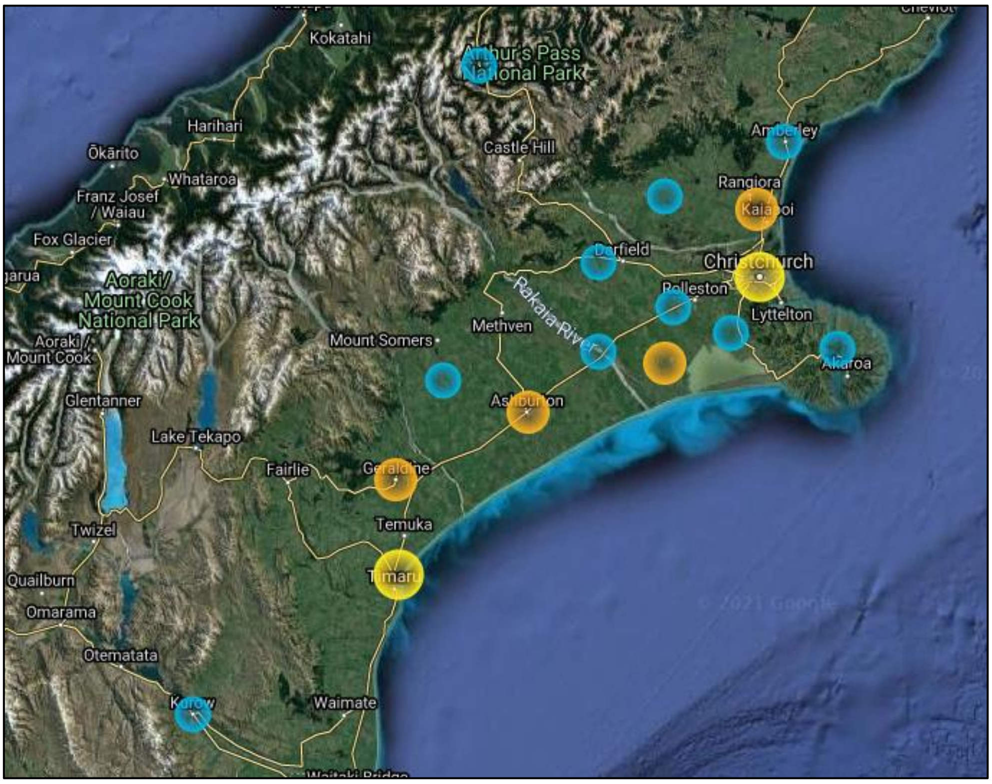

Figure 55: Aggregated representation of Earthquake prone building localities in Canterbury.

2.22. EQC MINERVA Modelling – (EQC)

Relevant results from previous EQC-MINERVA impact and loss modelling for an AF8 event are summarised within an EQC web portal. The authors of this report have been unsuccessful at gaining access to this data, however the Canterbury CDEM Group will have their own access. The data includes ranges of potential damage to housing stock and vulnerable groups based on an AF8 scenario. It's joined with the census data and shows age demographics, high value assets etc.

3. Potential Gap Assessment

Although the data summary presented above is thorough, it may not be entirely exhaustive. In that context, a number of research gaps have been identified for Project AF8, with respect to CDEM response and recovery planning, through the summary of data presented in Section 2. These are summarised below.

- Disaster waste management planning: Environment Canterbury (ECan) has a DWM template, but no actual plan has been sourced during this reporting.
- Casualties: Although casualties have been reported by (Robinson et al., 2014; Horspool and Fraser, 2016) the former has inherently high levels of uncertainty and the latter was for a specific exercise scenario which used hazard information that has since been superseded.
- Building impacts: Building impacts have been estimated by a number of projects and modelled by (Horspool et al., 2018) but the underpinning asset attribute data is not developed enough for accurate impact estimates.
- Earthquake prone buildings: Although the EPB data set is available and presented in this report for seismic exposure, a more useful result would be EPB susceptibility and/or impacts and human exposure to these structures, including occupied commercial and residential EPB and/or neighbouring properties/populations exposed to potential building collapses.
- Dynamic population exposure and susceptibility: This was indirectly considered by (Horspool et al., 2018), but the underpinning data and vulnerability modelling led to results with high uncertainty. Transient population is a big focus of this.
- Vulnerable populations: Assessment of vulnerable populations is a potentially huge task and opportunity. We note there are various quantitative spatial metrics and datasets e.g. census, which could be applicable. However, many of the vulnerable attributes of communities are inherently qualitative. Engagement with social agencies and social science researchers should occur. We recommend this as a priority for AF8 related planning going forward.
- Evacuations: evacuation modelling and understanding evacuation behaviour and movements should be conducted to help assist with AF8 evacuation response planning.

The National Lifelines Council have also identified some infrastructure specific, but not AF8 specific, knowledge gaps in this domain: Gaps identified in the knowledge of critical lifelines and community impacts include (New Zealand Lifelines Council, 2020):

- Lack of a national view on nationally significant customers and their dependence on lifelines and backup arrangements (e.g., alternate telecommunications, backup generators). This is also a gap at regional and local levels.
- Lack of a national view on lifeline utility organisational resilience.
- Understanding of the community impacts of prolonged lifeline service outages.
- Low level of community and critical customer awareness of infrastructure service vulnerabilities and likely outage durations to plan for.
- Understanding of impacts of critical telco infrastructure failure (MBIE has been working with the telco sector to improve the national understanding).
- Confidence that electricity distribution systems provide the resilience many communities expect and are willing to pay for.
- Understanding the vulnerability of key supply chains for lifeline utilities (such as bitumen supply for roads, availability of aggregate, Bailey Bridge stocks, availability of critical components and access to critical skills).
- Impacts resulting from GNSS failure and mitigation strategies.
- No mechanism for prioritising across infrastructure and decisions between investment in new assets or renewal/repair of existing assets.
- Gaps identified in the knowledge of likely impacts of hazards on lifelines infrastructure include:
- In general, further work on translating research into practical guidance such as damage matrices
- Further work on earthquake and cascading impacts on electricity (e.g., landslides / hydro lakes).

- Understanding of dependence on satellite GPS and likelihood/impacts of failure.
- More collaborative cross-regional work to understand impacts and plan response.
- Cumulative impacts and implications of climate change on infrastructure in the near to long term, particularly coastal and river flooding, intense rainfall, landslides, wind, rising groundwater and the emergence of compound hazards (combinations of these hazards coinciding or being sequential)

4. Ongoing Research Projects:

There are a number of ongoing research projects addressing some of the gaps identified above (Section 3). These are summarised below for reference.

4.1. Modelling Post-disaster Habitability and Population Displacement – (PhD project, Finn Scheele, University of Canterbury)

Ongoing PhD project: Habitability, sheltering and the population displacement following disasters are key issues for emergency management, asset management, planning and prioritisation of resources. Loss of habitability may result in the displacement of occupants from both residential and commercial buildings, with some of those displaced requiring temporary shelter, whereas some residents will prefer to shelter in place. Assessing the impacts to buildings and displacement of populations following a disaster is a complex process that is influenced by many factors. These include physical factors (e.g. building damage, loss of utilities), social or demographic factors explaining relative levels of vulnerability, and decision-making by authorities and affected populations. Risk and impact modelling for natural hazards to date is primarily focused on assessments of the built environment (e.g. buildings, infrastructure) and potential damage, monetary loss or service outage. There are relatively few assessment or modelling techniques for estimating the impacts to populations within affected communities. Utilising existing methods of assessing built environment impacts in combination with novel techniques using social data (e.g. demographics, community attributes) has the potential for producing useful household impact outputs for response and recovery decision-making. This project aims to develop models for estimating household impacts from various natural hazard events. Proposed case studies could include a Wellington Fault earthquake, an Alpine Fault earthquake, a Hikurangi Subduction Zone earthquake and tsunami, or a Mt. Taranaki volcanic event. These events represent different scales of impact across a diverse range of communities within New Zealand, covering urban and rural areas of different sizes and varied severity of physical impacts. AF8 will be a modelling scenario but no specific outputs to detail just yet.

4.2. Rural Community Resilience to Secondary and Cascading Natural Hazards – PhD Project, Sonja Mueller, University of Otago)

Ongoing PhD project: Resilience of rural communities to natural hazards is a vital research focus in New Zealand, highlighted by the recent 2016 Kaikōura earthquake and West Coast flooding of 2019. Hazard events are often followed by a sequence of secondary or cascading hazards, such as landslides following earthquakes, and the medium to long-term consequences of secondary hazards can be just as devastating as the immediate impacts. Both climatic and geophysical hazards are considered in this study, including drought, flood, earthquake, and landslide. This research focusses on community resilience to natural hazards in rural places, including a consideration of the secondary hazards that can continue to affect communities well after the triggering event, into the disaster recovery and reconstruction phases. This study will use participatory workshops and interviews to explore a case study community and run a disaster simulation scenario to identify potential hazards, impacts and resilience strategies. This research aims to provide proactive solutions for rural communities to help them become more resilient to future disasters. AF8 will be the event for a disaster scenario simulation looking at the recovery and reconstruction disaster phases.

4.3. Towards real-time indicators of population exposure for disaster risk assessments – (PhD Project, Mat Darling, University of Canterbury)

Ongoing PhD project: Global approaches to understanding population exposure are often limited to formal data capture means, such as population census. Recent experience in Aotearoa-New Zealand has shown a series of significant and disruptive ‘shocks’ to the traditional understanding of [a] population movements and [b] population census counts. For disaster risk reduction activities to be effective they must be representative; as such we build an understanding from ‘informal’ data capture methods towards near real-time indicators of disaster risk exposure.

This study builds off an understanding from a series of targeted interviews with disaster risk reduction (DRR) practitioners, and experience from localised disasters; including the Murihiku Southland floods (2020), Rangitata flood event (2019), the Kaikōura Earthquake (2016), and the current COVID19 crisis. Through this experience we consider opportunities for novel dataset to inform DRR activities. This ongoing research presents some of the initial findings from data capture exercises; practitioner requirements; and opportunities to improve exposure datasets in a near real time sense. These initial principles will be adopted to develop a methodology to inform a localised disaster risk context and exposure; the road to Piopiotahi Milford Sound.

4.4. Development of an Earthquake Casualty Model for New Zealand – (PhD Project, Nick Horspool, GNS Science/ University of Auckland)

In the past 8 years, earthquakes in New Zealand have injured over 12,000 people and killed 187. This has had a huge impact on the affected individuals, families, businesses and communities across the country. Understanding the key drivers of earthquake injuries and fatalities are critical for reducing the future socio-economic impact of future earthquakes. Previous studies on earthquake injuries (e.g. Cousins et al, 2008, Spence et al, 2011), globally and in New Zealand, have significant limitations. This include injury data that is biased towards the more severe injuries as this is what is generally reported internationally, or the data is dominated by countries where building codes are not present or not enforced. The research draws on a globally unique injury dataset from ACC that contains reported injuries from 8 New Zealand earthquakes that span from the 2010 Darfield earthquake through to the recent 2016 Kaikōura earthquake.

5. Mapped Data at Territorial Authority Scale

The following section presents mapped data sets for each of the 9 Territorial Authorities (TA) under Canterbury CDEM Group. Each dataset has either not been previously mapped/published, or is deemed to be the most up to date version of their respective research areas. If a particular TA does not have a map for a particular piece of research, then there are either no assets/hazards/impacts and/or not data for that specific area. The presented data focusses on mainly the impacts to critical infrastructure and buildings from earthquake-derived hazards such as ground shaking, liquefaction, and landslides. The Modified Mercalli Index (MMI) is used as a ground shaking metric, while a qualitative susceptibility scale is used for liquefaction and landslides. Additionally, the earthquake prone buildings in each district are presented here and represent buildings that are likely to experience structural damage that can cause injury or fatality. Earthquake prone buildings are assessed and compiled by the respective Territorial Authority, the figures presented here may not accurately represent an up-to-date representation. Davies (2019) represents the most accurate representation of a level-of-service model for power transmission in the South Island, hence, this is used for each TA and provided here for context *(Figure 57).* The TA's are listed below in order from north to south.

Disclaimer: The following sections consist of data compiled from various peer-reviewed and non-peer-reviewed studies by the AF8 Science Team for the Canterbury CDEM Group. It is for the sole purpose of providing some context to the Canterbury CDEM Group in their preparations for AF8 planning under the SAFER Framework. There has been no attempt to add source references, to describe the methodologies used in its creation, or the robustness or otherwise of the compiled data. The compilers of this report note that there is likely an appetite to use this data for other purposes, however, many of these models have a number of limitations. Potential use of these data (even with good intentions) for other purposes could lead to incorrect or inappropriate analysis and subsequent decision making. Therefore, the compilers of this report request that the AF8 Science Team is consulted with regards to any potential usage of the science/data presented herein, so as that they can provide assistance and/or guidance.

For any enquiries about this data or subsequent use for any other purpose, please contact Prof Tom Wilson, University of Canterbury (thomas.wilson@canterbury.ac.nz) and James Thompson Canterbury CDEM Group (James.Thompson@cdemcanterbury.govt.nz).

Figure 56: Territorial Authorities (TAs) and main urban centres in Canterbury Region. Retrieved from. Note that Canterbury CDEM Group is not inclusive of Waitaki District. (*www.localcouncils.govt.nz*).

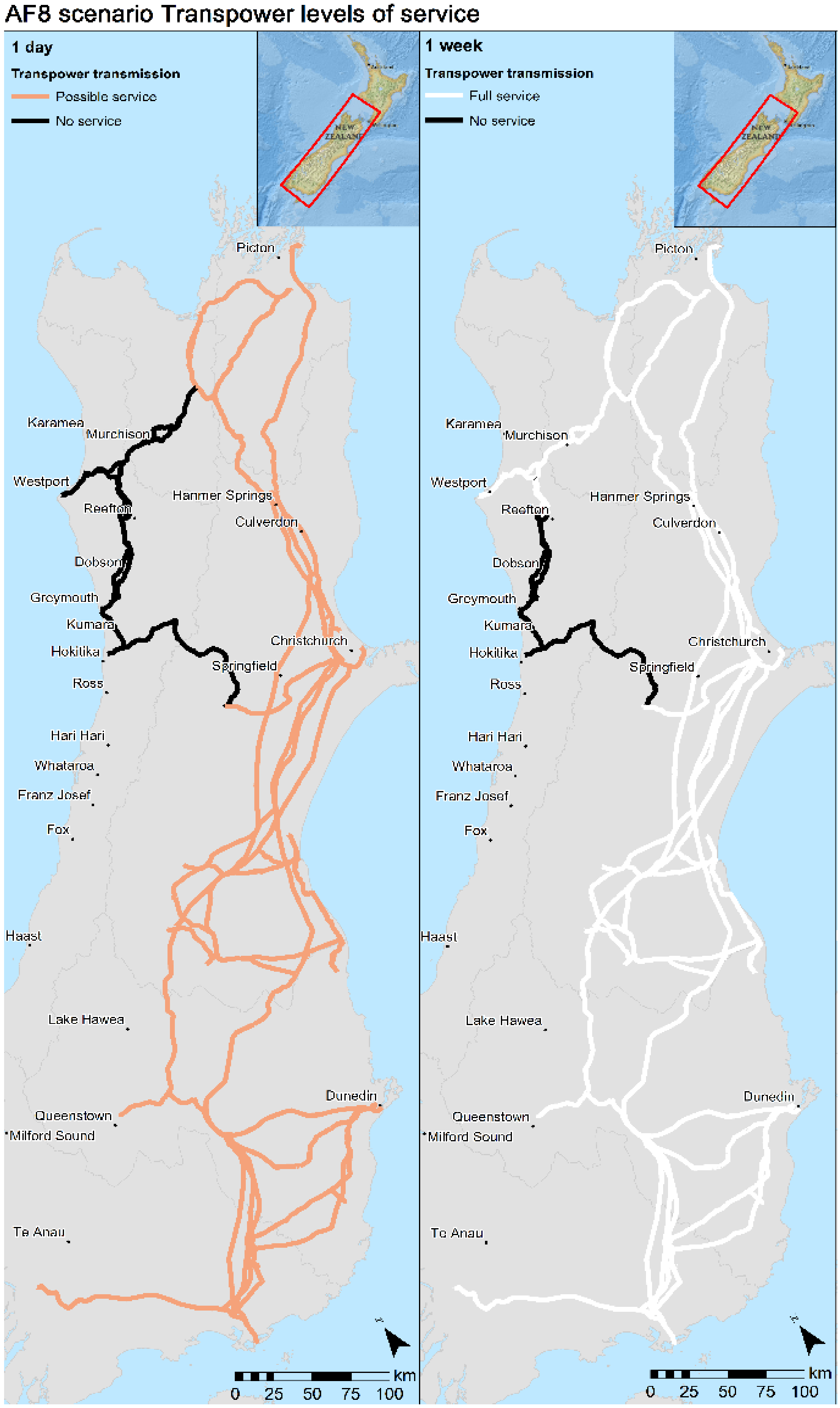

Figure 57: The co-created AF8+ impact maps for South Island electricity transmission service levels (Davies, 2019).

5.1. Kaikōura

The mountainous and fluvial landscape of the Kaikōura District is susceptible to considerable seismic hazards during an AF8 event. Kaikōura township is the main population centre in this district and is an important location for tourism, agriculture, and the local economy *(Figure 58)*. Figure 59, developed by QuakeCoRE, outlines the primary earthquake hazards anticipated during this event; ground shaking, landslides, and liquefaction. Kaikōura will experience MMI 6 and 7 in this scenario which as well as having direct impacts, will likely trigger landslides and liquefaction throughout the region. Steep mountainous aspects are susceptible to landslides and areas where soil water content is high (such as along the main river valleys in the region) are prone to liquefaction. These primary hazards will disrupt and damage the built environment as well as critical infrastructure and may reoccur due to repeated aftershocks.

The Kaikōura District houses the Main North Line and State Highway 1 which are major transportation assets and connect the North Island to southern population centres. This infrastructure has been highlighted as nationally critical infrastructure and is vulnerable to the impacts from landsliding and liquefaction. Figure 60 estimates the probability of landslide and liquefaction damage to these assets, where liquefaction on the Kaikōura plain has the highest likelihood of causing damage. While estimates on the level of service of these assets are made in *Figure 61*, which establishes that following an AF8 event there will be large sections of road and railway closed beyond 7 days after the initial earthquake severely restricting access to the region. The inland route will likely serve as the only road access to the district with SH1 closed in either direction from Kaikōura. While the Main North Line may still be closed several days after the initial earthquake. Robinson et al. (2014) also estimate that the railway line through this district will likely be completely impassable immediately following an AF8 event as rockfalls would likely cause considerable damage and isolated sections and tunnels along the route.

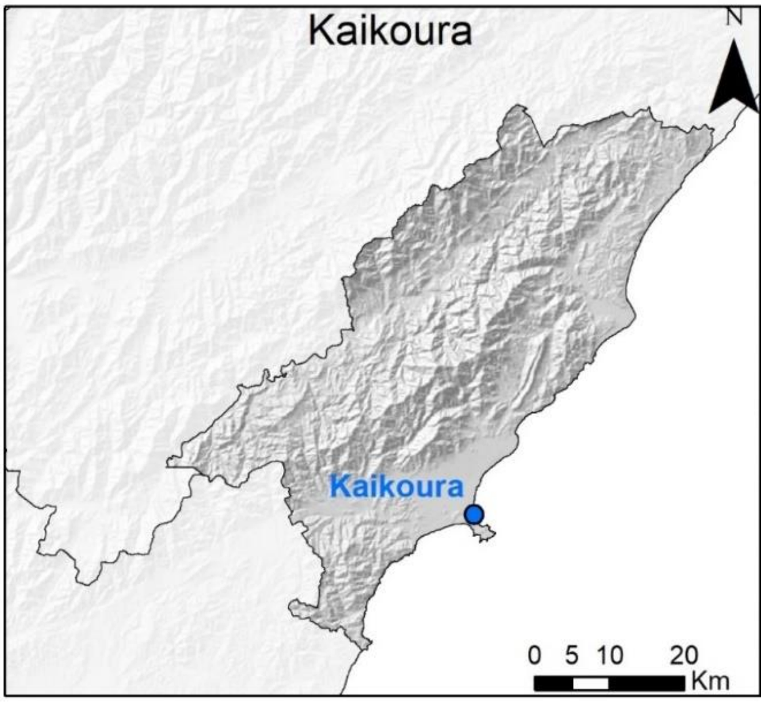

Figure 58: Location map for the Kaikōura District with main centres marked.

Figure 61 also estimates potential LOS for cell towers in the district following an AF8 event, where intermittent service may be provided throughout the first 7 days. The vulnerability of the telecommunications network in Kaikōura became evident during the 2016 ‘Kaikōura’ earthquake where the eastern core fibre route used by Chorus, Spark and Vodafone, sustained considerable damage (New Zealand Lifelines Council, 2020). During this event Kaikōura was effectively isolated from outside communications and the failure put a lot of pressure on the one remaining South Island fibre link to the west. The only intact fibre link in the Kaikōura area was offshore - the Vodafone 'Aqualink' cable which provides express capacity from Christchurch to Wellington. As the result of collaboration between the three parties, the Aqualink was able to be modified to provide service into Kaikōura and restore some redundancy in the core network. Coseismic hazards will likely disrupt telecommunications in Kaikōura during a future AF8 event and the Aqualink cable will become critical in maintaining communication beyond the district.

The electricity lifeline in Kaikōura may also be disrupted following this event resulting in power outages throughout the district. It is estimated by Davies (2019) that 24 hours following an AF8 event partial service may resume in some areas in Kaikōura, with full service restoration within 7 days *(Figure 61)*. Additionally, Robinson et al. (2014) concludes that after 8.25 hours power should be restored to Kaikōura township. These findings are discussed further in Section 2 of this report.

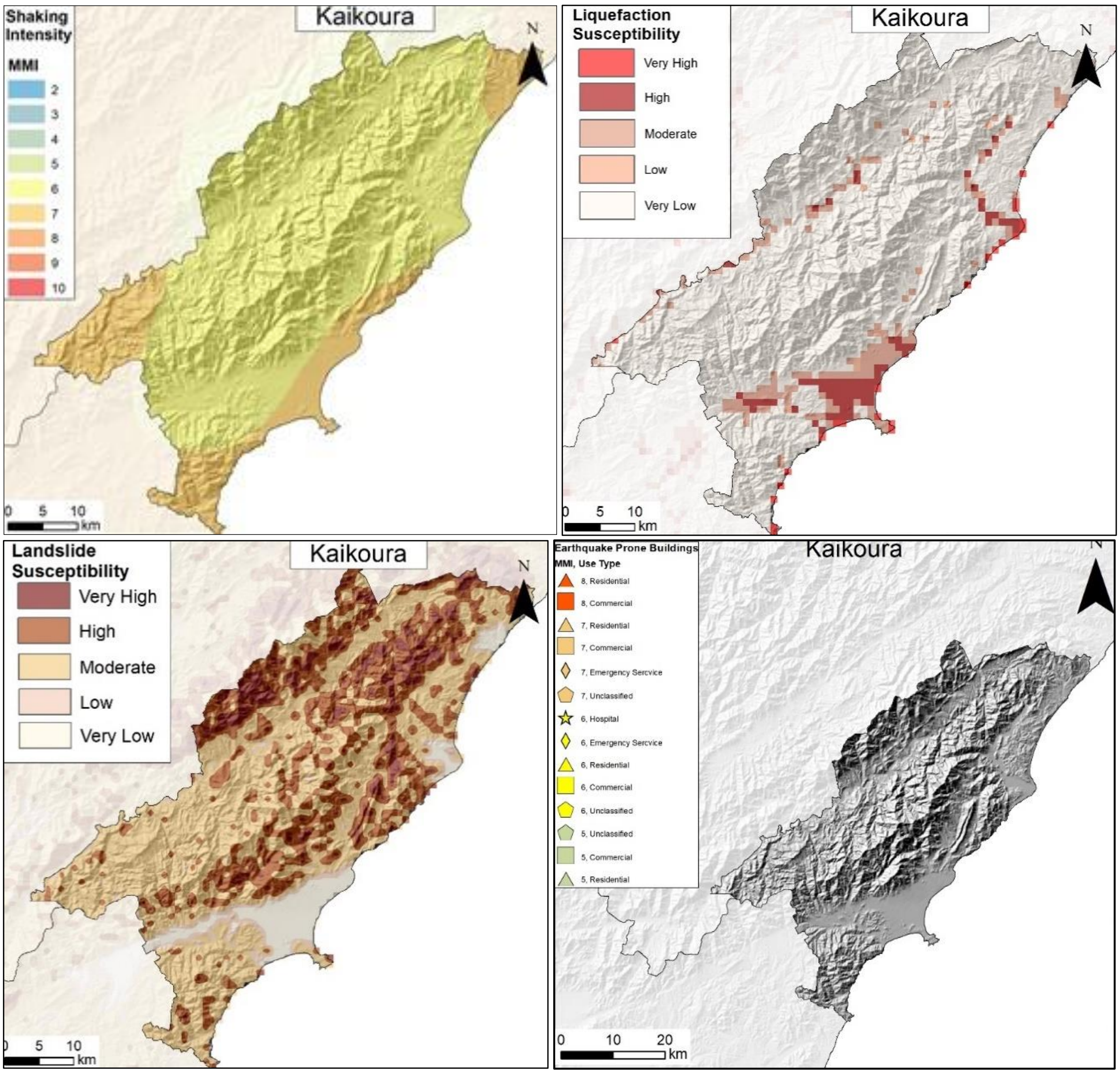

Figure 59: Hazard models for the Kaikōura District. Note there are no earthquake prone buildings registered for Kaikōura.

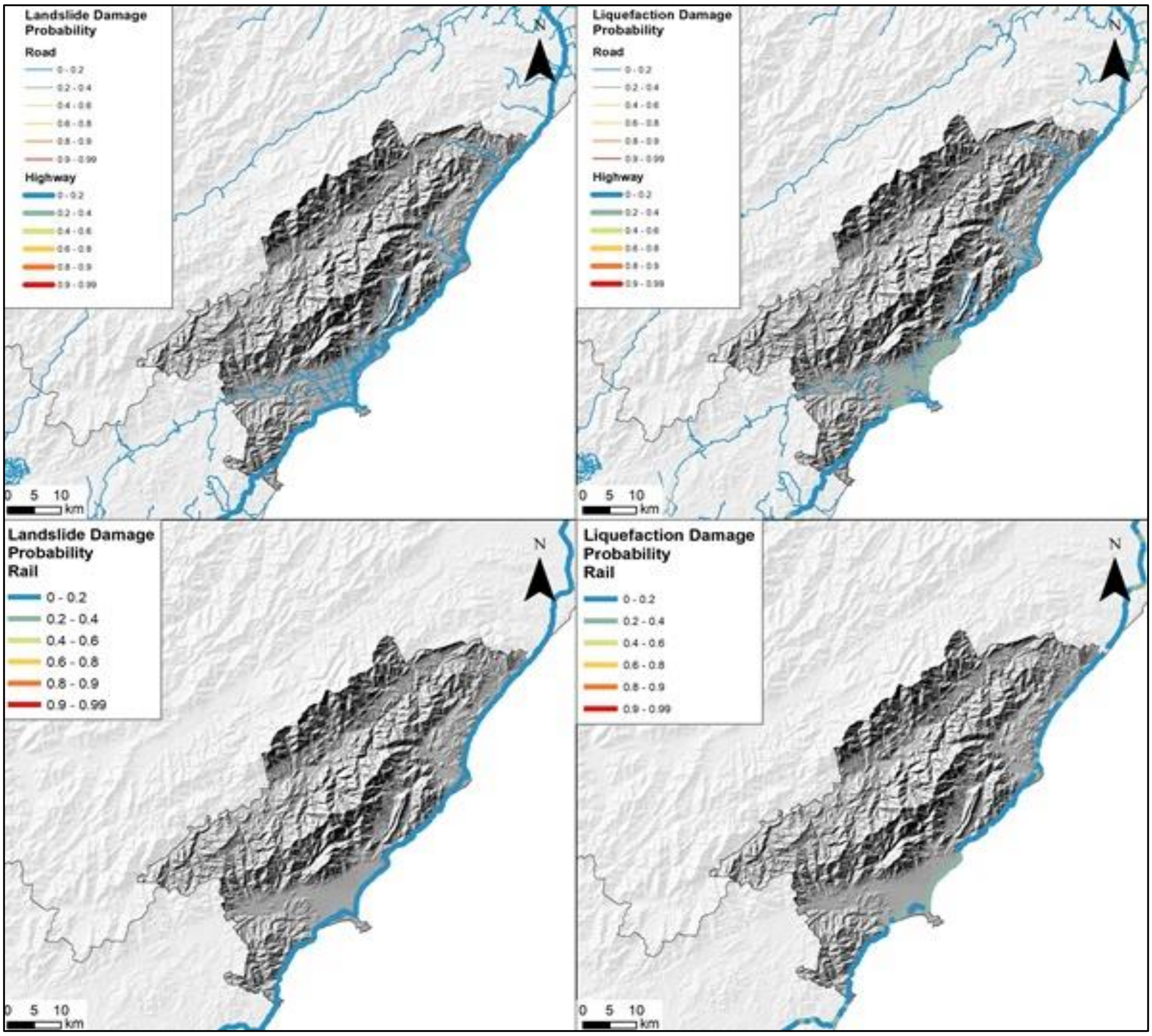

Figure 60: Landslide and liquefaction damage probabilities to road and rail in the Kaikōura District. Source: Amelia Lin (2020).

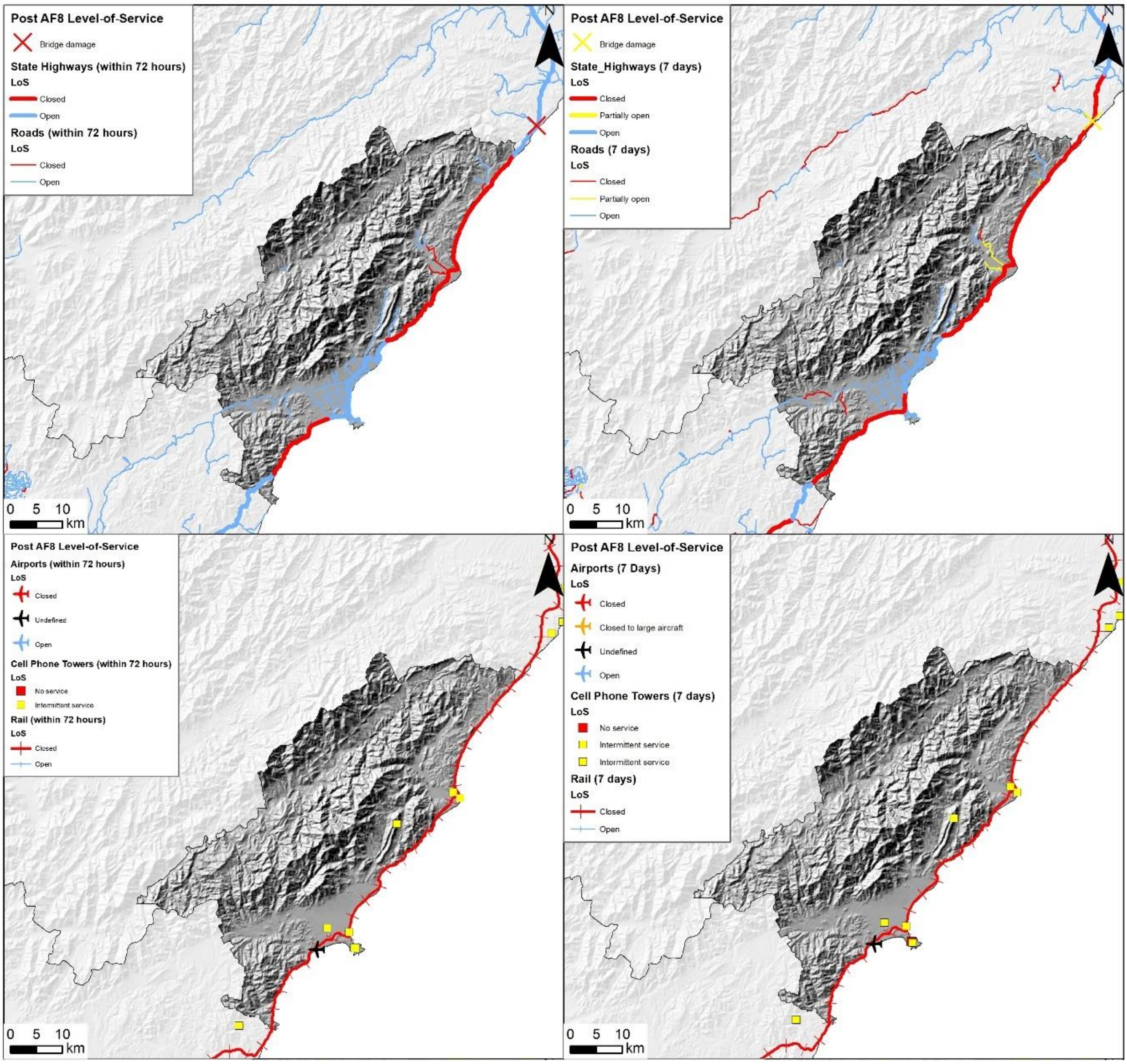

Figure 61: Level of service models for transportation and tele-communication infrastructure in the Kaikōura District. Produced by the AF8 science team. Note that in some cases the underlying continuation of seismic and coseismic hazards, considered in this study, leads to an increase in asset damage, and a decreased level of service, at 7 days compared with 72 hours.

5.2. Hurunui

An AF8 event will likely result in considerable ground shaking in the Hurunui district and is likely to cause casualties, direct damage to the built environment and trigger cosiesmic hazards such as landslides and liquefaction. Figure 62 displays the location of the main population centres within the district and serves as a spatial reference for the subsequent figures. In an AF8 event, Hurunui is likely to experience ground shaking levels of MMI 6, 7, and 8, where MMI 7 is the most common level in the district *(Figure 63).* The mountainous terrain in the west of the district is susceptible to landslides, while the river valleys and basins throughout the district are prone to liquefaction. Figure 63 developed by QuakeCoRE, outlines the spatial characteristics of the hazards in more detail. It also identifies one earthquake prone building in the district located in Amberley. This is identified as being a residential building exposed to MMI 7 shaking *(Table 32).* It is estimated that the Hurunui District may have 7 fatalities and 180 injuries during this event (Robinson et al., 2014).

The probability of road and rail damage due to landslides and liquefaction is outlined in *Figure 64*, while *Figure 65* displays the potential LOS for critical infrastructure in Hurunui. From this data, it is evident that liquefaction is the main concern for transportation infrastructure during an AF8 event, and may result in sections of SH1, SH7, and the Main North Railway being closed for several days following the event. In particular, 72 hours after the event SH7 near the Lewis Pass, SH7A to Hanmer Springs, and the Main North Railway may be closed. Road closures are likely to increase during the first 7 days due to aftershocks, however a section of SH7 may be able to partially open. The Main North Railway may remain closed after 7 days in this scenario. This could severely limit movement around the district and prevent access to the West Coast and upper East Coast.

Cell phone towers in the district are less adversely affected in this scenario and intermittent service may be re-established in the district in the hours to weeks following the earthquake. The national electricity grid which runs through the district could potentially provide some power to residents 24 hours following the earthquake, and will likely be fully restored within 7 days *(Figure 65).*

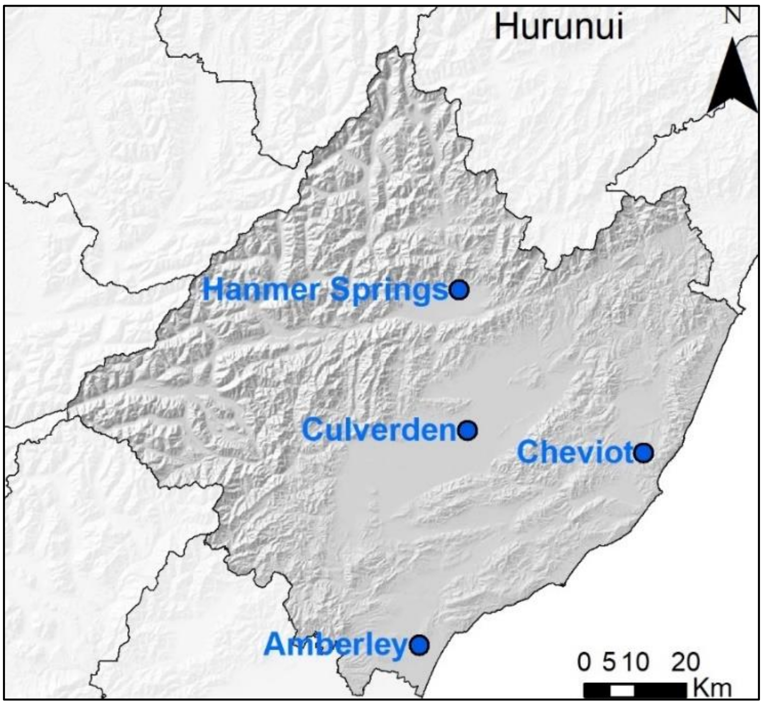

Figure 62: A location map of the Hurunui District.

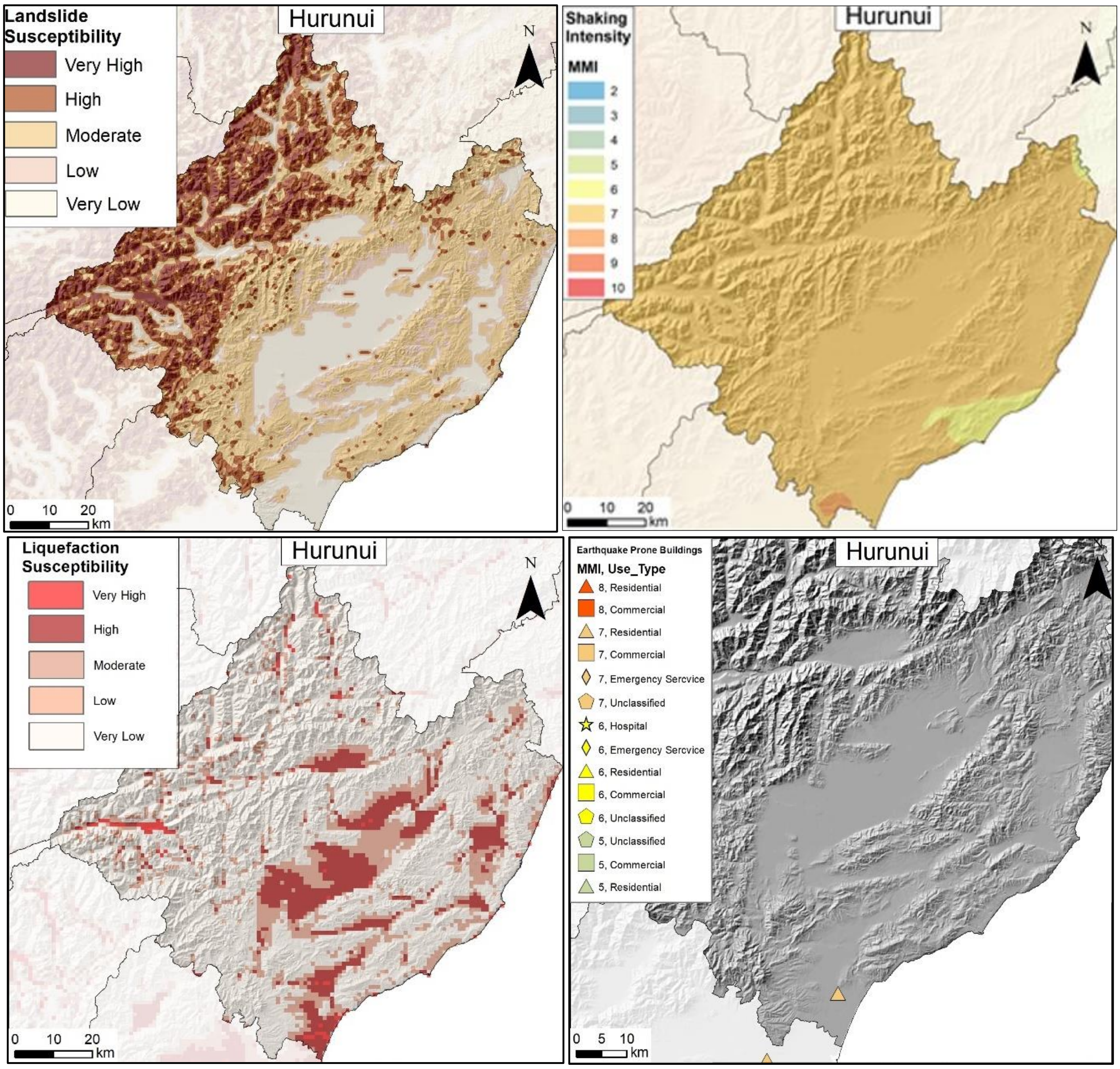

Figure 63: Hazard models and earthquake prone buildings for the Hurunui District.

Table 32: Summary of the earthquake prone buildings in Hurunui.

Building Type	MMI 7	Total
Residential	1	1
Total	1	1

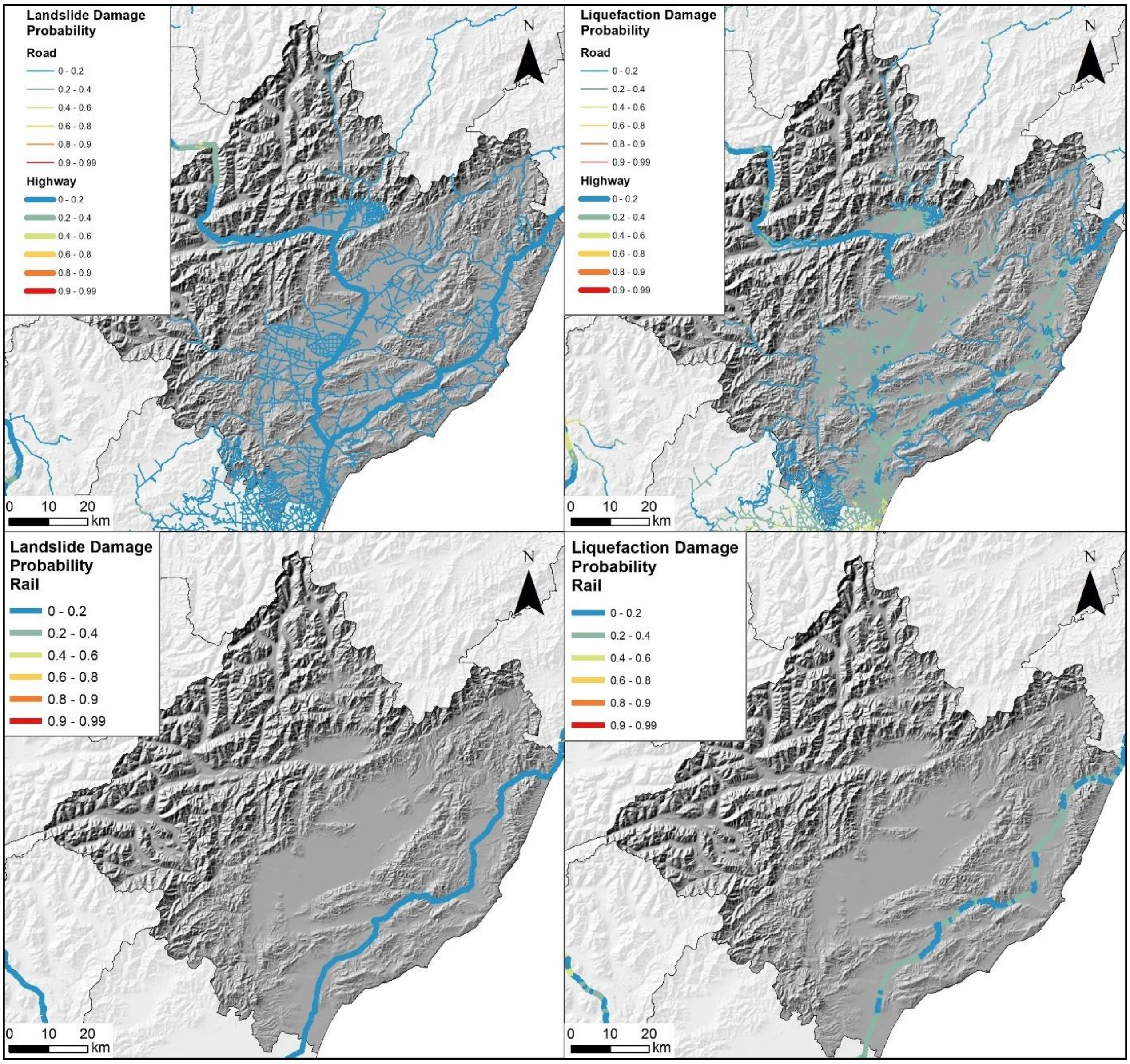

Figure 64: Transportation infrastructure landslide and liquefaction impact probability maps for the Hurunui District. Source: Amelia Lin (2020).

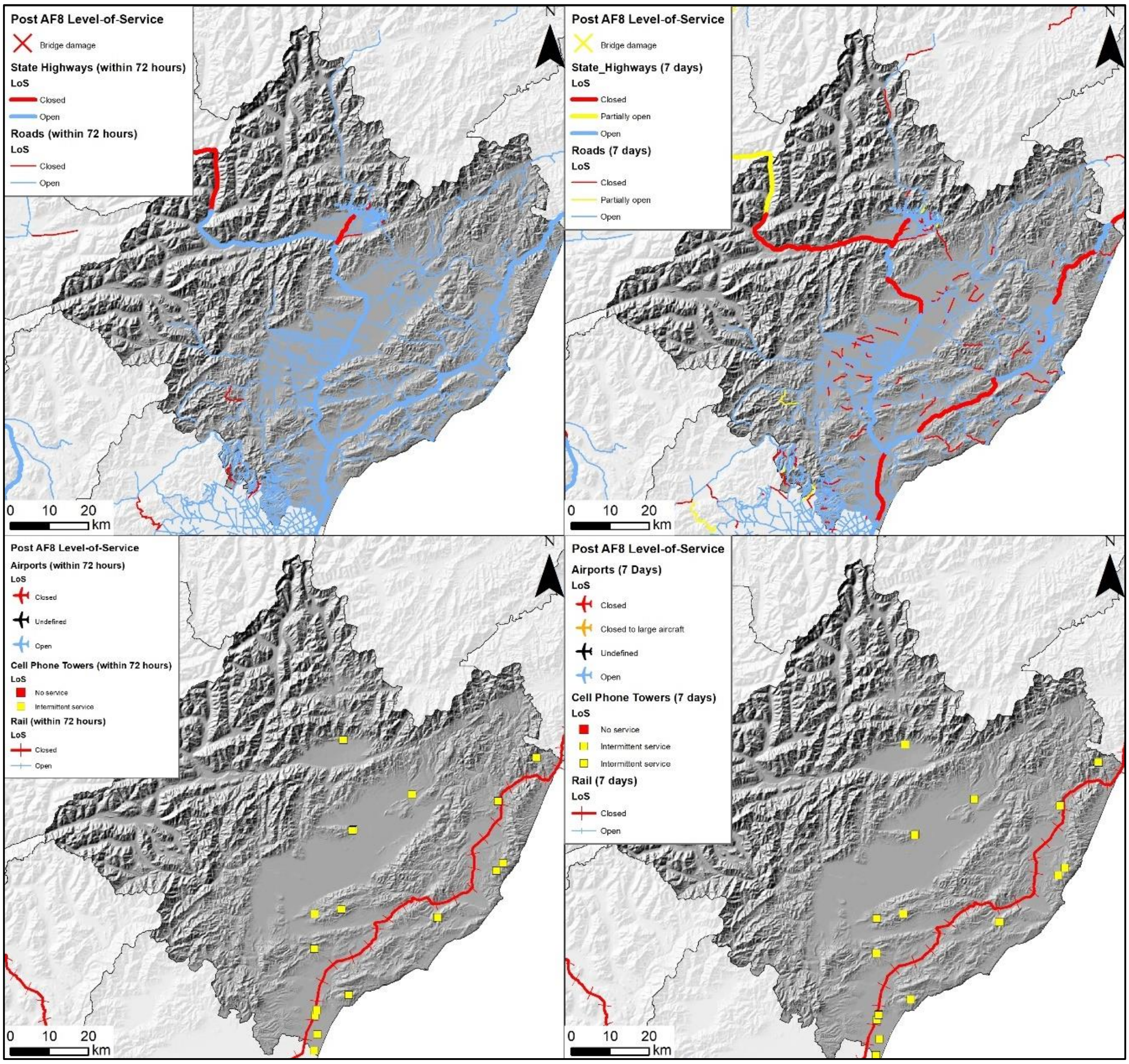

Figure 65: Level of service models for transportation and tele-communication infrastructure in the Hurunui District. Produced by the AF8 science team. Note that in some cases the underlying continuation of seismic and coseismic hazards, considered in this study, leads to an increase in asset damage, and a decreased level of service, at 7 days compared with 72 hours.

5.3. Waimakariri

The Waimakariri District is likely to experience considerable ground shaking that could damage the built environment, disrupt critical infrastructure, and cause several causalities. The main population centres and regional infrastructure in the district are situated on highly liquefaction susceptible soils which will cause substantial damage and losses during an AF8 event *(Figure 67 and Figure 68)*. Losses may also occur due to the 27 earthquake prone buildings in the district, which may experience MMI 7 and 8 shaking *(Table 33).* Collapse of earthquake prone buildings may contribute to the estimated 5 fatalities and 136 injuries in the Waimakariri District (Robinson et al., 2014).

Liquefaction is likely to damage roads and railway throughout Waimakariri *(Figure 68)* and will mean that road and railway closures are necessary *(Figure 69).* Liquefaction frequency will likely increase during the first 7 days due to aftershocks and lessen the capacity of transportation lines. While no major highways are estimated to be severed within the district during the first 7 days of this scenario, SH1 north of Waimakariri may be treacherous and closures could be frequent here. The Main North Railway could be closed several days after the initial earthquake which would require largescale remediation to restore capacity along this lifeline. Electricity may be partly restored within 1 day to the district and could be fully restored by 7 days (Figure 57). Cell towers are unlikely to be heavily damaged or disrupted and will provide intermittent service throughout initial earthquake and in the first 7 days.

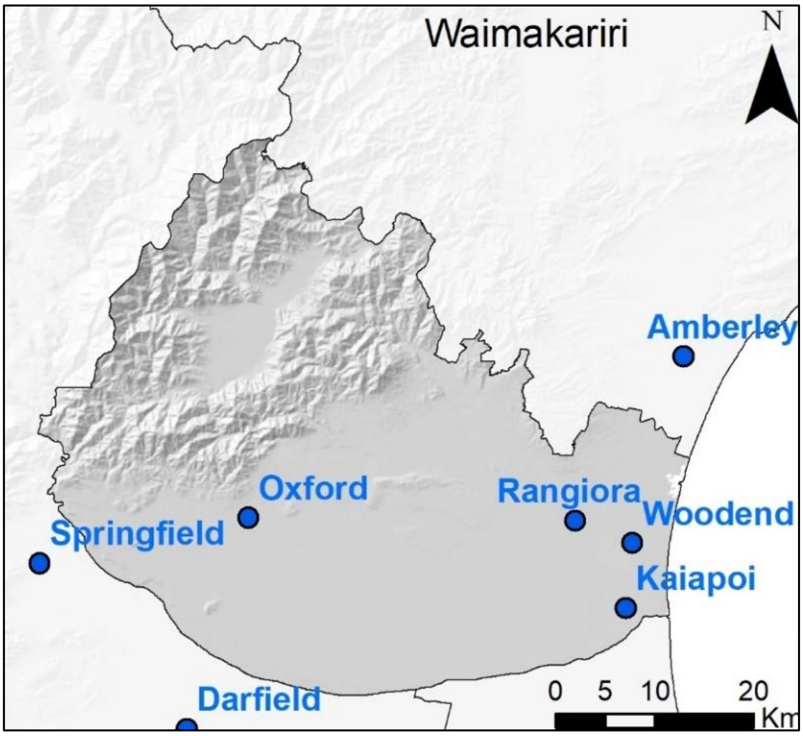

Figure 66: A location map for the Waimakariri District will main centres marked.

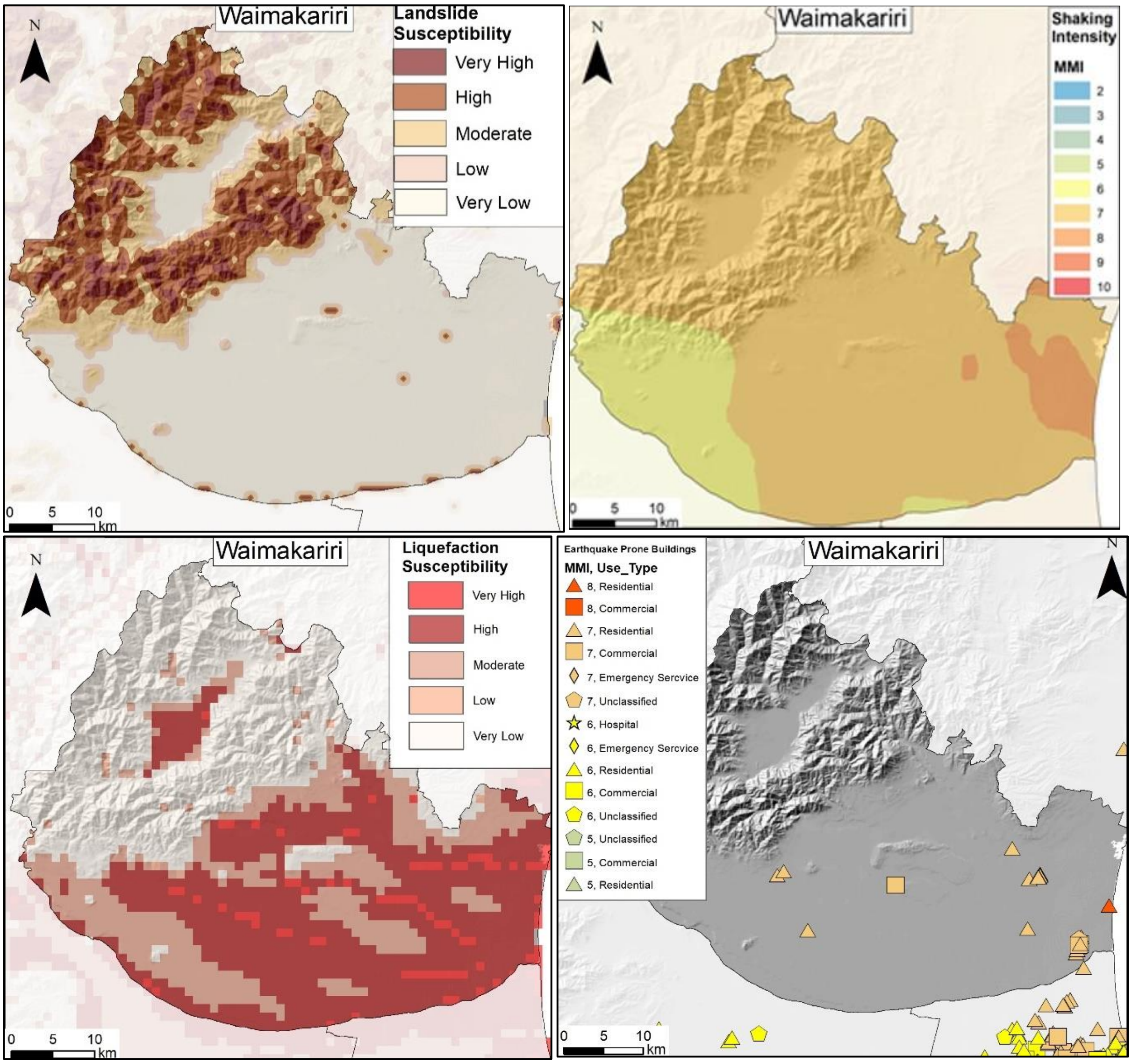

Figure 67: Hazard models for the Waimakariri District.

Table 33: The earthquake prone buildings in Waimakariri by building type and MMI exposure.

Building Type	MMI		Total
	7	8	
Residential	22	1	23
Commercial	3		3
Unclassified	1		1
Total	26	1	27

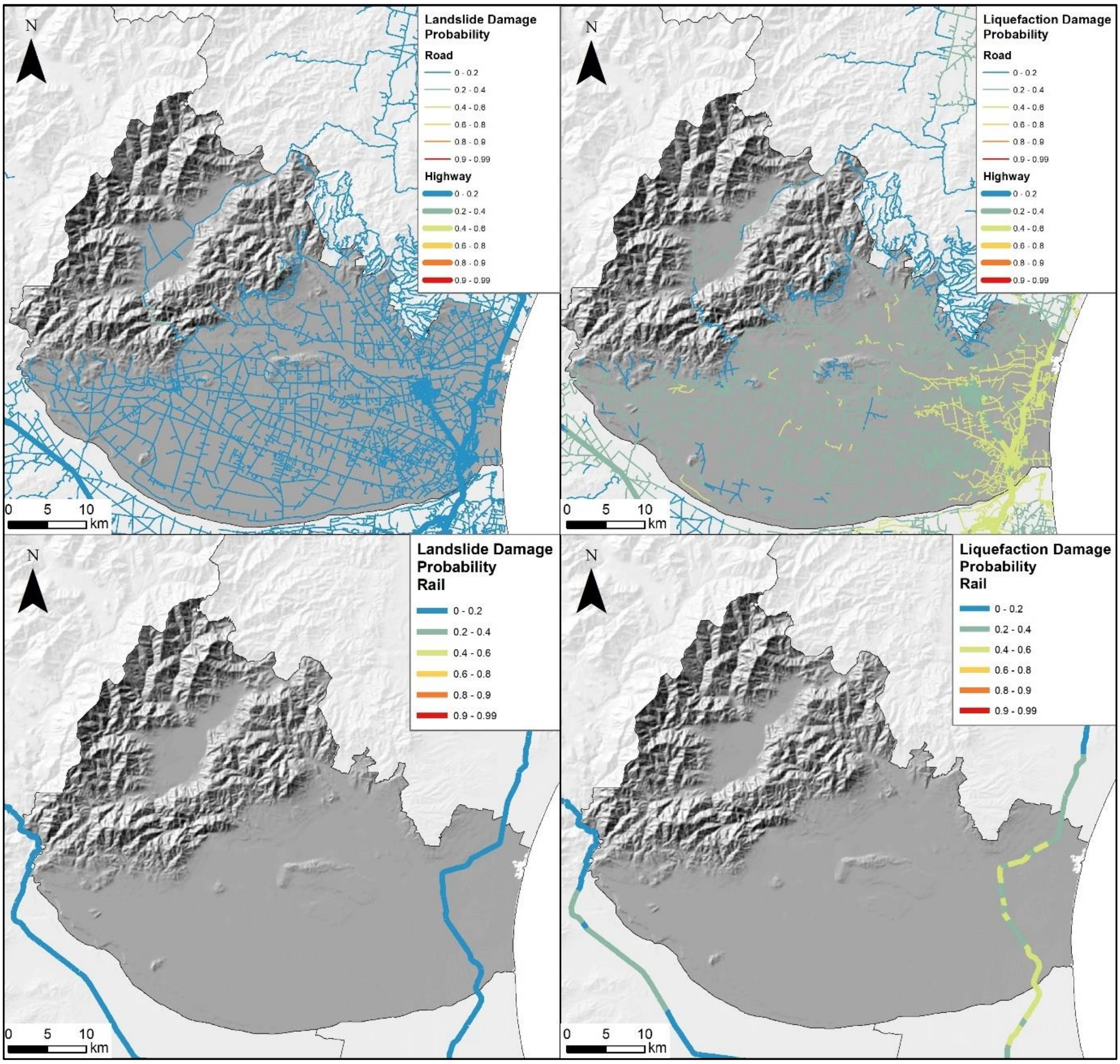

Figure 68: Transportation infrastructure landslide and liquefaction impact probability maps for the Waimakariri District. Source: Amelia Lin (2020).

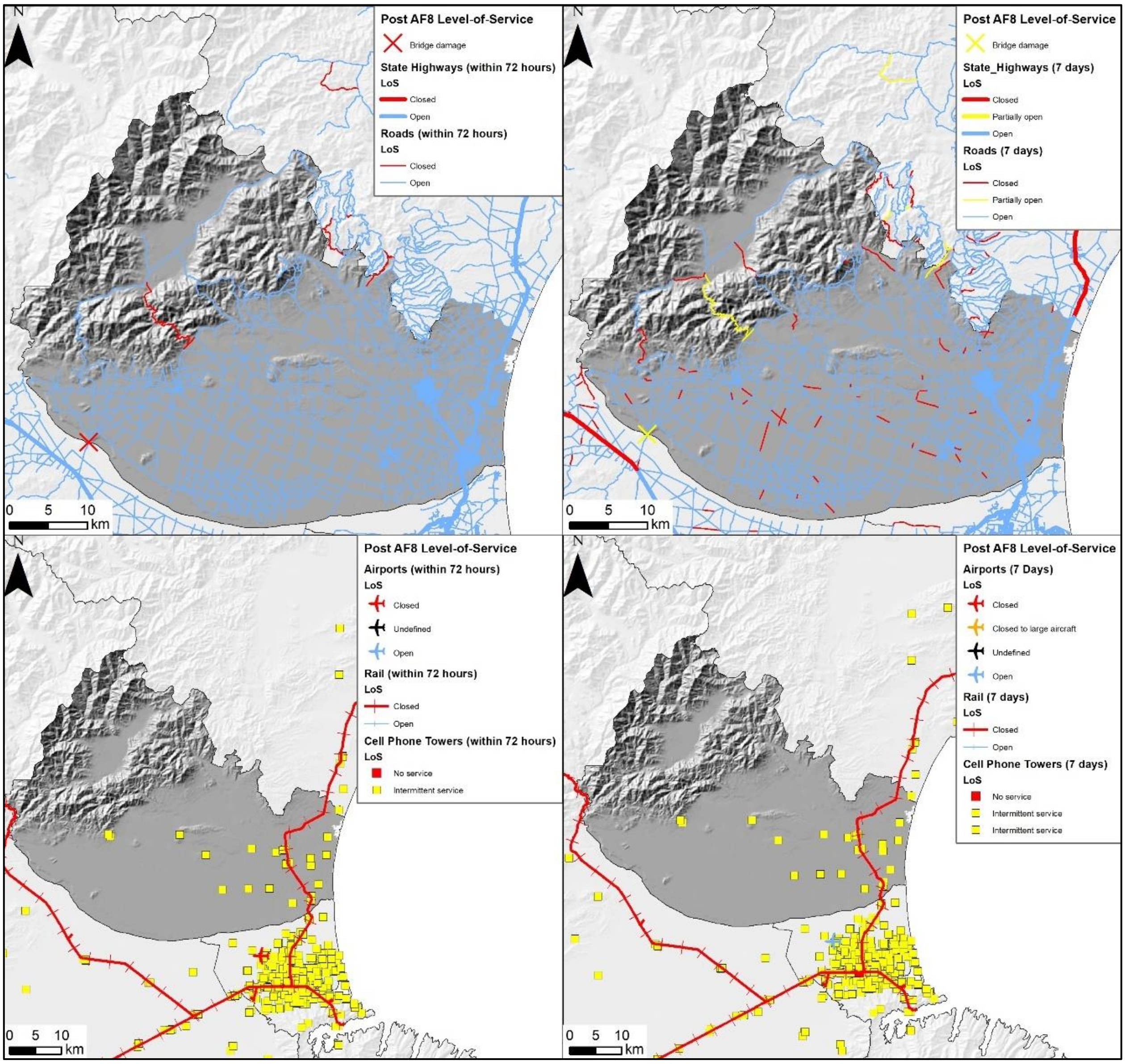

Figure 69: Level of service models for transportation and tele-communication infrastructure in the Waimakariri District. Produced by the AF8 science team. Note that in some cases the underlying continuation of seismic and coseismic hazards, considered in this study, leads to an increase in asset damage, and a decreased level of service, at 7 days compared with 72 hours.

5.4. Christchurch

The Christchurch District has proven to be highly susceptible to liquefaction, lateral spreading, and rockfall, which accounted for the majority of the damage absorbed during the 2010-2011 Canterbury Earthquake Sequence (CES). Figure 70 provides a location map with key locations marked for reference. Much of the eastern suburbs of Christchurch city are built on ground prone to slumping due to liquefaction, while the hill suburbs and Banks Peninsula are prone to landslides *(Figure 74).* Hence, there is a reasonable chance that infrastructure including roads and railway would be damaged in these areas during an AF8 event. After 72 hours, road services in the district would likely remain uninterrupted, but as liquefaction frequency increases due to aftershocks, closures could become frequent *(Figure 72).* Service on the Main North Line and Main South Line could be disrupted during the first 7 days of this event. Christchurch International Airport is likely to remain closed after 72 hours, with service able to be resumed 7 days after an AF8 event. Lyttelton Port and the Lyttelton to Woolston pipelines are key pieces of infrastructure in the area and will be vital with compromised road, rail, and gas transmission throughout the South Island (New Zealand Lifelines Council, 2020). These assets should be closely monitored, inspected and repaired in the event of damage to alleviate the stress on other transportation and gas infrastructure. Damage may also occur to the high number of earthquake prone buildings in the district which are exposed to MMI 5, 6, and 7 shaking as well as being susceptible to liquefaction and rockfall hazards *(Table 34; Figure 72).* It is important to note that the data presented in *Table 34* has likely changed as the council and government have retrofitted or demolished buildings since these numbers were compiled. The national electricity network is likely to receive damage during this event (within and beyond the district) and disruptions to power supply in Christchurch are likely, however, power is estimated to be fully restored by 7 days (Davies, 2019). Robinson et al. (2014) estimates that Christchurch could be without power for 7.5 hours following an AF8 event.

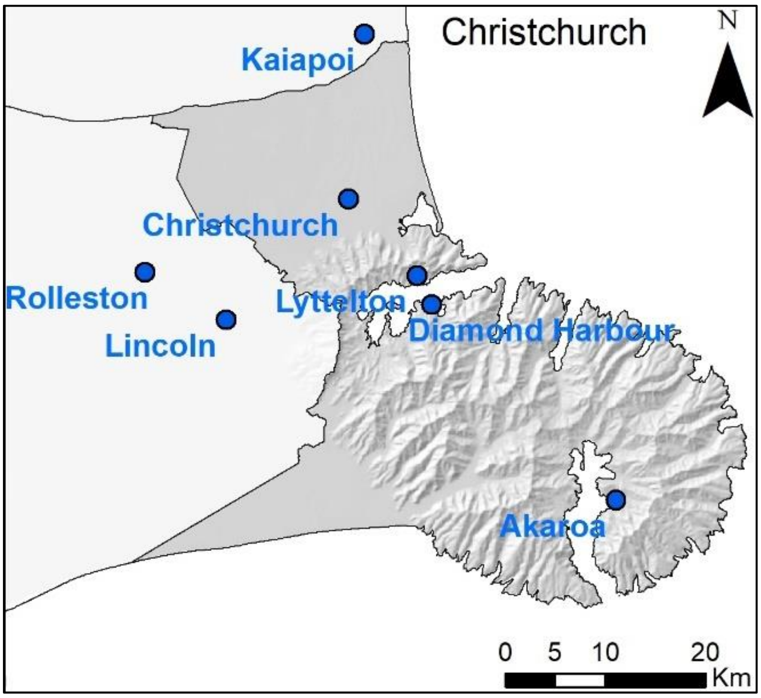

Figure 70: A location map of the Christchurch District.

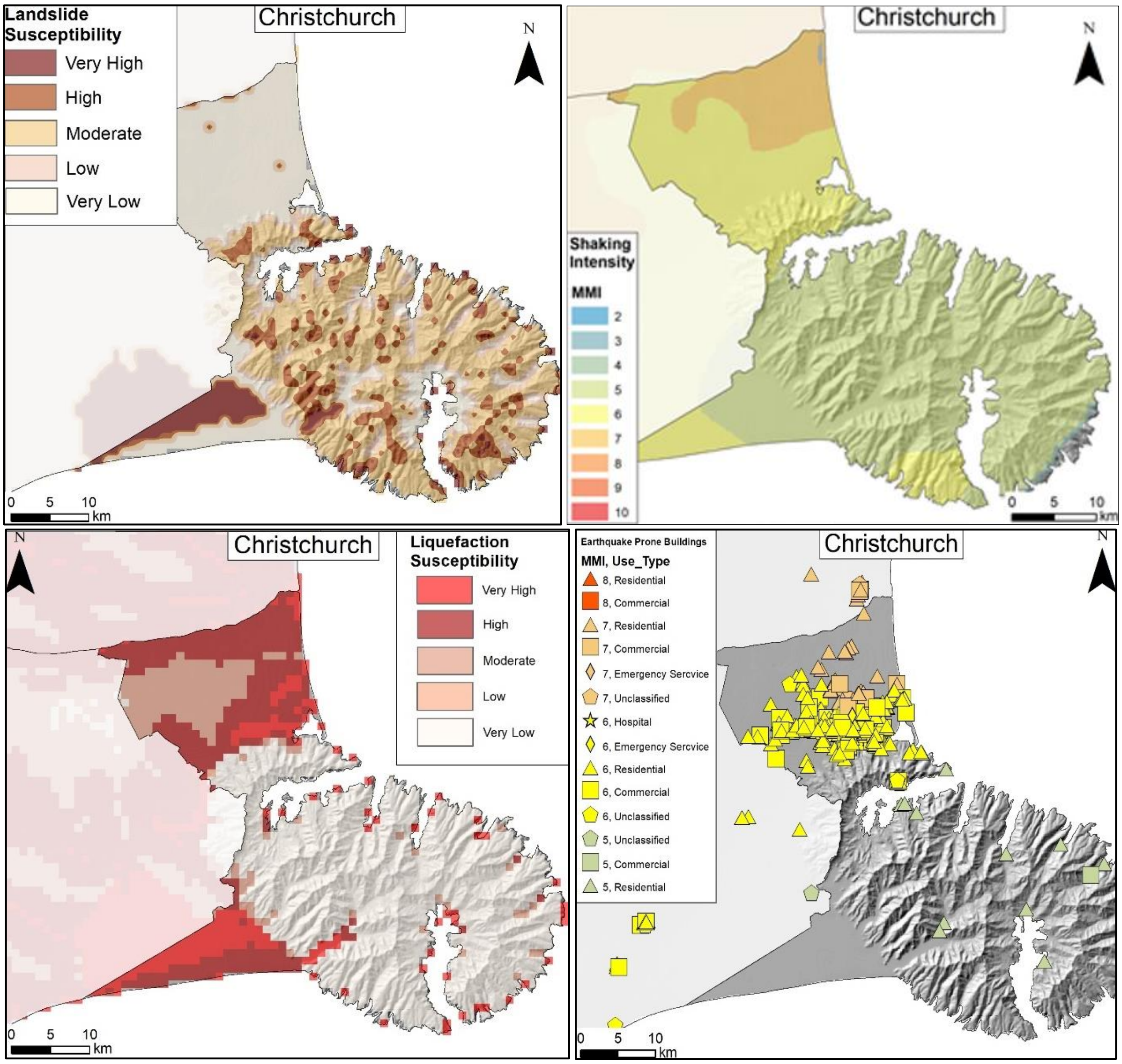

Figure 71: Hazard models and earthquake prone buildings for the Christchurch District.

Table 34: Summary data for the earthquake prone buildings in the Christchurch District.

Building Type	MMI			Total
	5	6	7	
Commercial	1	78	11	90
Emergency Service	-	2	-	2
Hospital	-	7	-	7
Residential	11	472	67	550
Unclassified	-	19	-	19
Total	12	578	78	668

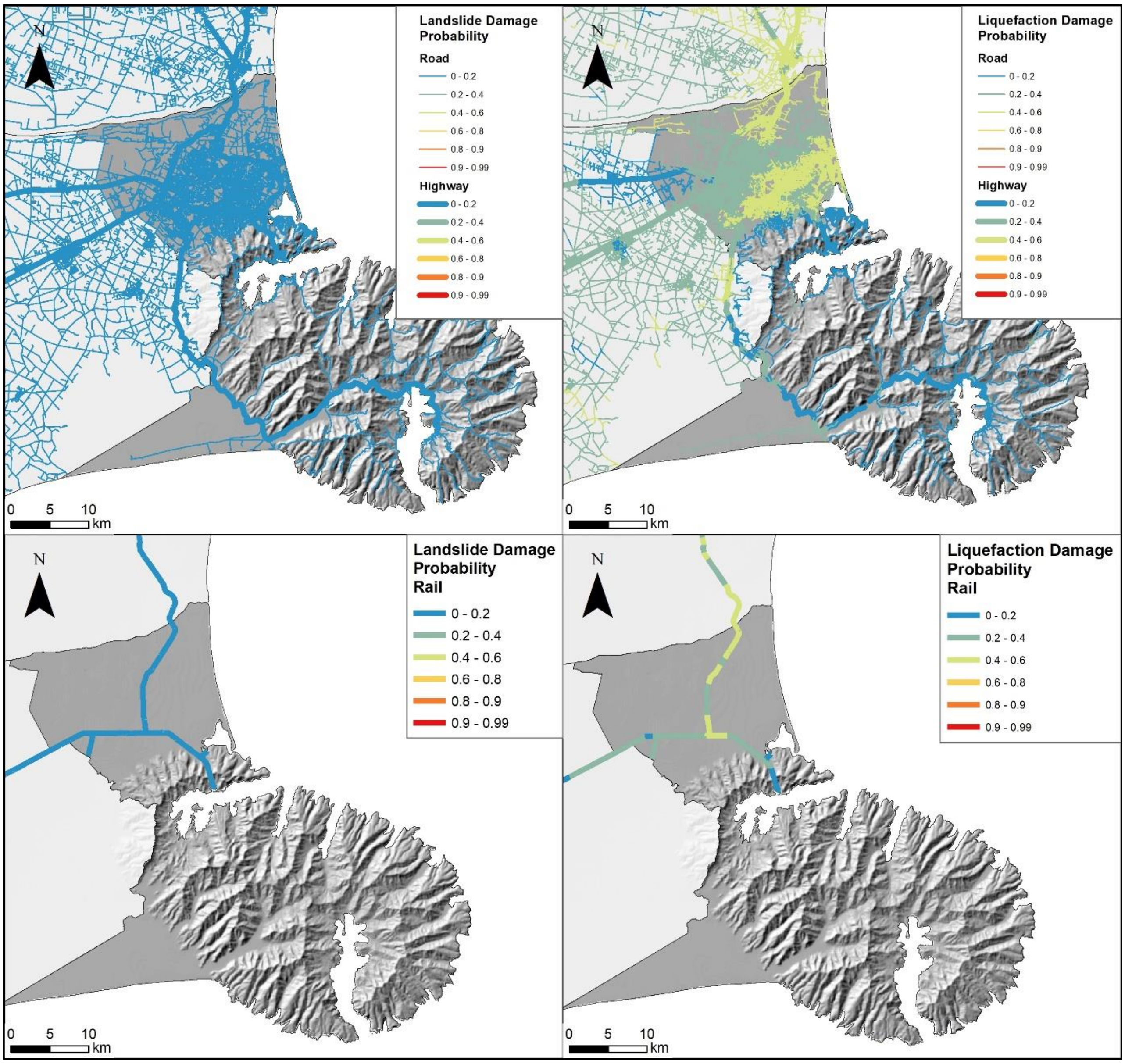

Figure 72: Transportation infrastructure landslide and liquefaction impact probability maps for the Christchurch District. Source: Amelia Lin (2020).

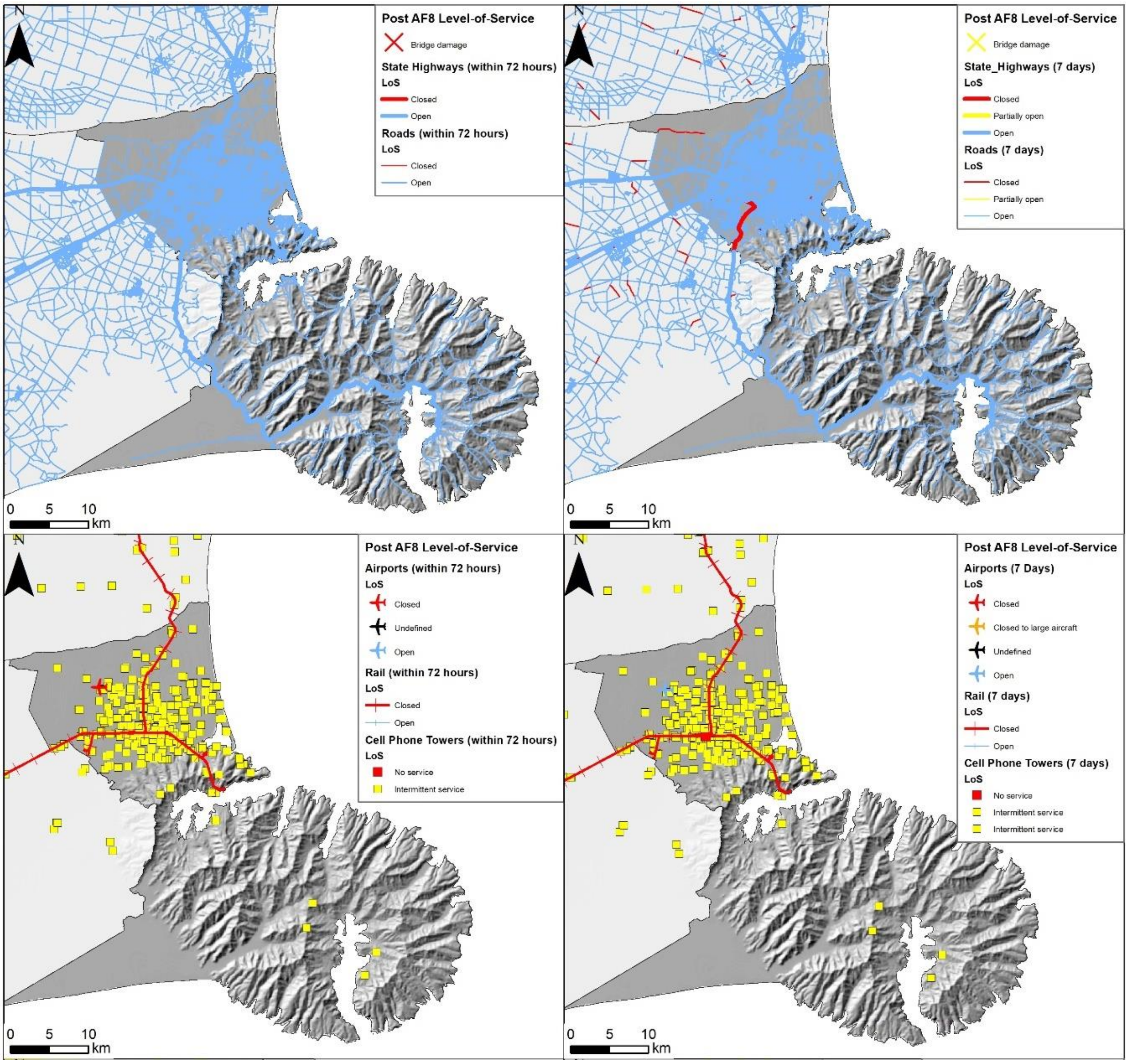

Figure 73: Level of service models for transportation, tele-communication, and electricity infrastructure in the Christchurch District. Produced by the AF8 science team. Note that in some cases the underlying continuation of seismic and coseismic hazards, considered in this study, leads to an increase in asset damage, and a decreased level of service, at 7 days compared with 72 hours.

5.5. Selwyn

The Selwyn District is exposed to considerable seismic hazard from the alpine fault and will likely experience high levels of ground shaking, widespread liquefaction and landslides *(Figure 75)* that all have potential to impact regional infrastructure and result in several injuries/fatalities. Figure 74 displays a location map for the district with main population centres marked for reference. Intensive liquefaction on the Canterbury plains and landslides in Arthurs Pass from an AF8 event are estimated to damage transportation and could result in a considerable loss of service to infrastructure in the district *(Figure 77).* Within 72 hours of the initial earthquake, SH73 and the Midland Line through Arthurs Pass is likely to be closed with widespread damage to bridges, road, and rail throughout the district *(Figure 77).* After 7 days, some road sections and bridges are partially open, however, major transportation links within the district remain closed. Robinson et al., (2014), estimates that during an AF8 event there will be no access along the Midland Line (rail) with rockfalls and landslides creating blockages in the Waimakariri Gorge and Arthurs Pass. While Robinson et al., (2016) conclude that it could take up to 9 months for the Midland Line to be fully restored, which includes repeated blockages and damage due to aftershocks. High hazard intensity in this region will directly influence the 7 fatalities and 167 injuries estimated *(Table 1).* The conclusions from these papers are discussed in more detail in Section 2 of this report.

Cell towers are likely to be able to maintain intermittent service during the first 7 days and as outlined in *Figure 77,* while electricity could be operating at full capacity within 7 days everywhere except for Arthurs Pass Village *(Figure 57).* As landslides in Arthurs Pass are likely to damage steel pylons, where 26 pylons carrying 60 kV cables are expected to receive damage (Robinson et al., 2016). The likelihood of mains power distribution through Arthur's pass is therefore unlikely. The district also has a number of earthquake prone buildings that will contribute to the total losses during this event (Table 35).

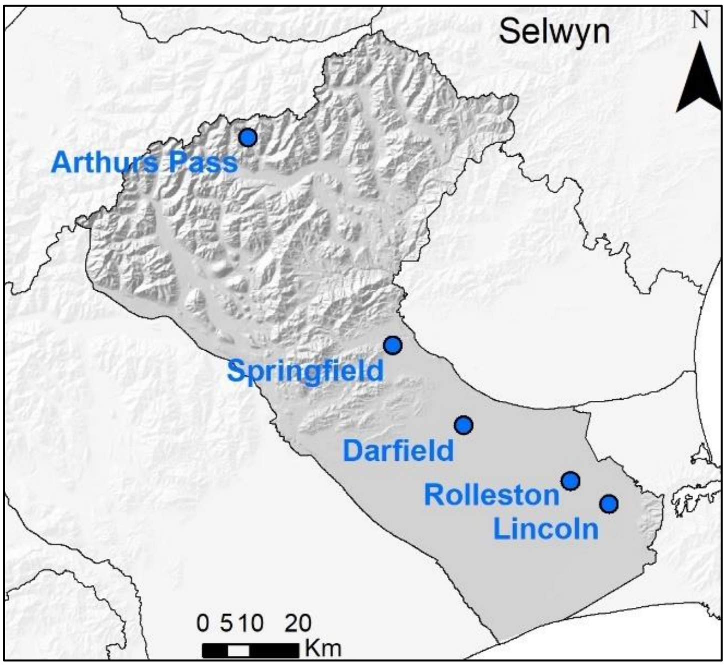

Figure 74: Location Map of the Selwyn District.

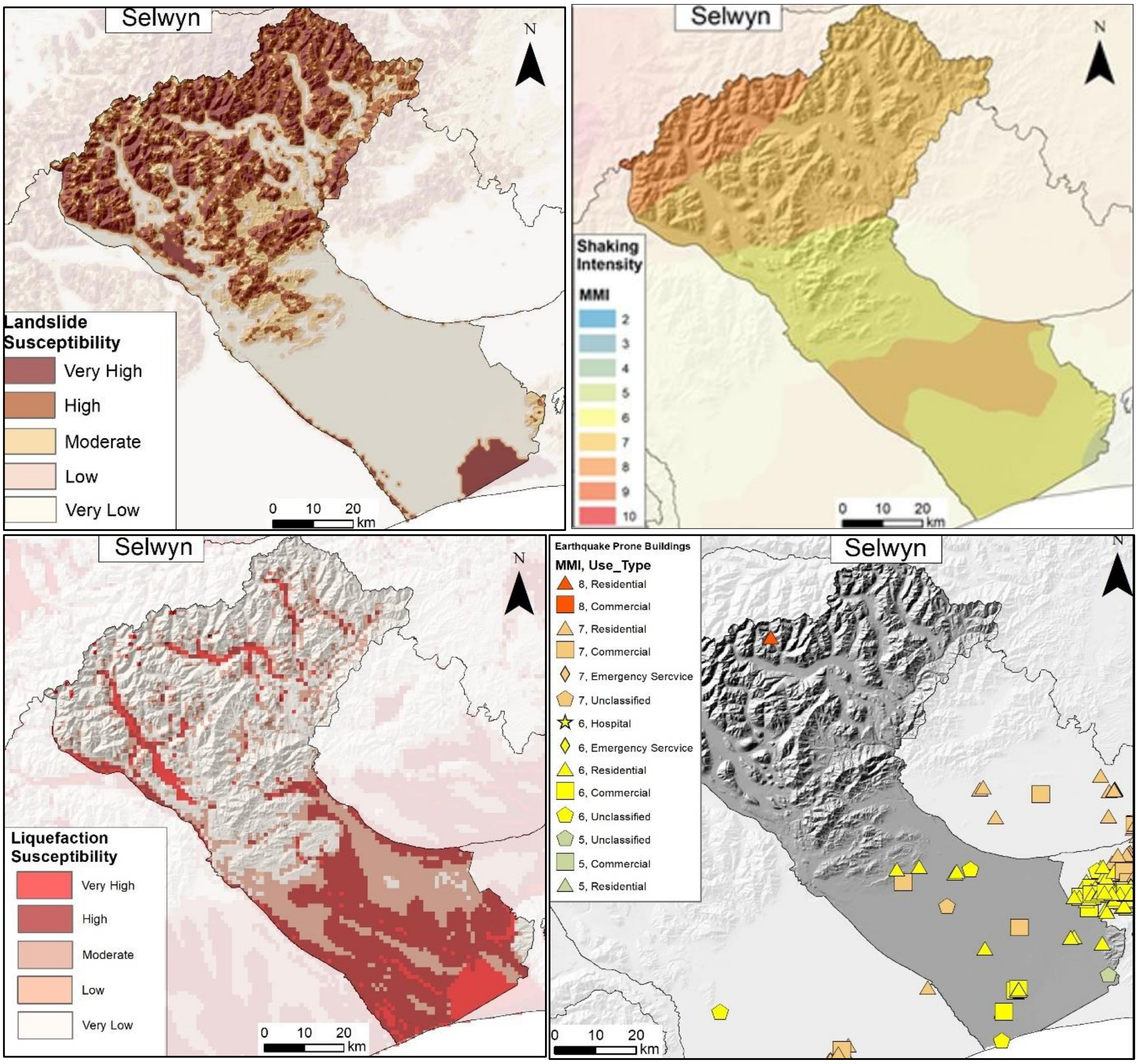

Figure 75: Hazard models and earthquake prone buildings for the Selwyn District.

Table 35: Summary of the earthquake prone buildings in Selwyn.

Building Type	MMI				Total
	5	6	7	8	
Commercial		5	4		9
Residential		21		1	22
Unclassified	1	3	1		5
Grand Total	1	29	5	1	36

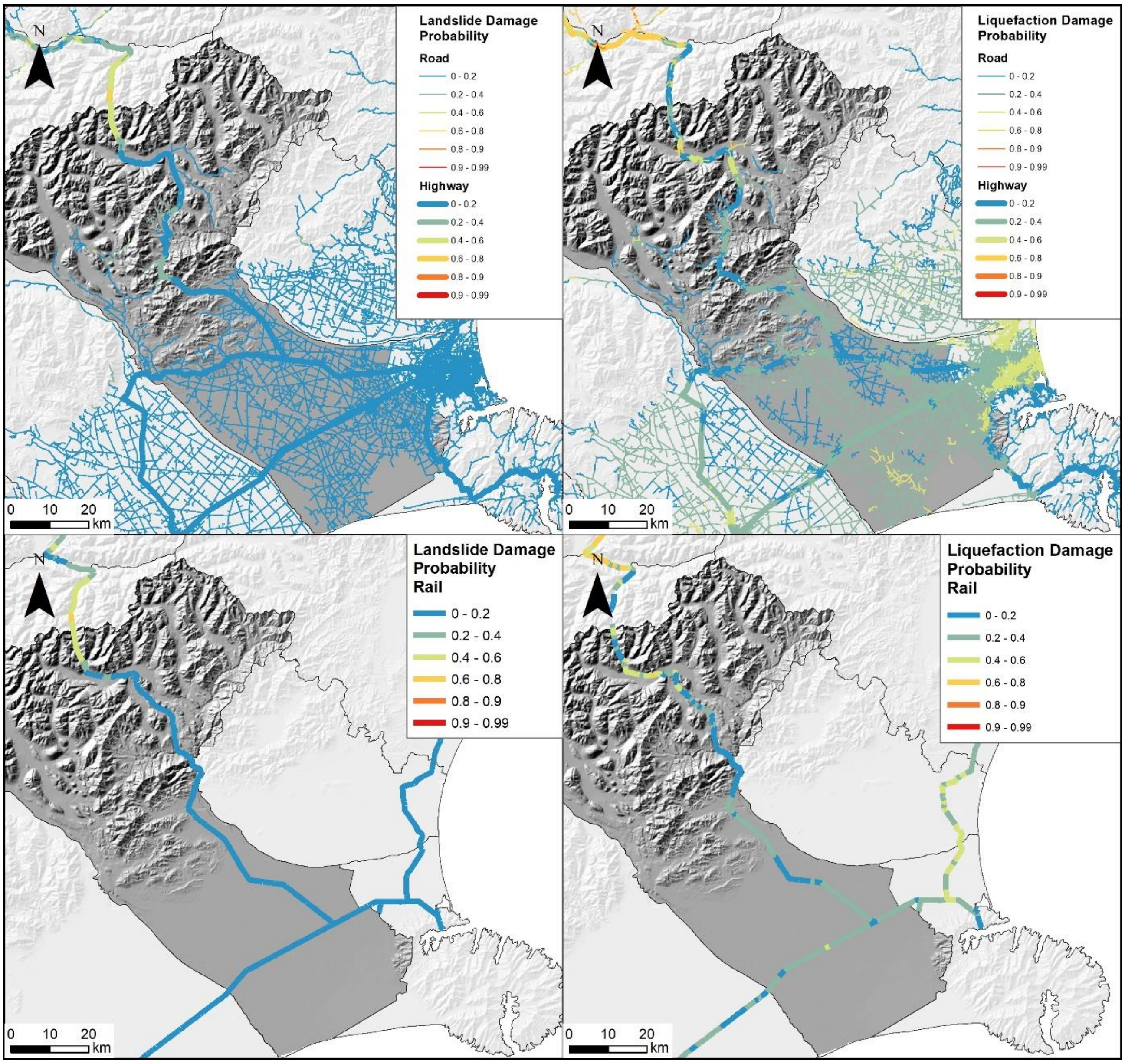

Figure 76: Transportation infrastructure landslide and liquefaction impact probability maps for the Selwyn District. Source: Amelia Lin (2020).

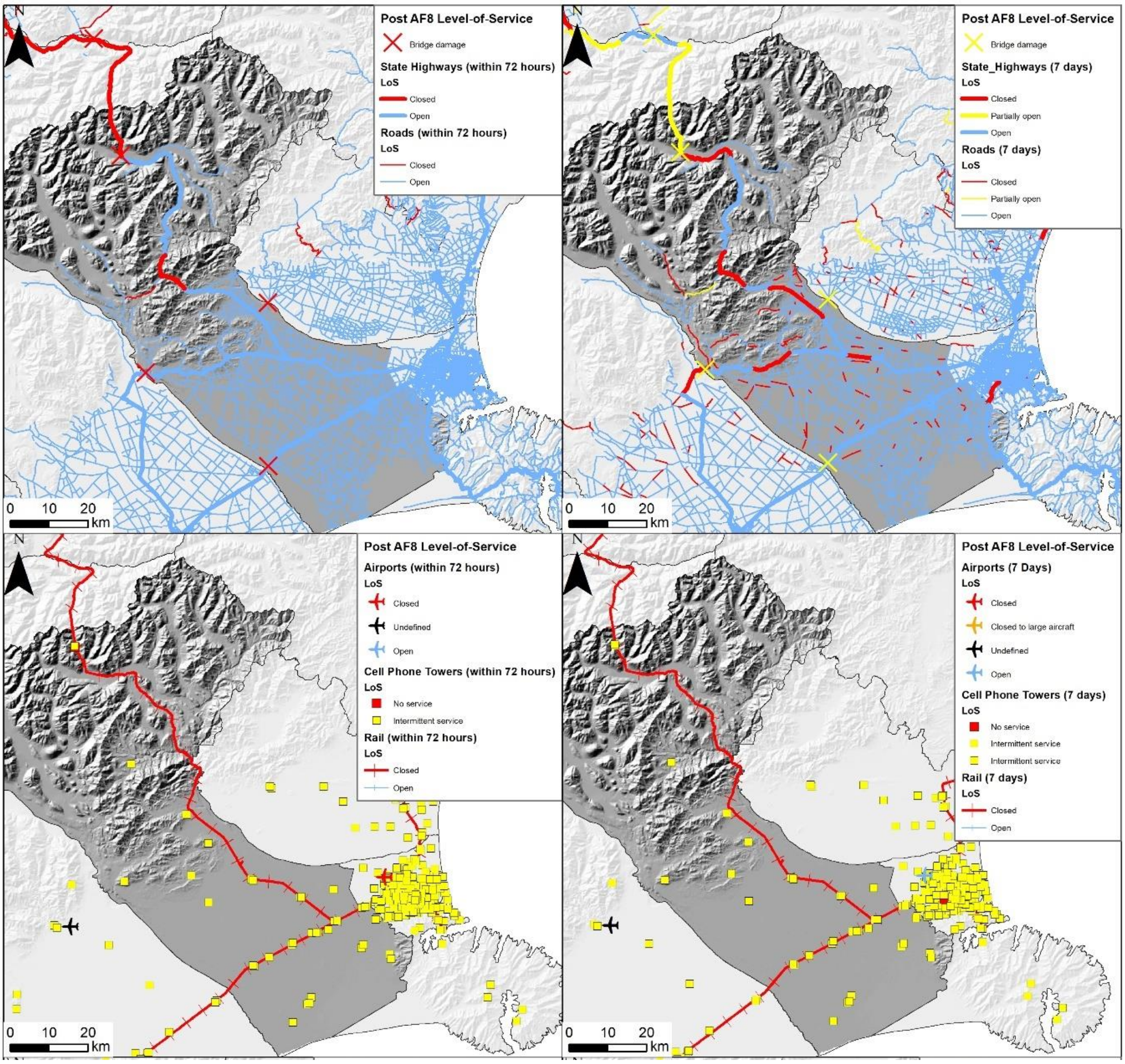

Figure 77: Level of service models for transportation, tele-communication, and electricity infrastructure in the Selwyn District. Produced by the AF8 science team. Note that in some cases the underlying continuation of seismic and coseismic hazards, considered in this study, leads to an increase in asset damage, and a decreased level of service, at 7 days compared with 72 hours.

5.6. Ashburton

The Ashburton District in central Canterbury is likely to experience high levels of ground shaking, landslides, and liquefaction during an AF8 event *(Figure 79)* where considerable losses to infrastructure and the built environment are anticipated. Figure 78 is a map of the district with the main population centres marked for reference. The geological characteristics of the Ashburton District means that it is highly susceptible to widespread landslides and liquefaction during high levels of ground shaking *(Figure 79).* Transportation infrastructure is likely to be damaged along the Canterbury plains during an AF8 event and could result in the closure of key routes *(Figure 79).* Within 72 hours of the event, bridges along the Rakaia River could remain closed and liquefaction damage could likely close the Main South Line for several days following the event *(Figure 80)* Within 7 days repeated aftershocks and increased liquefaction intensity could further damage infrastructure and could likely close sections of road and state highway throughout the district, while bridges along the Rakaia River may be partially open. Cell towers within the district should provide intermittent service throughout the first week and electricity is likely to be fully restored within 7 days *(Figure 57).* Further losses could occur due to damage to the 50 earthquake prone buildings in the district *(Table 36).* Where building collapse is anticipated to contribute to the 5 fatalities and 119 injuries estimated for the Ashburton District during an AF8 event (*Table 1*; Robinson et al., 2014).

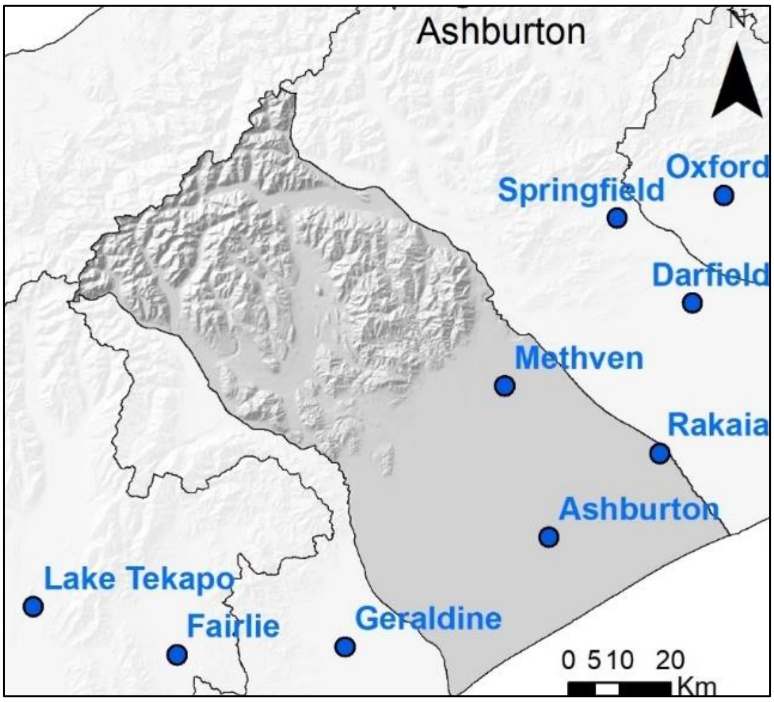

Figure 78: A location map of the Ashburton District.

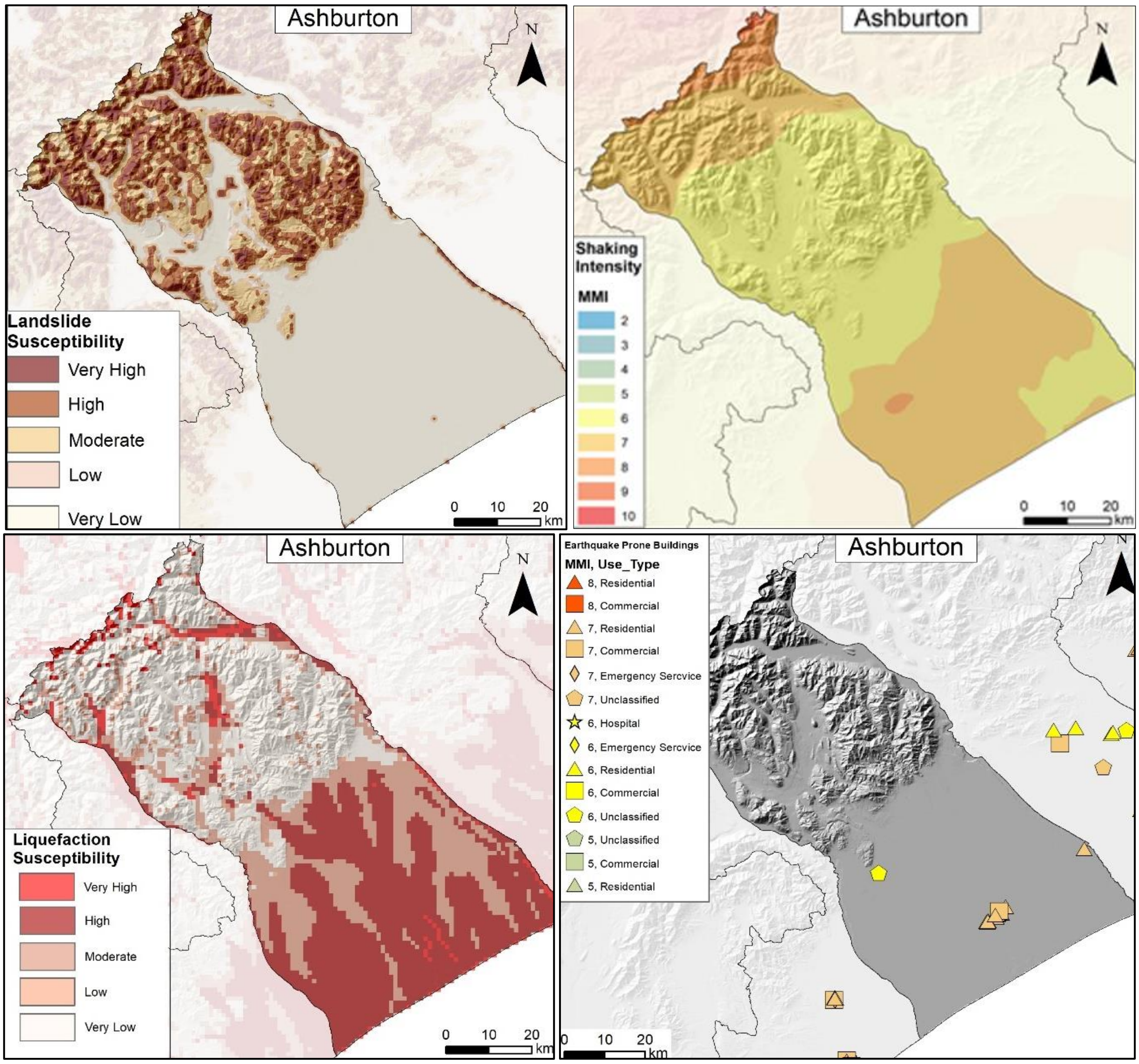

Figure 79: Hazard models and earthquake prone buildings for the Ashburton District.

Table 36: Summary of the earthquake prone buildings in the Ashburton District.

Building Type	MMI 6	MMI 7	Total
Commercial		2	2
Residential		46	46
Unclassified	2		2
Total	2	48	50

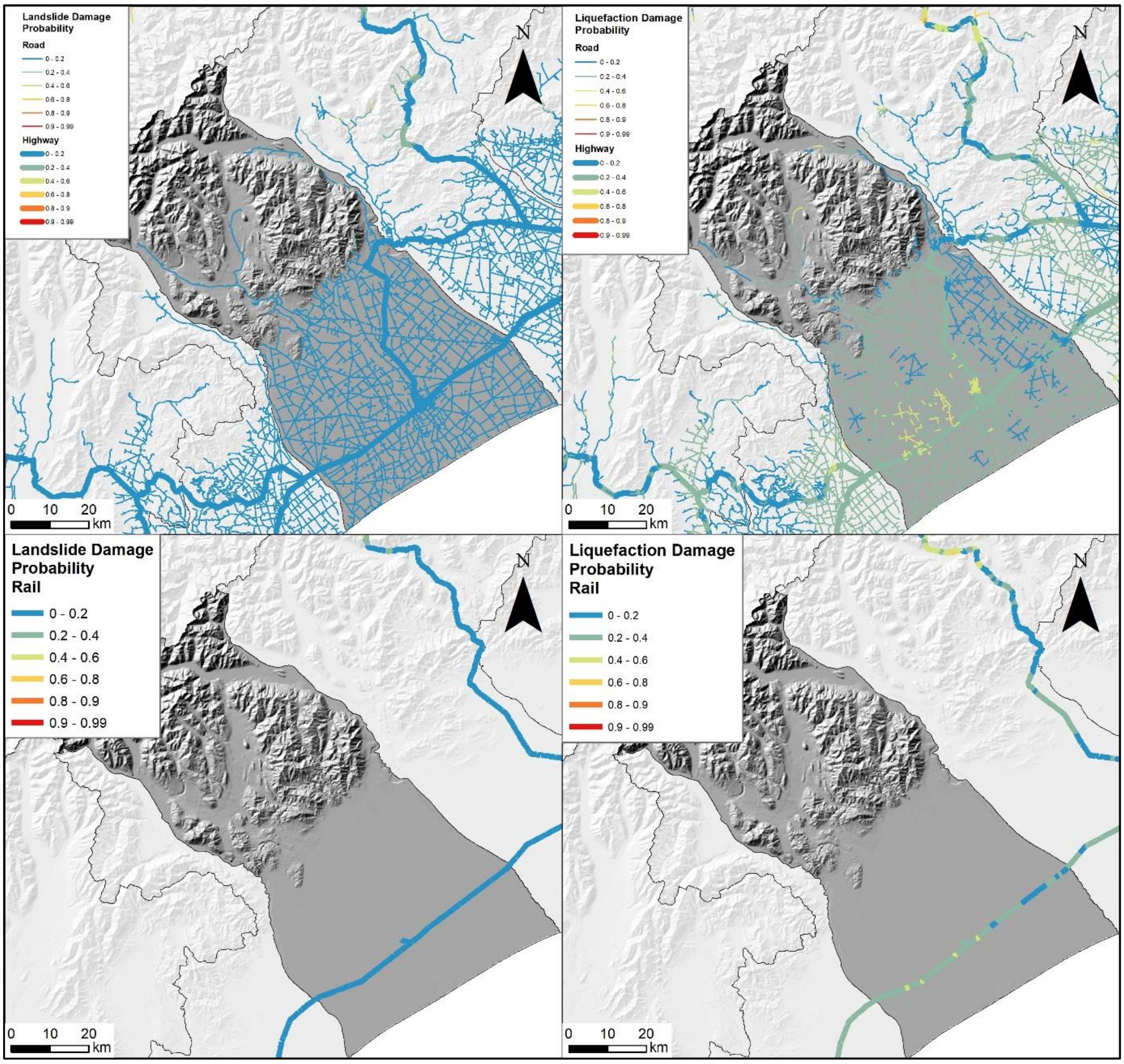

Figure 80: Transportation infrastructure landslide and liquefaction impact probability maps for the Ashburton District. Source: Amelia Lin (2020).

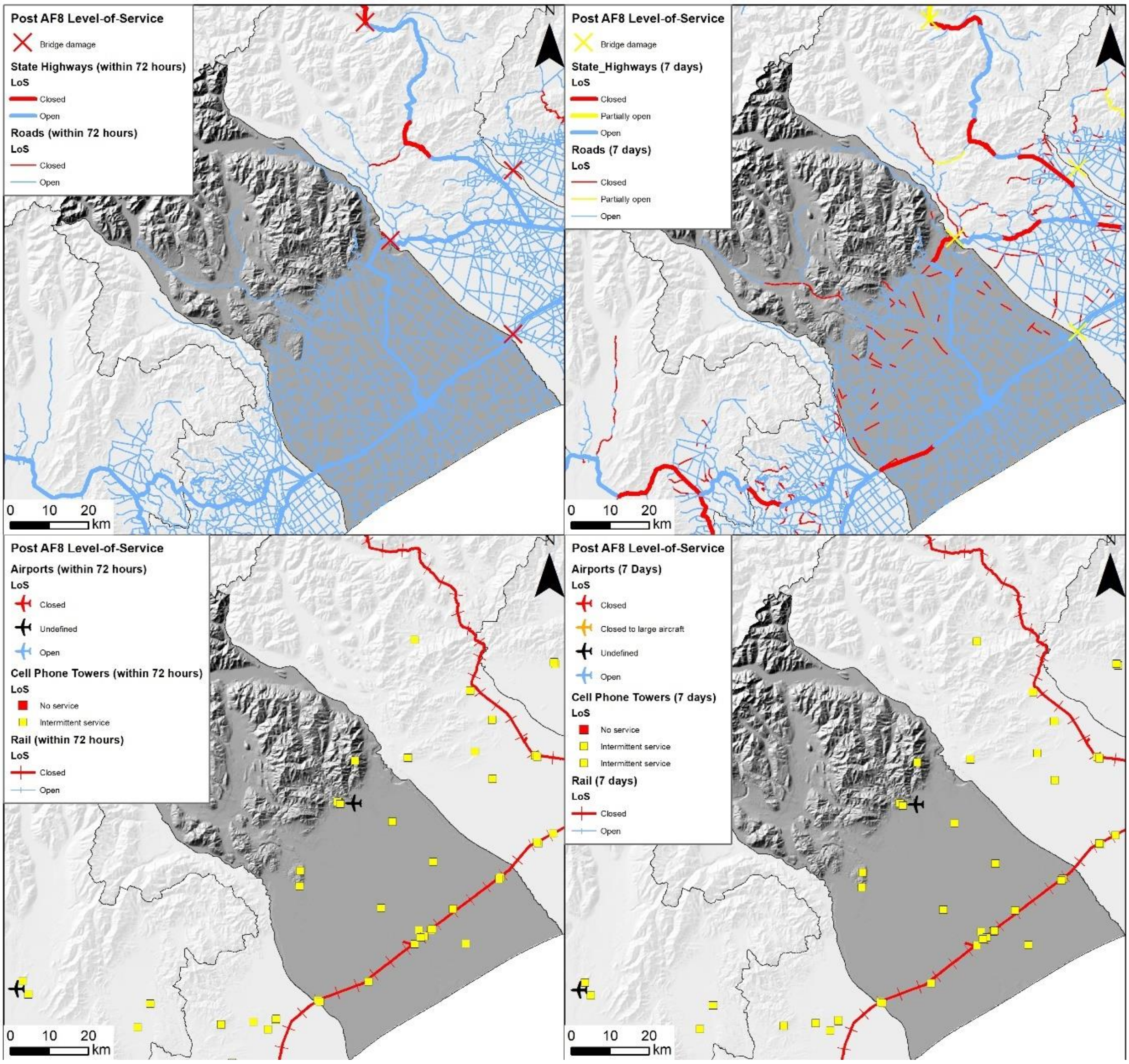

Figure 81: Level of service models for transportation, telecommunication, and electricity infrastructure in the Ashburton District. Produced by the AF8 science team. Note that in some cases the underlying continuation of seismic and coseismic hazards, considered in this study, leads to an increase in asset damage, and a decreased level of service, at 7 days compared with 72 hours.

5.7. Timaru

During an AF8 event the Timaru District could sustain considerable losses due to earthquake damage to key infrastructure and buildings. Figure 82 displays a location map of the district for reference. For an AF8 event the district is likely to experience high levels of ground shaking, liquefaction, and landslides which could be reoccurring hazards due to a considerable aftershock sequence *(Figure 83).* Figure 84 illustrates that liquefaction on the southern end of the Canterbury Plains is likely to cause damage to transportation infrastructure including State Highway 1, the Main South Line and Timaru Airport. In the first 72 hours following the earthquake, roads in the district are likely still open, however, the Main South Line could be closed for several days following the event (Figure 85). Additionally, the Timaru Airport is closed which further restricts the movement of people in the District. Within 7 days intensive liquefaction and landslides are anticipated to close sections of SH8 and 79 and could make access to the Mackenzie District difficult. However, the Timaru Airport should be open and could alleviate the stress on other transport corridors within the region. Cell towers and the electricity network should provide intermittent service within the first 24 hours of the event to the district, with full power restoration likely by the end of the first week *(Figure 57).* Robinson et al. (2014) estimates that power could be restored to Timaru township after 6.5 hours. Timaru also has a number of earthquake prone buildings that are exposed to considerable levels of ground shaking during an AF8 event, which could contribute to total losses *(Table 37).* Any likely structural damage to earthquake prone buildings could contribute to the 9 injuries estimated in the district (Robinson et al., 2014).

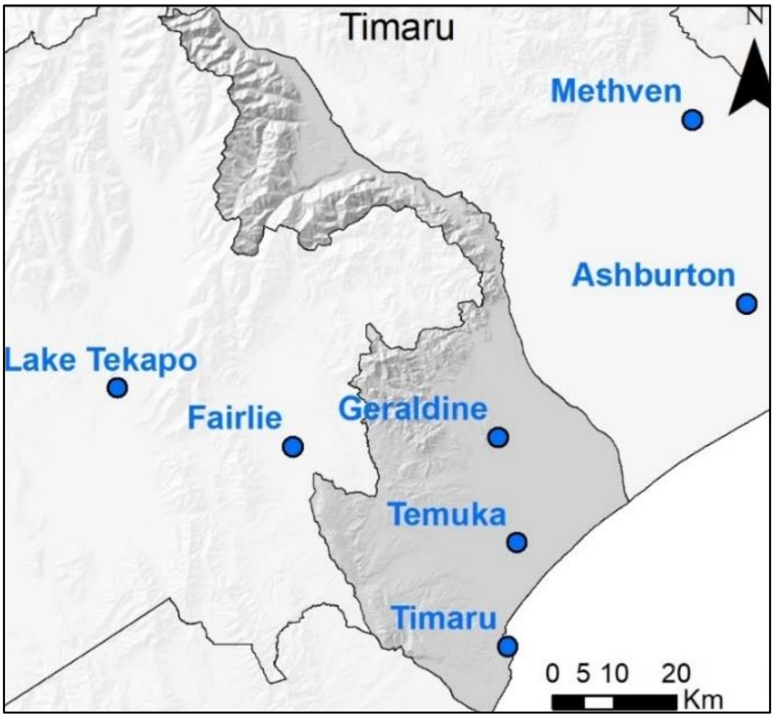

Figure 82: Location map for the Timaru District.

![AF8 Alpine Fault Magnitude 8 logo]

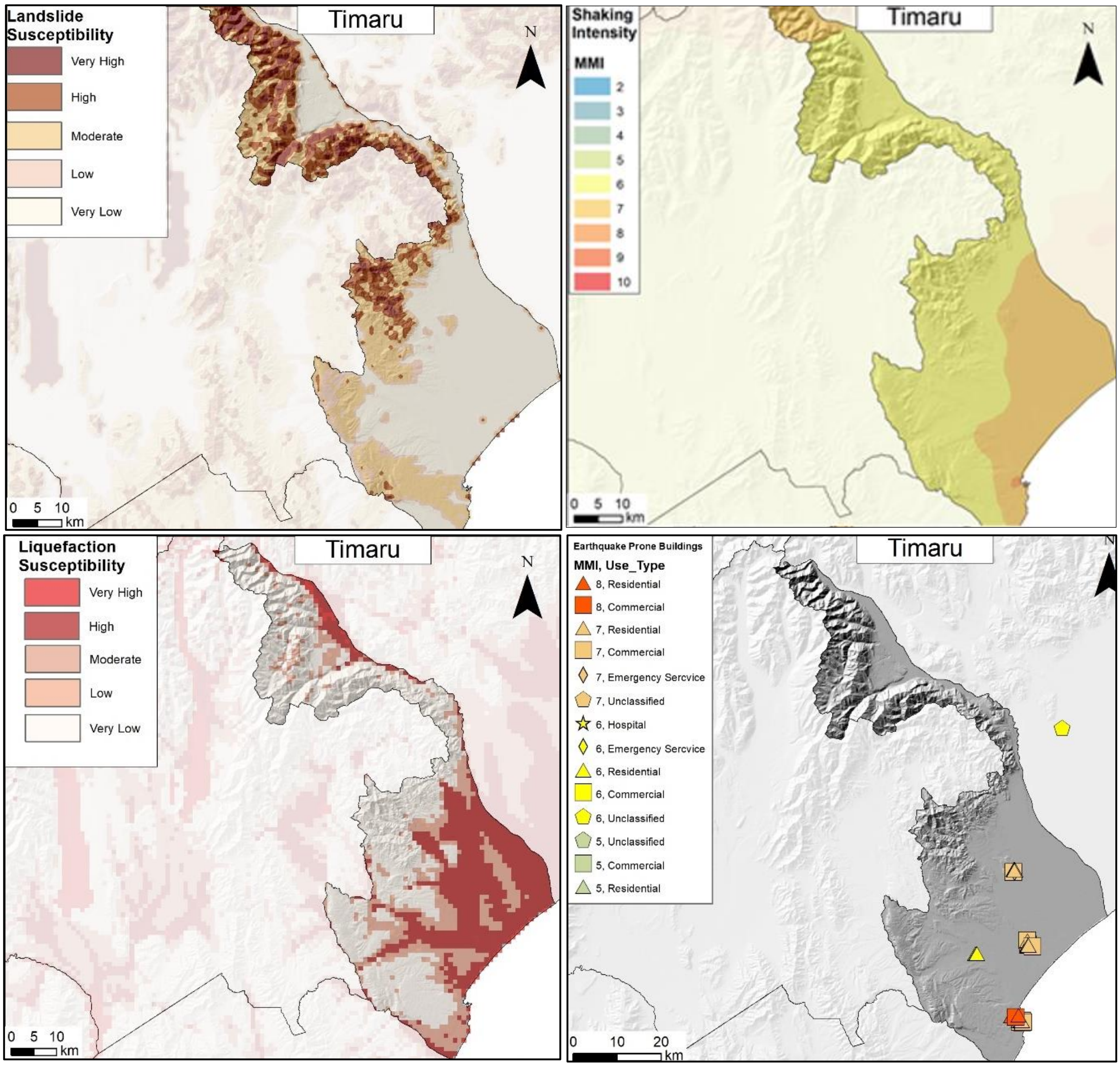

Figure 83: Hazard models and earthquake prone buildings for the Timaru District.

Table 37: Summary data for the earthquake prone buildings in the Timaru District.

Building Type	MMI 6	MMI 7	Total
Commercial		8	8
Emergency Service		1	1
Residential	4	32	36
Total	4	41	45

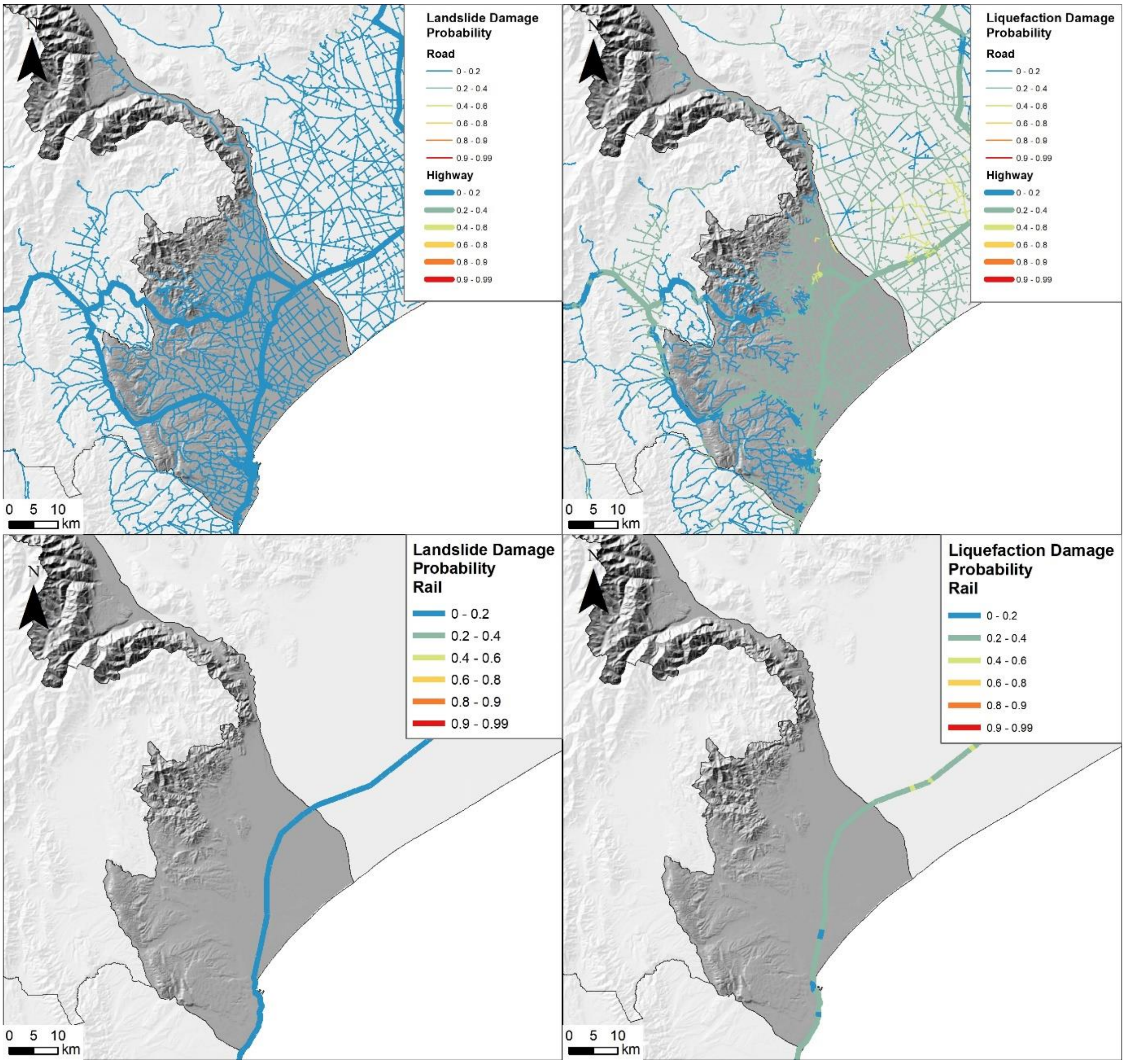

Figure 84: Transportation infrastructure landslide and liquefaction impact probability maps for the Timaru District. Source: Amelia Lin (2020).

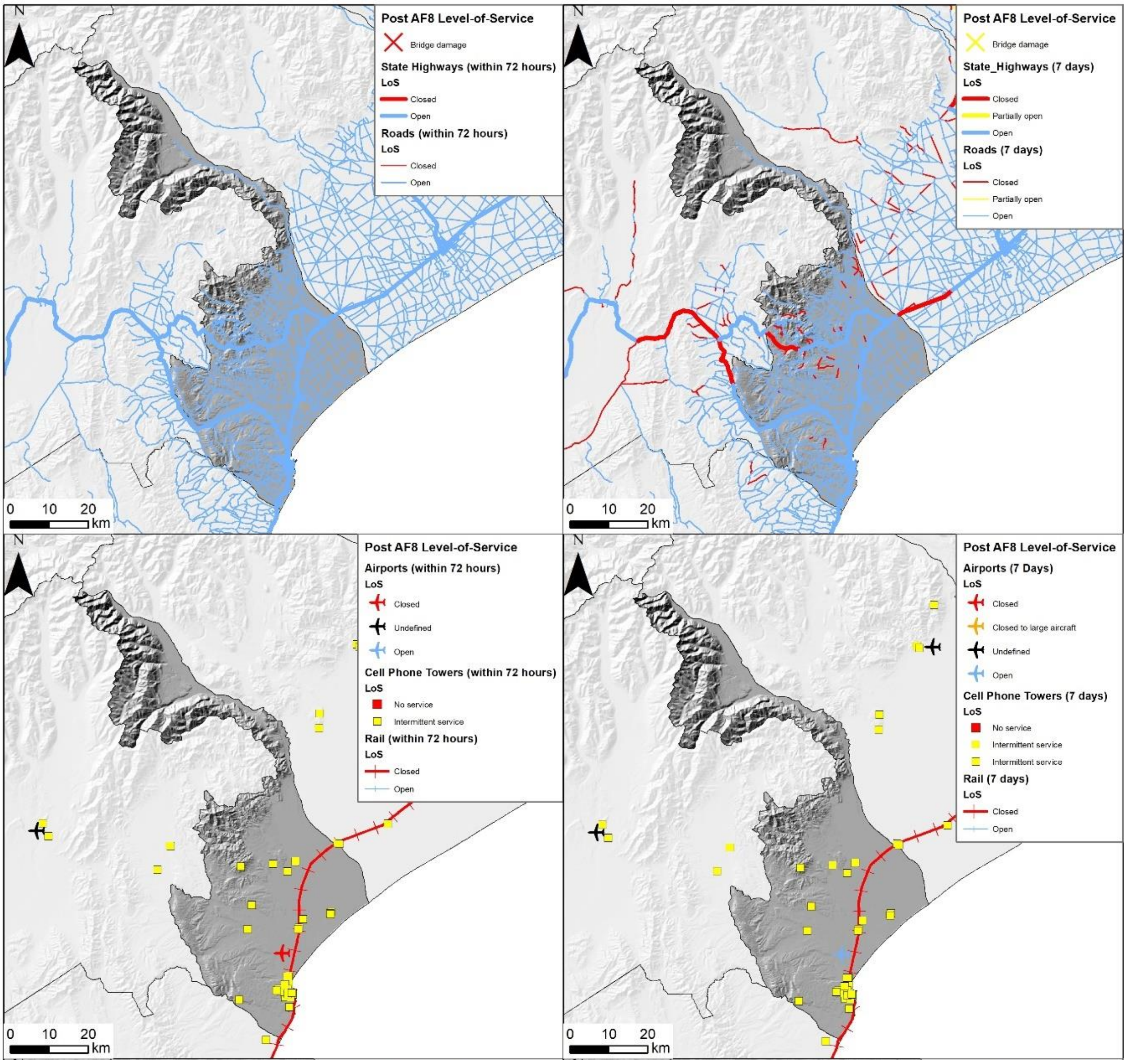

Figure 85: Level of service models for transportation, tele-communication, and electricity infrastructure in the Timaru District. Produced by the AF8 science team. Note that in some cases the underlying continuation of seismic and coseismic hazards, considered in this study, leads to an increase in asset damage, and a decreased level of service, at 7 days compared with 72 hours.

5.8. Mackenzie

The Mackenzie District could experience up to MMI9 ground shaking in an AF8 event and could experience widespread damage to infrastructure and buildings. Figure 86 is a location map with key towns marked for reference. Figure 87 illustrates Mackenzie's high susceptibility to liquefaction and landslides. Liquefaction is likely to occur along the region's river basins, while landslides could occur along steep aspects across the district. Liquefaction is likely to damage SH8 and SH80 to Mount Cook Village which could make sections of road treacherous and hinder evacuations *(Figure 88).* Furthermore, Waka Kotahi (NZTA) could be anticipated to close large sections of these main transportation links within 7 days of an AF8 event *(Figure 89).* Mt Cook Village could be isolated due to damage along SH80, closure of the Aoraki/Mt Cook airport and no telecommunication service. Efficient evacuations of this area would be a major priority for the District as this scenario predicts that Aoraki/Mount Cook Airport would be closed within 7 days of the event due to extreme liquefaction and landslides in the Tasman River catchment. The remainder of the District may receive some power and service within the first 24 hours, with full power restoration within 7 days *(Figure 57).* It is estimated that Twizel could receive power 6.5 hours after the initial earthquake (Robinson et al., 2014). The Mackenzie District is estimated to see the highest number of casualties in Canterbury with 8 fatalities and 210 injuries (Robinson et al., 2014).

Further studies have highlighted the vulnerability of the built environment to an AF8 event in Mackenzie. Clark et al (2015) assessed sources for tsunami and seiches for lakes Tekapo, Alexandrina, Pūkaki, Ruataniwha, and Ōhau, where landslides and delta collapse were described as the main reasons for a lake tsunami. Lakes Ōhau, Tekapo, and Pūkaki were found to have large landslide source areas capable of producing tsunami waves with run-up heights of 0.5 – 25m. Wang et al (2020) estimated that during an AF8 event Lake Tekapo could experience seiches that could elevate the normal lake level 1.5 -2.5m along many parts of the lakeshore. Furthermore, Mountjoy et al (2018) provided historical evidence for collapsed delta systems in Lake Tekapo which are thought to be capable of producing tsunamis. These phenomena could damage and disrupt the built environment and contribute to the total losses for the district. Also, Robinson et al (2016) estimates damage to 3 waters infrastructure for Mt Cook Village during an AF8 event. These papers are outlined in detail in section 2 of this report.

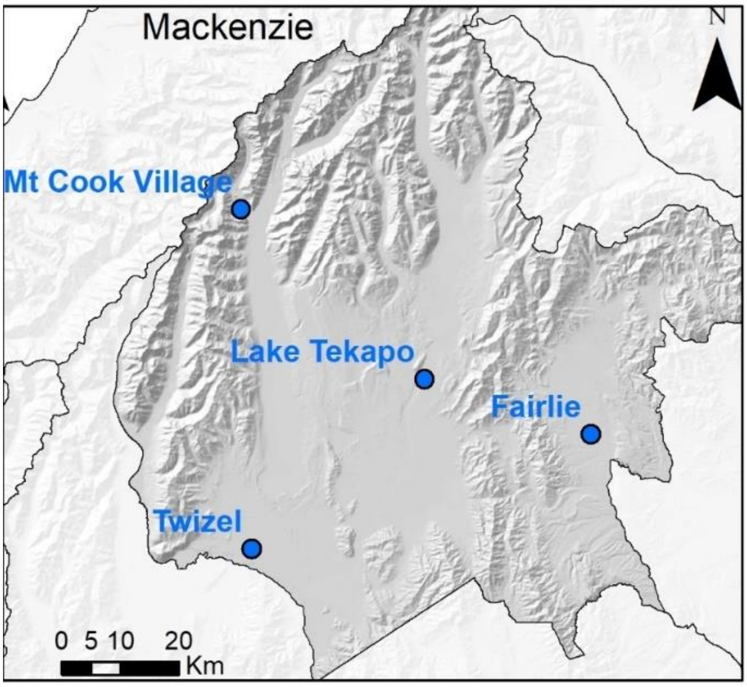

Figure 86: A location map of the Mackenzie District.

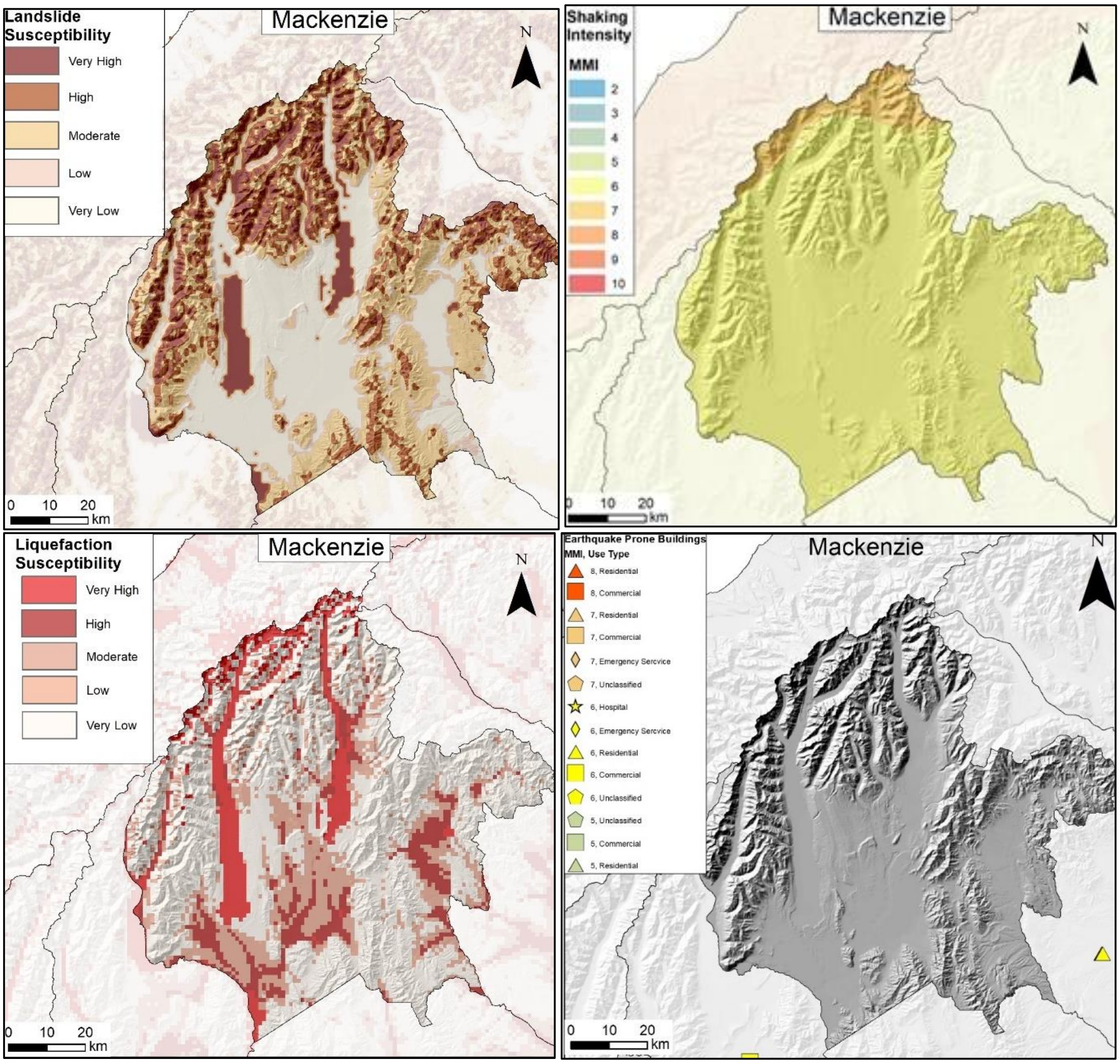

Figure 87: Hazard models and earthquake prone buildings for the Mackenzie District.

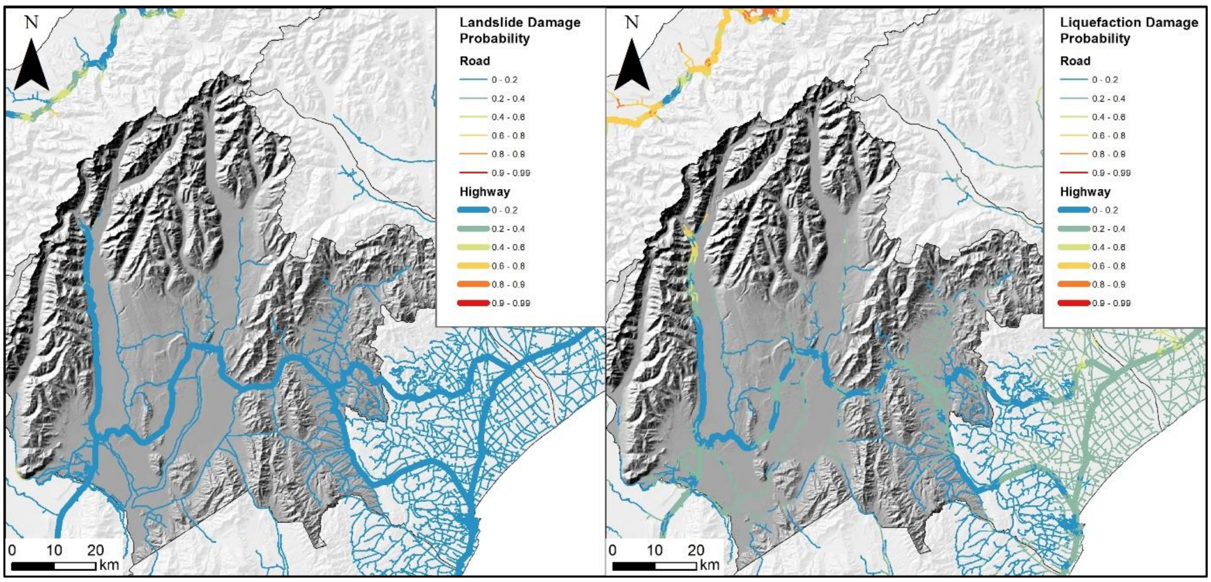

Figure 88: Transportation infrastructure landslide and liquefaction impact probability maps for the Mackenzie District. Source: Amelia Lin (2020).

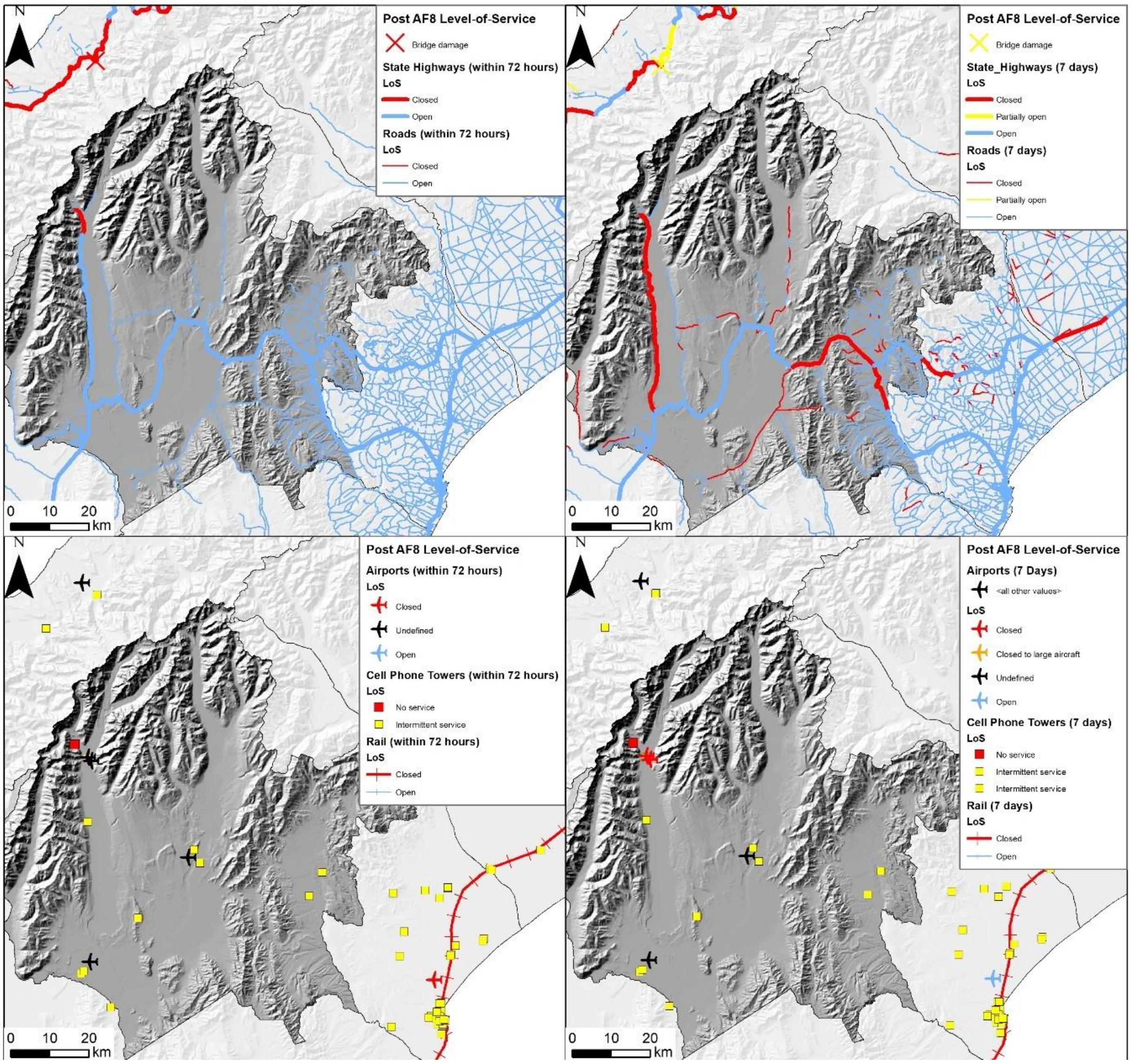

Figure 89: Level of service models for transportation, tele-communication, and electricity infrastructure in the Mackenzie District. Produced by the AF8 science team. Note that in some cases the underlying continuation of seismic and coseismic hazards, considered in this study, leads to an increase in asset damage, and a decreased level of service, at 7 days compared with 72 hours.

5.9. Waimate

The Waimate District in southern Canterbury is exposed to considerable seismic hazard during an AF8 event and could experience damage and disruption to key infrastructure. Figure 90 displays a location map for the District as a reference for the following figures. The primary coseismic hazards for this district are ground shaking (MMI), liquefaction, and landslides which will have prolonged impacts in an aftershock sequence. Ground shaking in Waimate is relatively low for the modelled event (MMI5 - 6) compared with other Canterbury Districts, however, much of the ground proximal to the coastline is susceptible to high levels of liquefaction *(Figure 91).* Liquefaction could cause damage to major roads and railway within the District, including SH1 and the Main South Line *(Figure 92).* Figure 93 illustrates the level-of-service of key infrastructure in Waimate for 72 hours and 7 days since the initial earthquake. In this AF8 scenario road transport routes could remain mostly open throughout the district for the first 7 days, however, SH83 and SH8 surrounding the Waimate area could be closed 7 days after the earthquake which would considerably restrict access to the Mackenzie District. The Main South Line could sustain extensive damage and could remain closed 7 days after the event. Cell phone towers in the district may provide intermittent service, while electricity should be partially restored after 24 hours and fully restored by 7 days *(Figure 57).*

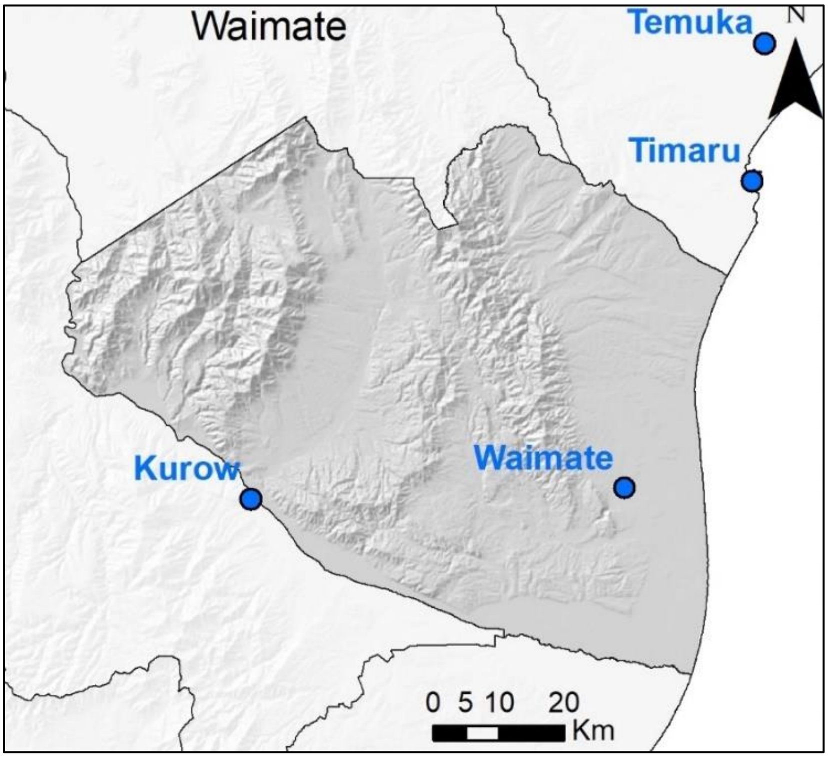

Figure 90: A location map for the Waimate District.

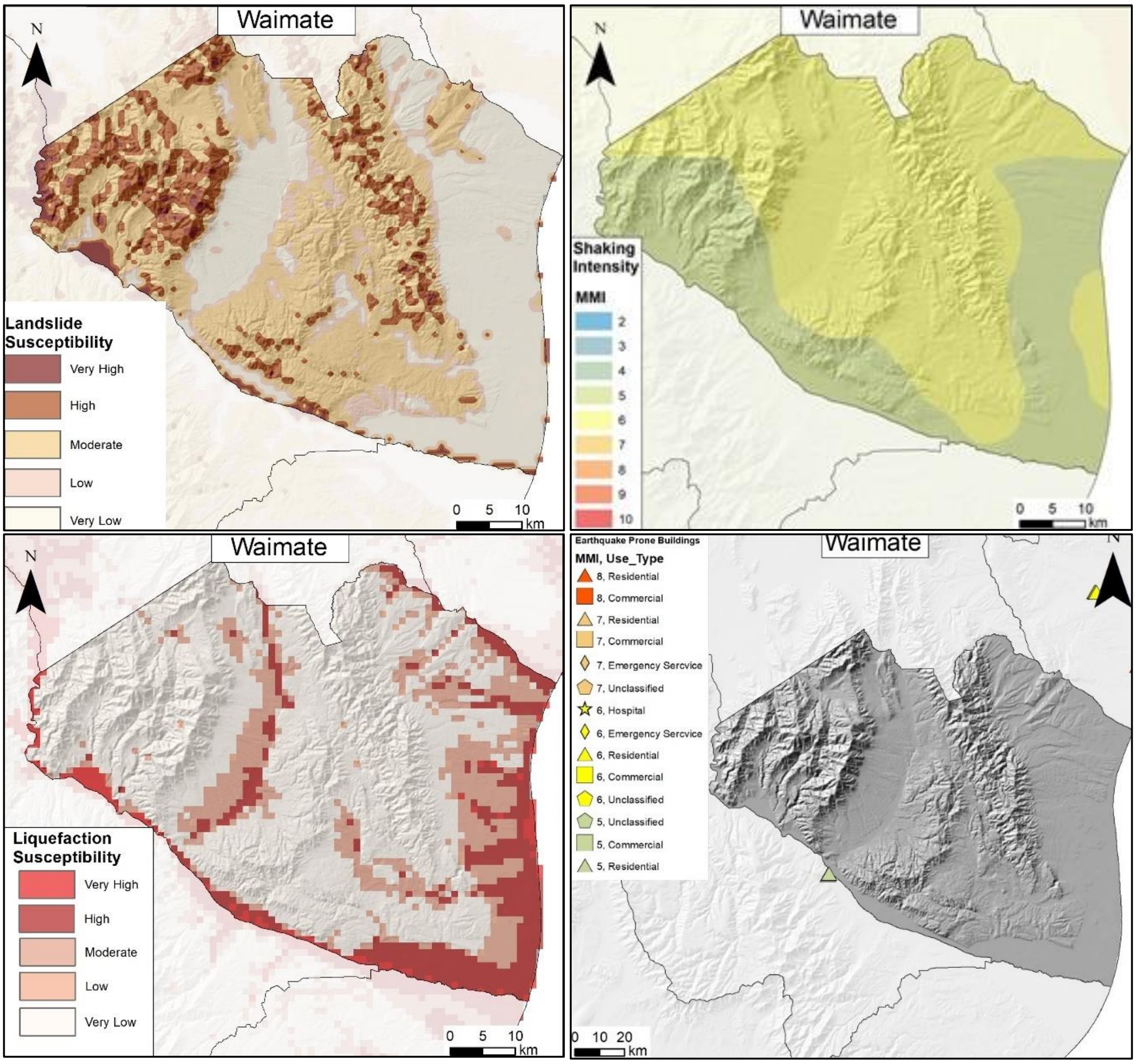

Figure 91: Hazard models for the Waimate District.

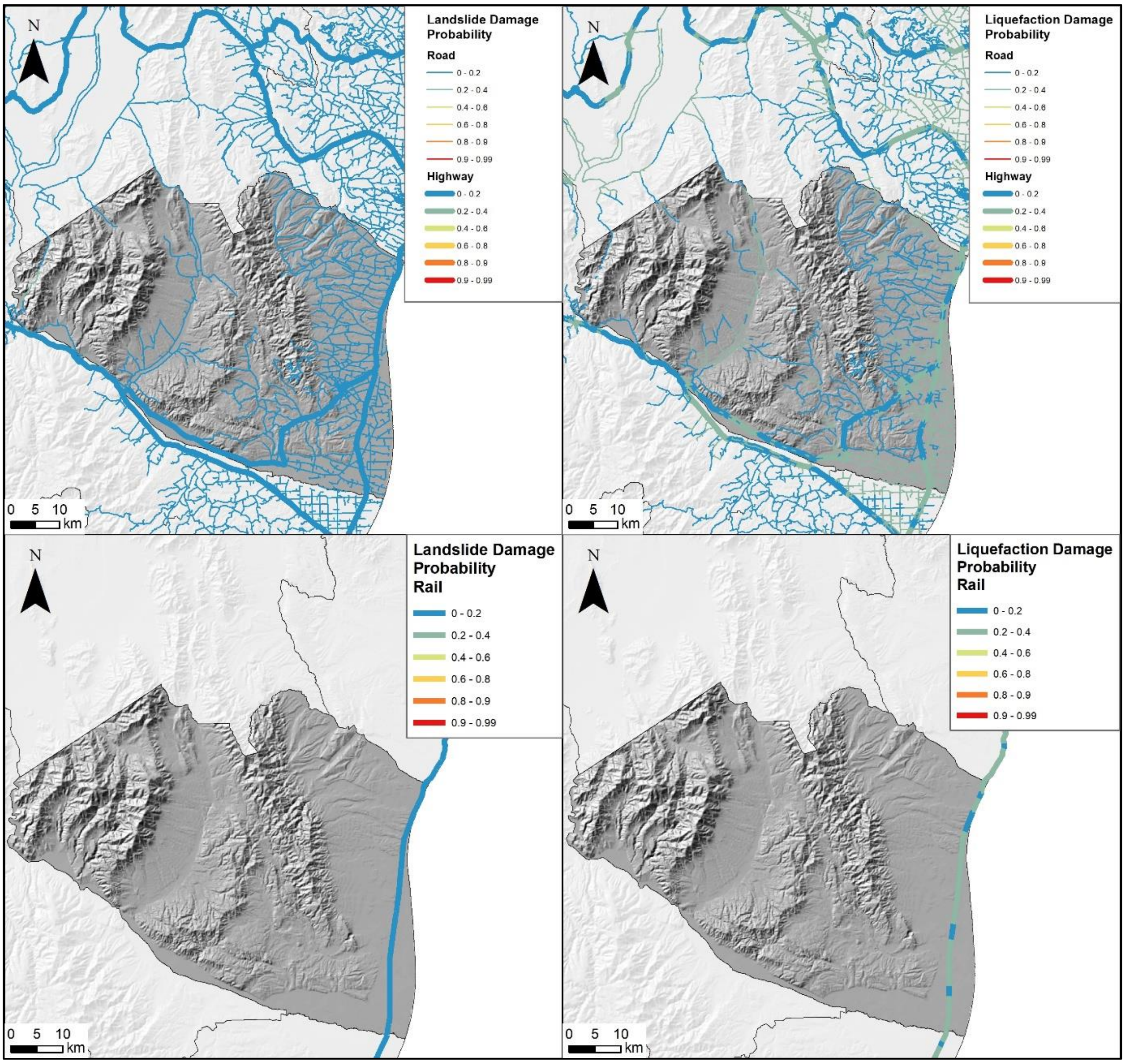

Figure 92: Transportation infrastructure landslide and liquefaction impact probability maps for the Waimate District. Source: Amelia Lin (2020).

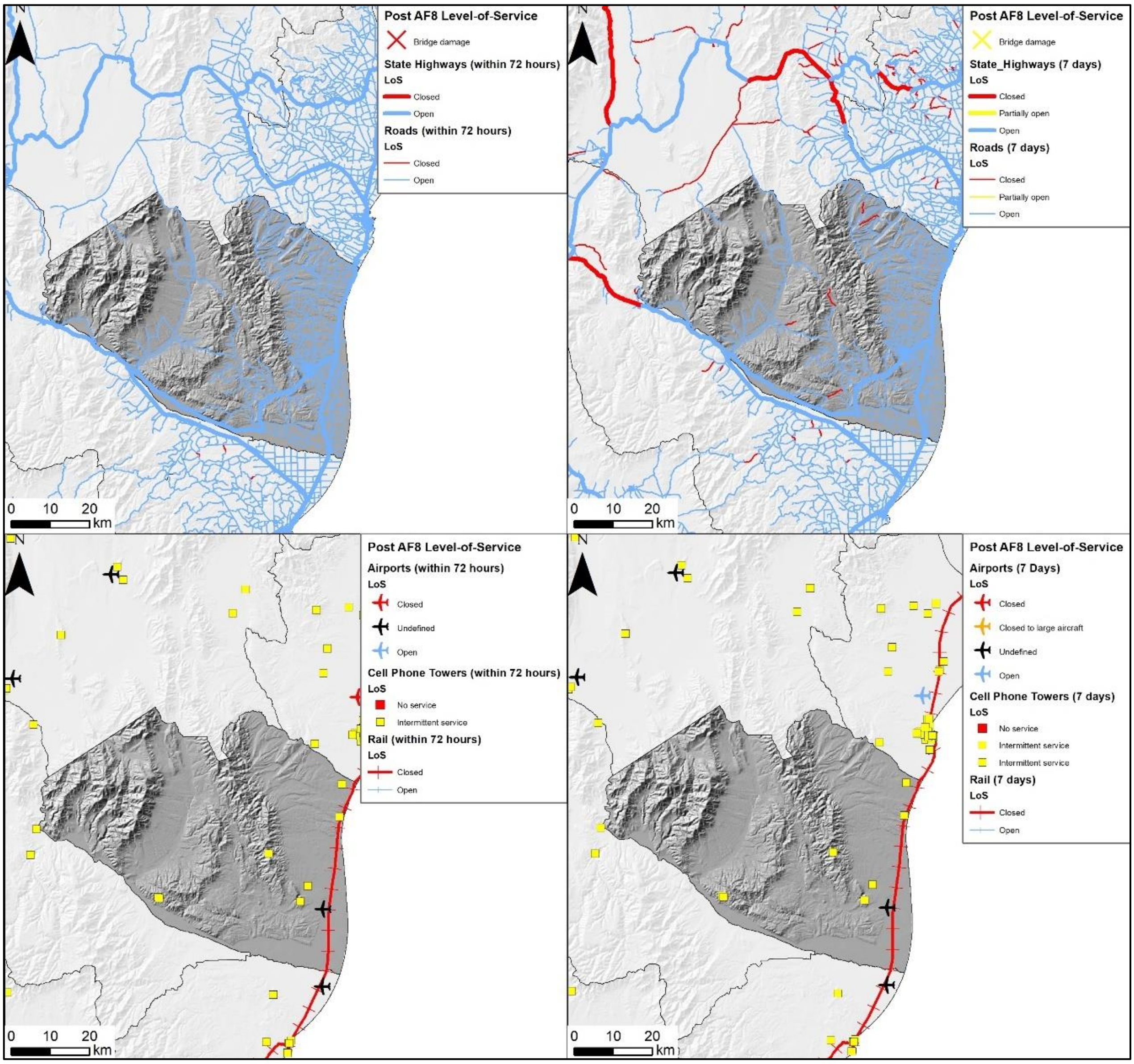

Figure 93: Level of service models for transportation, tele-communication, and electricity infrastructure in the Waimate District. Produced by the AF8 science team. Note that in some cases the underlying continuation of seismic and coseismic hazards, considered in this study, leads to an increase in asset damage, and a decreased level of service, at 7 days compared with 72 hours.

6. Summary

This report has provided a succinct compilation and summary of hazard, impact and risk science studies developed for and contributing towards Project AF8. The report has been developed at the request of Canterbury Civil Defence and Emergency Management Group with the specific purpose of informing AF8 emergency management planning at Territorial Authority scale in the Canterbury region.

In most instances, previous AF8 studies were presented at national scale, so this report presents relevant outputs at regional (i.e. Canterbury) scale and/or Territorial Authority scale (Section 5). It also compiles relevant national datasets (e.g. EQ prone buildings) and focused regional or local studies (e.g. co-seismic lake seiche studies in the Mackenzie District).

The curated summary of relevant science projects, which are typically either international-peer reviewed journal articles or internally peer-reviewed scientific reports, did not include any new science, except where explicitly stated. The inclusion criteria of studies were determined by relevance and availability. More detailed information for studies presented in Section 2 can be found in their respective publications/reports (see References and where necessary request from AF8 Science Team).

Section 3 highlighted the following key areas of knowledge gaps. It should be noted that several of these are the focus of ongoing research projects (Section 4):

- Disaster waste management planning:
- Casualty estimation
- Building impacts
- Post-event Habitability
- Earthquake prone building impacts
- Tourist exposure and susceptibility
- Vulnerable populations
- Robust infrastructure impact and service disruption estimations including interdependencies

Disclaimer: Section 5 consist of data compiled from various peer-reviewed and non-peer-reviewed studies by the AF8 Science Team for the Canterbury CDEM Group. It is for the sole purpose of providing some context to the Canterbury CDEM Group in their preparations for AF8 planning under the SAFER framework. There has been no attempt to describe the methodologies used in its creation, or the robustness or otherwise of the compiled data.

The compilers of this report note that there is likely an appetite to use this data for other purposes, however, many of these models have a number of limitations. Potential use of these data (even with good intentions) for other purposes could lead to incorrect or inappropriate analysis and subsequent decision making. Therefore, the compilers of this report request that the AF8 Science Team is consulted with regards to any potential usage of the science/data presented herein, so as that they can provide assistance and/or guidance.

For any enquiries about this data or subsequent use for any other purpose, please contact Prof Tom Wilson, University of Canterbury (thomas.wilson@canterbury.ac.nz) and James Thompson Canterbury CDEM Group (James.Thompson@cdemcanterbury.govt.nz).

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