New Zealand Lifelines Council

New Zealand Critical Lifelines Infrastructure
National Vulnerability Assessment

2020 Edition

Preface

This report provides a summary of information on the vulnerability of New Zealand's critical lifelines infrastructure to hazards, including those resulting from events such as volcanic activity, earthquake and flooding through to hazards resulting from the increasing interdependence of all infrastructure services. Infrastructure vulnerability can lead to substantial community impacts with recent experiences providing ample evidence of this.

This report is intended to:

- provide a unique strategic perspective of all infrastructure services (including energy, transport, telecommunications, and water) as they act in combination to deliver wellbeing for New Zealanders,
- stimulate awareness particularly with regard to interdependencies,
- increase the resilience of infrastructure to meet our community needs, and
- drive a change in approach to prioritising resilience investment.

First produced in 2017, this 2020 edition strengthens previous reports with:

- New information on nationally significant critical infrastructure gathered mainly through national lifeline utilities.
- New information from a number of major studies relating to significant New Zealand hazards.
- A new section on climate change risk and additional material on fire and pandemic hazards.
- An overview of resilience investment programmes for each sector.
- Takes a community and critical customer perspective to strongly recommend national investment in regional resilience business cases to recognise infrastructure interdependencies and prioritise across all infrastructure.

The use of this report by government, local authorities, utility service providers, researchers, communities and individuals is welcomed and encouraged. This is a national resource and an international exemplar. The New Zealand Lifelines Council is proud to deliver this flagship 2020 Edition.

The report is general in its application and subjective in its recommendations. While every effort has been made to ensure the accuracy of the report, no liability whatsoever can be accepted for any error.

Roger Fairclough
Chair, New Zealand Lifelines Council

New Zealand Lifelines Council Members

New Zealand Lifelines Council

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DISCLAIMER

The findings in this report are derived from general investigation and do not necessarily reflect official policy or position of any agency. Examples presented within this report are for the purpose of demonstration.

It is recommended that users exercise their own skill and care with respect to their use of the information contained in this report and that users carefully evaluate the accuracy, currency, completeness and relevance of the material for their purposes. This information is not a substitute for independent professional advice and users should obtain any appropriate professional advice relevant to their circumstances.

Contents

1. Executive Summary

1.1 Overview

Lifelines infrastructure includes the transport, energy, telecommunications and water services sectors that are fundamental to New Zealand's communities and economy. The importance of these assets and the services they provide cannot be overstated, and the impacts of their failure has been evidenced in many recent national and international events.

Through the New Zealand Lifelines Council (NZLC) and 15 Regional Lifelines Groups, New Zealand's lifeline utility organisations work together on projects to understand and identify ways to mitigate impacts of hazards on lifelines infrastructure. This report collates and summarises key findings from regional lifelines studies, national hazard studies, international experience and expert solicitation. It aims to provide insights on New Zealand's critical lifelines infrastructure and its resilience (and conversely its vulnerability) to major hazards. It further identifies knowledge gaps in our understanding and mitigation of New Zealand's critical infrastructure vulnerabilities.

Many significant research programmes are improving our national understanding of hazard risks and provide new information for this 2020 update. The Alpine Fault, Wellington Fault, Hikurangi Subduction Zone, Climate Change, Auckland and Taupo Volcanic areas and Mount Taranaki, are all the subject of ongoing major studies.

1.2 Purpose of this Report

The overall purpose of this assessment is to provide government, industry and communities with a better understanding of:

1. What is nationally significant infrastructure; and
2. Infrastructure vulnerability and resilience to hazards.

First produced in 2017, this 2020 edition strengthens previous reporting with:

- New information on nationally significant critical infrastructure.
- New information from a number of major studies relating to significant NZ hazards.
- A new section on climate change risk and additional material on fire and pandemic hazards.
- An overview of resilience investment programmes for each sector.
- A recommendation on national investment in regional resilience business cases.

1.3 Nationally Significant (Critical) Infrastructure

This report identifies *Nationally Significant Infrastructure* within each lifeline utility sector, broadly based on a criticality rating hierarchy which assesses the extent of loss of service that would result from the failure of a single utility asset or service.

Nationally Significant infrastructure assets are often where there are *single-site* 'pinchpoints' in the supply chain which, if they failed catastrophically, would cause a significant loss of service. These single-site pinchpoints typically relate to key energy and telecommunications sites, and port and airports. Other sectors such as road, rail and energy transmission have nationally significant assets which are *lineal* pinchpoints.

New Zealand's geographical nature and low population density makes the development of fully redundant (duplicated) networks challenging. This results in single points of failure in some networks, such as the Marsden-Wiri fuel pipeline and Maui gas line, which need to be carefully managed.

Section 3 of this report provides an overview of New Zealand's lifeline utility networks and critical infrastructure within those networks. Information for each sector on its vulnerabilities to hazards, critical customers that are dependent on its services, regulation and funding relating to resilience and current/proposed resilience investment programmes.

1.4 Interdependencies and Hotspots

Along with key sector pinchpoints such as those described above, there are also high risks associated with infrastructure 'hotspots'. These are where critical assets from a few sectors converge with a high consequence of failure associated with cumulative loss of services at that site and beyond.

The interdependent nature of infrastructure networks is a key focus of 'lifelines' projects. The interdependencies in lifeline networks are numerous and complex. For example, widespread electricity and telecommunications failures will have knock-on impacts on all other networks, along with major business and social disruption. Business continuity arrangements to mitigate those dependencies are vital.

Section 4 of this report characterises the interdependencies between the lifeline utility networks - that is, the extent to which each utility relies on other utilities in order to function and provide a service, and similarly for other 'critical customers' to lifeline utilities. Information is provided on national infrastructure hotspots where critical infrastructure assets are located.

1.5 Critical Customers

Lifeline utility services are important for the whole community and for functioning of critical community services such as health and emergency services. These service providers maintain business continuity arrangements for backup services based on their own risk assessments and commercial imperatives.

There is currently no national view on the extent to which these critical community sectors have alternative arrangements (such as radio/satellite or on-site backup generation). A brief overview of 'critical customer' sectors and dependence on lifelines services is provided in Section 4 of this report. Further analysis and engagement with these sectors will be carried out in future updates of this report.

1.6 National Infrastructure Vulnerabilities to Major Hazards

The resilience of New Zealand's infrastructure has been the focus of regional lifelines projects since the first work undertaken in Wellington in the late 1980s. This was followed by the Christchurch lifelines project - '*Risks and Realities*' (1997/98) - which was credited with driving a number of seismic mitigation programmes, the benefits of which were realised many times over in the Canterbury earthquakes in 2010/11.

Since then many other regional lifelines projects have been undertaken and continue to inform lifeline utility vulnerability assessments and risk mitigation programmes, typically as shown in Figure 1-1:

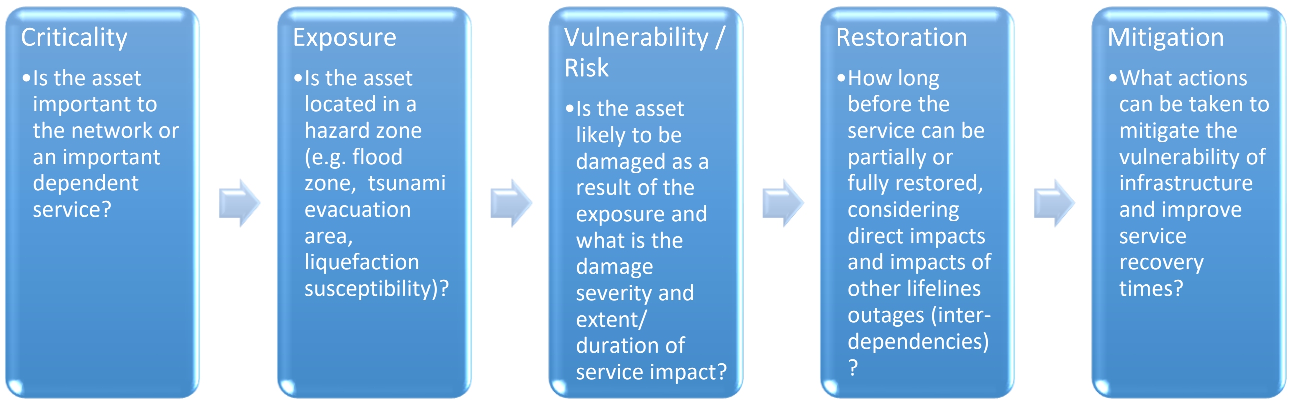


Figure 1-1: Overview of the Vulnerability Assessment Process

Section 5 of this report provides an overview of major hazards to New Zealand's infrastructure, including earthquakes, volcanoes, tsunami, severe weather and climate change, pandemic, fire, and more. For each of these hazards, the hazard context is summarised along with an assessment of impacts to lifelines infrastructure arising from that hazard.

1.7 Regulation and Funding for Resilience

Lifeline utilities operate under a variety of business and regulatory models. The CDEM Act 2002 is the only over-arching legislation for all lifeline utility sectors; this has a requirement for lifeline utilities to *"function to the fullest possible extent"* following an emergency. However, there are no nationally consistent standards for resilience (e.g., to better define 'fullest possible extent') - these are defined by each lifeline utility, and in some cases the individual sector regulator.

There are different funding constraints and regulatory regimes both between and within the public and private sectors and many organisations require a commercial return on resilience investment projects. These factors influence the level of investment in resilience improvements. A summary of the key regulatory and funding agencies for lifeline utilities that have a role in contributing to infrastructure resilience is outlined in Section 6 of this report.

1.8 Building Resilience into Infrastructure Networks

New Zealand's infrastructure networks are designed for (varying levels of) resilience. Technical resilience is inherent in many networks through redundancy (multiple paths of supply) and robustness (design codes for strength). However, there are geographical and other constraints in providing alternative supply routes and 100% security of supply is neither feasible nor affordable.

Billions of dollars have been and are continuing to be invested in projects that will increase the resilience of nationally significant infrastructure. This includes major projects such as Wellington's Transmission Gully as well as more incremental improvements which occur as renewal programmes replace older assets with modern materials and design.

The Wellington Lifelines Programme Business Case is the first regional lifelines project to quantify the economic impacts of infrastructure failure in a disaster (major Wellington Fault) and develop a costed, coordinated risk mitigation programme. This Business Case puts forward a $3.9B programme of work with an estimated $6B of benefits. The New Zealand Lifelines Council would recommend that similar or enhanced programme business cases be developed for every region in New Zealand.

There is currently no national picture or monitoring of planned investment in infrastructure resilience or understanding of societal risk tolerance. For the 2020 update to this report, there was an intention to collate a high-level programme of planned national infrastructure resilience investment. However, with some exceptions, most national lifeline utility organisations either did not have specific resilience categories in their investment programmes or noted that major resilience projects (without other drivers such as growth) fail to pass benefit-cost thresholds under current funding models.

Section 6 also provides information on proposed initiatives to improve resilience by individual lifeline utilities, regional lifeline utility groups, and national research and assessment programmes.

1.9 Conclusion and Recommendations

This report provides a summary of information on the vulnerability of New Zealand's critical lifelines infrastructure to hazards, gathered from existing lifelines project reports, research, inputs from New Zealand Lifelines Council (NZLC) members and expert solicitation. Section 7 identifies gaps in our understanding of critical lifelines and community infrastructure, their vulnerability to hazards and knowledge of the hazards themselves and the intention is to progressively update this report as further information becomes available.

It is recommended that:

1. NZ lifeline utilities use the information in this report to support their own risk mitigation and preparedness programmes.
2. The NZLC engage with its members and new stakeholders such as the Infrastructure Commission and Water Services Regulator to discuss the progression of 'next steps' included in Section 7 of this report.
3. The NZLC work with the research sector to identify which knowledge gaps are being addressed in current research programmes and where there are opportunities to progress remaining gaps.

2. Introduction

2.1 Background

New Zealand is formed on the collision zone between the Pacific and Australian plates, creating a high earthquake, volcanic and tsunami risk. Climate challenges across the country range from ex-tropical cyclones to drought, flooding, snow and ice, and severe weather events are expected to become more extreme with climate change. A 2018 study[1] of natural disaster loss risk rated New Zealand second in the world.

Together with this hazardscape, the long, skinny shape of the country creates infrastructure challenges, with electricity, telecommunications and transport networks running north to south sometimes with limited redundancy either side.

An increasing recognition of the risks that hazards pose to our infrastructure networks led to the development of many regional *lifelines infrastructure vulnerability studies*, dating as far back as the late 1980's. These studies aim to understand service impacts of natural disasters, such that impacts can be minimised and recovery times reduced. The outputs from this regional work are used by lifeline utilities, communities and others, to support risk mitigation efforts (such as seismic strengthening) as well as to support planning for response and recovery activities.

This report aims to provide a national level vulnerability assessment that addresses regional cross-boundary and national issues. It has been developed by the New Zealand Lifelines Council (NZ Lifelines Council, NZLC) with input from organisations across the lifeline utility, government, and research sectors.

Key Terms

Critical Assets: Assets with a high consequence of failure with potentially significant consequences to societal wellbeing.

Critical customers: Organisations that provide services deemed critical to the functioning of communities, including emergency services, health, banking, Fast Moving Consumer Goods (FMCG) and Corrections services, as well as the lifeline utilities themselves.

Exposure: The extent to which an asset is potentially exposed to a hazard.

Hazard: Something that may cause, or contribute substantially to the cause of, a utility performance failure.

Interdependence: Relationship between infrastructure types characterised by one's need for supply from another for their service to function.

Note: A one-way reliance is 'dependence' but 'interdependence' is used in the lifeline utility sector to reflect that, collectively, all lifeline utilities rely on other services to some degree.

Mitigation: The pre-event, asset-related, steps of a utility to reduce or eliminate supply outages.

Resilience: The state of being able to avoid utility supply outages or maintain, or quickly restore service delivery when events occur.

Risk: Risk is defined as the probability that exposure to a hazard will lead to a negative consequence

Vulnerability: The state of a utility being susceptible to loss of service delivery / outages when events occur.

2.2 NZ Lifelines Council

This assessment was undertaken by the NZ Lifelines Council in support of its stated goals:

Mission

Enhancing the connectivity of lifeline utility organisations across agency and sector boundaries in order to improve infrastructure resilience.

Purpose

Promote arrangements to improve **infrastructure resilience** to support **community wellbeing.**

Functions

- Connecting and Supporting Regional Lifelines Groups
- Connecting with National Agencies
- Facilitating the annual National Lifeline Utilities Forum

The Earthquake Commission (EQC) contributed additional funding in support of this project.

[1] Lloyds of London Insurance Risk Index Report 2018.

2.3 Purpose of this Report

The overall purpose of this assessment is to provide government, industry and communities with a better understanding of:

1. What is nationally significant infrastructure; and
2. Infrastructure vulnerability and resilience to hazards.

It is intended to inform a range of activities, including:

- National policy setting, and the development of strategies to mitigate risks.
- Lifeline utility resilience planning (e.g. support prioritisation of resilience projects with consideration of wider infrastructure impacts).
- Regional lifelines projects, to provide an understanding of the cross-boundary issues that need to be considered in regional vulnerability assessments (impacts within the region impacting outside the region and vice versa).
- Future infrastructure and hazard research priorities.

2.4 Key Audience

This report has been written to inform:

- Lifeline Utilities
- Regional Lifelines Groups
- Government agencies and CDEM Groups involved in emergency management and infrastructure policy.
- Research agencies.
- Infrastructure funding and regulatory agencies.
- Key users of national lifeline utility services.

2.5 Scope

The primary scope of assets and services covered in this study are 'lifeline utilities' as defined in the CDEM Act 2002 – specific organisations are included in the box to the right.

Internationally, many other sectors are defined as 'critical infrastructure'. One definition states that critical infrastructure:

can be broadly defined as the systems, assets, facilities and networks that provide essential services and are necessary for the national security, economic security, prosperity, and health and safety of their respective nations[2].

Other sectors that may be deemed critical infrastructure under this definition, such as health, emergency services and the food industry, are covered in this report as 'critical customers' (to lifeline utilities). *Refer Section 4.2.*

National Lifelines

This study focuses on the assessment of 'nationally significant' networks and services of the following organisations.

Energy

- Transpower (national grid)
- Generators (Meridian Energy, Contact Energy, Mercury, Genesis Energy and TrustPower)
- First Gas (gas transmission North Island)
- Electricity Distribution companies
- Refining NZ (Marsden Refinery and Pipeline to Wiri, Auckland).
- Wiri Oil Services Limited.
- Fuel companies (BP, Z, Mobil, Gull).

Transport

- Waka Kotahi (New Zealand Transport Agency)
- Airways
- KiwiRail (rail network)
- Maritime New Zealand
- Auckland Airport
- Wellington Airport
- Christchurch Airport
- Ports of Auckland Ltd
- Ports of Tauranga Ltd
- CentrePort (Wellington)
- Lyttelton Port (Christchurch)
- Picton Ferry Terminal
- Local authority road networks

Telecommunications

- Chorus
- Spark
- Vodafone
- 2degrees
- Kordia
- Vital

Water

- Watercare
- Wellington Water
- Local authorities – three waters providers

[2] Critical 5 – Forging a Common Understanding for Critical Infrastructure, shared narrative, March 2014, New Zealand Treasury.

2.6 Approach

This report presents an overview of national infrastructure vulnerability. It draws on regional lifelines vulnerability studies, multi-region hazard studies and inputs from national lifeline utilities.

Regional Lifelines Groups have traditionally focussed on major natural hazards, with varying attention given to other hazards such as pandemic, space weather and technology failure (both deliberate cyber-attacks and unplanned disruptive events). This report is therefore more comprehensive with respect to the major natural hazards, and further information will be included on a wider range of hazards as this becomes available.

2.7 Structure of this Report

Figure 2-1 provides an overview of the structure of this report. It is noted that the two largest sections have some overlap with each other but enable readers to have both a lifeline utility-centric view (Section 2) and a hazard-centric view (Section 3) to lifeline utility vulnerabilities to hazards.

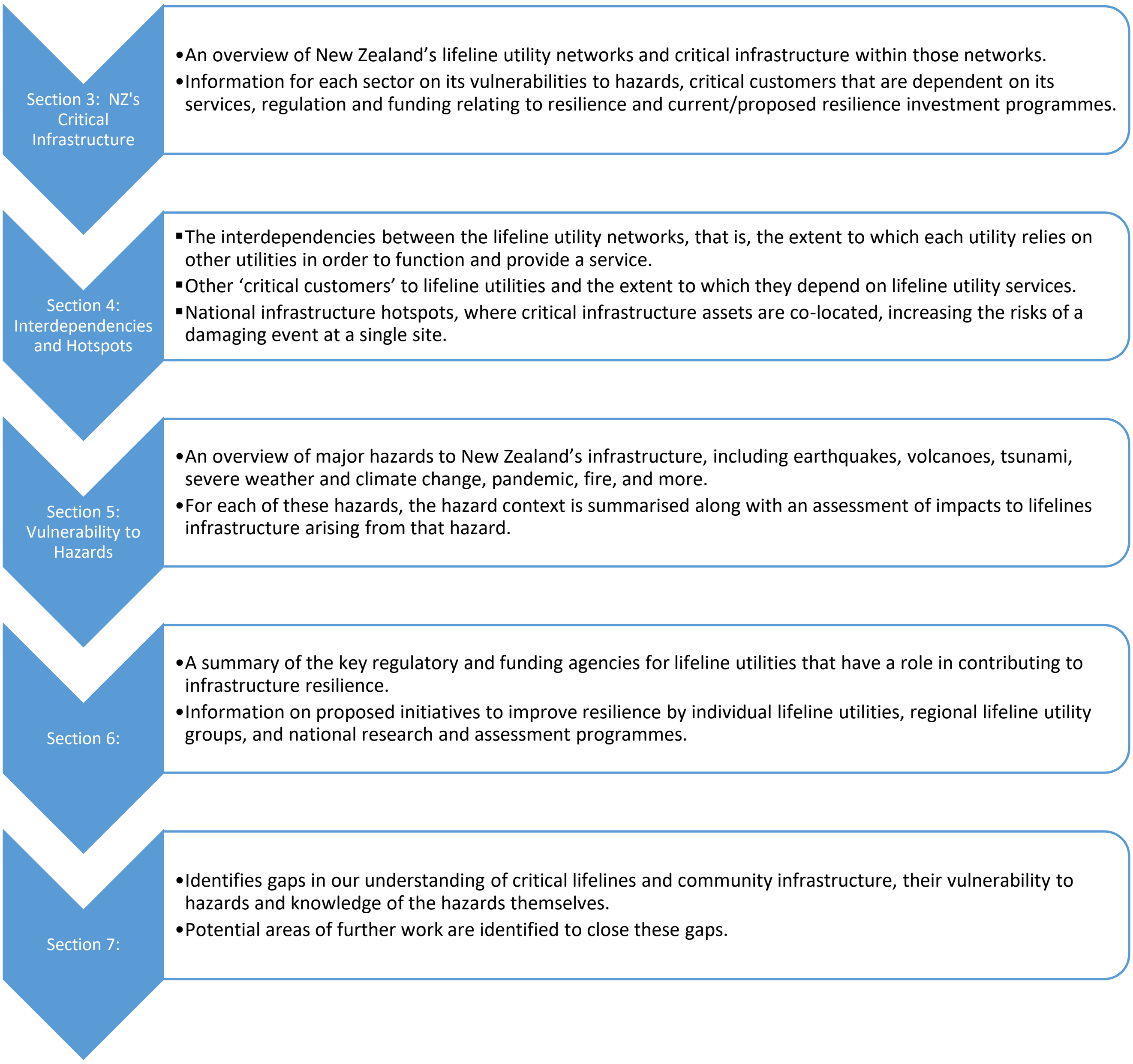


Figure 2-1: Structure of this Report

2.8 Methodology

Figure 2-2 illustrates the general methodology used to assess infrastructure vulnerability in regional lifelines projects, while noting there are variations.

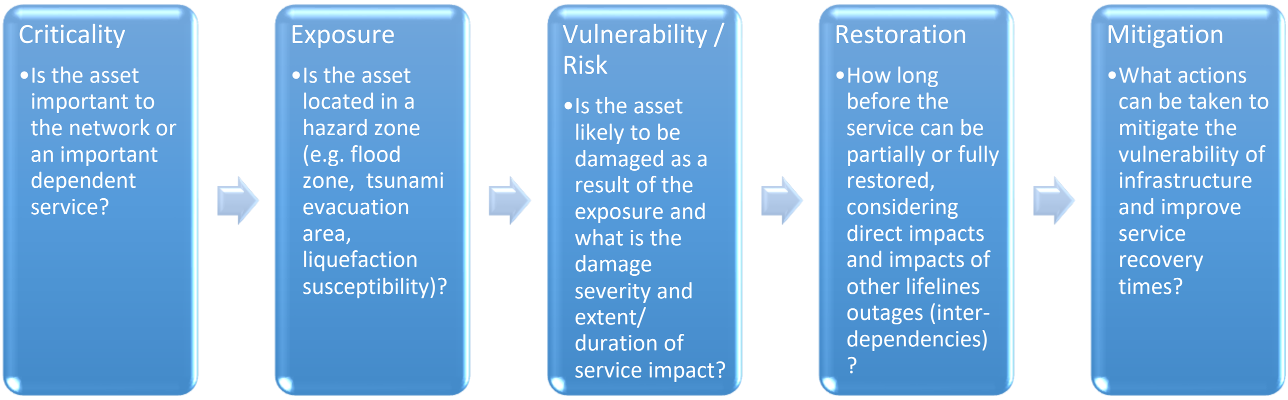


Figure 2-2: Overview of the Vulnerability Assessment Process

Rating Infrastructure Asset Criticality

The starting point is identifying critical infrastructure in the region and focussing on assets that are likely to have the highest consequences of failure for our communities.

The NZ Lifelines Council encourages a common approach to defining critical assets for regional lifelines projects, illustrated in Figure 2-3, to provide a consistent language within the infrastructure lifelines sector and an ability to compare and prioritise infrastructure importance nationally. The methodology has been used in all regional lifelines projects in the past decade (sometimes in a modified form).

The criticality rating depends on both the numbers of customers impacted and the criticality of those customers (e.g. other lifelines, hospitals, etc.) to reflect the overall consequence of the asset failing.

In this report, information has been collected from regional lifelines reports, lifelines groups and lifeline utilities to identify 'nationally significant' infrastructure assets for each sector using this categorisation. However, it is acknowledged that this is a simplistic and somewhat blunt tool, and NZLC have been working with New Zealand Treasury on potential enhancements (refer Discussion Box, page 15).

Exposure and Vulnerability Assessment

The extent to which quantitative scoring systems are used in regional lifelines projects varies; some earlier studies used detailed asset lists, spreadsheets and multi-criteria analysis to rank asset risks. More recently, several regions have undertaken a higher-level lifelines project approach which provides a more strategic view of the potential infrastructure impacts from natural hazards.

A notable exception is the recent Wellington Lifelines Group Regional Resilience Project which used seismic damage assessment and economic impact models to identify potential costs and benefits from a coordinated infrastructure resilience capital investment programme *(refer Case Study, Section 5.1).* It is envisaged that as asset and hazard data improves nationally, this will enable similar studies and integrated programmes in other regions.

Interdependencies

Understanding lifeline utility interdependencies is an important feature of vulnerability assessments. Firstly, this is considered in the criticality assessment, where an asset becomes more critical if it services another lifelines asset that requires the service to function. Secondly, when considering service impacts and recovery times, consideration is given to the impact from other lifelines failures, e.g. road access, telecommunication disruptions.

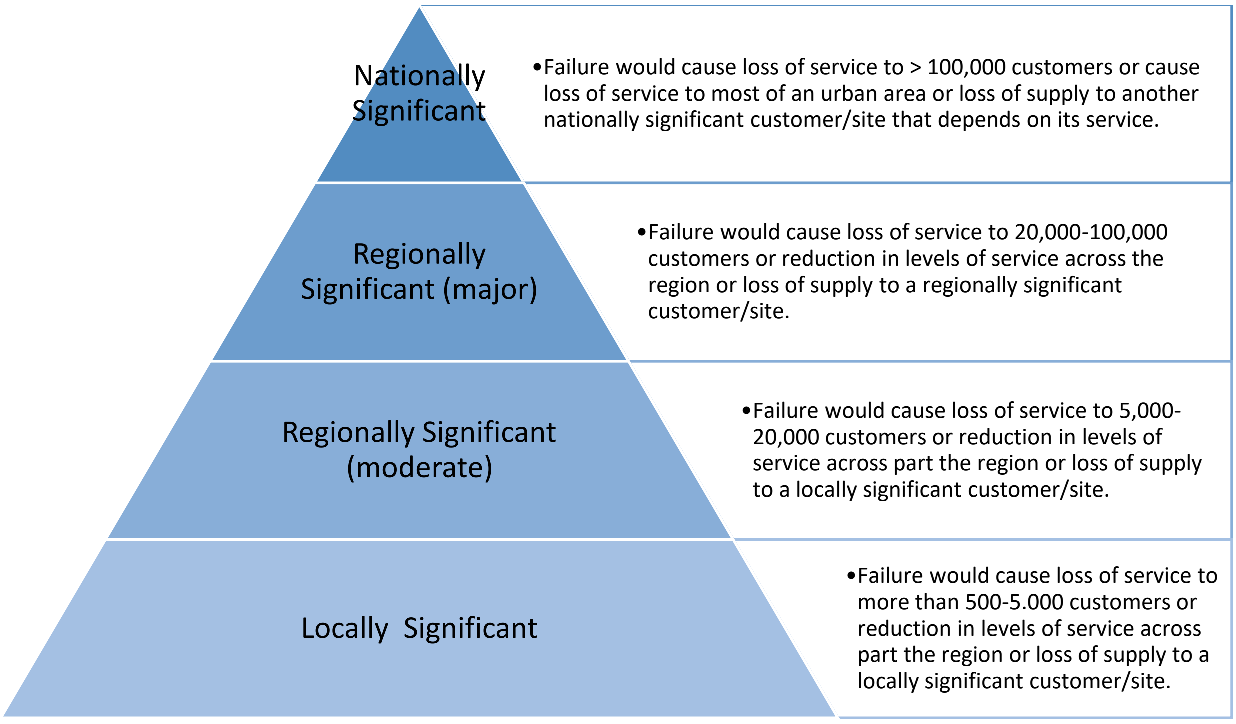


Figure 2-3: Assessing Infrastructure Asset Criticality

Notes about the criticality framework illustrated above:

- *The definitions are intended to represent the service impact of an asset or service failing – both in terms of the numbers of customers affected and the importance of the services to those customers (e.g., hospitals).*
- *The framework does not incorporate the concept of 'duration' of outage as the duration will depend on the cause of the outage. Similarly it does not explicitly cover gradual onset events such as climate change. This framework is scenario-neutral.*
- *The framework does not attempt to rank sectors (e.g., whether an electricity asset supplying 100,000 customers is more important than a gas asset supplying the same number of customers).*
- *The application of the 'numbers' should allow for some judgement, considering factors such as the length of time to restore an alternative supply (or detour route) and the social implications, e.g., isolated communities.*
- *This framework is applied in this national assessment, but regions and organisations have modified the thresholds for 'regionally' and 'locally' significant – reflecting the regional context.*
- *A basic rule is applied to reflect redundancy in the networks – if work-arounds are in place to largely maintain service the asset criticality rating level is dropped by 1.*
- *Previous versions of this framework had a 3-tier rating, with the middle two tiers combined.*

Discussion Topic: Identifying Nationally Significant Infrastructure

NZLC noted in the 2017 'Stage 1' edition of this assessment an intention to review the criticality assessment framework, recognising some key limitations of the existing approach, such as:

- The framework treats the consequence of a service failure the same across all lifelines sectors (e.g., an electricity outage is equivalent to a gas outage affecting the same number and type of customers).
- Service failure (numbers and types of customer impacted) is the driving criteria for criticality – without specifically considering other consequences such as economic and environmental impacts.

The NZLC also sought to review the alignment of its framework with those used by lifelines sectors and organisations. A review of common approaches found that while the broad principles are the same there are many different scales and criteria applied:

- Electricity agencies typically use a 1-5 multi-criteria criticality rating approach, where the criticality factors relate to impacts on service ('volume of lost load'), safety and the environment.
- Similarly, local and water authorities use a 1-5 multi-criteria approach, which considers social/service consequences of failure, governance/regulatory impacts, and financial/economic impacts.
- NZTA's One Network Road Classification (national, regional, collector, local) is the starting point for its criticality framework (currently in draft form), overlaying other impacts of road failure on lifeline utilities, emergency services and evacuation routes to produce a 4 point criticality rating .

In 2019, the NZ Treasury also initiated a project to identify government's most critical assets and NZLC and Treasury agreed to collaborate on the review. Treasury's (draft) framework shown on the following page was developed following research on many criticality frameworks used by other countries, regions, sectors and organisations. It provides a common framework to measure relative criticality for all assets at a national level. It is not intended to replace organisational risk frameworks (which are scaled to fit their organisation). This approach also enables integration with the NZ Treasury's Higher Living Standards Framework.

For this report, NZLC updated its framework with a minor change from 3 to 4 tiers. This minimises impact and most 'nationally significant' assets tested with the Treasury framework also come out with high criticality. *An exception is water supply assets, where the inclusion of a human/life factor would likely raise the significance of water assets treated as only 'locally' or 'regionally' significant in the NZLC framework.*

However, NZLC will encourage regional and local lifelines projects to consider the framework below in undertaking more detailed criticality assessments.

Consequences		Insignificant	Minor	Moderate	Major	Extreme
	Scope	1	2	3	4	5
Human (life)	Human health and wellbeing, physical and mental. Includes impacts of illness, injury, income, skills, knowledge and the things that enable people to engage in society.	Mild impacts and inconvenience	Local/moderate illness or injury with no deaths, or serious hardship for <1000 people	Regional/serious illness or injury, 1 death likely, or serious hardship for >1000 people	National/serious illness or injury, up to 10 deaths, serious hardship for >10,000 people	more than 10 deaths, or serious hardship for >100,000 people
Social (&cultural)	Social and cultural structures and norms in NZ, law and order, cultural identity, communities, and community, social, and cultural facilities	Local public issue and sense of frustration or disadvantage	Regional public issue, loss of community facilities or impacts to social or cultural practices, sense of injustice within communities.	National sense of injustice, damage to many communities, social or cultural values challenged, public protests	Damage to social or cultural structures or values for up to 1 year, serious protests/disruptions, or loss of high value heritage	Long-term or permanent loss of social structures or key cultural values/identity. Civil disobedience and extended disruptions.
Governance (political)	Trust in government or management, maintaining credibility and a mandate to lead and/or continue to supply services. Includes international reputation.	Local issue (single region), stakeholder frustration	Issue for <1 month, with embarrassment for Govt or asset manager and some loss of confidence	Issue for <3 months, with loss of confidence in responsible ministers/officials/executives	Issue for >3 months, with loss of confidence and trust in Govt or organisation (asset manager)	long-term loss of trust in Govt or organistion (reputation), impaired ability to govern
Environment (natural env.)	All aspects of the natural environment to support NZ and the planet (biodiversity) and human wellbeing. Includes land, water, plants, animals, and other natural resources.	Minor, very localised impact <1ha, no residual effects	local area impact, recoverable, effects last <3 months	Local/regional impact, recoverable, effects last < 1 year	Regional impact, effects last > 1 year, some long-term residual impacts	Regional impact > 1 year, or long-term or permanent loss of ecosystem, species, or a natural resource
Economic (#people)	The economic impact to NZ (GDP). This is broadly indicated by the number of people impacted directly and indirectly, and may include customers, customers of impacted businesses, suppliers, and others.	Proxy= Total people impact, direct and indirect. # people <500	# people > 500	# people > 5000	# people > 50,000	# people > 500,000
Physical (asset value)	The value of the physical (or intangible) asset being assessed. An estimate of the replacement value of the asset (an indicator of impact to the asset owner).	Proxy= Total replacement value of asset. asset < $10m	asset > $10m	asset > $100m	asset > $1B	asset > $10B

Figure 2-4: Draft Treasury Criticality Model, 2020.

3. New Zealand's Critical Infrastructure

Section 3 provides an overview of New Zealand's lifeline utility networks and critical infrastructure within those networks. It contains information on each sector's vulnerabilities to hazards, critical customers that are dependent on its services, regulation and funding relating to resilience and current/proposed resilience investment programmes.

3.1 Electricity

New Zealand's electricity network broadly comprises:

- generation stations
- national transmission grid
- 'distributors' - electricity networks connecting to the national grid and to consumers
- system operation
- electricity retailers - which buy wholesale electricity and sell to consumers

The transmission grid, generation sources and main load centres are illustrated in Figure 3-1. The National Grid system is operated by Transpower.

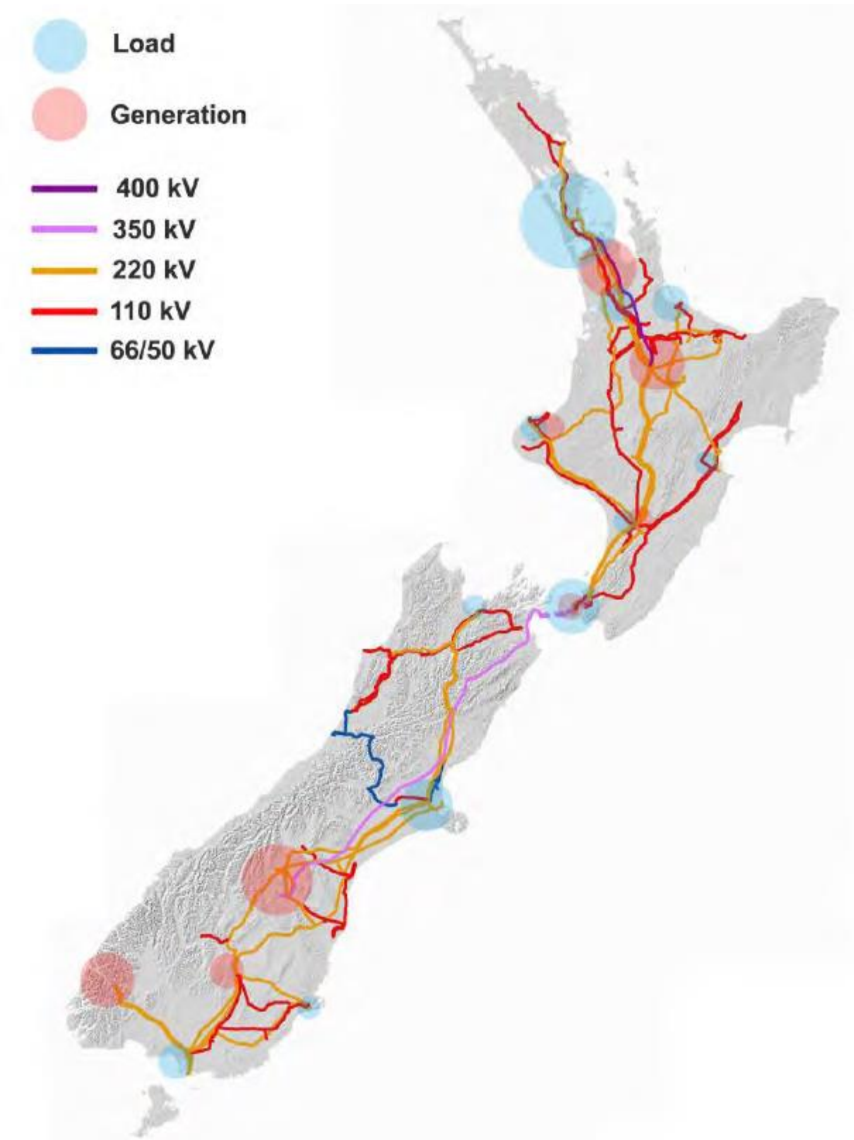


Figure 3-1: The National Grid (Transpower Transmission Planning Report, 2019)

Electricity Generation

Actual generation from each source varies by time and season and is managed by Transpower as Network Operator. The varied source types (refer Figure 3-2) provide some redundancy against source-specific hazards, such as South Island droughts impacting hydro generation and disruptions to Taranaki gas fields.

However there are some major generation schemes that are critical to NZ's electricity supply and would have supply security impacts if there was a major system failure.

The largest capacity sites/systems include:

- The South Island is home to the majority of NZ's hydro generation capacity, meeting 38-48% of NZ's electricity; including Manapouri (800MW capacity), Benmore (420MW), Clyde (400MW) and Roxbourgh (200MW). However, depending on hydrology and water storage factors, actual generation can vary considerably.
- The Waikato River hydro schemes are also significant nationally. Operating at maximum capacity all sources in the Waikato region (including Huntly, the second largest capacity generator after Manapouri) can potentially meet 50% of NZ's demand.

In addition to generators, reservoirs are also critical to maintaining hydro generation capacity, with Lakes Pukaki, Tekapo and Taupo accounting for a high proportion of manageable hydro storage.

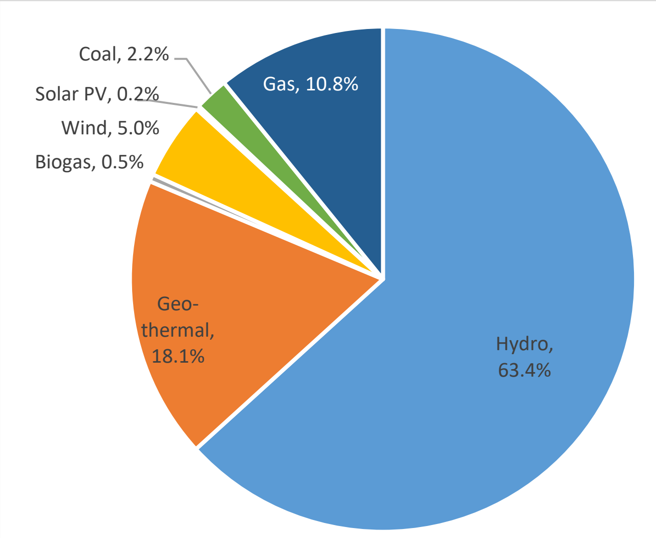


Figure 3-2: New Zealand's Electricity Generation by Type, 2018 (MBIE website)

Providing a reliable electricity supply

Electricity is an important lifeline from an interdependency perspective. It is needed for refining and distributing fuel and gas, treating and distributing water, operating telecommunications networks, ports, railways and many other lifelines. Backup electricity (generators and batteries) is in place at many key sites, but generally not sufficient to maintain full services in a widespread electricity outage.

Maintaining a reliable electricity supply is core to the business of electricity generators and distributors. Key facets of resilience include:

- The National Grid connects most generation sources, such that isolation of any single generation source may result in lower security, but probably not loss of supply.
- Most of the critical parts of the transmission and distribution network operate with at least n-1 security (have alternate paths of supply), again meaning that asset failure generally causes minimal loss of supply.
- Critical assets are designed to avoid or withstand natural hazard impacts.
- Rapid response plans and critical spares are a key part of the resilience strategy.

An important aspect of electricity is that supply into the grid must always equal demand. Very small deviations are manageable, but should these continue for extended periods the frequency is no longer within tolerance and all consumer equipment can be affected. The electricity system therefore includes multiple layers of critical protection equipment.

Since the early 2000s, around 1500MW of coal and gas-fired thermal generation plant has exited the market due to economic reasons, of which more than 500MW was in urban Auckland (Southdown and Otahuhu). With the increasing shift to renewables, gas and coal are likely to continue to exit the market and the sector continues to investigate alternative energy options such as solar PV, wind and storage (including high capacity batteries).

Increasingly generation is further away from demand centres, such as Waikato and north, this area representing approximately half of New Zealand's population (while generation is increasingly being installed by consumers (e.g. solar PV), it is unclear at this stage to what extent this will meet demand). Another potential strategic resilience issue is that the coal capable generation plant at Huntly Power Station may cease operating in 2022, with implications for national electricity supply during an extended period of low hydro inflows and for supply security in the upper North Island. Consents have been issued for sufficient renewal capacity to more than replace Huntley, though these generators are not yet built.

Transpower's publication *Transmission Tomorrow* (Attachment 4: References) outlines the strategic changes in the industry and their proposed responses.

Electricity Transmission – the 'National Grid'

The National Grid transmits electricity from generation sites to electricity distribution companies and some major consumers supplied directly from the grid.

The most critical components of the transmission and distribution network are generally those that transmit the largest volume of electricity and/or have limited redundancy and/or which supply critical customers. Regional lifelines projects and groups have identified the following 'nationally significant' components of the National Grid (refer also Figure 3-3):

1. The transmission line to Northland and substation supplying the Marsden Point Oil Refinery (the Refinery cannot operate without supply from the national grid).
2. The highest capacity transmission line in New Zealand, the 610km 350kV HVDC (High Voltage Direct Current) line from Benmore (Waitaki River basin) to Haywards (Wellington) across the Cook Strait, which normally provides around 15-30% of North Island demand. When all generators are operating, each island is able to generate sufficient capacity to meet demand within the island, however there is likely to be constraints in the North Island at peak loads. The HVDC line is particularly critical when drought or other conditions impact generation in either island.
3. Haywards substation is important as part of this link as well as being the main substation supplying Wellington.
4. Bunnythorpe substation, which is a key switching point between South Island generation and North Island demand (and sometimes vice versa), and the transmission lines from Bunnythorpe to Haywards substation.
5. Whakamaru substation is a key point of supply to the Waikato, Auckland and Northland. The first 400kV transmission line was completed between Whakamaru and Auckland in 2012 but is presently operated at 220kV. It also connects around 800MW of hydro and almost 1000MW of geothermal generation from the Waikato region north to Auckland.
6. Benmore substation, a major hub linking the South Island generation and the 350kV HVDC transmission line to Haywards (Wellington) and the North Island.
7. The Roxburgh and Clyde substations adjacent to the Clutha River.
8. A number of Auckland's substations service greater than 50,000 customers, including Penrose, Otahuhu, Mt Roskill and Albany.
9. South Island transmission lines north of Christchurch from Islington substation into Kikiwa and Stoke substations (supplying the upper South Island). Islington is an important substation as it is a major substation for supplying Christchurch as well as a hub for lines connecting the lower and upper South Island.
10. Plus a number of areas that receive a single line of supply, including Queenstown (transmission lines through Kawarau Gorge), double circuit transmission from Wairakei in to the Hawkes Bay and north, circuits from Stratford to Opunake and New Plymouth which service the onshore gas fields (which rely on the National Grid to operate).

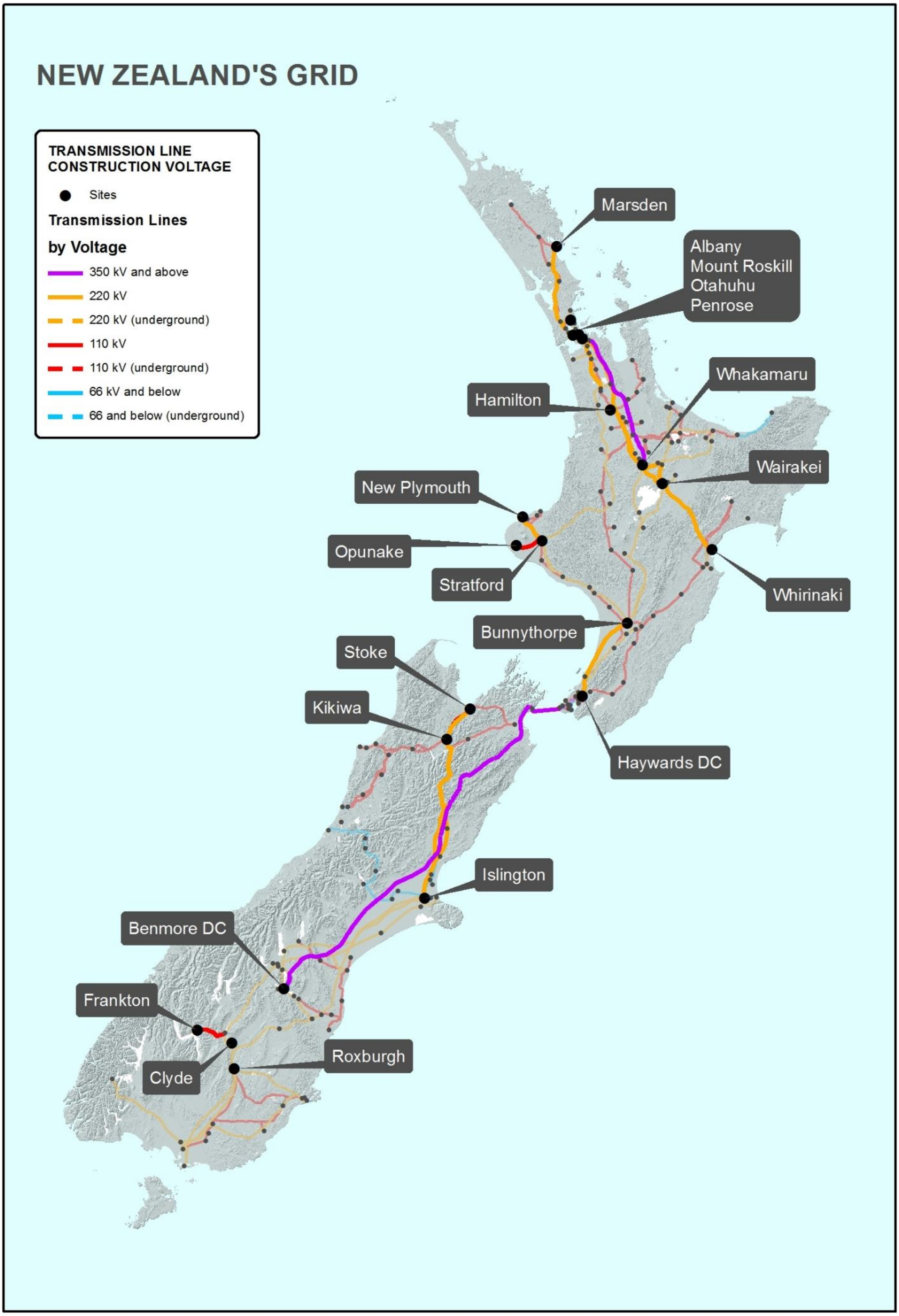


Figure 3-3: Nationally Significant Assets in the National Grid (recognised in regional lifelines studies)

System Operation

As well as managing the national grid, Transpower is the national "System Operator", responsible for managing the real-time power system. In this role it aims to balance supply and demand – as a last resort to avoid system-wide blackouts it can respond to major imbalances through mechanisms such as AUFLS (Automated Under Frequency Load Shedding). The main control room in Wellington is a critical site for the System Operator with a hot standby site in Hamilton.

The system operation relies heavily on automated processes. Digital technologies, cyber incursion, space weather and other causes of technological failure are all major risks.

Electricity Distribution

Around 30 electricity distribution companies take electricity from the National Grid at Grid Exit Points (GXPs) and distribute them to customers via a network of substations, cables, and lines.

Nationally significant distribution assets are generally those that supply critical sites dependant on electricity. While many sites have more than one line of supply and/or alterative power sources, some parts of the network, and the supplies to some single assets, do not have either redundancy in the network or viable back-up power supplies.

As well as the critical transmission network assets listed on the previous page, the distribution networks do contain some 'nationally significant' assets such as the Vector (electricity and gas distribution company) tunnel to the Auckland CBD.

Major Customers

Most businesses and households rely on electricity supply to function. From a consumption perspective, Tiwai Point Aluminium Smelter is the largest electricity user in the country and there are many other major industrial users in the steel, wood, pulp, paper and printing sectors. However, while the cost implications of a major industrial shutdown are significant, from a wider community and economic perspective the most critical large user of electricity is probably Marsden Oil Refinery (refer Section 3.2), followed by the onshore gas processing sites in Taranaki, which also cannot operate without the national grid. Fonterra is also a major customer with most dairy processing facilities relying on mains electricity supply and having limited on-site generation backup. Other critical customers are discussed in Section 4.2.

Lake Pukaki accounts for a high proportion of manageable hydro storage in New Zealand.

Vulnerability to Hazards

The national grid passes through areas vulnerable to all NZ's major natural hazards. Most of the South Island's generation sources have proximity to the Alpine Fault. Some major substations are in tsunami zones, such as Bream Bay which supplies the Marsden Refinery. Critical transmission lines pass through many areas of slip-prone terrain.

Most transmission lines span between lattice steel towers which are robust and not expected to incur damage from seismic or flood activity unless there is major ground rupture or land instability 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). There are a number of places where space is constrained, and towers are being replaced by pole structures.

The smaller distribution networks are a combination of overhead lines and underground cables – the former tend to be more resilient to seismic activity and cable 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.

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. Tsunami waves are considered more potentially damaging for substations and overhead lines, though in many cases the area supplied by those assets would be damaged and resupply could be prioritised accordingly. Volcanic ash can cause flashover and disrupt electricity supplies.

Hydro generation is vulnerable to low rainfall and drought conditions with potential impacts on security of supply. Another potential vulnerability is the impact of an earthquake on lake sediment and water turbidity which has the potential to close generation plants.

Some distribution companies have assets in commercial premises in urban areas and are reliant on access to maintain and repair these assets. An example is a building demolished in Molesworth Street in Wellington following a Kaikōura earthquake. But even buildings with lesser damage may be inaccessible due to safety issues. Some building types have proven vulnerable to earthquakes, such as Statistics house in Wellington with pre-cast floors (a common form of construction 1970s-1990s).

Key Learnings from NZ Studies

Alpine Fault (AF8)

- Electricity throughout the South Island will be affected with likely blackouts 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.

Wellington Quake/ Wellington Lifelines Group

- Wellington Electricity networks will be impacted for weeks to months following a major Wellington earthquake.
- The Wellington Lifelines Resilience Programme Business Case (2019) identified three major Wellington Electricity projects ($205m).
- A $30m programme of strengthening of key assets, and the procurement of equipment to restore services faster is underway (to be completed in early 2021).

DEVORA/Auckland Lifelines Group

- Worst case volcanic scenario is around the isthmus where all transmission lines from the south converge in a relatively small area.
- Ongoing outages caused by ash-induced flashovers, for the duration of the eruption.

Hikurangi Fault (Subduction Zone)

- Widespread outages in Wellington / East Coast for several days to weeks.

Central North Island Volcanic Zone

- Loss of central North Island generation sites and ash disruption to transmission lines would severely constrain electricity supply to the upper North Island.

Mt Taranaki (Taranaki Lifelines Vulnerability Study)

- Widespread outages due to transmission /distribution failures and closure of electricity generation sites both within and near the region. Service outages from 'Flashover' failure from ash.

Climate Change

- Risk of coastal inundation in a 1% storm is 122km of transmission lines and 182 sites, increasing to around 165km of transmission lines and 277 sites in a 0.6m sea level rise, predicted between 2070-2130 (MfE 2017).

Regulation and Funding

While most parts of the electricity supply chain operate as a commercial business, resilience is also influenced by sector regulation. In general, investment in transmission and distribution services is governed by the Commerce Commission and other parts of the supply chain are governed by the Electricity Authority. Both regulators have statutory objectives to promote reliability and the Electricity Authority to promote competition and efficiency. The Security and Reliability Council is a special-purpose advisory group with a mandate to identify risks affecting the sector and make recommendations to the Electricity Authority.

Transmission investment is, in part, driven by the grid reliability standards (GRS) administered by the Electricity Authority under the Electricity Industry Act. The standards are rules that incentivise investment meeting an economic cost-benefit test. Economic evaluation typically takes into account the 'value of lost load' (VoLL) (an estimate of the economic impact from non-supply) and the probability of disruptive events. Assessment involving 'high impact low probability events' is challenging (as for all infrastructure).

The VoLL is an estimated default figure that may not accurately reflect the relative cost of interruptions to different customers or communities, nor the impacts of longer-term outages (such as major ashfall disruptions), or the second and third order effects in the case of cascading impacts resulting from interdependencies. The Security and Reliability Council (SRC) reviewed VoLL in March 2020 and has advised the Electricity Authority that the current VoLL contained in the code should be reviewed. The Lifelines Council is facilitating consideration of a more sophisticated methodology utilising tools such as MERIT (Measuring the Economics of Resilient Infrastructure), to better represent the overall impacts of outages on a more site-specific basis.

The Commerce Commission regulates maximum revenues for 17 distribution businesses (of 29 in total), incorporating incentives for them to maintain or improve reliability (relative to performance over the last ten years). But in general, distributors make their own investment decisions about resilience levels. Under the "information disclosure" regulations they also produce a summary and analysis of this information to help people understand the performance of individual businesses, how they are performing compared to each other and any changes over time.

Hydro generation (dams, canals and stations) are subject to specific safety provisions in the Building Act.

Other general regulation and funding constraints for lifelines are discussed in Section 6.

Resilience Investment Programmes

Most electricity distributors have some level of capital investment proposed in their Asset Management Plans to increase security of supply, often by creating redundancy / looped systems as part of growth upgrades or just through renewal programmes that replace older materials with more durable modern ones.

Transpower continues to invest in national grid resilience but does not have any major specific resilience investment projects planned in the short to medium term. Transmission upgrades are largely responding to areas of growth in demand and where changes to generation outputs require transmission grid upgrades (*Transpower Transmission Planning Report 2019*). For example, if Tiwai Point Aluminium Smelter closed, this would require additional transmission capacity to bring surplus load from the lower South Island. The closure of North Island generation sites previously mentioned required larger transmission capacity to Auckland and Northland.

While there are opportunities to provide more redundancy to regions that have limited points of supply (such as Northland, West Coast and Hawkes Bay), none of these are expected to meet funding criteria thresholds. This raises the question about whether the funding threshold is too high and does not allow more local discussions on what level of resilience customers want versus are prepared to pay.

There is ongoing work to understand risks relating to space weather, tsunami and climate change, but these are only signalling modest improvements such as raising equipment levels within stations (at this time).

In 2020, the Electricity Engineer's Association is releasing a Resilience Guideline for the electricity sector.

3.2 Fuel

Overview of the National Supply Chain

Around two-thirds of New Zealand's fuel is refined at the Marsden Oil Refinery, south of Whangarei, including most aviation and shipping fuel. All fuel into New Zealand is imported by BP, Mobil and Z (which refine fuel at Marsden and also import refined fuel products) and Gull (directly imports refined fuel to ports in the North Island).

Two ships distribute fuel from the Marsden Refinery to ports around New Zealand. The majority of Auckland usage is supplied to Auckland's Wiri facility by pipeline, with the remainder transported by road from Marsden to Northland and North Auckland. Other ships bring in refined fuel from international ports. The quantity and type of fuel delivery varies - for example, only diesel gets shipped into Taranaki while other types of fuels are supplied by road.

A number of transport companies distribute fuel from ports to customer supply points.

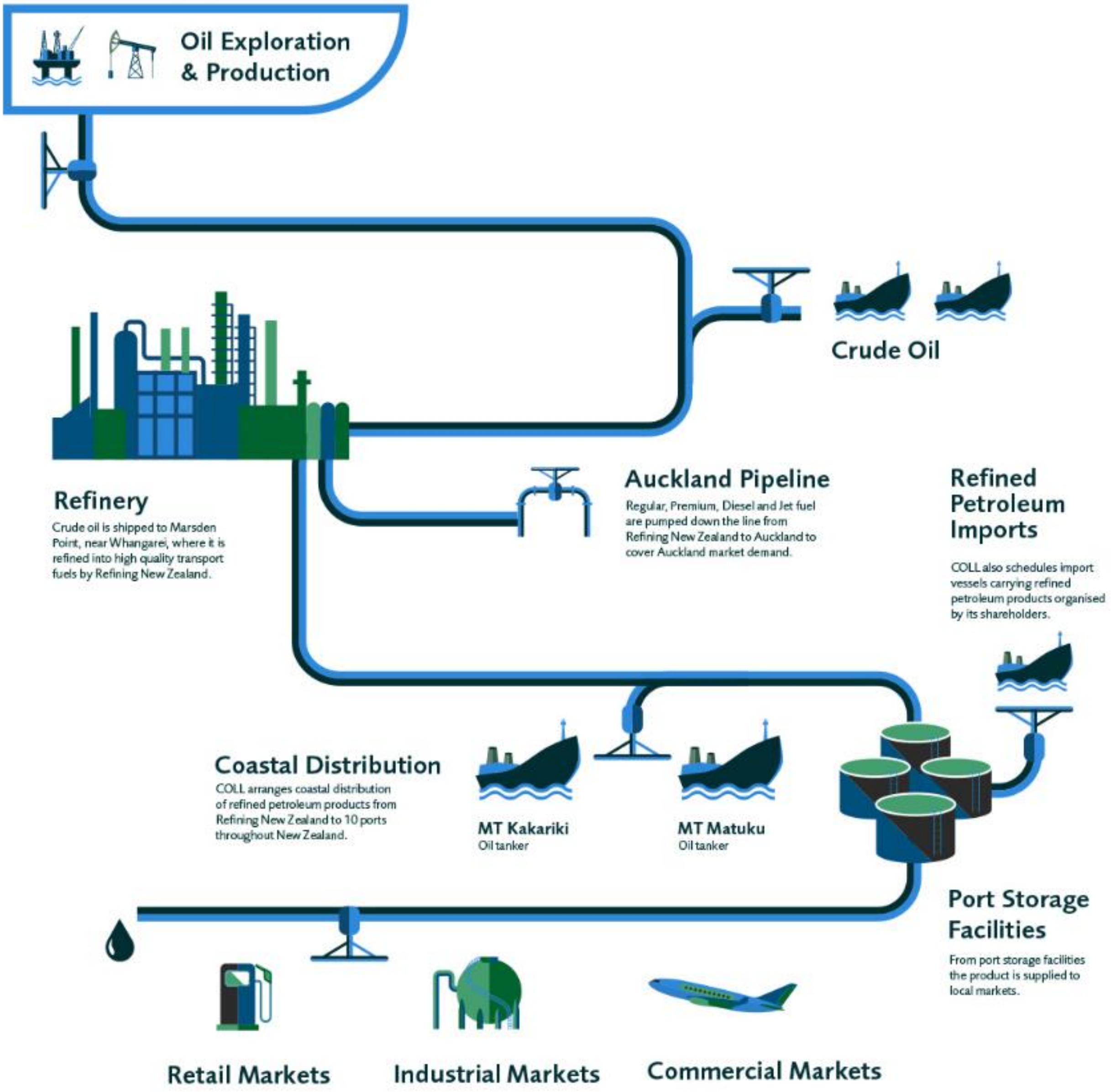


Figure 3-4: New Zealand's Fuel Supply Chain (www.coll.co.nz)

Taranaki is an important region for the production and refining of petrochemicals. Currently, most of the high-quality petroleum products are sold into the international market while New Zealand imports and refines cheaper fuel for domestic use.

Supply Chain Vulnerabilities [3]

Marsden Point

The Marsden Point Refinery and jetty are critical points in the national fuel supply chain. Without Marsden Point Refinery, or its jetty operating, there would be fuel shortages in many parts of the country unless demand was constrained. Refinery production can be replaced by imported fuel, though this would take some time to get here (days-weeks).

If the jetty were damaged this would affect the ability to import crude oil to the Port, the use of the Refinery-Auckland Pipeline (RAP) and the ability to ship refined fuel to other ports.

Fuel Storage and Pipeline Facilities

In most cases of an isolated failure of a single port (or associated fuel storage facility), normal demand could be met by surging capacity at surrounding ports and trucking in fuel supplies. This is dependent on roads being open and the capacity in the trucking fleet, both of which could constrain the ability to meet normal demand.

The Wiri Oil Terminal and the Refinery-Auckland Pipeline are critical facilities in New Zealand in terms of numbers of customers potentially affected by outages. The availability of suitable trucks, drivers and a functional road network to distribute fuel are the key constraints in the ability to supply Auckland from other ports.

In Wellington, without the Seaview Terminal, the region would have to be served by truck from Taranaki and Napier, and, again, the trucking / logistics will be a constraint in meeting demand.

Fuel Supply and Tsunami

In 2016, a national CDEM Exercise 'Tangaroa' tested the nation's ability to respond to a tsunami exercise event. The event was triggered by an earthquake near the Kermadec Trench and generated waves on the NZ coast of up to around 10m.

Exercise Tangaroa highlighted some aspects of NZ's fuel supply that make it vulnerable to disruption.

The refinery and most of the fuel storage and offloading facilities are on the east coast, the coast most vulnerable to tsunami. The exercise scenario is likely to have caused significant damage to this infrastructure. There are currently no viable plans to get fuel to shore if there is major damage to wharves and tanks.

NZ's jet fuel is refined at Marsden with the majority going by pipeline to Wiri and then to Auckland Airport. There are only a few days demand of jet fuel stored in New Zealand and there are constraints on the ability to import refined jet fuel to alternative ports.

In recent years, jet fuel demand and Auckland regional fuel demand has increased significantly. While the Wiri Oil Terminal used to hold up to one week's demand, fuel supply is increasingly 'just in time', increasing the fuel shortage risks associated with a pipeline or refinery failure (there is typically 6 days supply at Wiri terminal and 2 days of Jet A1 at Auckland Airport). Pipeline capacity has been increased to mitigate this risk to some extent.

The other critical fuel supply facilities are in Mount Maunganui, Christchurch, and Wellington. Lyttelton is important for the whole South Island. Further south, both Dunedin and Bluff terminals are critical supply points, particularly following a major earthquake as road and rail links will likely be compromised.

Refinery-Auckland (at Wiri), Wiri-Auckland Airport and Lyttelton-Woolston Pipelines are designed to withstand seismic events but are at risk from major land movement. Regular inspections, testing, spares management and contingency planning are all undertaken to mitigate the risk of failure and facilitate

[3] Extracted from the NEMA/MBIE National Fuel Emergency Plan, 2020.

restoration as soon as practicable if failure does occur. The consequences of outages lasting longer than a few days were discussed earlier in this section.

Risks of Facility Outages

The operators of fuel storage facilities take risk management very seriously. However, there are many potential hazards that are challenging to mitigate, for example:

- Marsden Point Refinery and many fuel terminals are in potential tsunami impact zones. Sea level rise will exacerbate coastal hazards.
- The Marsden Point Refinery is dependent on the electricity supply, (which is in itself vulnerable to hazards).

Other terminals are also dependent on electricity supply though some have generator backups.

- Fire is a risk for all fuel terminals.
- Fuel pipelines are at risk from major landslides, third party damage / explosion and loss of electricity supply to pump stations feeding the pipeline.

Road Distribution Network

The primary fuel distribution points, such as the refinery, ports and terminals all rely on roads to connect to supply points. These are vulnerable in many hazards, and sea level rise is expected to cause future challenges.

Secondary fuel distribution in New Zealand is also highly road dependent. Many areas and in fact some entire regions (the West Coast of the South Island and Manawatu-Wanganui) are dependent on trucked fuel. Many other regions, such as Wellington, are likely to see damage to coastal terminals in many hazard scenarios and may be reliant on trucked road fuel for weeks or months. The fuel industry, through the Fuel Sector Coordinating Entity chaired by MBIE, is working on methods to supply fuel from ship-to-shore for these scenarios.

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. This is a significant risk, particularly for large populations such as Wellington.

Key Learnings from NZ Studies

AF8/Alpine Fault

- Isolation of communities by roads will disrupt fuel supplies. Only small amounts of airlifted fuel are likely to be available on the West Coast in the first weeks.

Wellington Quake (Wellington Lifelines Group)

- Wellington fuel terminals are vulnerable to earthquake damage and transportation by road also disrupted – expect significant fuel impacts.
- The Business Case (2019) identified a project to strengthen a key wharf (circa $35m).

DEVORA/Auckland Lifelines Group

- Worst case scenario is an Auckland eruption destroying the Marsden-Wiri fuel pipeline – likely to have severely constrained supplies in Auckland/Northland and national impacts on the fuel supply chain (particularly jet fuel).

Hikurangi Subduction Zone

- Fuel supplies by Port into Wellington/Hawkes Bay likely to be disrupted, alternate road supplies also.

Central North Island Volcanic Zone

- Major fuel terminals are unlikely to be affected but expect knock-on effects from road and electricity disruptions.

Mt Taranaki (Taranaki Lifelines Group)

- Road and port disruptions will impede fuel supply into the region.

Climate Change

- Major risks to fuel supplies have not been identified in national climate change studies to date, however coastal terminals can be expected to be impacted by sea level rise to varying degrees.

Customer Supply Points

Fuel is stored for supply at retail outlets supplied by the four oil importing companies (Mobil, BP, Gull, Z). Some of these retail outlets are oil company owned and managed, with others independently owned and managed. The re-fuelling rates and the stock levels vary considerably, but stock levels are typically in the range of 'days' of supply during normal levels of use.

A key vulnerability in the retail outlet network is the dependence on electricity to pump fuel. Only a few fuel stations in New Zealand have on-site standby generation, with a few having 'plug in' generator capability. Retail reliance is increasing on internet and wi-fi access, becoming as important as electricity to enable sites to dispense fuel. If there is no internet access to the site, many may be unable to dispense fuel.

If there is a widespread power outage, the number of generators available for hire in NZ would cover the fuel stations in one region and not much else. This is a concern for key facilities such as rest homes that are assuming that they are 'at the top of the list' for generator provision in an outage.

Many farms and industries also have their own 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 being collated as part of regional fuel planning by CDEM Groups.

Regulation and Funding

The entire fuel supply chain is operated on a commercial basis with competition amongst suppliers. Like the telco sector, supply resilience is largely driven by businesses' motivations to maintain and promote market share and corporate reputation. There is no sector regulation specifically relating to resilience, but the regulation of workplace safety and hazardous substances has a significant influence on fuel assets' resilience.

As a member of the IEA (International Energy Agency) International Energy Programme, New Zealand is required to hold 90 day's stock to promote resilience to very significant global supply disruptions (such as Hurricane Katrina and the Gulf War). However, as on-shore stockholdings fall short of this, the Government makes up the shortage with 'ticket' contracts (an option to purchase stock in an IEA declared emergency).

Other general regulation and funding constraints for lifelines are discussed in Section 6.

Resilience Investment Programmes

There has been some discussion about whether the amount of stock stored in NZ is sufficient to ensure the right level of resilience, given possible impedance to uplifting stock options in a global crisis. Concerns have also been raised about the resilience of fuel supply infrastructure in several reports (including the first edition of this report):

- MBIE's most recent national Petroleum Supply Security Review (*ref Hale and Twomey 2017*) concluded that the cost of holding additional supply in NZ was not justified by the mitigated risk cost. However, it also concluded further work was needed on mitigating jet fuel supply risks (including possible additional storage in Auckland) and noted the importance of Wynyard Wharf as a backup option for Auckland.
- Following a failure of the Marsden-Auckland pipeline in 2017, a Government Inquiry was undertaken (report released in 2019) which recommended a need for further investment in national fuel supply infrastructure including jet fuel storage capacity at Auckland Airport, sufficient cover for outage events at all terminals and, ideally, a second permanent supply chain.
- The Wellington Lifelines Group Resilience Project raised concerns about the vulnerability of the Seaview Terminal and the impact on both normal response and recovery operations. It is unclear who would be accountable for setting up temporary offloading facilities and the like (in Wellington or elsewhere).

Decisions on resilience considerations in matters such as location of fuel terminals, minimum storage volumes and backup generators at facilities are made by the fuel companies on a commercial basis and investment is on a 'just-in-time' basis. The 2019 Government Fuel Inquiry noted that while fuel companies are undertaking preliminary planning, more timely investment in upgrades is needed.

3.3 Gas

Natural Gas

Natural gas is an important source of energy in New Zealand.

Production

Natural gas in New Zealand is sourced from 15 gas fields in the Taranaki, with most of the gas coming from the four largest fields – Pohokura, Mangahewa, Maui and Kupe. Product is piped to onshore production stations and from there condensate is piped to the Omata Tank Farm for shipping to Marsden and offshore refineries. Gas is fed into the national pipeline network.

The Maui pipeline and Omata Tank Farm are both rated as nationally significant assets.

Transmission

The national gas transmission network owned by First Gas supplies a number of cities and towns across the North Island, as shown in Figure 3-5. The main north-south line on the west side of the North Island supplies Auckland, Hamilton and Wellington and is a nationally significant asset.

There is little loop redundancy in the transmission network, however short-term pipeline disruptions do not necessarily affect supply continuity as gas pressure is maintained in the pipeline that can be drawn down to a limited extent. There are contingency arrangements in place to reduce demand through demand curtailment measures and details for critical contingency operation can be found at www.cco.org.nz .

The primary focus of the contingency arrangements is maintaining a minimum pressure in the piped gas network. Once pressure within local distribution networks drops below a certain level the process to restore supply can take weeks or months as it requires manual reconnection.

The gas transmission network is a pressurised pipe network designed and operated to the AS/NZS 2885 suite of standards and can withstand significant seismic shaking, though there is a risk of gas pressure loss. Risks mainly relate to major land movement from differential ground movement (fault rupture, liquefaction) local weather-related land slips, coastal erosion, the impact of urban encroachment and third-party mechanical damage.

Some LPG is also transported by ship, road and rail around the country.

MBIE commissioned a report on gas disruption risks in 2014 which concluded that the significant risks in the industry were well understood and managed (*ref Worley Parsons 2014*).

Maui Pipeline Outage 2011

This 5-day pipeline outage resulted from a slow-moving landslide and saw curtailment measures instigated for all consumers apart from essential services and residential consumers. The outage had a significant effect on many sectors – from restaurants to crematorium but long-term impacts were avoided by protecting the system through these contingency curtailment measures. http://www.mbie.govt.nz/info-services/sectors-industries/energy/energy-security/documents-image-library/Review-Maui-pipeline-outage-october-2011.pdf

Land movement is a key hazard for gas pipelines, as they are long, linear assets spanning variable terrain, often in remote locations. This risk is mitigated by careful monitoring and land stability management. Also, spare lengths of pipe are available to quickly repair any pipeline breaches.

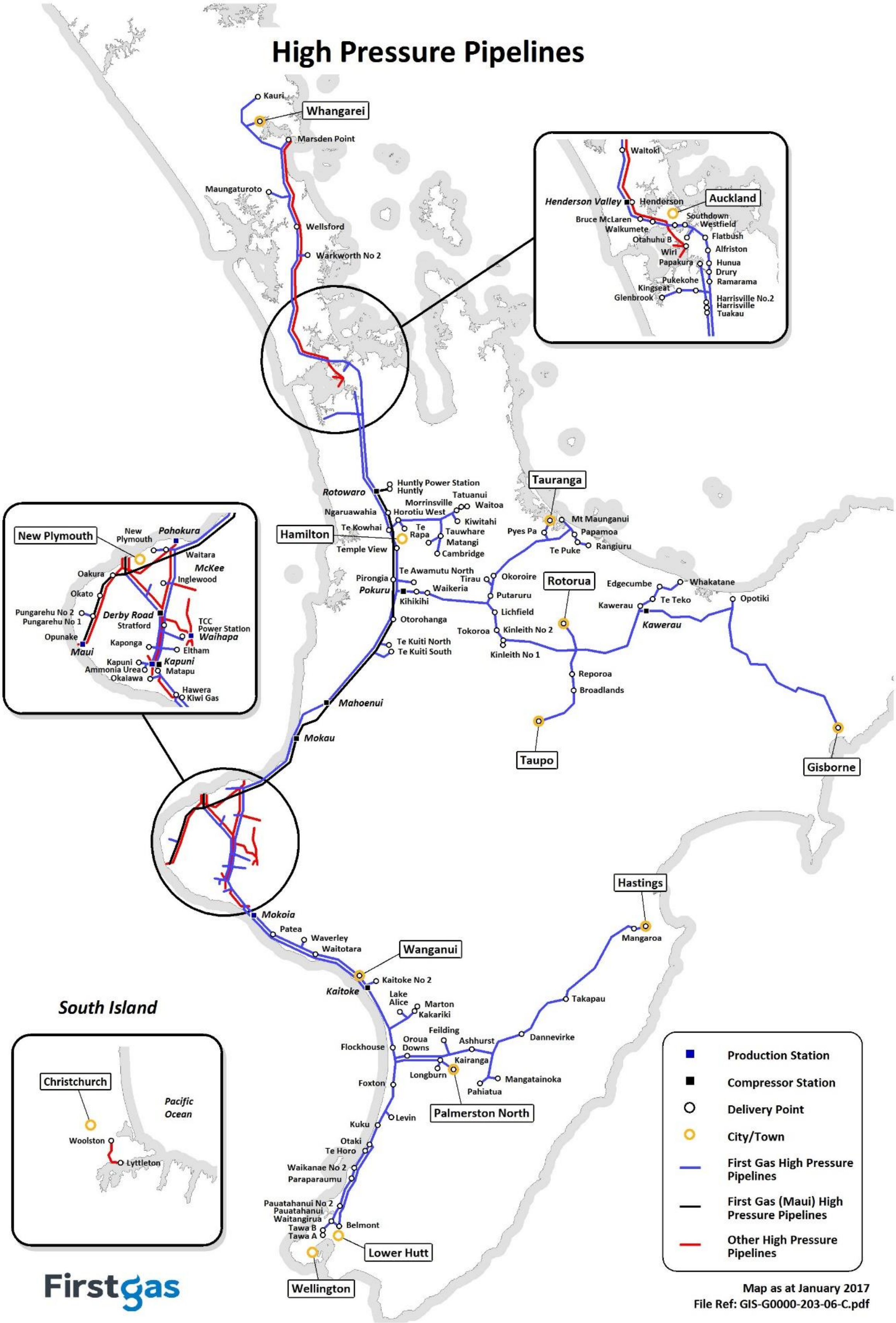


Figure 3-5: Gas Transmission in the North Island

Distribution

Open access gas distribution networks are owned by First Gas, Vector, Powerco, and GasNet, while Nova Energy owns several small private pipelines.

Major customers

Gas is critical to the petrochemical industry, electricity generation, and large industrial consumers such as dairy plants, oil refining and wood processing. Many hospitals use gas for heat, hot water and laundry.

While household consumers only use a small amount of the gas produced (<5%), this represents 300,000 homes (2019 Gas Information Disclosures), some of which may have gas as their primary source of heating.

Vulnerability to Hazards

The box to right summarises key hazard risks. In a natural disaster, damage to the gas network could present its own challenges because it could be a fuel source for fire.

Key Points from NZ Studies

Mt Taranaki Volcanic Eruption

- Probable loss of natural gas production would have a significant impact on national electricity security of supply.
- Possible damage to gas transmission lines to the north from lahars / lava flows, potentially causing long term gas supply disruptions in the North Island.

Wellington Quake (Wellington Lifelines Group)

- Gas networks would be impacted for weeks to months in this scenario.
- The Business Case identified a project *Strengthening Middleton Road walls* that would improve the resilience of the gas mains in the area.

Hikurangi Subduction Zone

- Gas asset damage possible at a number sites creating challenges in the re-establishment of supply (Wellington, Hawkes Bay).

AF8/Alpine Fault

- Bottled gas supplies will be disrupted where road access is cut off.

Climate Change

- Potentially there are risks arising from coastal land instability exacerbated by sea level rise (the transmission lines run near the coast in some areas).

LPG

LPG is supplied into New Zealand from Taranaki – a combination of imports and NZ gas field sources. Around 180,000 tonnes of LPG are consumed in New Zealand each year.

LPG is shipped to the South Island ports of Lyttelton and Dunedin by coastal tankers from where it is distributed by a local pipeline network around Christchurch and by road tanker to downstream wholesalers who have their own bulk storage facilities throughout the South Island.

The North Island is supplied by road tanker from bulk storage facilities at Taranaki and Wiri. An import terminal at Manukau was mothballed due to cost (the harbour can only take small coastal tankers), and a new import facility was established at Port Taranaki.

Liquigas provide a tolling service for the bulk supply of LPG into, out of and around New Zealand. Downstream companies include Rockgas , Elgas, Ongas, and Genesis.

LPG would have high significance in a scenario where electricity supply is cut and water supply is compromised (such as in an earthquake). LPG could be a high-requirement resource for boiling water and cooking food at household level.

Some coastal transmission lines are at risk from coastal land instability and sea level rise.

Regulation and Funding

The regime is broadly the same for electricity, except that there is no regulated investment test for gas transmission.

The Gas Industry Company (GIC) is a co-regulatory body that is responsible for developing arrangements, including regulations where appropriate, to improve the operation of gas markets, access to infrastructure, and consumer outcomes. The GIC's report on Gas Transmission Security and Reliability (*A Gas Industry Co Issues Paper – April 2016*) provides a good summary of the various regulatory and non-regulatory drivers of resilience in the sector.

Other general regulation and funding constraints for lifelines are discussed in Section 6.

Resilience Investment Programmes

As can be seen from the Figure 3-5, both major transmission lines are located close to the coastline north of Taranaki. Specific locations in this area have been experiencing significant coastal erosion, threatening the security and stability of the pipelines and heightening the risk of a major gas outage. First Gas is completing several projects to manage geohazard risks in the area and to realign the pipelines away from the coast:

- Pariroa: The first stage (completed) was a temporary above-ground bypass pipeline around the defect caused by ground movement. The second stage will replace the damaged section of underground pipe.
- Gilbert Stream: Relocation of the pipeline away from the coast (scheduled for early 2021).
- Mangapuketea (White Cliffs): Due to coastal erosion near pipes, First Gas continues to monitor the risk to pipeline integrity and plan for a realignment of both pipelines.

The current fleet of gas compressors consist of various legacy models (some over 30 years old), sizes and technology that were configured to operate the Maui and non-Maui pipelines separately. Subject to regulatory approval, First Gas is planning to reconfigure the network and replace the existing fleet of compressors with new, standardised and best available technology compressors.

A summary of gas transmission risks and investment plans is provided in First Gas' Asset Management Plan: https://firstgas.co.nz/wp-content/uploads/First-Gas-Transmission-2019-AMP-Update.pdf

Future gas supplies

The past 20 years have seen some significant changes to New Zealand's gas supply, with declining production from the Maui field and new production coming on stream. The figure below shows that over the past 20 years, New Zealand has maintained proven and probable (2P) gas reserves of more than 2,000 PJ and has consistently had more than 10 years of reserves to production available.

The stability of gas reserves has received significant public interest following the Government's 2018 decision to end the practice of issuing new permits for offshore oil and gas exploration. This was given effect under the Crown Minerals Act by providing for:

- No new offshore permits to be issued, with existing permits extended or amended on their merits
- No new onshore permits to be issued for any land area outside of the Taranaki region
- Applications for subsequent permits to be unaffected by the amendments.

Investment in increased gas production from within existing permits has continued since these changes were made, and several parties have raised the prospect of future importation of natural gas (LNG).

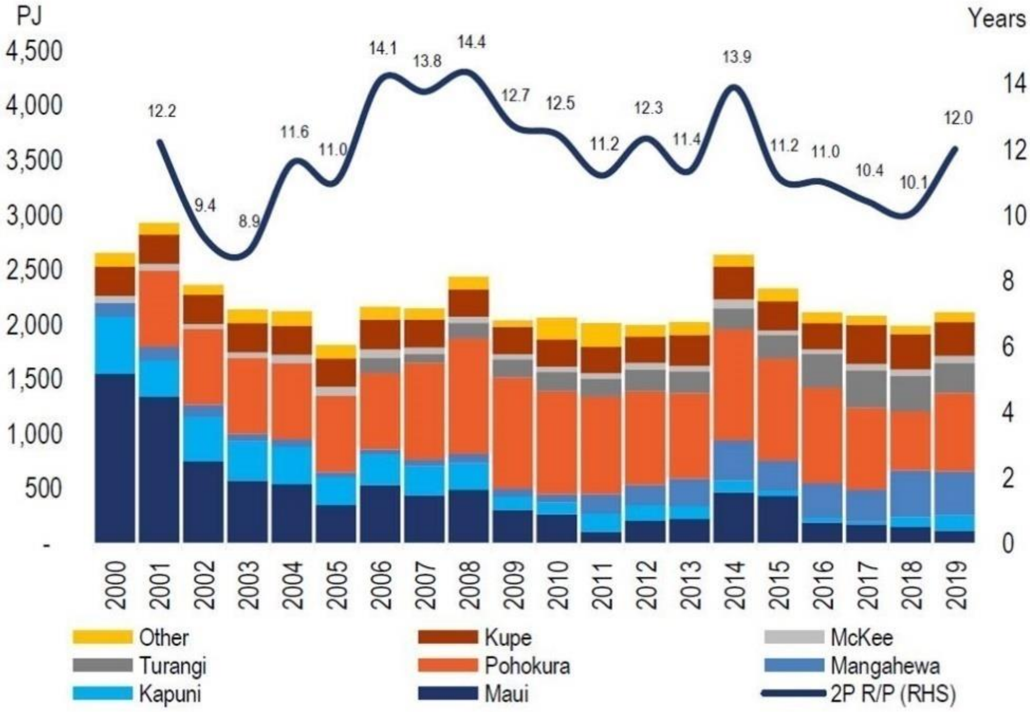


Figure 3-6: Gas Reserves and Reserves to Production Ratio (Source: Enerlytica)

3.4 Roads

Nationally Significant Assets

The significance of roads can be reflected in a classification schema. NZ road authorities use the One Network Road Classification (ONRC) system which divides New Zealand's roads into six categories. The categorisation is based on factors such as how busy they are (traffic volumes) or whether they connect to important destinations[4].

This classification provides a useful baseline for criticality assessments for lifelines vulnerabilities studies, e.g., Roads of National Significance are categorised as 'High Volume' or 'National'. However, Road Controlling Authorities participating in regional lifelines projects have in some cases classified roads as nationally or regionally significant that are not rated as 'High Volume' or 'National' under ONRC criteria. For example, NZTA recognises two 'local' roads as nationally significant – the roads to Ports of Auckland and the Marsden Refinery - which have lower classifications.

Bridges on roads often carry critical infrastructure assets of other lifelines organisations, making the consequence of their failure even more significant.

Vulnerability to Hazards

NZ has many events in recent history showing the damage that seismic and storm hazards can cause. Flooding hazards frequently close roads during heavy rainfall or coastal flooding, sometimes causing significant washout damage. Major slips from ground shaking (such as Kaikōura, illustrated right) can take months to repair.

Roads are also highly vulnerable to volcanic ash – while generally ash does not cause long term damage it can render the road temporarily impassable and result in a costly clean-up regime.

Low lying coastal roads are vulnerable to tsunami, storm surges, wave over-topping and coastal erosion.

Traffic on the road is also a hazard to road assets, such as bridge strikes by trucks.

NZTA's Resilience Programme

Road networks have been shown to be vulnerable to both high frequency (floods) and low frequency (earthquake) events with long recovery times following some events.

NZTA's *Resilience Programme* aims to address these challenges and has been underway for many years. Key projects undertaken include (outputs are available on NZTA's website):

- A national scan of exposure to low frequency hazards and expected impacts on the road network.
- A framework for assessing criticality of the road network.
- A sea level rise exposure study for coastal State Highways and KiwiRail lines is nearing completion and will complement a similar LGNZ report of 2019.
- A Generation 2 version of the MERIT tool is nearing launch, to enable estimates of wider economic impacts from major highway disruptions.
- A number of business continuity and emergency response projects.
- *Also refer to 'Investing in Resilience' in this Section.*

Kaikōura Earthquake

[4] The Road Efficiency Group (REG) is currently reviewing the ONRC with a view to better recognise adjacent land users and non-motorised road users.

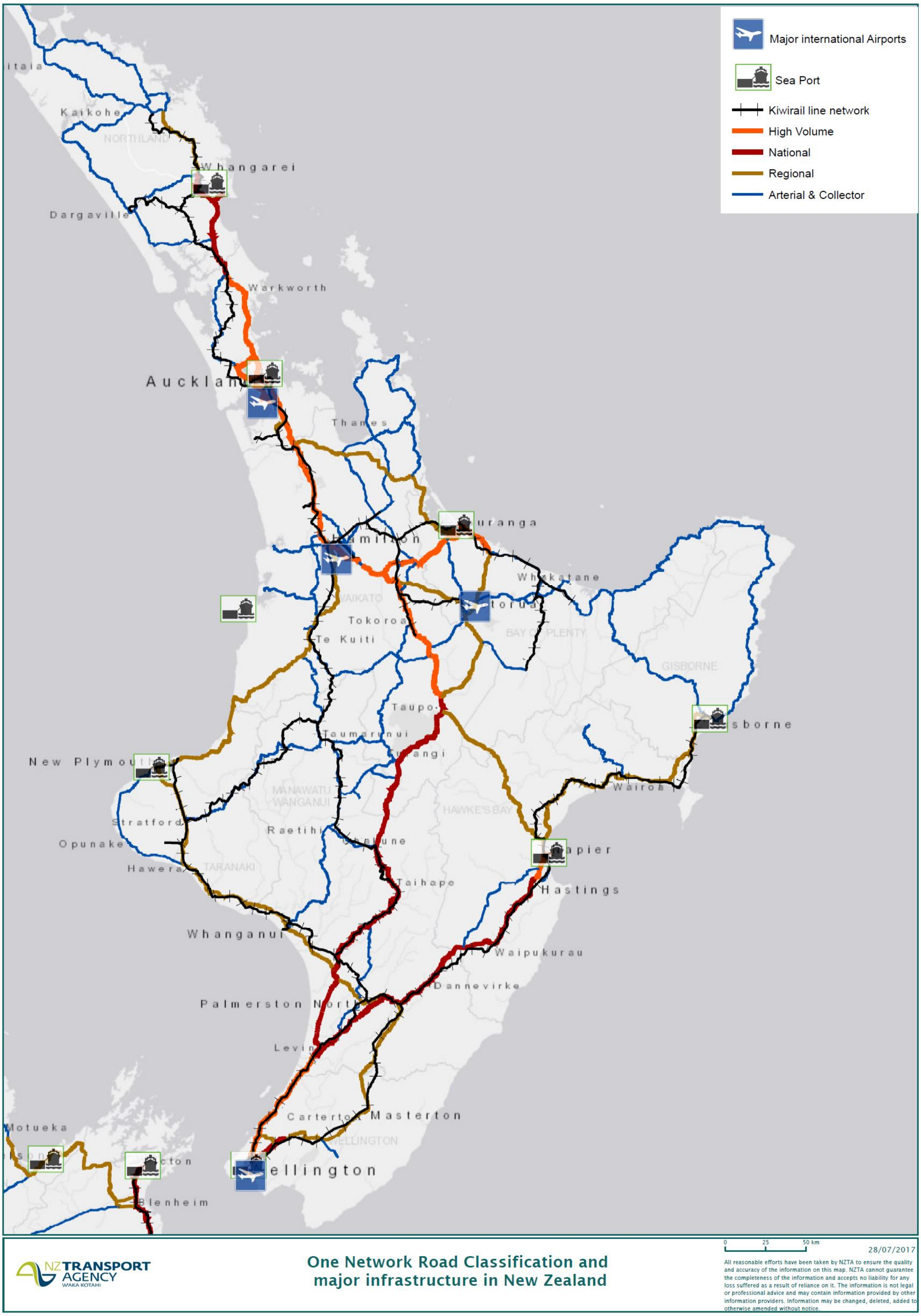


Figure 3-7: North Island Transport Infrastructure

Figure 3-8: South Island Transport Infrastructure

Nationally significant, vulnerable roads identified in regional vulnerability study reports and the 2016 National Lifelines Utilities Forum workshop are shown in Table 3-1. For many of these roads, the alternate routes are also prone to the same hazards.

Regulation and Funding

Waka Kotahi, The New Zealand Transport Agency (NZTA) allocates funding from the National Land Transport Fund on behalf of the government for both State Highways and local roads using a prescribed business case model. Funding allocation is also guided by the Government Policy Statement on Land Transport 2018, which identifies resilience as a strategic priority. The business case model is being reviewed, including in terms of how it supports investment in resilience. Further work needs to be done on supporting less resourced regions to be able to monitor, report and progress resilience programmes.

There is no specific regulation relating to minimum resilience standards, outside the CDEM Act. However, the ONRC performance measures, which in some outcome areas set benchmark standards that could be referenced in funding applications, do include some relating to resilience.

Other general regulation and funding constraints for lifelines are discussed in Section 6.

Location	Hazards	Comments
SH 1 Brynderwyns.	Floods/slips	Highway to Whangarei – detour via Dargaville.
SH1 and 16 in Auckland.	Tsunami / coastal surge / volcano	High risks are onramps to Harbour Bridge and SH1 at Pakuranga over Pahurehure Inlet.
SH1 High Productivity Freight Network.	Seismic (Pokeno / Tuakau).	
SH 29, Port of Tauranga.	Tsunami.	Important part of the FMCG and fuel supply through Port of Tauranga
SH1, east coast, several locations.	Vulnerable to tsunami along several stretches.	
SH 1 Desert Road.	Volcanic and snow/ice.	
SH5, Taupō-Hawkes Bay	Seismic and flooding/slips. Snow/ice.	Main road to Hawkes Bay.
SH 3 Taranaki North.	Volcanic and flooding/slips.	Important oil, gas, freight and evacuation route
SH 1 and 2 into Wellington.	Seismic and flooding/slips.	
SH 1 Kaikōura Corridor.	Landslips (rain and earthquake).	Road and rail in narrow corridor. Major mitigation work following 2016 quake.
Lyttelton Tunnel and access roads.	Seismic.	Access to Lyttelton, Port, Fuel.
SH1, 6 and 8 in Otago.	Seismic / alluvial activity / flooding.	Long detour routes. SH1 near Oamaru flooded for a few days in 2019.
SH6 Kawarau Gorge	Seismic and flooding. Slope instability.	Key route into Queenstown - alternate route adds 4 hours.
SH6 Hokitika-Haast Pass and SH94 Milford Sounds.	Seismic and weather (flooding, snow/ice).	Important tourist routes
SH6, 7 & 73, West Coast	Seismic and weather (flooding, snow/ice).	Only links to the West Coast – potential isolation in a major alpine fault. Coastal erosion and flooding near Punakaiki.
SH88, Dunedin	Tsunami / coastal flooding	Link to Port Chalmers
In addition, roads to nationally significant transport links such as major ports and airports.		

Table 3-1: Nationally Significant Roads with Hazard Exposure.

Note this table lists specific 'nationally significant' roads identified in regional lifelines projects and is illustrative rather than exhaustive.

Resilience Investment Programmes

As part of NZTA's Resilience Programme, there have been two recent initiatives to identify capital investment opportunities in state highways:

- A '***Quick Wins'*** project in 2019-20 assessed critical lifelines routes and detour routes where there is potential for high risks of disruption and a low-cost response – leading to a prioritised list of smaller scale projects for delivery in 3 years.
- A ***Resilience National Programme Business Case*** (all roads and rail) was also developed in 2019-20 to identify on a common national basis critical and high-risk locations and issues.

As many projects have multiple drivers and there is no exclusive 'resilience' budget, those projects that are primarily targeted at resilience improvements are prioritised against all other project types and often do not show a good return on investment. Minor resilience works (<$1M) are undertaken through a separate Low Cost/Low Risk budget category. Reactive repair work occurs through the emergency works programme (around $50M pa).

Recent major projects providing a significant 'resilience' benefit (by providing alternate routes for high risk highways) include Transmission Gully, Manawatu Gorge and Auckland-Whangarei highway upgrades. No other major projects like these are in the pipeline.

The national bridge seismic strengthening programme is considered complete (all bridges have been upgraded to a seismic level of service) and scour protection for critical bridges is a current focus.

NZTA has been reviewing its exposure to sea level rise, but this is unlikely to drive significant capital projects in the short-medium term although some responses will be integrated in the renewals programme. The most immediate priorities are likely to be in the Hauraki Plains, Coromandel, Petone-Ngauranga and the motorway north of the Auckland Harbour Bridge.

When the alternate routes tool is complete (expected in 2020), NZTA will be reviewing the adequacy of alternate routes and this may identify resilience upgrades to address deficiencies along alternate routes.

Key Learnings from NZ Studies

AF8 (Alpine Fault)

- Roads and bridges are likely to be damaged and seriously obstructed across wide areas of the most severe shaking.
- Large parts of the South Island (notably the West Coast) normally accessed through alpine passes or steep sided valleys nearer to the Alpine Fault will be inaccessible by road, potentially for weeks to months.

Wellington Quake (Wellington Lifelines Group)

- Severe road damage and isolation of many areas by road.
- Current projects such as Transmission Gully (2021) will improve resilience.
- The Business Case (2019) identified eight further projects (total value circa $1.3b) to improve the region's road resilience.
- NZTA is working on a Programme Business Case for resilient transport links in the Wellington Region.

DEVORA/Auckland Lifelines Group

- Any major Auckland route disruption will worsen congestion and constrain evacuations. Road travel can be compromised by ashfall.

Hikurangi Subduction Zone

- Ground shaking of MMI 7-9 around the North Island with impacts as per Wellington Fault but for a wider area of the North Island and upper South Island.
- Tsunami is a significant hazard with very short warning times.

Central North Island Volcanic Zone

- Several State Highways may be heavily disrupted or closed by ash, including some with no nearby detours available (SH1, SH5) and urban roads in Tauranga, Whakatane Rotorua and Taupō. This will also disrupt fuel transportation.

Mt Taranaki (Taranaki Lifelines Group)

- Isolation by road (lava flows / lahars crossing SH 3 in a number of places).
- Damage from ground shaking.
- Roads not damaged by near source impacts are likely to be difficult to drive on due to ash.

Climate Change / Deep South Science Challenge

Present day risk of coastal inundation in a 1% storm is 1,400km of roads. This increases to around 2,300km in a 0.6m sea level rise – predicted between 2070 and 2130 (MfE 2017).

3.5 Air Transport

Nationally Significant Assets

There are 5 public international airports (refer Figure 3-9) plus the RNZAF base at Ohakea. Auckland Airport carries 75% of international passenger traffic while Christchurch is the main gateway into the South Island. Auckland and Christchurch are the only two hubs for international USAR assistance. Clearly, the closure of Auckland, Christchurch and Wellington airports would cause the most significant air travel disruption both nationally and internationally.

Regional airports service the balance of New Zealand. These can also have national significance; for example, in a major Alpine Fault earthquake, Hokitika Airport potentially becomes highly critical for the West Coast if it is isolated by road. Similarly, Queenstown Airport could be extremely important in the evacuation of tourists (and other people) and for bringing in emergency supplies and responders (noting the airport only holds 3 days of jet fuel which is transported by road from Dunedin). Kaikōura Aerodrome became critical infrastructure following the 2016 Kaikōura earthquake for moving supplies and evacuating people.

Airways provide national air traffic control infrastructure for airports and airlines operating in NZ. Nationally significant assets include:

- The Airways centre in Christchurch, which monitors all the air traffic in NZ and the Oceanic Control Centre in Auckland which monitors traffic outside NZ (both sites have hot standby sites to maintain functionality).
- Radar installations in Wellington, Auckland, and Christchurch (while these are being replaced with satellite surveillance as part of the *New Southern Skies* programme, they will remain as backups in some locations).

Failure of these assets slows down, but does not necessarily halt, air transport. There are robust and extensive backup plans for the failure of all these assets.

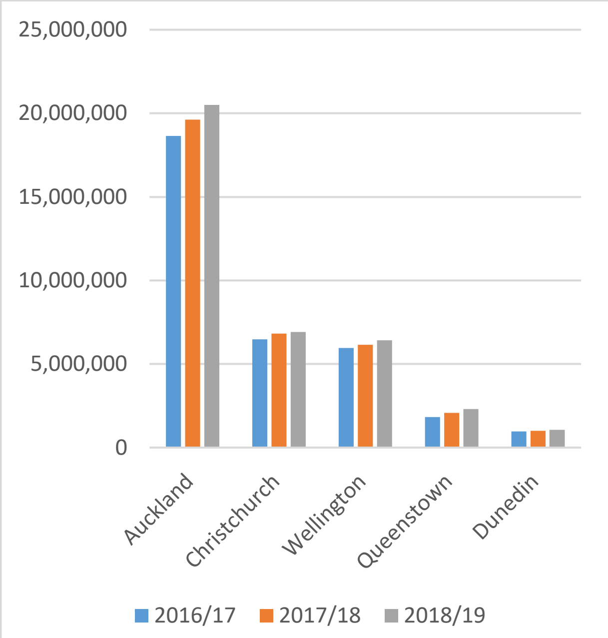


Figure 3-9: International Airports – Passenger Numbers (NZ Airports Association)

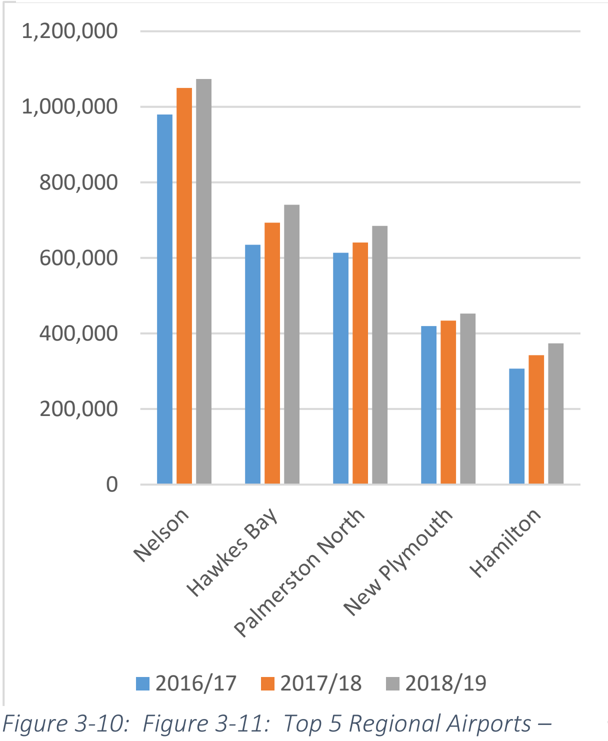


Figure 3-10: Figure 3-11: Top 5 Regional Airports – Passenger Numbers (NZ Airports Association).

Navigation aids such as Ground based navigation aids (GBNAs) provide a critical service and are used for navigation by aircraft flying under instrument flight rules (IFR). GBNAs are maintained by Airways NZ at all airports with air traffic control services as well as Kaitaia, Hokitika and the Chatham Islands (which are uncontrolled). If these systems are impacted by a disaster of some sort, critical infrastructure that the air transport sector is highly dependent on could be unavailable for a period of time.

The Airways telecommunications network is also critical infrastructure, enabling air traffic control towers and centres to communicate. Surveillance and Flight Plan information for the air traffic management (ATM) system is likewise necessary.
Air Traffic Management requires other Instructure Landing Systems and three main sensor systems – radar, multilateration and ADS-B. The latter uses a distributed network of sensors that can cope with a localised outage, although it is also heavily reliant on both GPS and the telecommunications network.

Vulnerability to Hazards

Airports and runways are designed to withstand seismic events, however there is still likely to be damage in a major event. Queenstown is notably in an area of high seismic risk (and has geographical significance as discussed above) and some airports are prone to liquefaction, such as Wellington and Dunedin).

Other vulnerabilities for air transport include:

- Volcanic ashfall disrupting flights.
- Technological disruption, vulnerability to technological failure, impacting any of the air control services described above.
- Human pandemic – while air services can keep functioning (albeit in a situation of severely reduced demand) – loss of critical personnel such as firefighters and air traffic control and the potential to impact services.
- Dependence on jet fuel. The loss of jet fuel supply to Auckland Airport would have a significant impact on international and domestic travel in the country. Some international flights could pre-load in Australia, but the full impact of a prolonged jet fuel shortage is unclear.
- Aircraft accident (of many causes).
- Low lying airports near the coast vulnerable to tsunami and storm surge. Sea level rise associated with climate change will exacerbate those hazards. 13 of the 28 domestic and international airports in NZ are exposed up to a 1 m sea-level rise.
- Hazard impacts on road access to airports – many airports have single road access and many of these roads are also vulnerable to flooding (e.g., Dunedin) and other hazards.
- Flights can be disrupted by general weather conditions, with knock-on effects on other transport systems and for air service customers (including the FMCG sector).
- If the MetService weather forecasting and telecommunications system is compromised, this would limit flying capability.

Key Learnings from NZ Studies

AF8 (Alpine Fault)

- Hokitika, Greymouth, Westport, Manapōuri, Milford, Queenstown, Wānaka, Glentanner, Mt Cook, Twizel and Tekapo Airports may be compromised (and most other airports in the South Island will need to be inspected before operation).

Wellington Quake (Wellington Lifelines Group)

- Wellington Airport is expected to be to be inoperable for at least the first two days and the road to the airport for up to two weeks. Palmerston North, Ohakea, Kapiti Coast (Paraparaumu), Masterton, Nelson and Blenheim airports will potentially be damaged or disrupted.

DEVORA/Auckland Lifelines Project

- Potential significant disruption to Auckland Airport flights and other North Island airports. Major disruption of air travel into and within New Zealand.

Hikurangi Subduction Zone

- Severe damage to Napier Airport and possible disruption to Wellington and other airports in south and east of North Island.

Mt Taranaki (Taranaki Lifelines Group)

- Significant and ongoing affects to North Island air transport for the duration of the eruption (which may be months to years).

Climate Change

- 13 airports in NZ are currently exposed to coastal inundation in a 1% AEP storm – a 14th airport is at risk under 0.6m sea level rise *(Deep South Science Challenge 2019).*

Regulation and Funding

Air transport services are largely privately funded through charging from airlines (who in turn are charged by Airports and Airways to provide their services).

The Civil Aviation Authority (CAA) has primary regulatory responsibility for aviation safety and security.

The Ministry of Transport contributes funding in the aviation space.

The Commerce Commission manages an information disclosure regime for Auckland, Wellington, and Christchurch airports.

Other general regulation and funding constraints for lifelines are discussed in Section 6.

Resilience Investment Programmes

The research sector, partnering with air operators, continues to work on volcanic ash modelling science to improve prediction of volcanic ash fall following an eruption and minimise 'no-fly' areas.

New inter-operable, robust radar centres are being built in Auckland and Christchurch (these will be operational during 2020).

While there is also plenty of capital investment in airport infrastructure, major airport expansions in Auckland, Wellington and Christchurch are being driven by growth in demand, rather than any specific 'resilience' improvements. Major airports are already designed to withstand major hazards such as earthquakes.

3.6 Rail

The national rail network moves around 16% of NZ's total freight and carries around 1million tourists and 35million commuters each year (*KiwiRail Asset Management Plan AMP 2020*).

Nationally Significant Assets

The rail network is illustrated in Figure 3-12. The map shows that there is little redundancy in the main trunk network. Effectively the road and marine network become alternative routes for freight movement and commuter travel if the rail corridor is closed.

Nationally significant assets in the network include the North-South trunk line in the North Island, Auckland-Tauranga line, the inter-island rail route and Wellington and Auckland metro lines (based on railway lines with the highest percent of freight and commuter traffic). KiwiRail's AMP identifies other 'very high' criticality lines as the Picton to Christchurch line and the Christchurch metro.

Many road and rail lines follow the same route and are susceptible to the same hazards with long detour routes if they are impassable. For example, the movement of freight by road following the closure of the Kaikōura Corridor after the 2016 earthquake caused immediate issues on the inland road between Picton and Christchurch. In response, KiwiRail entered the coastal shipping freight market with a NZ Connect Service to quickly move domestic freight from Auckland to Christchurch. Extra capacity was made available at the ports, and by using rail in Auckland and Christchurch, added benefits of reducing truck congestion from already busy roads.

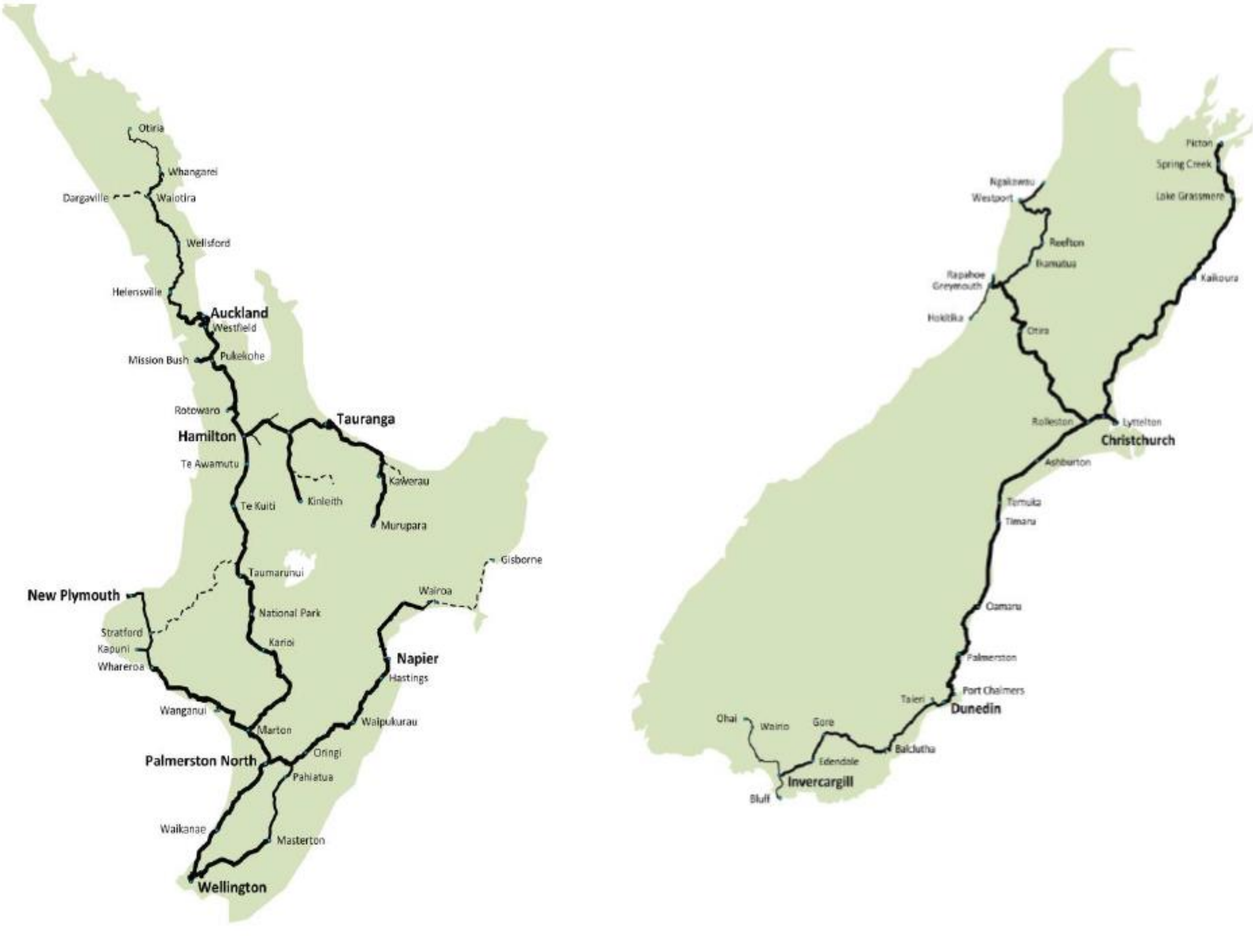


Figure 3-12: National Rail Network

Vulnerability to Hazards

Vulnerabilities in the rail network are similar to those discussed for roads – notably flooding, coastal erosion, earthquakes and landslips.

The box to the right presents a summary of findings from recent research programmes as to the impacts of major natural hazards on the rail network.

Regulation and Funding

KiwiRail is registered as a State-Owned Enterprise and operates within the policy and regulatory frameworks of the State-Owned Enterprises Act 1986 (the Act). As a State-Owned Enterprise it seeks to self-fund, with additional Government funding sought for new initiatives and investments to support a resilient network.

The Government Policy Statement on land transport 2018 makes provision for the improvement of rail through new urban and interregional commuter rail services. Rail has a prominent focus as an enabler of economic development, which links New Zealand's regions and ports to export markets overseas.

The NZTA has primary regulatory responsibility for rail safety in New Zealand in accordance with the Railways Act 2005. This role includes issuing rail licences for operating rail vehicles or managing rail networks, checking licensees' compliance with approved safety cases through assessments, reviewing and approving variations to approved safety cases.

Resilience Investment Programmes

The country's largest transport project is currently underway with the development of the Auckland CityRail Link, which will quadruple the capacity of the Auckland rail network. It will create flexibility and resilience in the network by changing Britomart (downtown Auckland) from a dead-end to a through-way station.

More widely across the network, KiwiRail is seeking to address significant underfunding of rail infrastructure in recent decades with re-vitalised renewal and strengthening programmes.

At the time of writing this report, the Government had recently announced funding of new investments most notably to the north of Auckland to Whangarei, new train control centre in Auckland, and replacing aging inter-islander ferries.

Key Learnings from NZ Studies

AF8 / Alpine Fault

- Rail to the West Coast and the far South is likely to be seriously disrupted – mainly affecting freight supplies such as coal and dairy products (road alternates are also likely to be impassable for freight trucks).

Wellington Quake (Wellington Lifelines Group)

- Rail lines between Wellington and Levin, Wellington and Masterton, Palmerston North and Woodville and Kaikōura and Picton are likely to be inoperable.
- National control of rail operations may also be severely disrupted, due to damage to rail communication and signalling facilities in Wellington. This means that a major earthquake damaging control centre operations in Wellington could cause outages on the Auckland metro network.

Hikurangi Subduction Zone

- Impacts in the southern North Island are potentially as significant as a Wellington Fault, along with likely major disruption to rail to Napier Port for months to years.

DEVORA/Auckland Lifelines Group

- A worst-case location for an Auckland volcano would be the Auckland CBD, impacting Britomart, the Port and the Auckland metro network for months to years.

Central North Island Volcanic Zone

- Central North Island eruptions may cause temporary disruptions to rail services due to ashfall.

Mt Taranaki (Taranaki Lifelines Group)

- The Stratford – New Plymouth rail line passes through lahar hazard zones.

Climate Change

- Present day risk of coastal inundation exposure in a 1% storm is 86km of rail track (Deep South Science Challenge, 2019). This increases to around 142km in a 0.6m sea level rise – predicted between 2070 and 2130 (MfE 2017).

3.7 Sea Transport

Ports are important economic hubs for our remote country, connecting New Zealand to international markets and facilitating billions of dollars of trade both internationally and nationally. In regions at risk of being isolated by road for long periods, such as Wellington, Taranaki and the West Coast, ports become critical for evacuations and transport of emergency supplies.

Nationally Significant Infrastructure

There have been two recent examples when NZ ports have been unable to operate for extended periods - Lyttelton and Wellington post-earthquakes. The market responded within a couple of days and workarounds were put in place demonstrating that there is capacity for other ports to pick up trade should a closure occur. For example, Wellington's container freight was shifted quickly to Napier (and to a lesser extent Nelson). The relatively large number of ports for our size of population proves extremely useful in terms of resilience when there are natural disasters.

However, Tauranga as by far the largest export port (refer Figure 3-13) would pose a major issue for New Zealand should it close for an extended period. Auckland and Napier would be under severe strain, as would the road/rail and coastal freight networks.

Marsden Port (included in the figure under Whangarei ports) also has national significance in its role in the fuel supply chain, and Wellington and Picton as part of the cross-Strait ferry crossing. Northport is capable of taking 50% of Auckland's freight, if Ports of Auckland is unable to operate.

Vulnerability to Hazards

A study was carried out by the University of Auckland in 2012 (*Ref: Vulnerability of New Zealand Ports to Natural Hazards*). The aim of this report was to review the exposure of New Zealand's coastal ports to natural hazards and examine aspects related to access routes to the port. 14 major ports were assessed.

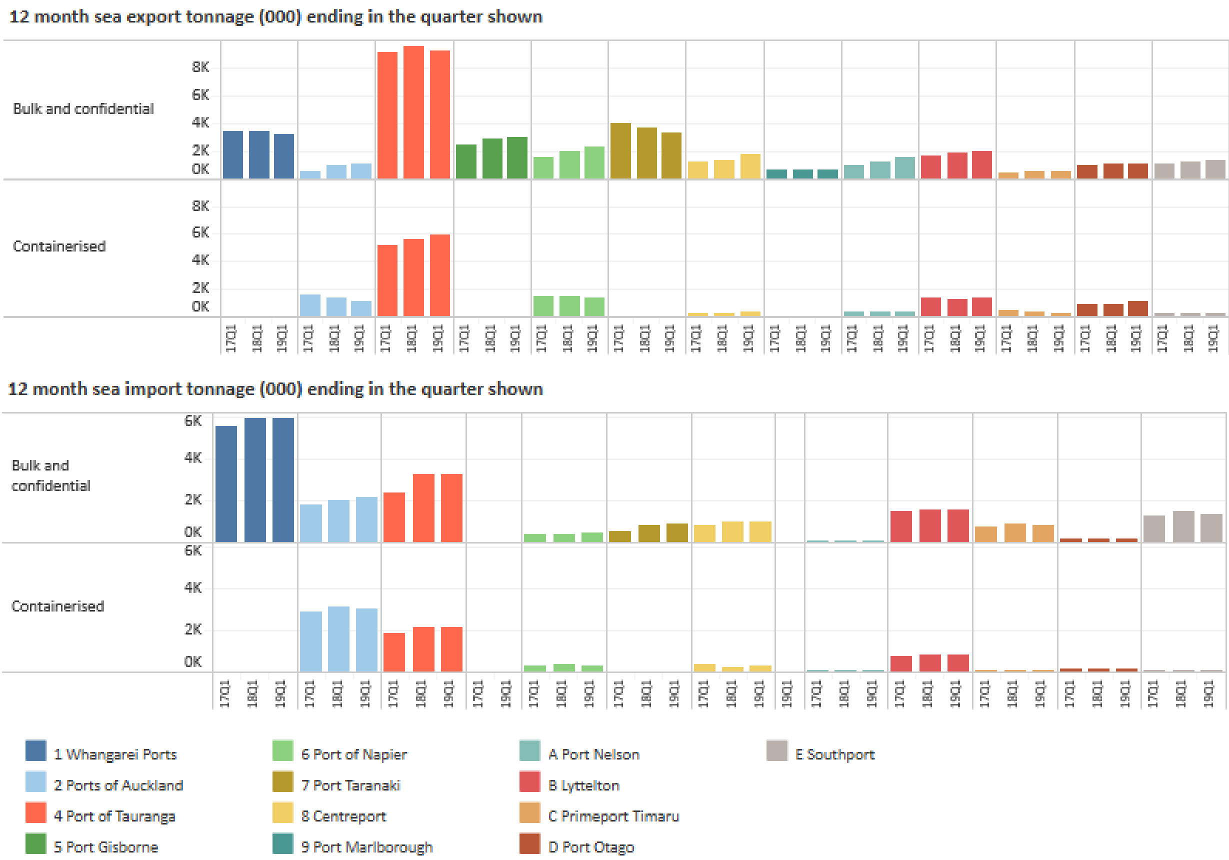


Figure 3-13: Sea Import and Export Tonnage, first quarter 2017, 18, 19 (https://www.transport.govt.nz)

The review demonstrated the wide range of exposure to seismic, tsunami and volcanic hazard throughout the port network. Some key findings included:

- Seismic hazard is closely aligned to the main faults that run through the centre of New Zealand, with Eastland Port, Port of Napier, CentrePort, Port Marlborough and Westport exposed to the highest seismic hazard over a range of return periods.
- The scenario most likely to affect several ports is a rupture in the northern section of the Alpine Fault with Westport, Port Nelson, Port Marlborough, Lyttelton Port, CentrePort and PrimePort expected to experience seismicintensities of MM 7 (Damaging).
- Volcanic hazard in Taupō Volcanic Zone, Auckland Volcanic Field and Mount Taranaki. Port Taranaki and Ports of Auckland and Tauranga potentially directly impacted, with ash fall identified as a hazard for most of the North Island ports and is dependent on prevailing wind directions. Even if the port isn't directly impacted, there is expected to be a major increase in demand during recovery.
- The primary tsunami hazards are discussed in Section 5.4, and create hazards for major ports on the east coast. Even where ports aren't inundated, tsunami have potential to significantly disrupt ship movements and damage ships and docks (e.g., ships pulling moorings).
- The majority of the ports are located on reclaimed land that varies both in age of construction and quality and is typically highly vulnerable to even moderate shaking.
- Access routes to most ports are susceptible to some level of damage as a result of one or more of the natural hazards identified here, potentially restricting access to the port.

These findings are supported by more recent studies, summarised in the box to the right.

Key Learnings from NZ Studies

AF8 / Alpine Fault

- Major ports in the South Island may be affected (Nelson, Marlborough, Timaru, Otago, Lyttelton). Smaller ports in Jacksons Bay, Westport and Greymouth likely to be severely compromised.

Wellington Quake (Wellington Lifelines Group)

- CentrePort is seismically vulnerable, though very limited operation is probable after a week.
- The Business Case (2019) identified two key projects, including port seismic strengthening works and a new ferry terminal ($550M).

DEVORA/Auckland Lifelines Group

- Worst case scenario could see the Port directly impacted by a nearby eruption. Otherwise ashfall would impact Port operations (safety and equipment protection issues).

Hikurangi Subduction Zone

- Severe damage expected to Port of Napier and CentrePort, possibly others in the south of the North Island and top of the South Island.

Mt Taranaki (Taranaki Lifelines Group)

- While Port Taranaki itself is not in a lahar flow area, port operations are likely to be disrupted by ashfall, electricity, telecommunications and road disruptions.

Climate Change

- Ports were not included in the Deep South Science Challenge 2019 report.

Regulation and Funding

Port facilities in NZ are owned and operated by private companies that are majority owned by local government. Maritime New Zealand has prime regulatory responsibility over the operation of vessels, ports, and offshore installations as well as provision of navigation aids. Other general regulation and funding constraints for lifelines are discussed in Section 6.

Resilience Investment Programmes

The Cross-Strait ferry is a significant transport asset for New Zealand, and ports at both ends have significant seismic and tsunami vulnerabilities. Both Picton and Wellington are working on a new system designed to be more resilient in case of an earthquake/tsunami. Many other ports are in the process of upgrading their infrastructure with, for example, Port Nelson investing around $20M in 2020 on an upgrade that will aim to get the Port operable more quickly after a disaster.

3.8 Telecommunications

Sector Overview

The telecommunication sector is one of the most complex of the lifelines sectors – technology changes rapidly and there is a high level of inter-connectedness between the various providers which share parts of the network and exchange voice and broadband data between networks.

As technology changes, so does consumer demand – increasing numbers of households have replaced POTS (the Plain Old Telephone Service) phones with other options derived from either land-based fibre or wireless access. Fixed and Mobile Cellular is also particularly important for some more rural and isolated communities who are also increasingly being served by WISPs (Wireless Internet Service Providers).

The capabilities of the telecommunications sector, and the resilience attributes inherent in that, are significantly contributing to New Zealand's response and recovery in the current COVID-19 pandemic situation. An example is the ability for many to work from their own residences using high speed internet and video conferencing functionality – national recovery will be faster because of this.

Figure 3-14 indicates the diversity of telecommunication providers ranging from the fixed line carriers to the high-level application layer media providers delivering services via a broadband connection or broadcasted at radio frequencies. There are over 100 Retail Service Providers that deliver a wide range of services over the aggregation of NZ telecommunication networks.

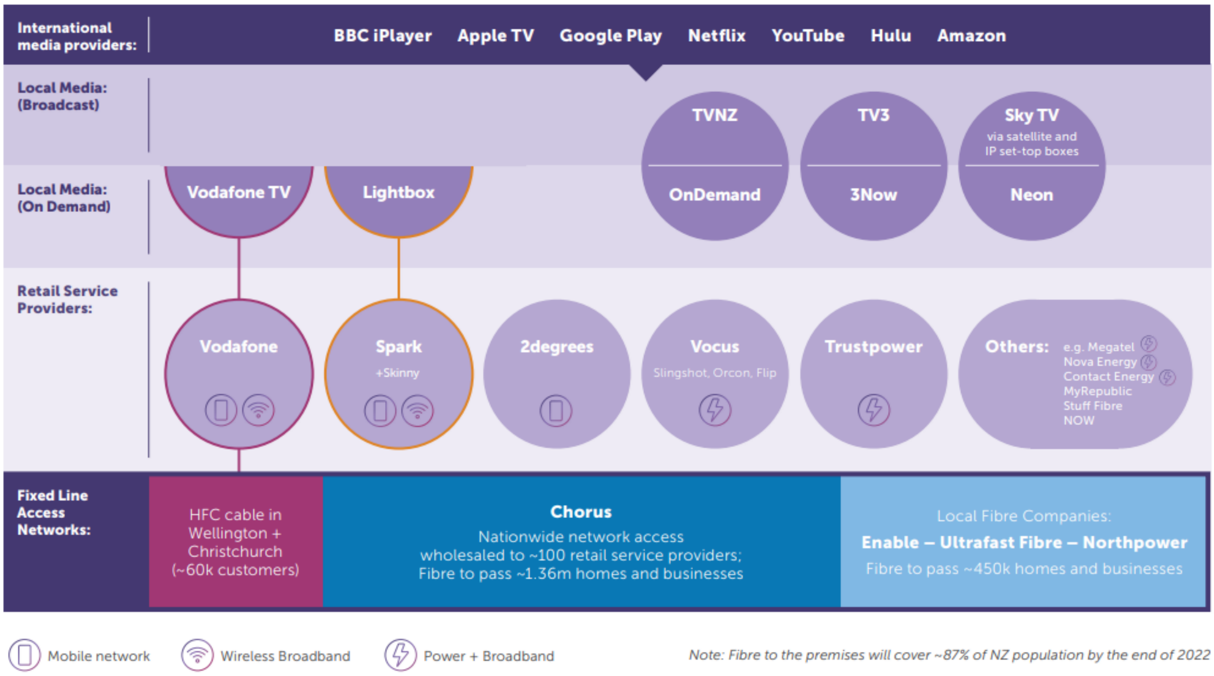


Figure 3-14: Telecommunication Providers in New Zealand

Fixed Line Networks

The Fixed Line network can generally be divided into:

- *Transport* - the network that interconnects nodes such as exchanges either regionally or nationally. The Transport links are dominantly Fibre with some microwave radio sectors
- *Access* (reticulation from a telecommunication node or exchange to the subscriber). There is an increasing migration of Access subscribers to Fibre from which they derive all their telecommunication needs over broadband using VOIP (Voice Over Internet Protocol) such as Skype.

The digital data rates that are now available over UFB (more than 1Gb/s) can provide a diverse range of services to the consumer and society's reliance on these services is higher than ever before.

The role of the "Telephone Exchange" has changed from mainly supporting a POTS (Plain Old Telephone Service) switch to becoming a Network Node that is part of a distributed and diverse protected network carrying both internet and non-internet communications traffic. It is anticipated that most POTS switches will be turned down within five years and replaced with digital services.
Figure 3-15 shows the fixed fibre *Access* network, showing how the network known as UFB is reticulated. While this network is physically and optically very robust, it relies on the consumer to have a reliable power supply to sustain the connection services between the fibre and the consumer's modem (the connection is called the ONT, or Optical Network Termination).

Figure 3-16 shows the interconnectivity between the Access network subscriber, through the meshed and the diverse national / regional core transport network and arriving at a handover site which is where the RSP (Retail Service Provider) gains access to their customer.

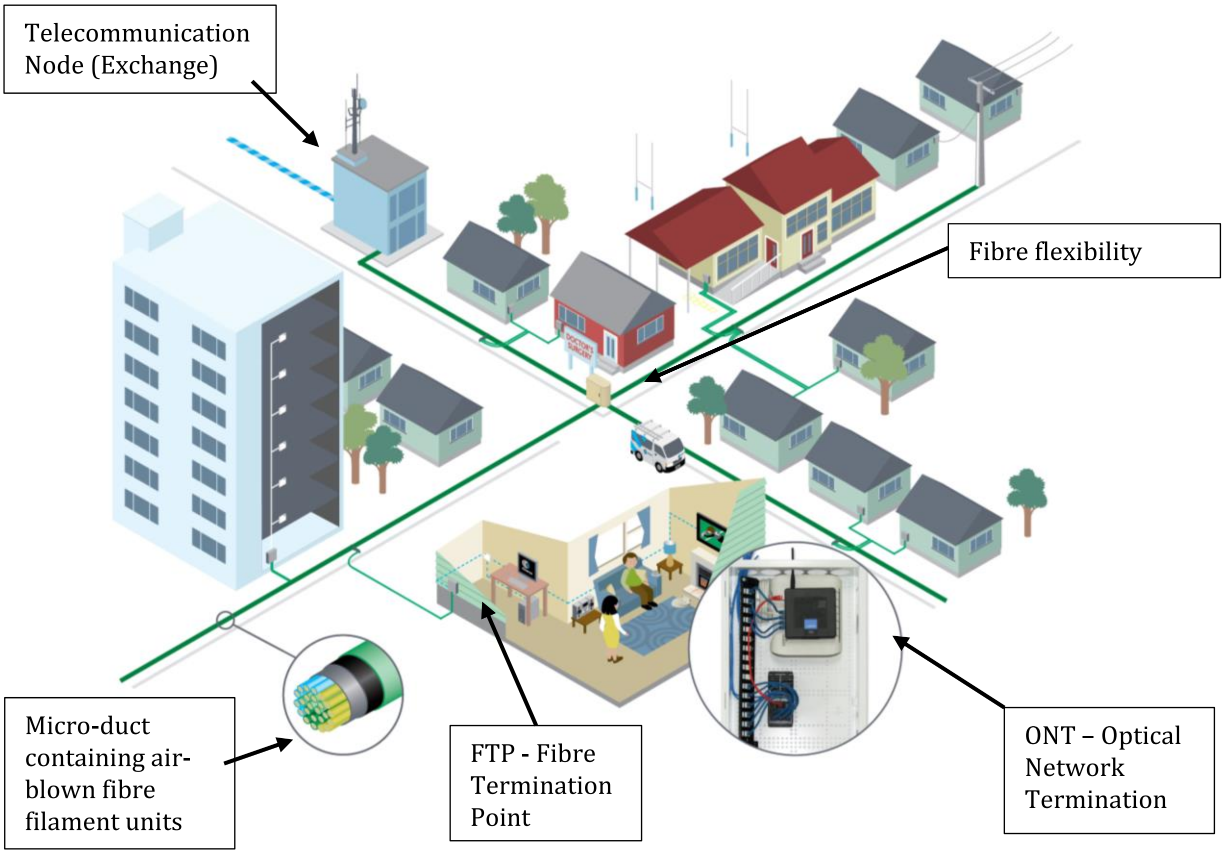


Figure 3-15: Fixed Fibre Access Network

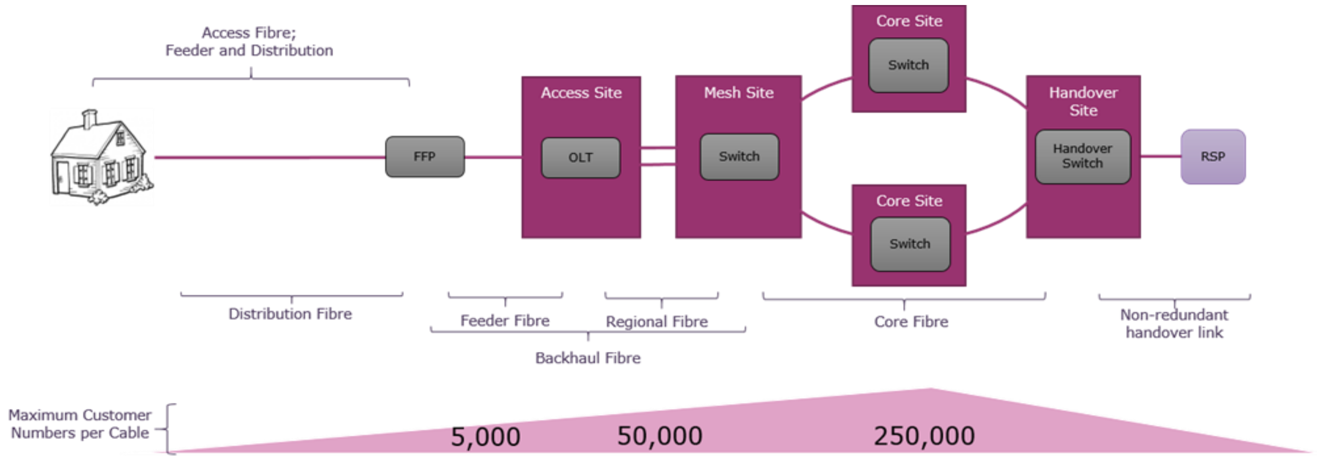


Figure 3-16: Connection between the Access Network Subscriber and the Retail Service Provider

Core (Telecommunication) Networks

Figure 3-5 shows an example of a diverse Core Transport fibre network on the left; each node on the network has either automatic or command-driven failover to diverse geographical fibre links to sustain either full or predetermined priority levels of service. The right-hand diagram shows a service connectivity or "Neural" view of the same network at any given moment; the patterns would alter depending on the availability of components of the network (links and nodes)

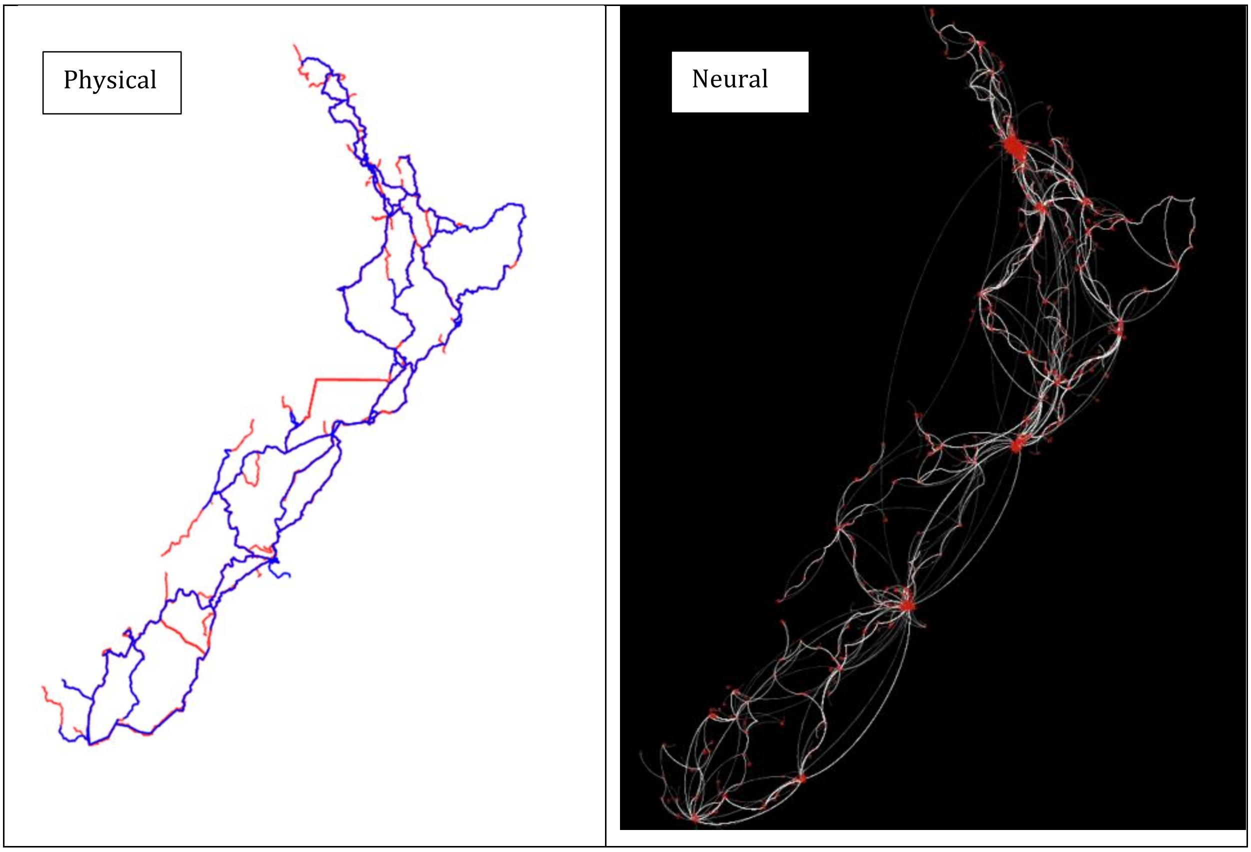


Figure 3-17: Example of a diverse Core Transport Fibre network (left shows geographical links, right shows 'neural' view)

Mobile (Cellular) Networks

There are three Cellular Mobile service providers in New Zealand. Spark, Vodafone and 2Degreesmobile.

Cellular networks are comprised generally of four principal building blocks.

- The Cell Site provides the local coverage, and a mobile phone will connect to the cell site with the strongest signal, usually, but not always the nearest cell site.
- Transmission links connect the cell site to the Aggregation Node and the Aggregation Node to the Exchange. The transmission links are fibre, copper or microwave radio (increasingly, transmission links are moving to fibre connections).
- The Aggregation / Intermediate Node is linked by transmission links to the exchange.
- The exchange (Mobile Telephony Exchange, or Strong Node) is the brains of the operation; it makes the connection between the caller and the called. If the transmission links are broken, the call cannot be completed. It is not possible for a cell site to work in local mode.

The network operators in New Zealand operate several Exchanges (strong nodes) and these are also connected by fibre transmission links. If these links are broken, the network functionality will be severely impacted. These links are therefore heavily protected with redundant links and automatic failovers.
Because of the dependence of telecommunication sites on electricity supply, there are a range of backups if mains supply fails:

- Strong-nodes are equipped with battery backup and fixed diesel generators
- Aggregation points are equipped with batteries and either a fixed generator or the facility for connecting portable generators.
- Cell sites are equipped with battery backup (typically between 4 and 12 hours depending on priority) and either fixed generators or generator plugs.
- The network operators hold their own portable generator stocks to maintain some basic coverage in a limited area.

Telco Cooperation – Kaikōura 2016

The November 2016 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. However, it is worth noting that because the area had a 'POTS' switch, people within Kaikōura were able to contact each other.

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 diversity in the core network.

The restoration of the eastern core fibre route occurred through cable overlays where the fault was inaccessible, some slung from helicopters for hundreds of metres. Chorus and Spark also brought forward plans for an inland fibre route to increase diversity.

The event highlighted how important telco sector and Lifelines / CDEM relationships are in an emergency, and how valuable Regional Lifelines Groups are for fostering those relationships.

Nationally Significant Assets

Major Telecommunication Nodes (Exchanges)

Both Spark and Vodafone's main Exchanges are in Auckland, Wellington, Christchurch, and Hamilton. Porirua is another critical exchange for Spark as it is the terminal for Spark's inter-island cable. Chorus retains a core network presence by co-locating in Spark exchanges, but it is gradually diversifying its national network nodes into its own key sites. 2degrees has its major exchange for mobile in Auckland and Wellington, with a disaster recovery site in Hamilton. For broadband (fixed), the major exchange is in Christchurch with disaster recovery in Auckland and Hamilton being built up.

Core Transport Network

The international fibre links into New Zealand are nationally significant but the four main links (terminating at Waipu, Muriwai, Takapuna and Raglan) do provide redundancy for each other.

The Chorus shared core fibre network connecting the major telecommunication nodes in both the North and South Islands includes three main north-south cables – broadly described the 'eastern', 'central' and 'western' cables. These are considered as nationally significant assets and provide redundancy for each other if one fails through a 'ladder network'. This core network carries all services (i.e. mobile/landline, voice/data). Due to the active redundancy of these networks, it is difficult to determine the relative criticality of various links.

Other providers such as Vodafone, Spark and Vocus have their own networks, generally on high capacity routes such as inter-city core backhaul networks.

Network Vulnerability

The highly interconnected nature of the telecommunications networks makes it complicated to predict the impact of specific asset outages, such as loss of a major Exchange. These sites are designed to 'fail over' to the remaining sites if one fails though there are some limitations.

Spark's Mayoral Drive Exchange (and nearby Airedale) is possibly the country's most significant telco site though the implications of a major failure have not been quantified. The worst case (though very low probability) is a volcanic eruption in this area, which also has the main Vodafone Exchange and the Sky Tower (a major telecommunications hub) in the vicinity.

There are other key nodes exposed to risks such as flood inundation and tsunami. Fire is a major hazard as well – a multi-storey building fire in Auckland in 2017 was not far from the Mayoral Drive Exchange and wildfire can destroy above ground assets.

As a network, the sector is most vulnerable to power outage. Backup arrangement were described previously, but batteries have limited operating time before re-charging is required and generators need fuel. In a major, prolonged electricity outage, fuel and access for re-fuelling become critical. Even with the main telecommunications networks operating on backup power, most homes rely on electricity to consume phone and internet services.

The other major hazards are seismic activity – land displacement snaps fibres and damages bridges carrying cables, fire, and volcanic ash impacting on air conditioning systems required to keep equipment cool.

Another risk which surfaced in both Christchurch and Wellington (2016 Kaikōura earthquake), was the vulnerability of the building stock housing telco equipment.

Key Learnings from NZ Studies

AF8 (Alpine Fault)

- Standard networks will be damaged with remaining networks overwhelmed by increased telecommunications traffic. In ground infrastructure is likely to be severely damage.
- Electricity outages will have knock-on impacts on telecommunications services.

Wellington Quake (Wellington Lifelines Group)

- The region's networks have diversity and resilience, however, would be unavailable for weeks in a major Wellington earthquake, (partly due to power and fuel disruptions).
- The Business Case (2019) identified a project to provide back-up power at cell sites (circa $12m).

DEVORA/Auckland Lifelines Group

- Potential ash damage to air conditioning systems resulting in disruption to telecommunication systems.
- If major exchanges such as Mayoral Drive impacted, cellular and landline coverage could be intermittent across Auckland, Waikato and Northland, with very significant slowdown in broadband speed. Systems will also be disrupted by electricity outages, especially during initial period of fuel disruption where diesel for generators will be limited.

Mt Taranaki (Taranaki Lifelines Group)

- Potential loss of Chorus fibre both north and south, isolating New Plymouth.

Climate Change

- Telecommunication sites were not included in the *DSCC Coastal Flooding Exposure under Sea Level Rise*. No quantitative information about coastal exposure is available.

As discussed earlier, smaller POTS switching exchanges (such as Whataroa) are progressively being shut down and any remaining POTS services digitally transported to nodes at other centres. This means that where a community could previously have been able to make local calls even if the fibre link connecting it to the rest of the NZ network failed, with the centralising of services onto the digital environment these communities now need to find alternative communication methods and procedures, such as satellite, to be able to communicate if a core connecting link fails.

Furthermore, increasingly fewer homes have 'landlines', increasing the impacts from cellular outages.

However, it is not advisable to put all faith in a satellite solution either as services, especially those serving into the 40s latitudes that have indeterminate grades of service, whilst working well in peacetime conditions, may not be effective during the early stages of a crisis where multiple handsets / terminals are vying for service.

Broadcasting

Kordia owns and manages the broadcasting network in New Zealand, which includes FM radio.

The major transmission sites are illustrated in Figure 3-18. 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.

Kordia manages, maintains, and operates the safety of life at sea network for the Maritime Safety Authority of New Zealand. From the Kordia Maritime Operations centre at Avalon, Kordia constantly monitors the internationally designated call and reply distress frequencies in New Zealand's area of responsibility (known as NAVAREA XI) this includes all the coastal waters around New Zealand.

This service also broadcasts Maritime Safety Information including meteorological information and navigational warnings. The coastal broadcast sites have overlapping coverage for redundancy and resiliency investment in the MOC technology allows it to operate and function from anywhere with an internet connection should that be required.

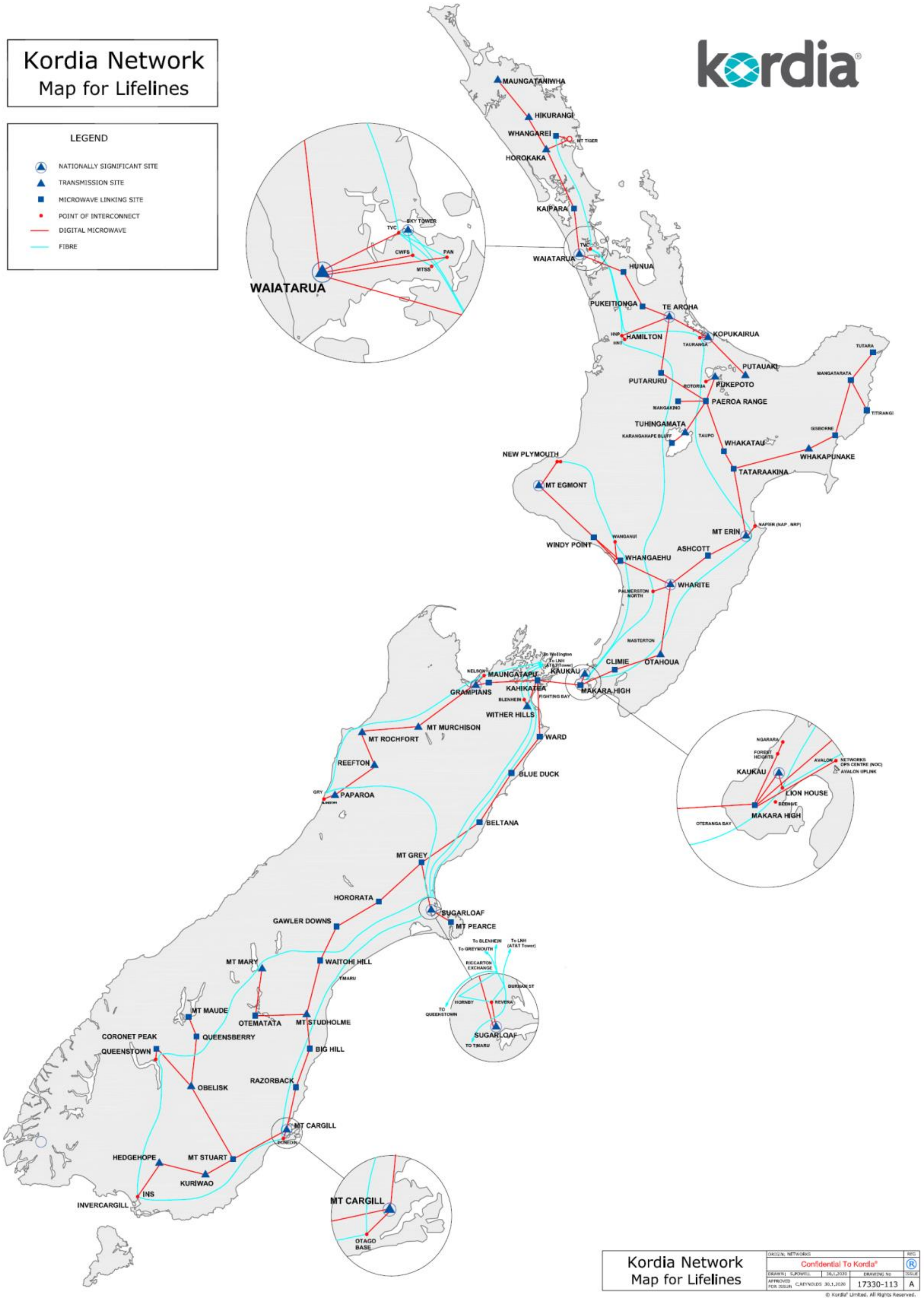


Figure 3-18: Kordia's Transmission Network

Radio

Vital (ex TeamTalk) is the major provider of analogue and digital mobile radio in the country (used for handheld VHF communication devices) and provides services to a number of lifeline utilities and emergency services in the region including Ambulance Services and CDEM communities.

Vital is the amalgamation of two companies that provide critical telecommunications in New Zealand, these former companies being;

1. Citylink New Zealand – a fibre provider in Wellington and Auckland
2. TeamTalk New Zealand – a telecommunications provider specialising in Microwave Radio and Land Mobile Radio Communication through New Zealand.

The fibre assets in Wellington and Auckland, have recently been refreshed and moved from the trolley lines in Wellington to underground. This fibre network is extensively used by Retail Service Providers to provide connectivity to and within Wellington and Auckland. These assets are of national significance as they interconnect and provide network redundancy for significant government agencies, such as Parliamentary Services, the Treasury, Defence, NEMA, MSD, MBIE, Police and Fire. These fibre assets do not use the historical telephone exchanges that are used by Chorus, thus providing their customers a level of redundancy.

The land mobile radio assets are a significant national asset. They have the widest coverage of any telecommunications network and are used by organisations that rely on one to one or one to many communications, within a workplace or region, nationally across New Zealand, outside mobile coverage, or when the mobile networks are congested or fail.

Within our land mobile radio networks, we have several networks that operate, either in a public or private manner, in VHF or UHF, Analogue or Digital Radio in several different digital formats.

These land mobile radio networks are interconnected with fibre and our above ground national digital microwave network. This network allows our land mobile network to operate in national disasters, as they are not reliant on underground fibre networks and reticulated power. Many of our sites are built for our customers to operate for up to 72 hours with-out power/fuel top ups and dual microwave radio installations for robustness.

The land mobile radio networks are accessed by our customers by using a;

- traditional radio telephone in a vehicle
- radio telephone installed in as a base station, for example within a sub-station
- portable handheld radio (normal or intrinsically safe)
- data collection radio devices capturing data from remote locations
- merged device (cellular mobile and land mobile radio telephone)
- PSTN to/from the land mobile radio network
- software applications on devices (IOS/ANDROID) that connect to/from the land mobile network
- console software from call centres to/from land mobile radio telephones

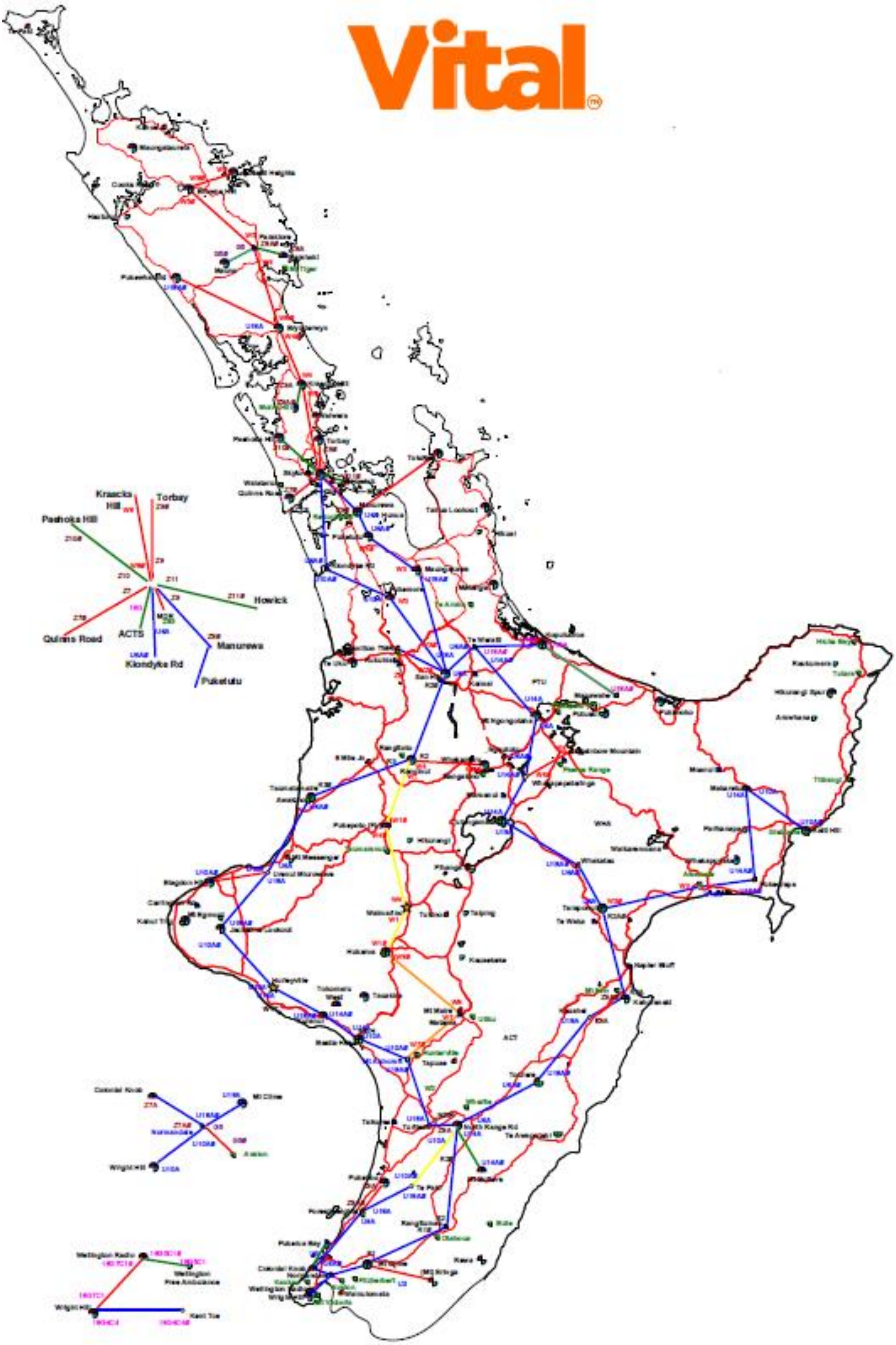


Figure 3-19 North Island land mobile radio network

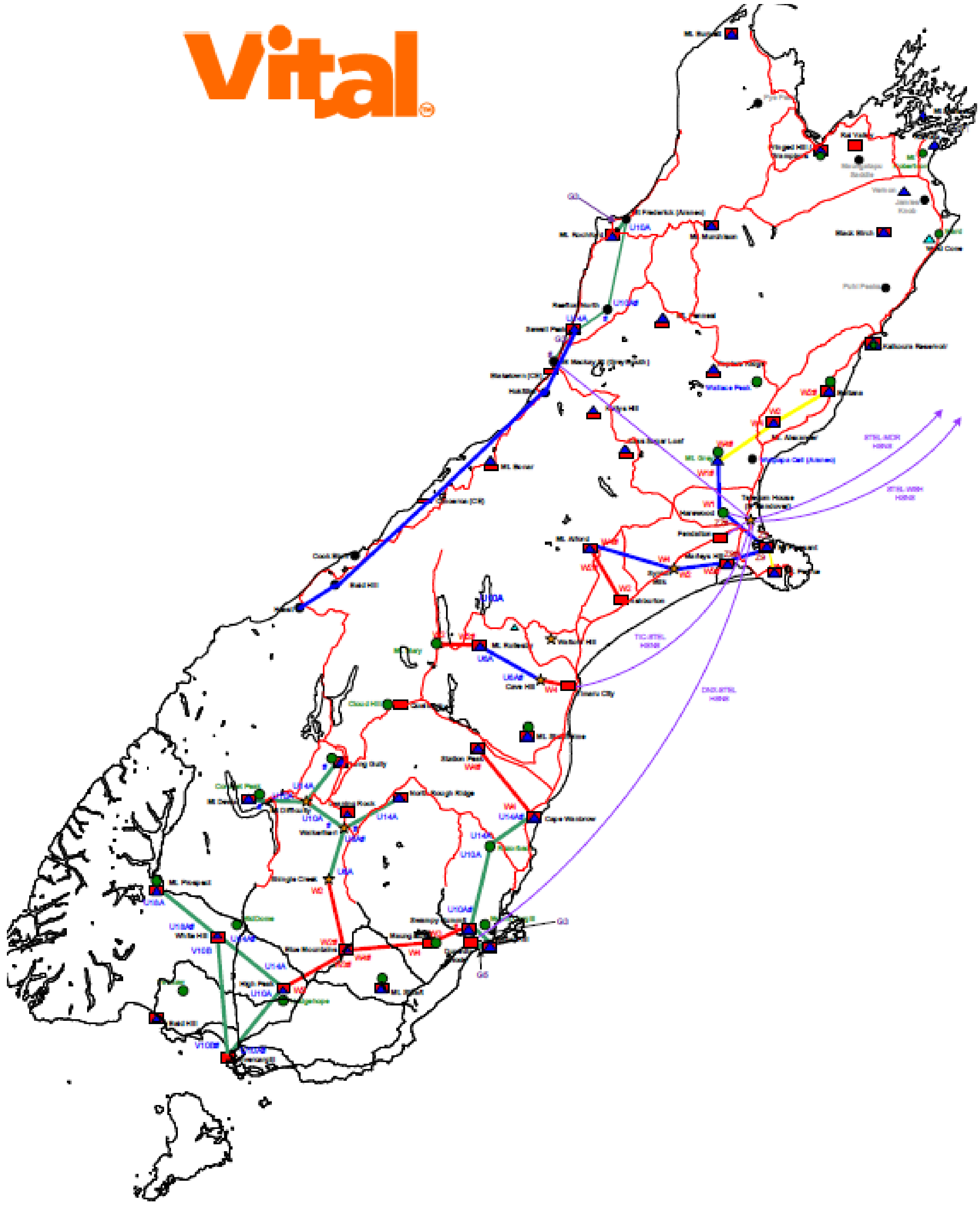


Figure 3-20 - South Island land mobile radio network

The following networks and customer specific deployments are of significant national significance;

1. Ambulance New Zealand – Vital provides the National VHF land mobile radio network and interconnection that St John use for the dispatch of ambulances, patient transfers and air asset deployment.
2. Fire and Emergency – Vital provides the fire radio network for Auckland and Greater Auckland used for the dispatch of fire and rural fire appliances
3. Public National Radio Network – we provide a national public radio network that is used by a significant number of utility companies, power generators, lines companies and nationally critical pipeline companies
4. Dedicated Radio Networks – we provide critical radio assets for several critical companies, for instance Vital has just completed the dedicated Wellington Electricity emergency land mobile radio network
5. Microwave Radio Network – we provide a nationwide microwave network to provide redundancy of fibre cuts, for example we provide the redundant voice network for the Civil Defence at the Beehive.

Vital is also under contract from MBIE and provides IP/Internet connectivity to the Chatham and Pit Islands.

Regulation and Funding

The historical development of the core national 'ladder network' with robust core Exchanges was based on strong resilience principles driven by a Government owned sector (at the time). Today, apart from the CDEM Act, there are no regulatory requirements to maintain resilience of the telecommunications infrastructure and service. The effectiveness of CDEM Act obligations on operators is difficult to measure or enforce for private companies. The Building Code does mandate standards around critical buildings housing telecommunications equipment though design standards for other components of the network are not prescribed (apart from as part of Government funded initiatives such as ultra-fast and rural broadband).

The commercial imperative to keep customers connected is the main driver for resilience investment, and the Christchurch earthquake spurred investment in seismic retrofitting and backup generation.

The New Zealand Telecommunications Forum (TCF) is a pan-industry body fostering cooperation among telecommunications service providers to develop standards and other industry wide solutions for ensuring the efficient supply of telecommunications equipment and services in the long-term interests of consumers. The TCF is recognised by the government as the "Telecommunications Industry Forum" referred to in the Telecommunications Act 2001 as having authority to develop access codes for regulated services.

As with the fuel sector, MBIE maintains oversight of the resilience of the telecommunications network. In 2019, MBIE undertook a collaborative study with the telco sector to investigate telecommunication services vulnerabilities and risks. This confirmed the network vulnerabilities discussed above, along with some other key issues, such as specific communities relying on single fibre transmission lines. MBIE is continuing dialogue with the telecommunications sector as to the appropriate response to identified risks.

Resilience Investment Programmes

The 2019 government review of telecommunication network resilience found the sector focussed on preparedness and response arrangements rather than investment in risk mitigation. However, there are some government-funded resilience improvements such as the 'Blackspots' programme to improve mobile coverage in remote areas and new fibre routes on SH6 and SH 94 providing operational monitoring and route diversity.

3.9 Water

Water supply and wastewater services are fundamental to public health and firefighting. In urban areas, the absence of water and wastewater networks for long periods has the potential to render areas effectively uninhabitable. Three days without water is considered life threatening, hence water supply is typically the highest priority lifeline following a disaster.

Water and wastewater schemes are vulnerable to many natural hazards, as discussed in the box to the right. Electricity outages are another potential vulnerability, electricity being required for treatment and pumping processes. Larger and more critical sites tend to have on-site backup generation, or at least 'plug-in' generation capability. Water and wastewater systems are increasingly managed through automated computerised systems and many pumps and machinery can be operated remotely through the internet or telemetry. This technology is dependent on electrical, telecommunications and internet integrity. Failure of these systems or malicious interference through cyber-attack is yet another hazard for water authorities.

Water Supply

Potable water supplies are vulnerable to both water quantity and quality disruptions. In fact, most of the significant incidents in the last decade relate to water contamination issues, including the 2016 Havelock North and 2017 Dunedin, and Auckland Hunua supply issues following heavy rain in the catchment causing high water turbidity, illustrated below.

The Havelock North incident, which caused thousands of illnesses, hundreds of hospitalisations and (an estimated) four deaths, led to a government water review discussed later.

Currently (early 2020) an extended drought is threatening water supply to numerous urban areas in the North Island.

Water Network Resilience Challenges

Climate change patterns mean that droughts are increasingly becoming an issue for water supplies and investment in more drought-secure sources and increased seasonal storage will be needed in coming years.

Water supply and wastewater distribution networks are highly vulnerable to seismic events, as evidenced in the long recovery times from the Christchurch earthquake.

The older pipes in NZ's water and wastewater reticulations commonly include materials that may be considered brittle such as asbestos cement and earthenware pipes. These materials performed poorly during ground shaking and deformation during the Christchurch and Kaikōura earthquakes, associated with the effects of liquefaction and lateral spread. More modern materials such as PVC and polyethylene performed better but were still vulnerable to major ground movements particularly at connection points to structures such as manholes and pump stations.

Local authorities are systematically replacing the older pipes with the more resilient, ductile pipes through their renewal programmes. However, progress will be slow as there is a considerable legacy of old materials and other competing demands for infrastructure investment. Adoption of good asset management practice is helping to prioritise the most critical and vulnerable pipes (refer Case Study *Waimakariri District Council)*.

Cyclonic heavy rainfall / wind events are another challenge for the sector – many water sources are in slip prone catchments with erodible soils. Heavy sediment loads associated with floods cause regular issues for some water supplies.

Other major natural hazard risks include tsunami (many wastewater treatment plants and some water supply plants are on the coast) and volcanic ash – which can impact treatment quality.

A brief discussion on the water supply for the four largest cities follows. Other than key assets in these cities, another notable 'nationally significant' water supply scheme is owned by Whangarei District Council which supplies water critical for Marsden Refinery operations.

Outside the metropolitan areas, schemes are typically locally sourced supplies to individual towns (or several towns in proximity). It is not uncommon for a scheme to rely on a single water source and therefore that site, the trunk mains, and reservoir that connect the source into the reticulation, become highly critical.

Auckland

Auckland's water supply is supplied from the Hunua (around 60%), Waitakere Dams (around 25%) and Waikato River (around 10%). Future regional growth and security will be met by development of the Waikato source and upgrades to existing treatment plants (there is around $5B in Watercare's asset management plan for renewals, growth and resilience projects).

There are a number of assets rated as 'nationally significant' which have the potential for major impacts on Auckland's water supply.

Failure of the major Hunua sources and/or Ardmore treatment plant for longer than 24 hours would cause major service disruption and restrictions. There are multiple hazards that could impact the operation of these sites, most recently experienced in early 2017 following upstream slips in the Hunuas highlighting catchment protection and activity risks.

Auckland's most critical main 'Hunua 3' brings water from the Hunuas into the central Auckland. There has been a significant investment in a new main which follows a different route 'Hunua 4' and now provides redundancy for Hunua 3.

Government Water Review

The Government Inquiry into the Havelock North water supply contamination raised broad questions about the effectiveness of the regulatory regime for the three waters (potable, wastewater & stormwater), and the capability and sustainability of water service providers.

Since 2017, a cross-government water sector review has been underway. In 2019, the Water Services Regulator Bill was introduced to Parliament to establish a new regulatory body to administer and enforce a new drinking water regulatory system (alongside some complementary functions to improve the environmental performance of wastewater and stormwater networks).

The Three Waters Review Team has also been considering responses to the wider affordability and capability challenges facing the three waters sector. This includes supporting councils to investigate collaborative approaches to water service delivery. The Review Team continues to investigate high-level options for service delivery in the longer term.

Source: https://www.dia.govt.nz/Three-waters-review

Wellington

Wellington is supplied from sources on the outskirts of the City and transmitted by trunk mains – around 20% from dams in Te Marua, 50% from the Hutt Aquifer and 30% from Wainuiomata. In Wellington, these mains pass through high-risk fault areas and previous studies have shown that a major Wellington Fault quake could cause damage taking up to three months for restoration of bulk supplies to parts of the City. Wellington Water have already done significant work to reduce the restoration time and further projects are planned, including looking at alternative water sources and containerised water treatment plants in potentially isolated areas.

Christchurch

Christchurch's water supply is more resilient than Auckland and Wellington in terms of having multiple bore sources (providing redundancy from each other) from deep, well protected aquifers. However, the supply is not treated and is more vulnerable to contamination, as occurred in the Canterbury earthquakes. Those parts of the network damaged in the earthquakes have been replaced with more resilient materials and design standards (work is ongoing in this respect).

Hamilton

Hamilton's water supply comes from a single abstraction point on the Waikato River. The risk associated with failure of the single supply point is mitigated by a deployable pumping platform for abstraction and a multi barrier treatment process to ensure source water can be treated at most levels of contamination. The treatment infrastructure allows for redundancy to ensure ongoing resilience of the treatment processes. Multiple reservoirs and a ring main provide resilience if any part of the reticulation is damaged.

Wastewater, Drainage, Flood Protection and Solid Waste

Limited information has been collected on these assets and services for this assessment. This will be expanded in future updates.

Some brief commentary includes:

Wastewater

Wastewater services are highly dependent on electricity services and there is limited backup generation at sites (only around 10% have on-site backup generators).

In terms of 'nationally significant' assets, the largest wastewater asset in New Zealand is the Mangere Wastewater Treatment Plant, which services the western, southern and central Auckland areas and there are many critical interceptor mains bringing wastewater to the plant (a major upgrade will provide redundancy for these).

Land Drainage and Stormwater

Stormwater networks are considered a lifeline utility under the CDEM Act 2002. Regional lifelines projects have not at this stage identified any specific 'nationally significant' stormwater infrastructure though attention is certainly given to it at a regional and local level.

Flood Protection

Again, these assets are managed locally and regionally, however there has been a national study to collate stopbank data, in part to lead to a nationally consistent approach to flood protection.

Climate change will be a significant issue in this sector, as flood intensities and frequencies continue to increase. For example, a stopbank that was originally designed to protect against a 1:50 year flood will over time find this protection level reduced.

Solid Waste

Solid waste services are highly road dependent, to enable collection and distribution to transfer stations and landfills. A key issue for the sector is managing large volumes of waste arising from natural hazards – including ash from urban areas in a major volcanic eruption and debris in an earthquake or tsunami.

Key Learnings from NZ Studies

AF8 / Alpine Fault

- Damage to 3-waters networks througout the South Island, with West Coast and Queenstown hardest hit in the AF8 scenario earthquake (months to years restoration).

Wellington Quake (Wellington Lifelines Group)

- Reticulated supply unavailable for weeks to months for most areas.
- The Business Case identified nine projects to mitigate impacts, total value circa $1.3B.
- The Community Infrastructure Resilience project will provide backup water to suburbs in a major outage. (Value circa $16m.)

Hikurangi Subduction Zone

- Impacts potentially similar to above for Wellington / lower north Island, plus extensive damage to schemes in Hawkes Bay / Gisborne (weeks to months restoration).

DEVORA/Auckland Lifelines Group

- Most of Auckland's water is from large, open impoundment dams and river abstraction. Ash causes treatment and other water quality issues. Restoration of treatment and transmission systems damaged by ash or eruption could take months or years.
- There would be increased demand for water for cleaning ash and further impacts from electricity / fuel disruption.
- Wastewater treatment plant processes can be disrupted, and equipment damaged. Also ash ingress into wastewater networks (particularly in combined systems).

Mt Taranaki (Taranaki Lifelines Group)

- Ash likely to impact water source and treatment plant operation, potentially across the whole region. Ash will also impact wastewater plant – air blowers, etc., and can cause major damage.
- Lahars will potentially damage or destroy the Inglewood water and wastewater facilities even in the small eruption scenario, cause major damage to the New Plymouth scheme in a large eruption.

Climate Change

- Coastal wastewater treatment plants and stormwater outlets will be impacted by sea level rise.
- Inreasing drought conditions will impact many NZ water supplies.

Regulation and Funding

New Zealand's public water supply and wastewater and stormwater networks are managed by local authorities or entities under their jurisdiction.

The sector is complex in that there is no national provider and there are many parties involved in the provision of water services and responding to disruptions, such as local government, Ministry of Health and NEMA. Response roles are not always well understood by the wider sector.

Water Supply is regulated through the NZ Drinking Water Standards which include requirements for water quality and reliability though do not explicitly require minimum emergency response standards.

Wastewater standards are imposed by Regional Councils through consent conditions for discharges (including overflows, though very few authorities have consents for these yet).

Stormwater standards for the whole network are not generally mandated, however primary systems are usually designed to pass a 1:10 year rainfall event and secondary systems (overland flow paths, detention areas) a 1:100 year event. The Building Act requires new houses and habitable buildings to be designed with the floor level above the 50-year ARI event. It also requires the 10-year ARI event not to cause nuisance to other properties. Urban stormwater systems need to be designed and managed to meet this requirement. These design standards are often at odds with planning for other hazard types which specify standards for much lower frequency events. Decisions on funding and levels of resilience are made by local authorities or their governing boards.

Other general regulation and funding constraints for lifelines are discussed in Section 6.

Resilience Investment Programmes

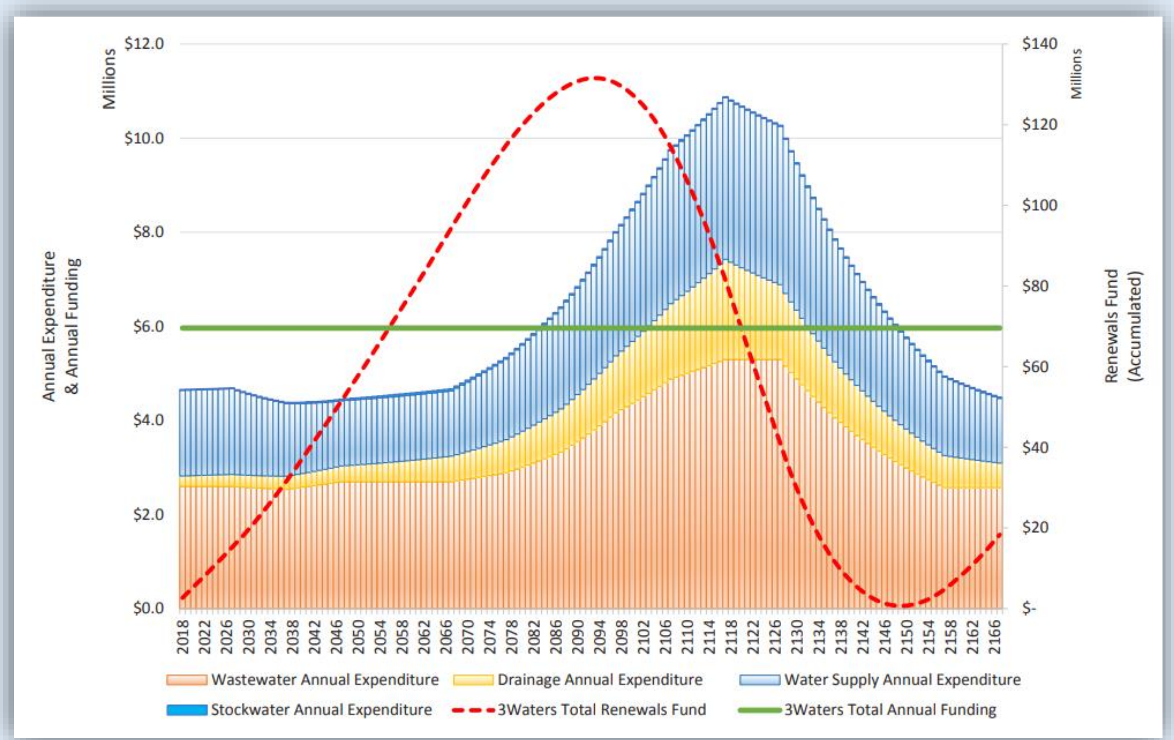
With the large number of water authorities in the country, it was not possible to gain a national picture of planned resilience investment for this report. The Wellington Lifelines Programme Business Case stands out as an example of a costed risk programme to mitigate against earthquake (and other) hazards. However, there are other excellent examples of local authorities approaches to building network resilience – an example is presented in the following case study.

Case Study: Waimakariri District Council, Prioritising Renewals to Build Resilience

The Waimakariri District was significantly impacted by the Canterbury Earthquake sequence and, ten years on, is still in a regeneration phase. It is looking long into the future for opportunities to gradually build infrastructure resilience.

The three-waters network is relatively young and expected renewal investment peaks are decades away (refer first figure below). However, in taking a risk-based approach to the renewals programme, asset criticality and vulnerability are being used to bring forward renewals of these assets and improve the resilience of the networks in a prioritised way.

The second and third figures below illustrate examples of criticality and vulnerability factors which are applied to asset lives.



Utility	Water Supply Reticulation		Wastewater Reticulation	
Criticality Rating	Early Asset Renewal Date	Late Asset Renewal Date	Early Asset Renewal Date	Late Asset Renewal Date
AA	70%	85%	80%	100%
A	80%	95%	85%	105%
B	90%	110%	90%	110%
C	95%	120%	95%	120%

			Earthquake Vulnerbility		
		Likelihood	Low	Medium	High
		Description	Brittle Pipe (ie AC and Earthenware) in Low Liquefaction prone zone. Plus all Ductile and modern pipe materials.	Brittle Pipe (ie AC and Earthenware) in Medium Liquefaction prone zone. Does not include modern pipe materials.	Brittle Pipe (ie AC and Earthenware) in High Liquefaction prone zone. Does not include modern pipe materials.
	Criticality Rating	Consequence			
Consequence	AA	High	Default	0.85	0.75
	A				
	B	Low	Default	Default	0.95
	C				

4. Lifelines Interdependencies

Section 4 provides information on:

- The interdependencies between the lifeline utility networks, that is, the extent to which each utility relies on other utilities in order to function and provide a service.
- Other 'critical customers' to lifeline utilities and the extent to which they depend on lifeline utility services.
- National infrastructure hotspots, where critical infrastructure assets are co-located, increasing the risks of a damaging event at a single site.

4.1 Lifelines Sector Interdependence

Figure 4-1 and Figure 4-2 summarise interdependencies between lifelines sectors during business-as-usual and major disaster events where disruption is expected to roads and electricity networks.

The ratings presented are indicative only – obviously, the extent of dependence in a response and recovery situation will depend on the specific scenario and there is some variation by region. The total interdependency scores illustrate the importance of electricity, roads, fuel and telecommunications to the other sectors, with air transport, VHF and broadcasting becoming more important in a major disaster event.

Key
3: Required for Service to Function,
2: Important but can partially function and/or has full backup,
1: Minimal requirement for service to function.

The degree to which the utilities listed to the right are dependent on the utilities listed below	Roads	Rail	Sea Transport	Air Transport	Water Supply	Wastewater	Stormwater	Electricity	Gas	Fuel Supply	Broadcasting	VHF Radio	Telecomms	**Total Dependency**
Electricity	2	2	3	3	3	3	2		2	2	3	3	3	**31**
Roads		3	3	3	2	2	2	2	2	3	2	2	2	**28**
Fuel	2	3	3	3	2	2	2	2	2		2	2	2	**27**
Tele-comms	2	2	2	2	2	2	2	2	2	2	2	3		**25**
Water Supply	1	1	1	2		3	1	1	1	1	1	1	2	**16**
VHF Radio	2	2	2	2	1	1	1	1	1	1	1		1	**16**
Stormwater	2	1	1	2	1	1		1	1	1	1	1	1	**14**
Wastewater	1	1	1	2	1		1	1	1	1	1	1	1	**13**
Rail	1		1	1	1	1	1	1	1	1	1	1	1	**12**
Sea Transport	1	1		1	1	1	1	1	1	1	1	1	1	**12**
Air Transport	1	1	1		1	1	1	1	1	1	1	1	1	**12**
Gas	1	1	1	1	1	1	1	2		1	1	1	1	**13**
Broadcasting	1	1	1	1	1	1	1	1	1	1		1	1	**12**

Figure 4-1: Interdependency Matrix – Business As Usual

The degree to which the utilities listed to the right are dependent on the utilities listed below	Roads	Rail	Sea Transport	Air Transport	Water Supply	Wastewater	Stormwater	Electricity	Gas	Fuel Supply	Broadcasting	VHF Radio	Telecomms	**Total Dependency**
Fuel	3	3	3	3	3	3	3	3	3		3	3	3	**36**
Roads		3	3	3	3	3	3	3	3	3	2	2	3	**34**
Tele-comms	3	2	2	2	3	3	3	3	3	2	2	3		**31**
Electricity	2	2	3	3	3	3	2		2	2	3	3	3	**31**
VHF Radio	2	2	3	3	2	2	2	2	2	2	2		2	**26**
Broadcasting	2	2	2	2	2	2	2	2	2	2		2	2	**24**
Air Transport	2	1	1		2	2	2	2	2	2	2	2	2	**22**
Water Supply	1	1	1	2		3	1	1	1	1	1	1	2	**16**
Stormwater	2	1	1	2	1	1		1	1	1	1	1	1	**14**
Wastewater	1	1	1	2	1		1	1	1	1	1	1	1	**13**
Rail	1		1	1	1	1	1	1	1	1	1	1	1	**12**
Sea Transport	1	1		1	1	1	1	2	1	1	1	1	1	**13**
Gas	1	1	1	1	1	1	1	1		1	1	1	1	**12**

Figure 4-2: Interdependency Matrix – During / Post Disaster Event

Dependence on Electricity

During normal operations, electricity is required to operate most of the other lifeline utilities to some degree and, because of this dependence, typically utilities have backup generation at their most critical sites. However, a widespread regional electricity outage would, after varying periods of time, still impact on telecommunications, water supply, wastewater, gas, fuel supply and traffic management services.

Dependence on Telecommunications

A major telecommunications failure will impact the business sector and wider community and impede the efficiency of utility businesses. Almost all businesses rely on telecommunications to operate and to receive payments. However, most utilities could continue core services without telecommunications in the short term. Impacts on control systems would mean that some utilities would need to revert to manual operation and monitoring of facilities and response to service requests could be impaired. As technology enables more complex operations arrangements, the service impacts of reverting to manual operation may be significant.

The situation changes in an emergency because telecommunications become critical for coordinating response and recovery efforts. The cellular network may become overloaded during or shortly after an event. However, the copper, fibre, and wireless infrastructure (including cellular) provides diversity. Most utilities use a combination of the above technologies and some have their own dedicated network of links and radio.

Dependence on Broadcasting

Broadcasting is not generally considered a critical supply to other utilities during business as usual. However, in a response situation, particularly where other telecommunications are impacted, broadcasting is a means of communicating public information such as road disruptions, public water supply warnings and advising of fuel shortages.

Dependence on Roads

The road network is important for all utilities to operate, particularly for sea/air/rail networks which are connected by road and for fuel distribution. Road failures during business-as-usual may affect response to service requests and asset failures. In an emergency, staff need to be able to access facilities and diesel and plant needs to be transported to reinstate services.

The Interdependent Lifelines Sector

In 2006 an outage on the Transpower Otahuhu substation caused widespread loss of electricity service across Auckland and resulted in several other lifelines sector failures, even though supply was largely restored within 12 hours. Investments in electricity transmission and distribution networks have substantially reduced this particular vulnerability, however, the event remains a useful example of the interdependencies in the lifelines networks with the following results.

- Approximately 20 sewerage pump stations overflowed at some stage.
- Most petrol stations in affected areas were unable to pump petrol.
- There was road congestion, mainly due to traffic light failures, which in turn impacted on other utility's ability to get generators to wastewater pump stations.
- All organisations reported difficulty making connections on both landlines and cell phones. Many offices had PABX failures and could not be contacted. The failure of PABX caused many people to revert to cell phones, causing overloading of that network. Some small areas, served by small cell sites without battery backup, lost cell phone service completely.
- The primary impact on train services was due to disruption at Britomart (which has only limited electricity backup on site) due to local signalling being off and station services including fume ventilation fans being off. *The subsequent electrification of the rail network is likely to have exacerbated impacts.*
- There was total plant-site shutdown at Wynyard Wharf, however the Wiri fuel depot was active so there was no need to load vehicles manually with diesel trailer pumps. Chemical and bitumen vehicles were also stranded.
- Some utilities, along with the wider business community, felt an impact in terms of loss of productive office time (those without backup generators / batteries on site).

Dependence on Air Transport

Air services also become important to other lifelines in a major disaster; to assess damage, bring in responders, equipment and spares and access sites when there is significant road disruption. It may be the only source for critical supplies in the early days of an event where roads are heavily disrupted and can be critical for evacuations.

Dependence on Sea Transport

The fuel sector is reliant on shipping for distribution of fuel, though most other sectors do not have a major dependency on sea transport during BAU operations. In a major disaster, some regions may be heavily dependent on sea transport for provision of emergency supplies (for example, Wellington and West Coast of the South Island) or evacuation of people.

Dependence on Water Supply and Wastewater

Water supply and wastewater services are critical for the community, both for public health and firefighting purposes, as well as some dependence on these services by other lifelines. For example:

- Fuel terminals require a high capacity water supply (or alternative firefighting capability).
- Building services require water and wastewater for health reasons, though alternative arrangements can be made such as re-location or using bottled water supplies and temporary wastewater facilities.
- Water supply is required for air-conditioning and plant cooling operations in some sectors.
- Air transport requires water supply at the airport (for passenger services for commercial flights), and telecommunications requires water for equipment cooling.
- Natural gas electricity generators require high quality water for cooling and compression.

Dependence on Petroleum

All utilities have some dependence on fuel for plant and vehicles for service personnel. If electricity is affected, diesel supply to critical sites to operate backup generators becomes more important. Even those sites with on-site diesel storage typically only hold a few days' supply. Refuelling of generators deployed to other critical facilities is likely to become a significant logistical issue.

Dependence on Gas

Lifelines networks are not generally reliant on gas for network operation, with the exception of gas-powered electricity generators and Marsden Refinery (it can function without a gas supply but may not meet consent conditions).

4.2 Critical Customers' Dependence on Lifelines

Lifeline utility services are important for the functioning of critical community services such as health and emergency services. These facilities and service providers maintain business continuity arrangements for backup services based on their own risk assessments and commercial imperatives.

There is currently no national view on the extent to which these critical community sectors have alternative arrangements (such as radio/satellite or on-site backup generation). As part of regional lifelines studies, each region identifies what they see to be critically important sites for their community. This information then informs each lifelines criticality analysis in that an asset that services a critical site (such as a hospital) that depends on them, also becomes critical.

A brief overview of 'critical customer' sectors and dependence on lifelines services is provided below. It is not complete, and as with all components of this report, mainly draws on existing documented information. Further analysis and engagement with these sectors will be carried out in future updates of this report.

The criticality of sites within these sectors can be rated using the criticality approach included in Section 1, and 'nationally significant' sites are identified in the discussion below.

Emergency Services

Emergency services (Police, Fire and Ambulance) are reliant on all lifelines to operate, including telecommunications, fuel, water (potable and wastewater), electricity, and transport (road) access. Emergency services have business continuity arrangements in place with generators at main depots and the ability to operate from vehicles and alternate depot sites. However, if multiple sites are affected by a lifelines service disruption e.g., a regional telecommunications outage; or if a lifelines service is disrupted for a significant period e.g., a fuel supply issue, emergency response could be impacted.

Health Services

Hospitals are also reliant on all lifeline utility services, including electricity, water (potable and waste), telecommunications, transport, fuel, and gas. Hospitals have a range of business continuity plans in place including back up generation and stored water, however this is generally only sufficient to maintain essential operations for a few days before resupply would be required.

A number of issues have been highlighted during regional lifelines projects in relation to the level of backup arrangements in place, common issues include:

- On-site water storage may not be potable if it isn't properly managed.
- Fuel stored for electricity generators is, in many instances, only sufficient for 2-3 days' operation (there are exceptions).
- Medically dependent customers may have partial or complete reliance on electricity to run medical equipment for dialysis, respirators, etc.

Critical health care services are also delivered from hospital campuses or by non-hospital providers. These include but are not exclusive to, primary care (general practice and pharmacies), public heath, dialysis centres, aged residential care facilities, and disability support services. Many of these services must also be considered critical customers both due to the services they provide and the fact that if they are inoperable hospitals would not have the capacity and capability to look after their patients.

Hospital and health services also depend on suppliers that are themselves dependent on lifelines services (e.g., food and linen suppliers reliant on gas supply).

Government

Government agencies are required to have and maintain business continuity arrangements. These arrangements are required to enable agencies to continue to deliver their critical functions in a disruption.

Business continuity arrangements may include staff working from home, fail over to alternate sites or working from existing facilities with emergency generation.

Delivery of some of these arraignments requires access to lifelines e.g., water (potable and waste) or telecommunications; some may require access to continued fuel supply for generators.

Fast Moving Consumer Goods (Food and Grocery)

The Fast-Moving Consumer Goods (FMCG) sector references groceries, many of which have a short shelf life. The major food depots are in Christchurch, Palmerston North, and Auckland. These sites are nationally significant.

Most of the country's food comes from, or passes through, Auckland. The sector is heavily dependent on roads and rail for the movement of goods. In Wellington the potential to be isolated from the main supply chain in Palmerston North is a noted vulnerability for the region.

Banking

The headquarters of the major banks are in Auckland and are rated as nationally significant. Banking services depend on electricity supply and telecommunications to operate and enable financial transactions.

Corrections Facilities

Prison facilities rely on lifeline utilities to function. They have business continuity plans in place for loss of this supply including limited (days) self-sufficiency for electricity and water. Prisons are dependent on roads and telecommunications to implement their business continuity plans i.e. re-supply for fuel, water, food and medical. They also have a dependency on wastewater services, which is critical from a Public Heath perspective.

Community Corrections have dependencies on telecommunications and roading to operate. Main sites also require water and electricity to support community corrections operations.

Solid Waste

Solid waste management services include collection from households and other sites, transfer and sorting (typically at refuse transfer stations) and disposal of non-recyclable / useable waste to landfill. Most transfer stations and landfills rely on electricity and fuel powered plant and equipment. Road access is critical, particularly following an event with major debris (from built infrastructure damage or from the hazard itself, such as volcanic ash).

Major Industry

Many lifelines projects consider major industry as critical community sites as well, Examples include freezing works, dairy processing sites and major construction depots.

4.3 Infrastructure Hotspots

Infrastructure interdependence increases the overall risk and consequence of a potential failure of a single infrastructure type. **Co-location** of critical infrastructure assets also increases the risks of a damaging event at a single site, both in terms of the direct impact of a number of critical assets simultaneously failing (e.g., a major landslide) and in terms of the potential hazards that some assets pose to others (major water main failure could wash away other assets in the area). These areas have been termed 'hotspots - where a number of critical infrastructure assets from different sectors converge in a single area.

Major hotspots identified in regional vulnerability studies include:

- Petone / Seaview Critical Areas – includes fuel offloading / fuel storage for Wellington plus regionally significant assets for water, gas, electricity, wastewater, and telecommunications, and is exposed to sea level rise.
- Thorndon Critical Area – several critical utilities within a narrow corridor traversing the Wellington Fault with much in liquefaction-prone reclaimed land.
- SH 6 Kawarau Gorge – primary road access and electricity transmission lines to Queenstown, along with one of the major South Island telecommunications fibre links – prone to alluvial activity, rock fall and landslides. The alternate Chorus transmission cable runs up SH73 and across the Alpine Fault
- Auckland Harbour Bridge is a major road pinchpoint. It also carries a number of critical utility pipes/cables and is exposed to coastal flooding at the northern approaches.
- Central Plateau (a hub of electricity generation and transmission and highways in a volcanic risk area).
- SH20 near Mangere Bridge – the Marsden-Wiri fuel line, electricity main transmission lines north and a large wastewater interceptor are all in the area.
- Low lying South Dunedin area contains a number of critical utility sites for Dunedin (Dunedin exchange, Tahuna wastewater treatment plant, etc).
- The Cook Strait – a major transport route (ferry) and carries transmission cables for electricity and telecommunications between the islands.
- The Lyttelton Tunnel.
- Kaikōura Coast – state highway, railway, core telecommunications cables.

Nevis Bluff, SH 6 Kawarau Gorge

5. Infrastructure Vulnerability to Hazards

Section 5 presents an overview of major hazards to New Zealand's infrastructure, including earthquakes, volcanoes, tsunami, severe weather and climate change, pandemic, fire, and more. For each of these hazards, the hazard context is summarised along with an assessment of impacts to lifelines infrastructure arising from that hazard.

5.1 New Zealand's Hazardscape

New Zealand is on the collision zone between the Pacific and Australian plates, creating an interesting geological hazardscape.

Earthquakes receive a lot of attention as the most potentially destructive hazard, but floods cause more frequent problems and tsunami threats are very real.

The Hikurangi subduction zone, parallel to the east coast of the North Island, is emerging as potentially one of our highest natural hazard risks and is the focus of a major research project.

Furthermore, impacts from 'super-eruptions' in the central North Island, or even just long periods of volcanic unrest, have the potential to have even higher impacts than major earthquakes.

Regional lifelines projects commonly use regional council hazards data and CDEM Plans as a source of information. A summary of hazard risk ratings from CDEM Plans is presented in Table 5-1 (the most current as at March 2017). While different approaches have been used, and the results aren't intended for cross-regional comparison, the table illustrates the diverse hazardscape across the country. While the major natural hazards feature predominantly across all Plans, other hazards such as human pandemic are also rated highly in some regions.

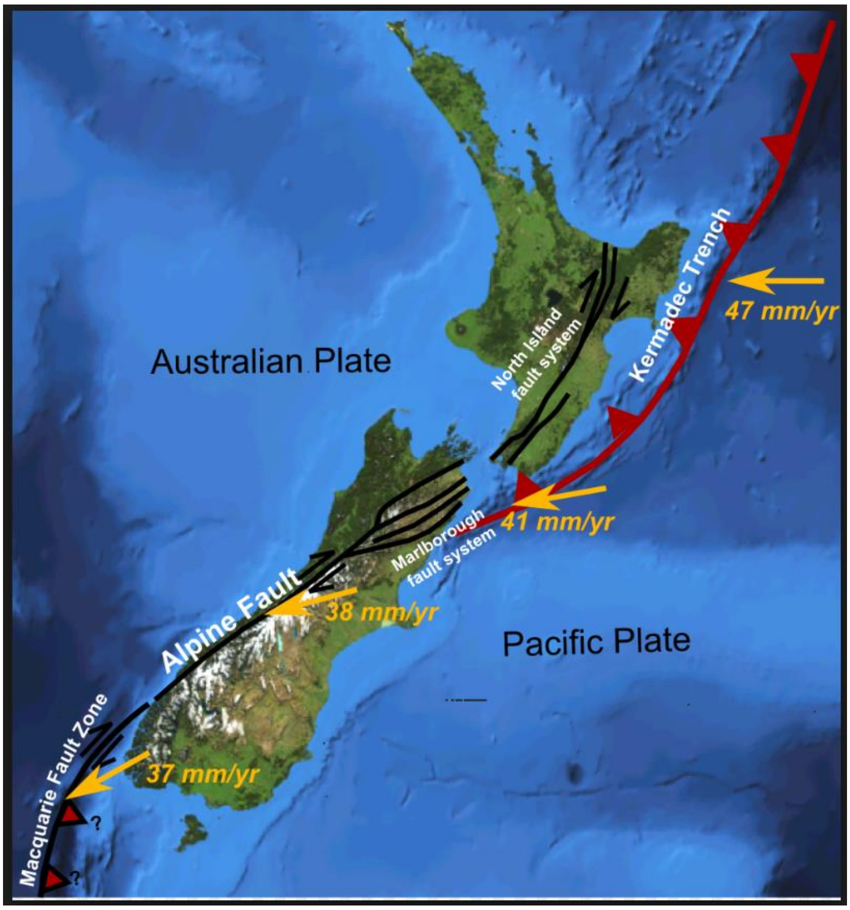


Figure 5-1: Major faults and tectonic plates in New Zealand

Table 5-1: Regional Hazard Risk Ratings (sourced from the regional CDEM Plans available online March 2017)

Key E: Extreme. VH: Very High. H: High. (lower rating hazards not shown)

Note: Ratings have been developed by regional CDEM Groups using NEMA Guidelines for CDEM Plans. Different scales have been used and the table is intended to represent risk priorities within regions, not for cross-regional comparison.

	Earthquake	**Volcano**	**Tsunami**	**Severe Storm / Flood**	**Infrastructure Failure**[5]	**Drought/Extreme Temp**	**Animal Pandemic**	**Human Pandemic**	**Rural Fire**	**Transport Accident**	**Other**
Northland			H	VH	H			H			
Auckland	H	H	H	VH	H			VH	H	H	Coastal erosion, hazardous spill, land instability, urban fire.
Waikato	H	VH	VH	H	H	VH	VH	VH			Marine Spill Land Instability
Bay of Plenty	H	H Local	H	H/M	M	H	H	H		H	Dam Failure, Storm surge
Gisborne					H	H	H	VH	H	H	Criminal
Hawkes Bay	'top 10'	'top 10'	'top 10'	'top 10'	'top 10'		'top 10'	'top 10'	'top 10'		Multiple urban fire Hazardous Substance
Taranaki	3	1	8	10	15	13	5	2	29	20	
Manawatu-Wanganui	VH	H	VH	VH	H	VH	VH	VH	H	H	Landslide, HAZMAT
Wellington	VH	H	VH	VH	VH			E			Landslide, Urban Fire
Marlborough	E		H	E	H	E	VH	VH	VH	VHV H	Pests and diseases, Malicious act Urban Fire, Hazardous Substance, Dam break, Landslide, Liquefaction, Coastal erosion
Nelson-Tasman	VH		H	H				H	H		
West Coast	1st		4th	3rd Flood 5th Storm	9th		7th	2nd	10th	8th	*Risk rating not listed – SMG results used to prioritise* *6th - Tornado*
Canterbury	VH		VH	H				VH			
Otago	Different process used which provides risk 'perception' this process groups all natural hazards in one line item https://www.otagocdem.govt.nz/media/1200/2017-risk-register-version-4-under-review.pdf										
Southland	E		E	VH	VH	VH	VH				Snow, frost

[5] Where sector-specific failures were identified, electricity was most commonly referenced.

There are several features of hazards that make them challenging to understand.

The ***composite, cascading, cumulative*** nature of hazards is not always well understood. The focus is often on direct impacts such as tsunami wave damage and landslips, not necessarily the cascading impacts such as increased flooding risk arising from ground movement (as occurred in the 2011 Christchurch earthquake). The 2011 Great Japan EQ was widely known for tsunami and associated loss of life, yet this wave only caused one third of the recorded damage - the rest being from widespread shaking.

An example of cumulative impacts is when a light rain accompanies volcanic ashfall increasing 'flashover' risks on electrical systems.

Long-term cumulative impacts will occur with climate change and sea-level rise, with eventual permanent loss of function e.g., low-lying coastal areas.

There is **a limited hazard event history** within our living memory and the low frequency events are not all well understood. There is limited understanding of some medium-term volcanic events as the geological records are relatively thin and have not been preserved in the geological record.

Availability of national hazard data. For some hazards there are national datasets such as 'active faults', earthquakes (GeoNet), tsunami and soil types. For others, hazard information has been developed at a regional or local scale and not always on a consistent basis. The challenge is often how to transfer raw data into usable form / product for studies such as lifelines projects.

Damage impacts cannot be accurately predicted. There are a huge range of contributing factors and damage / loss assessments at best can be only expected to provide a broad-brush estimate. For example, many earthquakes in recent times internationally have happened in areas not necessarily rated as having a high seismic risk.

Different hazard types are often assessed on different hazard levels, making it difficult to compare hazard risks. For various reasons, floods are typically analysed for much higher frequency events (1:100 yr) than tsunami or earthquake (1:500 or 1:2500 years). Climate change and particularly sea-level rise will shift the frequency of weather-related events (e.g., a 1:100 yr coastal flooding event will become a 1:1 yr event with only modest rises in sea-level of 30-40 cm).

The following sections summarise information on the 'big 4' natural hazards that are most commonly the focus of regional lifelines studies.

Climate change was dealt with as an exacerbator of other hazards in the first (2017) edition of this report but, as a significant cross-cutting issue, it warrants its own section (Section 5.6) in this edition.

Other hazards that are starting to receive more attention include technological failures arising from space weather, cyber-attack or other causes (Section 4.7). Risks associated with urban encroachment on areas where significant lifelines infrastructure is built are also being given consideration by lifeline utilities.

5.2 Earthquake

The Hazard

The Alpine Fault, the Wellington Fault and Hikurangi Subduction Zone are three major fault areas that are the focus of major research programmes presented in case studies in this Section.

The Alpine Fault runs for some 400 km through the South Island and the Wellington Fault intersects the capital city. The Hikurangi Subduction Zone has an associated high risk of generating a tsunami.

However, there are numerous other active faults and many unknown faults both on and offshore. In recent history, the largest magnitude earthquake was on the Wairarapa fault line in 1855, killing nine people and generating New Zealand's largest recorded tsunami.

Knowledge of Hazard

NZ's major earthquake faults have been well researched and there are several national earthquake risk datasets available (most are managed by GNS Science):

The **NZ Earthquake Catalogue** is a list of known events compiled from oral and written history, and since the 1930s, from instrument readings (GeoNet).

Figure 5-2: Active Fault Database (GNS)

New Zealand's major known faults are mapped in the **Active Faults Database**. While this dataset is common internationally, it is limited in its usefulness due to the inconsistent nature of how earthquake magnitude has been historically recorded. This can be remedied but requires investment.

The **National Seismic Hazard Model** provides probabilistic estimates of the strength of earthquake shaking that can be expected according to a user-defined time period and probability. This model is currently 20 years out of date and does not reflect the current understanding of the likely hazard in parts of NZ. MBIE have recently begun a programme to update this model but it will take 2-3 years and then will require translation into building code settings.

An initiative spurned out of the Canterbury earthquakes is the **NZ Geotechnical Database** which aims to collect and make available geotechnical investigations from all sources. While originating in Canterbury, the model aims to grow into a full national data repository.

The **NZ Landslide Database** holds data on historical major landslides including information such as triggering event and damage (GeoNet). However, this dataset is somewhat problematic to use and Auckland Council and EQC are currently building a more up to date system.

Key areas of further research include work on probabilistic hazard and risk. Refined earthquake and tsunami forecasting, liquefaction hazards and landslides at a national scale are progressing.

Impacts on Lifelines Infrastructure

The expected effects from earthquakes that create a potential hazard to infrastructure includes:

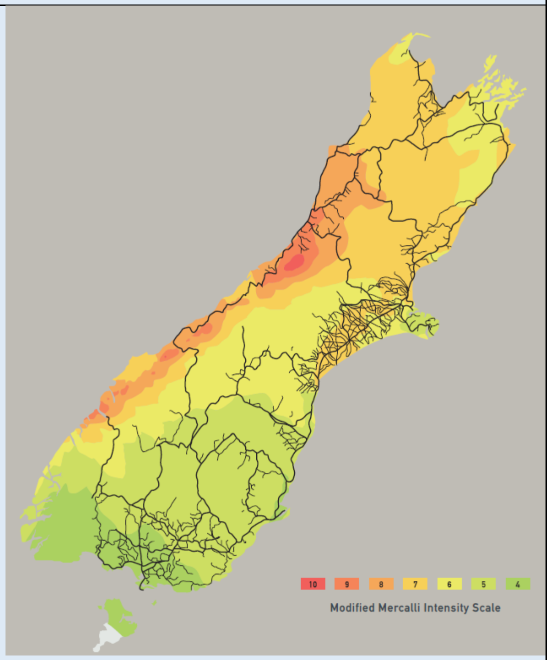
- Surface fault rupture – can range in length from a few metres to hundreds of kilometres and with ground displacements of several metres possible. Shearing of assets can result where ground displacements occur.
- Land movements – in a moderate to large earthquake the ground in nearby areas may be uplifted, dropped or tilted – again ground displacement can be several metres as experienced in the Edgecumbe earthquake (where a large part of the ground in the Rangitaiki Plain dropped by up to 2m) and more recently in Kaikōura.
- Strong shaking can cause damage to structures – the extent of damage can be mitigated through modern seismic design.
- The combination of ground shaking and earth movement can produce secondary effects including rockfall / landslides, tsunami, ground settlement and liquefaction.
- Liquefaction was shown in the Canterbury earthquakes to be particularly devastating to underground, brittle assets due to the associated differential ground subsidence and lateral spreading.

Distributed, lineal assets are at most risk from seismic hazard and recovery times can be years.

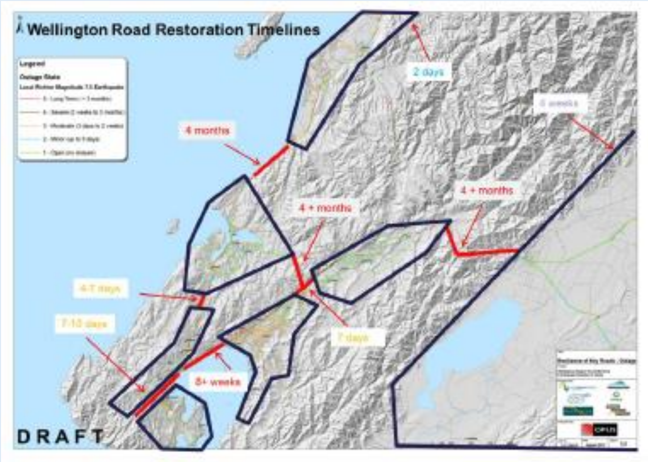
Infrastructure impacts arising from specific scenarios are presented in the following case studies, and by lifelines sector in Section 3.

Canterbury Earthquake, February 2011.

Case Study: Alpine Fault (AF8 Research Programme)

Scenario and Context	 ▪ The Alpine Fault has a high probability (estimated at 30%) of rupturing in the next 50 years. ▪ The Maximum Credible Event developed for AF8 initiates in Fiordland, propogating NE 400km to Kelly (inland from Greymouth). ▪ In this scenario, most structural damage is in western Southland/Fiordland, Queenstown Lakes, Central Otago, West Coast, inland Canterbury, southern parts of Tasman and Marlborough. ▪ Alternative north-south rupture scenarios could cause more damage to Central Otago, Dunedin, South East. ▪ Thousands of minor/moderate injuries, hundreds of serious injuries and fatalities are expected. ▪ Hundreds of thousands of landslides in steeper terrain throughout the South Island are probable, with cascading impacts such as landslides creating dams and flooding with subsequent landslide dam failure risks. ▪ Tsunami generation may occur in lakes and fiords near the Alpine Fault. Coastal tsunami is expected to be minimal but coastal populations may self-evacuate following a shake.
Infrastructure Impacts Electricity	▪ Electricity supplies throughout the South Island will be affected with likely blackouts within at least 150 km of the Alpine Fault and intermittent supply in areas considerably distant from the fault. The supply to the North Island may be also be affected. ▪ Most hydro generation plants will shut down for days for inspections, with some damage expected causing longer outages. Many substations will be heavily damaged.
Telecoms	▪ Standard telecommunications networks will be damaged with remaining networks overwhelmed by increased communications traffic. In-ground infrastructure is likely to be severely damaged.
Roads/Rail	▪ Roads, rail and bridges are likely to be damaged and seriously obstructed throughout areas of most severe shaking, including lower lying areas susceptible to liquefaction, lateral spreading towards waterways, landslide and rockfall. ▪ Large parts of the South Island (notably the West Coast) normally accessed through alpine passes or steep sided valleys nearer to the Alpine Fault will be inaccessible by road, potentially for weeks to months.
Airports / Ports	▪ Major ports may be affected (Nelson, Marlborough, Timaru, Otago, Lyttelton). Smaller airports in Jacksons Bay, Westport and Greymouth likely to be severely compromised. ▪ Hokitika, Greymouth, Westport, Manapōuri, Milford, Queenstown, Wānaka, Glentanner, Mt Cook, Twizel and Tekapo Airports may be compromised (and all others in the South Island will need to be inspected also).
Water	▪ Water (potable, waste and storm) systems are likely to be damaged around the South Island, particularly areas of most severe shaking.
Identified Mitigations	▪ The SAFER framework has been developed to provide a coordinated multi-agency framework which guides response priorities in the first 7 days following the first major quake. https://af8.org.nz/safer-framework/ ▪ Specific infrastructure mitigations were not identified as part of this project but are being progressed by Regional Lifelines Groups and individual lifeline utilities.

Case Study: Wellington Quake (Wellington Lifelines Group)

Scenario and Context	▪ The maximum credible event used is an M 7.5 earthquake on the Wellington Fault, which has a probability of occurence of 10% in the next 100 years. ▪ Estimates of fatalities range from 140 to 2,000 depending on the time of day. ▪ Significant displacement of people (if during working day, around 70,000 commuters in the CBD may be isolated from returning home). ▪ All healthcare facilities likely to be operating at an extremely reduced capacity.
Infrastructure Impacts Roads/Rail	▪ Major slip damage will likely isolate Wellington by road with regaining access taking up to 4 months (Transmission Gully, when open, will significantly reduce this time). Wellington is likely to be fractured by slips into 5 distinct areas with links between these taking up to 4 months to re-open.  ▪ Rail lines between Wellington and Levin, Wellington and Masterton, Palmerston North and Woodville and Kaikōura and Picton are likely to be inoperable. National control of rail operations may also be severely disrupted, due to damage to rail communication and signalling facilities in Wellington.
Airports / Ports	▪ Assumed that CentrePort will be able to provide a limited level of service after a week. Wellington Airport is expected to be inoperable for the first two days following the earthquake and the road to the airport for up to two weeks. ▪ Palmerston North, Ohakea, Kapiti Coast (Paraparaumu), Masterton, Nelson and Blenheim airports will potentially be damaged or disrupted.
Water	▪ Wellington regional potable water, stormwater and wastewater networks are highly likely to be severely disrupted or destroyed, taking months to restore in some areas. Water/wastewater systems across the rest of the affected area may be disrupted or damaged.
Electricity	▪ Electrical generation, transmission and distribution networks are likely to be inoperable or degraded between Palmerston North and Wellington, as well as Marlborough and the Hurunui District in the South Island, for weeks to months.
Telecomms	▪ Telecommunications networks are likely to be inoperable, overloaded or degraded, between Palmerston North and the Hurunui District.
FMCG	▪ Fast Moving Consumer Goods (FMCG) distribution system into the Wellington, Nelson, Tasman and Marlborough region will be inoperable via normal methods, due to road and port closures.
Fuel	▪ Fuel distribution system into and around the Wellington and Marlborough regions is likely to be inoperable. Fuel distribution system into the Manawatu-Wanganui, Nelson and Tasman regions will potentially be disrupted.
Gas	▪ Gas transmission pipelines supplying the lower North Island are likely to be damaged, isolated and either inoperable or degraded for weeks to months.
Identified Mitigations	▪ Wellington Earthquake National Initial Response Plan has been developed to provide a coordinated multi-agency framework which guides immediate response priorities. ▪ The Wellington Lifelines Project (2019) identifies 25 resilience projects at a total capital cost of $3.9B which, if completed, are estimated to reduce economic impacts by $6B (refer Figure 5-3).

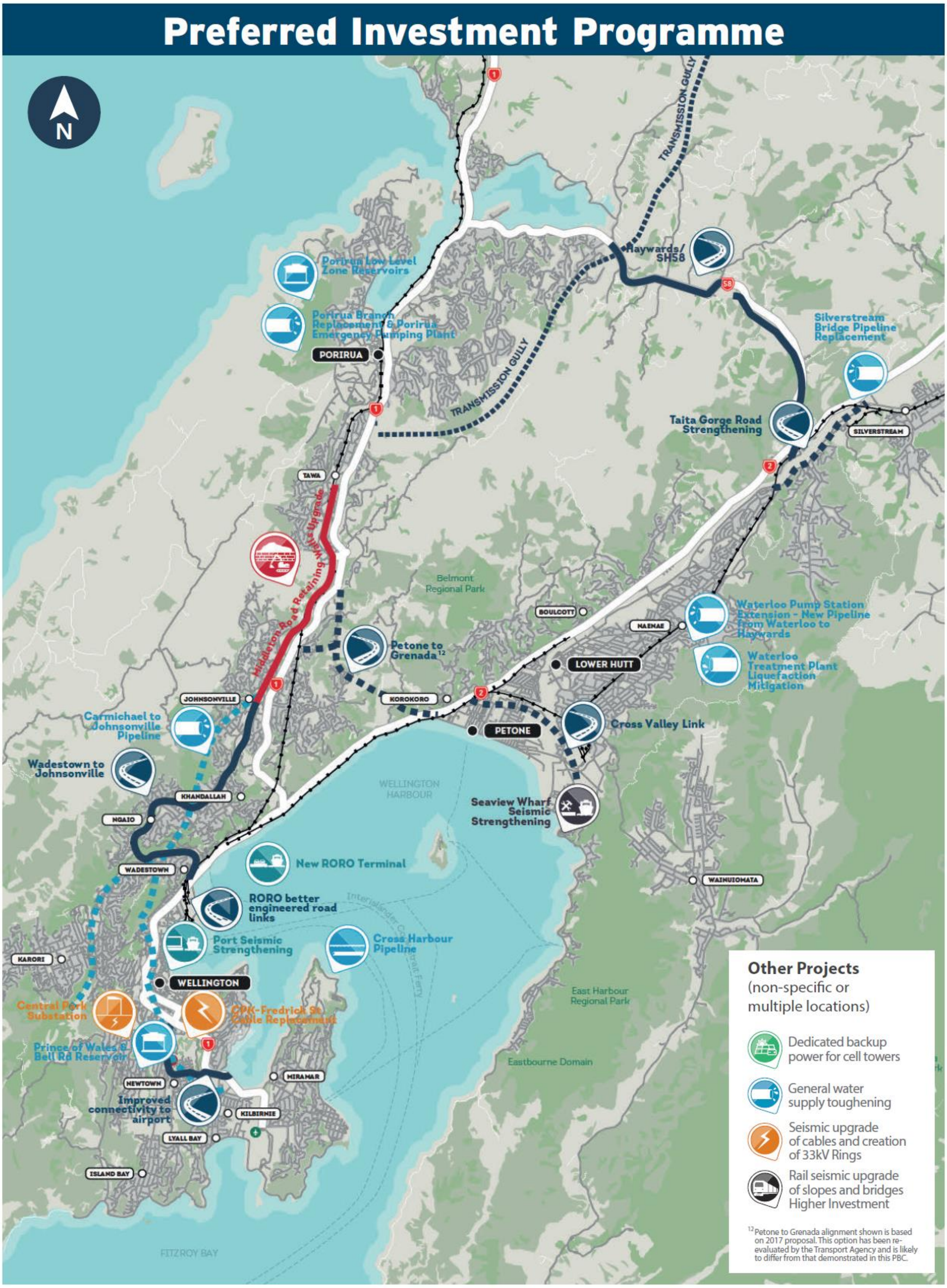


Figure 5-3: Wellington Lifelines Group Programme Business Case

5.3 Volcano

The Hazard

The central North Island is home to several large volcanoes and Auckland is uniquely (for a major city) located on a volcanic field.

Known, existing volcanic areas in New Zealand are shown in Figure 5-4.

Knowledge of Hazard

The eruption history of New Zealand has been well examined by the scientific community and return periods and ashfall projections continue to be analysed in depth by groups and programmes such as those listed in the box to the right.

The Auckland volcanic field is believed to be 250,000 years old and there have been 53 recorded eruptions, the most recent being Rangitoto around 600 years ago.

A national exercise based on an Auckland volcanic eruption 'Exercise Ruaumoko' in 2007 projected widespread infrastructure devastation from the region's main oil depot and wastewater treatment plant, isolating both major highways from the south (SH 20 and 1). The estimated loss of an 'Exercise Ruaumoko' scenario was 43% of Auckland's GDP (15% of NZ's GDP) with a 5% in 50 years probability of occurrence. More recent work shows Auckland eruptions are highly time-varying but may be a roughly 5-15% chance in a human lifetime.

The Taranaki, White Island and Central North Island volcanoes are more recently active.

The Taupō and Okataina caldera volcanoes are the largest in New Zealand and have generated some of the largest known eruptions globally. Lifelines studies have not really focussed on this risk because of its low probability yet potentially nationally catastrophic nature that makes it difficult to plan for. However, programmes such as ECLIPSE are also looking at the higher frequency 'volcanic unrest' periods which can also be highly disruptive. Also, note that a 'moderate sized' eruption is a 500-1500 year recurrence interval and, while high impact, is considered manageable and recoverable with high ability to plan for mitigation. A good case study is the Chaiten eruption 2008-2009 in Chile.

NZ's Volcanic Groups and Programmes

- DEVORA (Determining Volcanic Risk in Auckland): Research programme on the volcanic hazard and risk.
- ECLIPSE: Programme to prepare for future unrest and eruptions of all scales by the Taupō-Okataina supervolcano complex.
- TTVF (Transitioning Taranaki to a Volcanic Future) study to improve understanding of impacts and regional recovery options following a significant eruption.
- VISG (Volcanic Impacts Study Group): focusses on critical infrastructure preparedness and response.
- NZVSAP (New Zealand Volcanic Science Advisory Panel) - multi-agency pre-event and response coordination at national level.
- CPVAG (Central Plateau Volcanic Advisory Group), TVSAG (Taranaki Volcanic Scientific Advisory Group), CAG (Caldera Advisory Group) are for multi-agency pre-event coordination, and provide an avenue for socialising research findings, at regional level.

Figure 5-4 New Zealand's Volcanic Areas

Impacts on Lifelines Infrastructure

Volcanic ash is one of the major hazards associated with volcanoes. The Auckland Lifelines Group and the Volcanic Impacts Study Group (VISG) has undertaken a significant body of work on the impacts of volcanic ash on lifelines infrastructure.

An example of a poster output from this work is shown on the following page (all posters can be downloaded at http://www.aelg.org.nz/ document-library/volcanic-ash-impacts/).

Potential unmitigated impacts of volcanic ash include:

- Buildings rendered uninhabitable due to ash environment, impacts on air conditioning systems and, worst case, roof failure due to ash loading.
- Reduction in air cooling performance has the biggest potential impact in the telecommunications area.
- Flashover from ashfall is possible especially on mid and high voltage electricity distribution and transmission and distribution, at switching/transformer yards which requires cooling for equipment to operate.
- Intake of ash into plant and equipment can damage (directly or via water sources) and impact operations of facilities such as electricity generation plants, water intakes and water/wastewater treatment plants – hydro-electric turbines in the Tongariro Power Scheme were destroyed in the 1995 Ruapehu eruption.
- Ash may affect rural household water supplies, especially roof-catchment tanks.
- Wastewater collection networks can be blocked by ash entering through illegal stormwater connections.
- The potential for air transport disruption is significant, particularly as some volcanoes have a history of erupting for long periods of time.
- Roads will be unsafe to drive – both in terms of skid and visibility risks – and cleanup and disposal operations will be significant – this will have impacts on fuel transportation, solid waste collection and all other sectors (requiring access to their sites to manage impact).

The near-source volcanic impacts such as lava, lahars and ballistics can be destructive to any assets in the immediate eruption area. All infrastructure depending on vent location can be directly damaged, especially sub-surface infrastructure that may be affected by unrest activity (earthquakes, ground deformation).

From a lifeline utility perspective, the major impact of a Taranaki eruption would be potential for isolation by road and damage to the country's gas production facilities and transmission lines to the north. There would be likely significant and ongoing affects to North Island air transport, damage and/or curtailment of national oil and gas production and there would be major impacts on national poultry and milk supplies.

A major central North Island eruption could potentially close and damage State Highways for lengthy periods of time as well as impact on the main electricity transmission lines bringing electricity from South Island sources. There is also a risk to electricity generation in the Waikato.

A large rhyolite eruption from Taupō or Okataina Calderas could have a year of pre-cursory activity. This would present substantial challenges with respect to evacuation and other decisions. Most of these pre-cursory unrest periods do not lead to eruptions, but some do.

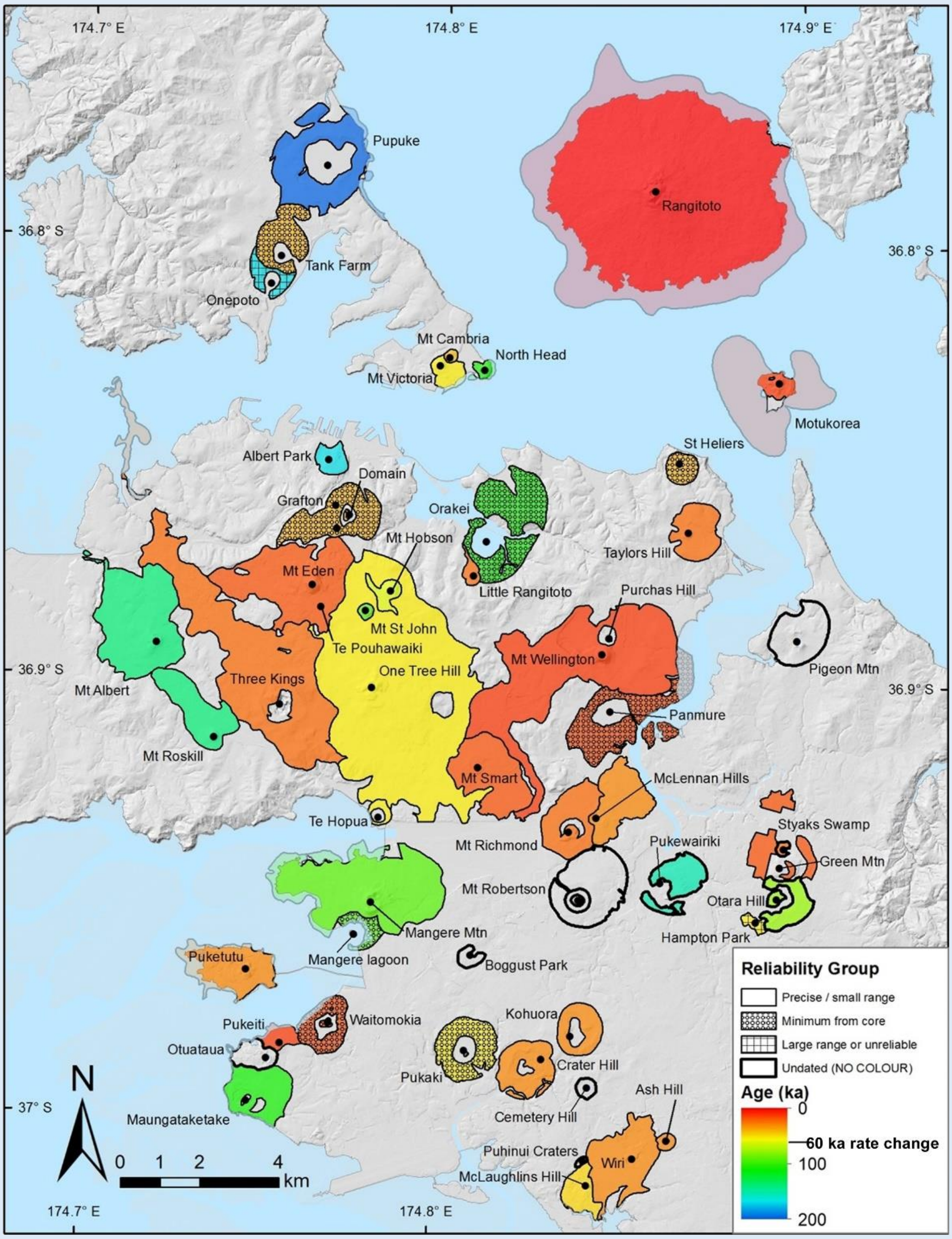
Infrastructure impacts arising from specific scenarios are presented in more detail the following case studies, and by lifelines sector in Section 3.

Figure 5-5: Example of a Volcanic Ash Management Poster (Auckland Lifelines Group, Volcanic Impacts Study Group). https://www.gns.cri.nz/Home/Learning/Science-Topics/Volcanoes/Eruption-What-to-do/Ash-Impact-Posters

Case Study: Auckland Volcanic Field (DEVORA/Auckland Lifelines Group)

Scenario and Context

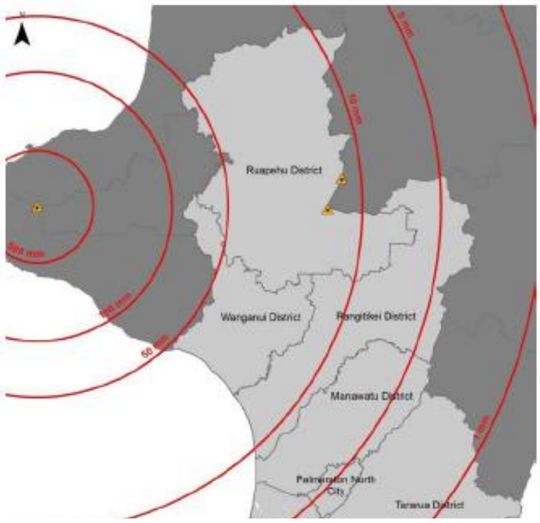
- Metropolitan Auckland is built directly on the Auckland Volcanic Field (AVF), which is 360 km^2 and has around 53 volcanic cones. The field is an ‘intraplate’ field that has been active from ca. 200,000.
- Over the entire history of the field, the rate is one eruption on average every 3.6 thousand years, yet since 60 thousand years ago the rate has increased to on average an eruption every 1.5 to 2.6 thousand years. The most recent eruption is Rangitoto, in 1446 AD.
- However, the use of a single rate is not particularly informative. Repose periods have ranged from ca. 50 to 10,000 years, volumes from ca. 0.001 km3 to 0.7 km3, and vent locations are spread with no clear trend across the volcanic field. There are therefore no grounds on which the duration of the current repose period or the site of the next eruption can be forecast.



Leonard 2017 Map AVF.

Infrastructure Impacts	
Electricity	▪ A worst case scenario for electricity would take out the main north-west transmission and major connecting substations supplying Auckland and Northland. Ash deposition could cause flashovers along transmission lines and at substations.
Fuel	▪ If the fuel pipeline suffers major damage, this could severely constrain supply in Northland/Auckland (particularly jet fuel) and impact the national supply chain.
Gas	▪ Similarly, if the gas transmission line is within the destruction zone, this would cause loss of supply generally north of that point.
Roads	▪ While there is route diversity in the road network, any major route disruption will worsen congestion and constrain evacuations. ▪ Roads can be compromised by only a few mm or more of tephra to Auckland, as tephra (ash) can decrease visibility and traction, cover road markingsand block drains. Secondary remobilisation of ash by vehicles and other environmental factor (e.g., wind or precipitation) can cause prolonged impacts.
Airport	▪ An eruption near the airport would likely result in airport closure due to airspace CAA regulation (or, worse, the airport could be directly damaged by volcanic activity if in close proximity). The airport could also be closed if there is insufficient water, electricity or fuel supplies.
Rail	▪ Track inspections mandated after earthquakes could cause service disruptions. Ashfall will reduce visibility and traction and signal connection between rail and wheels. ▪ The rail network in Auckland is more vulnerable following the electrification of the entire network, as electricity outages are likely.
Ports	▪ An eruption in proximity to Ports of Auckland could take years to recover from. ▪ Even without direct disruption, ashfalls will reduce visibility and floating pumice/scoria produced by an eruption may create hazards for ships. Shipping routes could be destroyed by an eruption in both harbours.
Water Supply	▪ The main water supply reservoirs are outside the volcanic zone and unlikely to be directly impacted by a local eruption. ▪ Once a likely vent area has been identified, parts of the water supply network close to vent area can be isolated to protect the remainder of the network; this asset-protection measure could cause severe disruption (>50 %) at the time. ▪ There will likely be greatly increased demand for water during clean-up operation.
Wastewater	▪ Areas with a joint wastewater and stormwater network are most vulnerable to ingress of tephra (pyroclastic surge and airfall deposits), which would reduce pipe capacity, likely for the lifetime of the pipe(s). ▪ If a local Auckland eruption destroys the Māngere Wastewater treatment plant, there will likely be raw sewage discharge into both harbours for several years. The network will be considerably more resilient once the North Shore wastewater treatment plant is opened.
Identified Mitigations	▪ The Auckland Lifelines Group co-participated and funded the development of volcanic ash posters which identify preparedness and response measures for volcanic ash.

Case Study: Mount Taranaki (Taranaki Lifelines Vulnerability Assessment)

Scenario and Context	▪ Mt Taranaki is an active volcano in a current state of inactivity. Moderate to large eruptions of the mountain have occurred on average every 500 years with smaller eruptions occurring about 90 years apart. The latest research indicates a 1.6 to 3.1 percent probability of eruption in any one year (*Taranaki CDEM Group Plan*). ▪ A volcanic eruption has the potential to affect Taranaki for a long period of time, both because of its after-effects and the potential for intermittent or ongoing volcanic activity. ▪ The Taranaki Lifelines Project (2018) assessed impacts on infrastructure which is used in the assessment below. ▪ A major study (*Transitioning Taranaki to a Volcanic Future 2019-2024*) is being undertaken to improve the understanding of wider economic and social impacts and long term recovery options for the region following a significant eruption.  *Figure ?-5-6: Volcanic Ash Modelling, Mt Taranaki (westerly, 1:2,500 yr event). Source: GNS for Manawatu-Wanganui Lifelines Project 2016.*
Infrastructure Impacts Roads/Rail	▪ Isolation by road (lava flows / lahars crossing SH 3 in a number of places). Roads not damaged by near source impacts are likely to be difficult to drive on due to ash.
Fuel / Gas	▪ Damage and/or curtailment of national oil and gas production. ▪ Loss of gas production will have a significant impact on national electricity security of supply ▪ Damage to gas transmission lines to the north from lahars / lava flows, potentially causing long term gas supply disruptions in the North Island.
Airports / Ports	▪ Significant and ongoing affects to North Island air transport for the duration of the eruption (which may be months to years).
Electricity	▪ Electricity failures to specific areas due to transmission line / site damage from lava / lahars (at risk electricity sites feed New Plymouth CBD and treatment plants, Bell Block, Waitara, Inglewood and many other areas. ▪ Widespread electricity failures due to closure of electricity generation sites both within and near the region, 'flashover' failure from ash on overhead electricity lines and loss of transmission lines from Bunnythorpe (which cross lahar/ lava flows).
Telecomms	▪ Potential loss of Chorus fibre both north and south (lahar crossings) isolating New Plymouth exchange and causing significant loss of telecommunications services.
Water	▪ Significant damage to wastewater and stormwater pipes from ash entering the network, potentially blocking pipes and even hardening.
FMCG	▪ Subsequent major impacts on national poultry and milk supplies (both directly from volcanic impacts and from lifeline utility disruption).
Identified Mitigations	▪ The Taranaki Lifelines Project (2018) identified a number of potential hazard mitigations. These include; consider future water supplies less vulnerable to ash (covered sources) or outside volcanic zone, provision of electricity black start (required to start stand alone network) capability in the region, improved alternate road access routes, provide redundancy in electricity supply to critical sites, and many others.

Case Study: ECLIPSE programme (Central-Taupō Volcanic Zone Calderas)	
Scenario and Context	▪ This programme is investigating how NZ can be more prepared for future unrest and eruptions by the Taupō to Okataina supervolcano complex. It is being led by a team of NZ and international geologists, funded through the government's Endeavour Fund. ▪ Taupō is a 'supervolcano' and one of the most frequently active and productive rhyolite caldera in the world. ▪ The Taupō eruption was the most violent eruption known in the world in the last 5000 years. Pyroclastic flows spread up to 90 km from the vent and covered all local features except Ruapehu. Deposits blocked the Lake Taupo outlet, raising the lake around 30m and caused a catastrophic flood when the deposit dam failed. ▪ A future eruption could cause similar outcomes, and have associated strong earthquakes, lahars and increased geothermal activity. ▪ Unrest hazards are much more frequent than eruptions (and may not lead to an eruption) and are somewhat unique to the calderas. They relate to magma or other hot fluid moving around underground resulting in ground deformation, shaking, changes to hot springs/geysers, and gas.
Infrastructure Impacts Electricity	▪ Depending on the location of the vent, direct damage could occur to national transmission lines and substations through the central North Island, generation sites in the Tongariro, Waikato River and geothermal fields. These facilities could also be impacted by flashover from ashfall, turbidity and debris in hydro dams. ▪ Significant constraints to electricity supply northwards would result, along with the knock on impacts for telecommunications, water/wastewater, gas and fuel (the Marsden Refinery requires electricity transmission from the south).
Roads / Fuel	▪ Roads within 10 km of a new vent could be directly damaged, particularly in the Rotorua Lakes and Taupō township areas. Heavy ashfall (>10 cm) could cause severe disruptions and closures to the national road network, including State Highways SH1 and SH5, and urban road networks in Tauranga, Whakātane, Rotorua and Taupō and other smaller towns in the Bay of Plenty. Clean-up could take months to years. This will also disrupt fuel transportation.
Air Transport	▪ Widespread (inter-continental) ash in the atmosphere can disrupt domestic travel for months to years and southern hemisphere air travel for weeks.
Sea Transport	▪ Lahars and sedimentation may affect the Matatā-Whakātane Coastline substantially, and turbidity/sediment across the wider Bay of Plenty to a much lesser extent.
Gas	▪ Gas transmission lines to Taupō and Bay of Plenty cross the area and may be damaged.
Telecomms	▪ While there is diversity in the major north-south trunk lines, telecommunication disruptions will result from local damage to sites and electricity outages.
Water supply	▪ Sedimentation, turbidity and flooding may affect the water intakes for Hamilton and Auckland if the Waikato is affected, and Kawerau/Bay of Plenty locations if Tarawera is affected. ▪ Ash may affect rural surface water supplies, and especially roof-catchment tanks. This would require disconnection prior to ashfall to protect quality, and/or testing and possible flushing after ash has affected a tank.
Wastewater and Stormwater	▪ Ashfall is likely to clog intakes for reticulated stormwater, direct damage can occur to above ground plant, and unrest can damage or change the falls/draining of underground pipes. Wastewater treatment plants can have months or longer of outage from ashfall affecting plant and also bio-activity.
Identified Mitigations	▪ An eruption or major volcanic unrest event has a very low probability and is unlikely to drive specific infrastructure mitigation programmes. Efforts are being focussed on understanding potential impacts and response and recovery planning.

5.4 Tsunami

The Hazard

Tsunami are typically generated by displacement of ocean water due to landslides, earthquakes, volcanic eruptions and meteorite impacts. Tsunami threats to New Zealand are broadly categorised as:

- Distant source; > 3 hours travel time to New Zealand from sources such as South America and to a lesser extent Cascadia (North America) and the Aleutian Islands.
- Regional source; 1-3 hours travel time to New Zealand from sources such as the Solomon Islands New Hebrides and the Tonga-Kermadec trench. National 'Exercise Tangaroa' in 2016 was considered a credible worst-case tsunami generated from a seismic event near the Kermadec islands (refer Figure 5-7).
- Local Source < 60 minutes travel time to the nearest New Zealand coast. Seismic activity on the southern end of the Tonga-Kermadec trench can cause tsunami to reach the Northland coast within 1 hour. Travel times from the adjacent Hikurangi subduction zone along eastern North Island could be as little as 15-20 minutes. There are many off-shore and shore-cutting faults around NZ able to cause tsunami such as those following the 2016 Kaikōura earthquake. Other sources include submarine landslides or a slump in the continental shelf.

The following is an example scenario used specifically for Exercise Tangaroa in 2016, it is not intended to be indicative of general tsunami arrival times. (Note – for real, future events, this map template format has now been updated to only show wave heights at the coast, with arrival times for different locations around New Zealand are provided separately in tabular format).

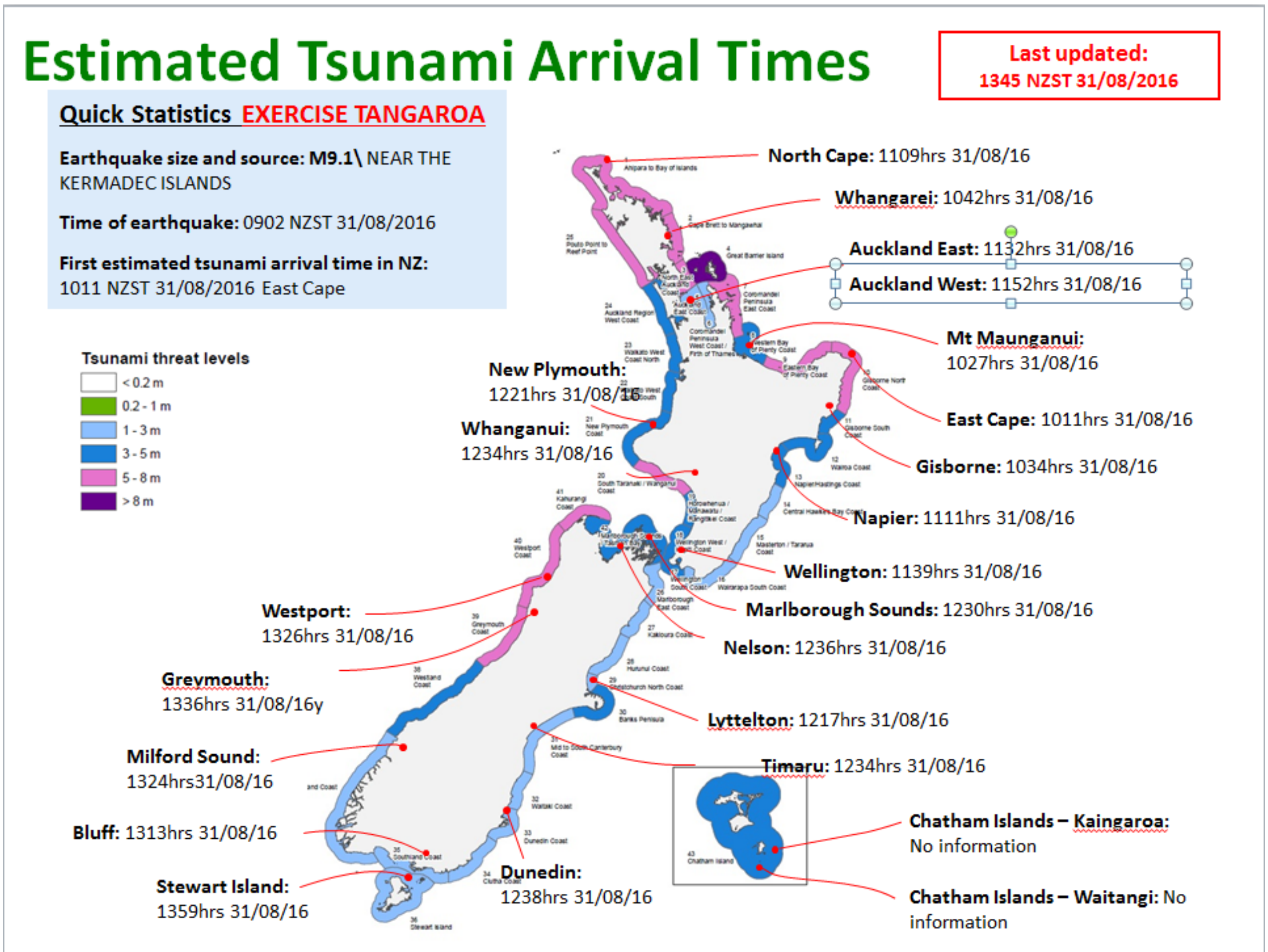


Figure 5-7: 'Exercise Tangaroa' Threat Map and Arrival Times since the earthquake

Knowledge of Hazard

There have been five events in the last 150 years which have produced moderate sized tsunami along New Zealand's coast as documented by historical observation. Prior to Kaikōura, the most recent event, the 1960 Chile earthquake magnitude 9.5, caused fluctuations up to 4.5m above sea level with damage confined to immediate coastal areas.

There is a national probabilistic hazard model (Power et al) and an older probabilistic risk model (Berryman et al 2005).

Tsunami evacuation zones have been mapped for much of NZ's coastline in accordance with the Director's Guideline *MCDEM DGL 08-16* based on a 'level 2' rule-based methodology. This essentially models the height of the wave with GIS-calculated attenuation rules for open coast, harbours, and rivers. Evacuation zones represent an envelope around all possible inundation from all known tsunami sources, taking into account all of the ways each of those sources may generate a tsunami (and therefore no one event is expected to inundate the majority of a zone). The zones have a significant factor of safety applied, reflecting the accuracy of the relatively simplistic empirical approach.

The availability of LiDAR datasets is a key enabler of more accurate tsunami modelling. Funding has been made available through the Provincial Growth Fund for councils to collect new land base LiDAR. This work is being coordinated through Land Information New Zealand (LINZ) and will see improved elevation data coverage over much of NZ over the next 2 years (to 2022). LINZ is also seeking to source improved elevation data in the coastal zone, considered not only important for tsunami forecasting but very important as we adapt to changing climate.

Tsunami Detection and Warning

New Zealand has adopted an end-to-end tsunami warnings system, from monitoring and detection, threat assessment, official decision-making and warnings process to public education and training.

This system has recently been improved through the establishment of the 24/7 National Geohazards Monitoring Centre operated by GNS Science to assess all possible tsunami threats and provide advice to decision-makers. The data is currently being significantly improved through the NZ Government funding the establishment a network of twelve Deep-ocean Assessment and Reporting of Tsunami (DART) buoys to detect tsunami close to New Zealand and in the Pacific.

Four buoys have already been deployed and are operational, and more are scheduled for deployment in 2020. The data from the DART buoys supports more accurate tsunami warnings and also more rapid confirmation of no threat.

Impacts on Lifelines Infrastructure

The Wellington and Auckland Lifelines Groups collaborated on a project in 2015/16 to review knowledge of tsunami impacts on infrastructure drawing from research on recent events[6]. Briefly, the study found that:

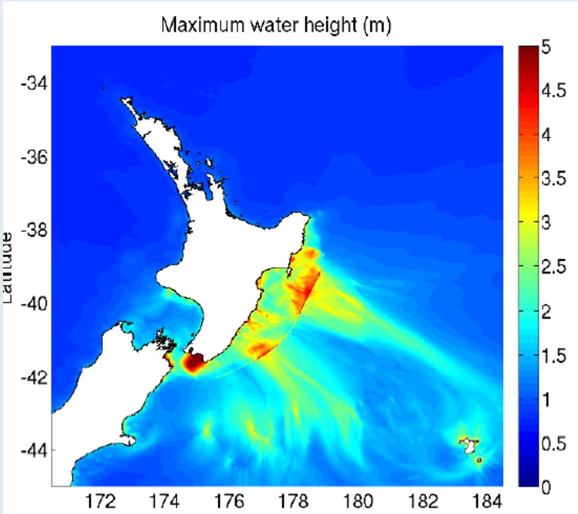
- Transportation networks will likely be damaged by even small tsunami (tsunami depths ~ 1m) due to scouring and deposition of debris.
- Wastewater and potable water networks are particularly vulnerable to tsunami at their facility buildings and pipe intake and outflow sites. Contamination of drinking water supplies or sewerage containment ponds can occur with even small amounts of intrusion of seawater from a tsunami.
- Telecommunications networks will most likely be disrupted locally due to damage to buildings and electrical equipment at exchanges and failure of cellular sites.
- Energy networks, particularly electricity, will be impacted due to shorting of buried cables if they become exposed to the water and have pre-existing casing damage. Also, overhead lines are susceptible to failure by toppling of poles, which can be damaged by debris strikes. Petroleum and gas terminals may suffer damage to their pipe networks and tank farms in tsunami depths of 2m or greater.
- Back-up services, such as generators, are often located on the ground outside of buildings, on ground floors or in basements, putting them at risk.
- Bridges are a lifeline component vulnerable to tsunami as are other lifelines services often co-located with the bridges and approaches.

[6] N.A. Horspool S. Fraser, An Analysis of Tsunami Impacts to Lifelines, Report 2016/22, May 2016

- Major ports can be damaged through tsunami waves; even where ports aren't inundated, tsunami have potential to significantly disrupt ship movements and damage ships and docks (e.g., ships pulling moorings).

<table>
<tr><th colspan="2">Case Study: Hikurangi Subduction Zone – Earthquake and Tsunami</th></tr>
<tr><td>Scenario and Context</td><td>

- The Hikurangi plate boundary, located off the East Coast of the North Island, is where the Pacific tectonic plate subducts the Australian tectonic plate.
- The Hikurangi subduction zone is potentially the largest source of earthquake and tsunami hazard in New Zealand, but there is still much to learn about it. A large team of scientists are studying the Hikurangi plate boundary to better understand risks (project 2016-2021).
- The base scenario developed for the Hikurangi Project is slightly less than the maximum credible event: a Mw 8.9 earthquake on the southern portion of the subduction zone (*Hikurangi Response Plan Scenario Development, GNS 2018*).
- Earthquake shaking is expected to be intense in Hawkes Bay (around MMI 9.0 in Napier, Wellington/Hutt Valley (MMI 8.0-9.0) and Eastbourne/Rimutakas (MMI 9.0-10.0).
- The base scenario is expected to generate tsunami up to around 8m with the worst impacts on the south eastern coast of the North Island and top of the South Island (refer Figure to right).



</td></tr>
<tr><td>Infrastructure and Human Impacts</td><td>

A detailed infrastructure impacts assessment is yet to be carried out for the Hikurangi Response Plan base scenario. However, some key assumptions in the initial base scenario development include:

- Wellington: Widespread loss of electricity (7-10 days restoration), water and wastewater (several months), gas pipeline damage (connection points to buildings could provide a fuel source for post-earthquake fires) and telecommunications. Port is unusable. Telecommunications failures once batteries run down (around 8 hours). Around 500 fatalities and 5,000 injuries.
- Napier: Severe damage to the Port and Airport (possibly permanent due to land uplift/subsidence), as well as some critical SH2 bridges and major slips on both SH2 and SH5 isolating Napier by road. Extensive damage to water pipes and electricity cables and highly limited electricity transmission into the region. Telecommunications failures once batteries run down (around 8 hours). The rail line to Woodville will take weeks to repair. Around 200 fatalities (most due to tsunami) and 700 injuries.
- Gisborne: Widespread tsunami damage to the south side of the CBD, isolation of the city by road, weeks of water, wastewater and electricity outages. Telecommunications failures once batteries run down (around 8 hours). Around 20 fatalities and 200 injuries.
- Elsewhere in the North Island, shaking of around MMI 7-8 is expected in Tauranga and Auckland. SH1 in Marborough is closed by slips. Airports and ports around the country will be coping with additional flights and ships diverted from their original locations.

</td></tr>
<tr><td>Identified Mitigations</td><td>

- Wellington Lifelines Group Programme Business Case (developed around the Wellington Fault) is a general reference for that region.
- More specific mitigations for this hazard are likely to be developed as the Hikurangi Project progresses.

</td></tr>
</table>

5.5 Severe Weather and Climate Change

Figure 5-8: A broadcasting tower (continuing to function in ice / snow conditions)

Hazard Overview

New Zealand's climate hazards vary by location and geography. In the north, ex-tropical cyclones, such as Cyclone Bola, causing intense rainfall and/or high winds occur every few years. Further south, along with flooding and high winds, snow and ice add to the climate related hazards.

Climate change - driven by rising temperatures due to increasing concentrations of greenhouse gases in the Earth's atmosphere - will intensify the risks and potential impacts of weather hazard events.

Infrastructure and communities affected by climate change hazards are more vulnerable to compounding and cascading impacts of other hazards. At approximately 1°C of warming, NZ is already experiencing higher sea levels and more volatile weather patterns. As rates of global emissions put NZ on track to between 3°C and 5°C of warming by 2100, the severity of interrelated natural hazard and climate change events and trends will increasingly disrupt lifelines infrastructure, putting communities at increasing risk.

Lifelines infrastructure is particularly impacted by climate-induced changes in hydrological cycles, ocean warming and sea level rise:

- **Intensification of the hydrologic (water) cycle increases hydrological hazards:** Resulting from increased atmospheric energy and evaporation rates, climate change will both cause and exacerbate changes to rainfall patterns and rainfall intensity, and changes in the levels and movement of surface and ground water (including snowmelt). NZ will experience more frequent and/or more extreme floods and droughts, extreme temperatures, storms and landslips.
- **Ocean warming adds energy to ocean weather systems, especially cyclones:** Ex-tropical cyclones, which create many of NZ's most severe storms, are likely to be stronger and cause more damage as a result of heavy rain, strong winds and storm surge. In 1988, Cyclone Bola created some of the largest rainfall totals for a single storm in the history of New Zealand and caused extensive damage across the North Island.
- **Sea level rise increasingly impacts natural and built environments:** Sea level around NZ rose at 2.4 mm per annum in the period from 1961 to 2018, more than double the rate in the previous 60 years (MfE, 2019). Sea level rise causes/exacerbates coastal erosion, magnifies storm surge impacts and undermines homes and infrastructure. It also pollutes freshwater supplies, such as underground aquifers, with salt water and can destroy protective coastal systems such as wetlands.

Hazard Knowledge

There has been a substantial amount of work undertaken in New Zealand in the last five years to assess the climate change hazard and risks associated with impacts on our built infrastructure, and the key documents and areas of study are listed below.

Most hazard information, especially in relation to severe weather and flooding, is managed by regional councils, developed using varying methodologies. Information in this area includes:

- rainfall history and probabilistic forecasting (NIWA).
- data of historic events (e.g., mapped 'historic flood' areas).
- predicted inundation from river and urban stormwater flooding – e.g., using hydrological models.

- for regional lifelines projects, rainfall-induced slope instability risk has sometimes been derived from contour and geological data, though accuracy is limited.

Some work is being done to standardise methodologies for flood modelling. Further work is also needed to improve understanding of lower frequency events (most is limited to 1:100 yr. events).

The most recent national study was part of the Deep South Science Challenge (DSCC) on coastal flooding exposure under future sea level rise (Attachment 4: References) which is summarised in the case study on the following page. Significantly, this report predicts that the present day 1% AEP (Annual Exceedance Probability, or chance of being exceeded in any one year) coastal storm-tide/wave flooding around NZ that will be realized much more often with rising seas, becoming an average annual event by 2035-2045. https://www.pce.parliament.nz/media/1382/the-effect-of-sea-level-rise-on-the-frequency-of-extreme-sea-levels-in-new-zealand-niwa-2015.pdf.

The 2017 MfE Climate Change Guidance for Local Government produced four sea level rise scenarios to support climate change planning and stress-test response options or designs (refer Figure 5-9).

The 2019 Zero Carbon amendments to the Climate Change Response Act 2002 set up a framework for preparing and adapting to climate change through a National Climate Change Risk Assessment NCCRA. Work on the first NCCRA is well advanced and the findings will be included in a future update of this report. The NCCRA will primarily be applied to development of the first National Adaptation Plan (NAP), due to be completed by 2022, and expected to recognise the significant vulnerabilities of infrastructure.

MfE projections on rain and wind increases associated with climate change will be incorporated into the structural design "Wind actions" standard.
Other noteworthy studies in the last decade include:

- The Parliamentary Commissioner for the Environment (PCE) 2015 study of coastal infrastructure assets potentially exposed to sea level rise (bathtub analysis). Largely superseded by subsequent studies. https://www.pce.parliament.nz/media/1384/national-and-regional-risk-exposure-in-low-lying-coastal-areas-niwa-2015.pdf

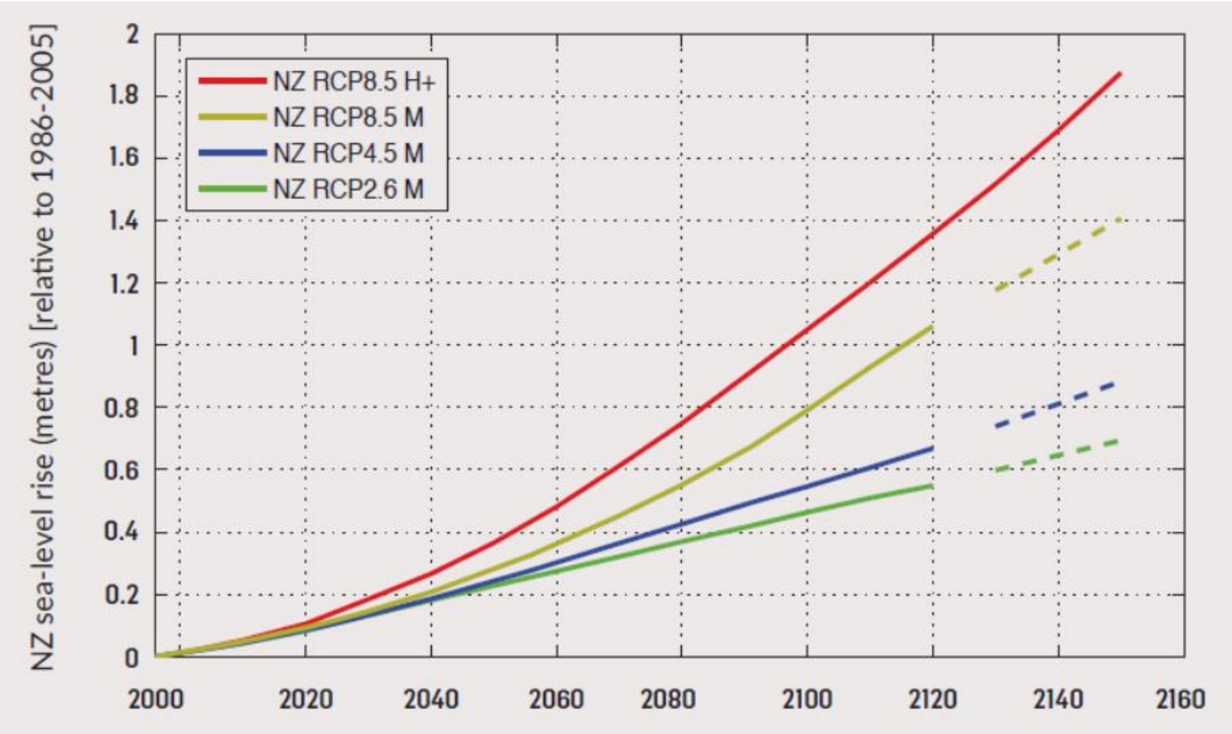


Figure 5-9: Sea level Rise Projections (excluding vertical land movement https://www.mfe.govt.nz/publications/climate-change/coastal-hazards-and-climate-change-guidance-local-government (RCP, or Representative Concentration Pathway, refers to different climate change projection scenarios)

- A subsequent Local Government New Zealand (LGNZ) report provided a more detailed quantification of exposure of local government assets to sea level rise (these studies did not assess impacts of coastal flooding events). It found that $14B of local government infrastructure is at risk from sea level rise. Many Councils and lifeline utilities have done their own more detailed assessments using PCE coastal exposure layers.
- The Deep South Science Challenge work builds on the above but also considers a present day 1% AEP storm tide and wave setup hazard to all built assets and populations. The storm hazard can increase coastal flood levels up to 1.5m in exposed areas and assesses additional exposure to 0.1 m increments in sea-level rise (Attachment 4: References). It is noted that the studies exclude protection from stopbanks/seawalls and tide gates, which form part of the residual risk (if they fail).
- Another DSCC study investigated cascading impacts of climate change hazards on built infrastructure, social, environmental, and economic outcomes (Attachment 4: References).
- Climate Change and Stormwater and Wastewater Systems (Attachment 4: References) was part of a 2019 DSCC / Motu report which explored more deeply impacts on these types of systems – such as increased wastewater pipe blockages in more frequent droughts and increased overflows associated with more frequent heavy rain. Increased reliance on pumping within stormwater systems (to discharge to higher coastal sea levels) creates further risks and resilience issues.
- LGNZ produced a toolkit for local authorities providing advice on their legal obligations relating to Land Information Memoranda and their ability to manage development in natural hazard areas.
- MfE produced another guideline in 2017 "Coastal Hazards and Climate Change" providing guidance for local government in assessing climate change risk, engaging with communities, and developing adaptation and mitigation strategies (Attachment 4: References).

Impacts on Lifelines Infrastructure

Sea level rise causing coastal inundation and flooding damage to infrastructure is a primary risk associated with climate change. Other impacts include:

- More frequent high-wind storms, which have a damaging impact on above ground electricity and telecommunications infrastructure, especially where trees are not managed away from lines. Restoration times can be weeks to months if there are widespread rural line outages.
- More frequent high rainfall storms, causing general property damage as well as specific infrastructure damage such as river sources being washed away and landslips impacting roads. National river floodplains have considerable direct and residual exposure on roads and rail (19,100km and 1,600km respectively if stopbanks are breached) that may be under increasing pressure. More analysis is required in this area.
- Flooding – including coastal, fluvial and pluvial flooding which may impact different types of infrastructure. The damage can depend on whether this is ponded or flowing water (e.g., rivers). Typically lifelines services are restored relatively quickly once flood waters recede, though in some cases damage can be more severe (floodwaters scouring bridges and attached pipes/cables).
- River/stream/coastal flooding and high turbidity can impact on the ability to treat water and infiltration of wastewater networks and cause overflows from the wastewater networks. High turbidity can also impact hydro-electricity generation. Coastal saltwater flooding can impact low-lying control or electrical systems or advance corrosion.
- Rainfall induced landslides – typically closing roads (in some events in the last two decades single regions have counted thousands of slips) and recovery work may take years.
- Snow and ice – mainly a temporary hazard to roads though can damage overhead infrastructure if heavy.
- Drought – more frequent and prolonged droughts; the main infrastructure impacts being on water supplies, as well as likelihood of increased blockages in wastewater systems.
- Increased fire weather conditions potentially causing impacts such as electricity outages.

Regional lifelines studies have not identified any nationally significant infrastructure vulnerable to floods. However, the low-lying Dunedin CBD area does contain several regionally important infrastructure sites.

New Zealand Lifelines Council

Case Study: Deep South Science Challenge Coastal Flooding Exposure under Sea Level Rise

Scenario and Context

- This study presents New Zealand's exposure to 1% annual exceedance probability (AEP) coastal flood inundation under present-day and future higher sea levels.
- Elements at risk were mapped and overlaid with projected sea level rise for infrastructure and land type (built, production, natural or developed). This information was used to derive the statistics summarised below, using available LiDAR DEM coverage.

Infrastructure Impacts

The table below summarises the elements at risk in present day and + 0.6m sea level rise in a 1% storrm. A 0.6m sea level rise is predicted to occur between 2070 and 2130 (MfE 2017)

	1% storm-tide flood levels, +0.6m sea level rise	
	Present Day (2018)	**+0.6m sea level rise**
Population	72,100 people	132,600 people
Roads	1,410km roads	2,270km roads
Railway	86km rail track	142km rail track
Airports	13 airports	14 airports
Electricity	122km transmission lines 182 structures/sites	165km transmission lines 277 structures/sites
3-Waters	3,180m pipeline	5,570m pipeline
Buildings	49,700 buildings $12.4B replacement value (2016)	93,900 buildings $26.2B replacement value

Identified Mitigations

- Most lifeline utilities are in the early stages of risk assessment with the intention to adopt adaptive planning for climate change (simplistically this involves identifying different options (pathways) for mitigation works but only progressing when certain trigger points are reached.
- Some utilities have modified design codes which require new infrastructure to be built with consideration of sea level rise and higher flooding frequencies.
- The most significant project is thought to be the raising of the SH 16 causeway on Auckland's northwestern motorway (shown below), which was being flooded in storm surges and high tides (e.g. flood event on 23 January 2011). The raising of the motorway was designed to future proof for potential sea level rise in the medim term and allow further raising of the road longer term by providing sufficient footprint and ground treatment up front.

5.6 Other Hazards: Pandemic, Fire, Space Weather and Technology

This report does not aim to exhaustively cover all potential causes of disruptions to lifeline utility services. The hazards dealt with in Sections 5.1 to 5.6 are those that have been most studied in New Zealand and are considered to have potentially highly damaging impacts on lifelines infrastructure.

This section features information on lifeline utility risks associated with pandemic, fire hazards, space weather and failure of satellite-based global positioning systems.

In future editions, NZLC will consider expanding coverage to other known risks to lifeline utilities such as failure of supply chains and dependent services, cyber-attack and system operator error, to name a few. An emerging threat for overhead line networks, and aviation, is the widespread use of Unmanned Aerial Vehicle (UAV's) or drones.

Human Pandemic

A human pandemic does not have the same damaging impacts as the hazards covered so far, but it does have the potential to disrupt lifeline services primarily due to disruption to staff operational activities and supply chains.

Lifeline utility planning and responses to a pandemic are based around good business continuity practice, such as understanding what critical functions and people need to be kept operational in a constrained operating environment such as 'lockdowns' and social distancing practices.

As the updating of this 2020 edition neared completion, the COVID-19 pandemic was having wide-reaching global impacts but so far (June 2020) NZ lifeline utilities' have followed their business continuity plans and maintained normal services. The case study on the following page identifies impacts and learnings to date.

Fire Following Earthquake

One of the consequential risks associated with a major earthquake is the outbreak and spread of fire in urban areas. The challenge is the limited ability to fight any fires that do occur, due to access challenges for fire-fighters and the real prospect of a lack of water in the mains due to network damage. Fires in the immediate aftermath of strong ground shaking can be caused from a variety of sources both internal and external to buildings. Damage to gas connection points at buildings could provide a fuel source to post-earthquake fires. If ignition then occurs, the extent of the resulting fire spread depends on a range of factors such as the combustibility of the buildings and the level and direction of wind at the time.

Fire Following Earthquake was a major contributor to the building damage in Napier following the 1931 Hawke's Bay earthquake, as has been the case in major overseas earthquakes such as the 1906 San Francisco and 1995 Kobe, Japan earthquakes. There were however very few instances of fires in Christchurch following the 2010/11 earthquakes, due largely to the limited extent and relatively new reticulated gas network.

There has been considerable research undertaken internationally and in New Zealand on Fire Following Earthquake, including a scene-setting report by the Wellington Lifelines Group in 2002.

Wellington's 'It's Our Fault' programme (Attachment 4: References), research and modelling work continues to look more closely at the factors involved in a fire following an earthquake and how the findings can inform emergency planning etc.

Mitigation of the risk requires a close dialogue between water supply authorities and Fire and Emergency New Zealand. There needs to be clear understanding of the risk of ruptures to water mains, and the dependable sources of water for firefighting should this occur. For Wellington, a potentially valuable auxiliary source of water for fighting fires in the CBD and surrounding suburbs is the harbour. The access to and use of water from the harbour is a key element of San Francisco's planning for firefighting following a major earthquake.

Case Study: HUMAN PANDEMIC (COVID-19)	
Scenario and Context	This case study is written in June 2020. ▪ The novel coronavirus was first identified in Wuhan in 2019 and has spread globally. At the time of writing, nearly 4 million people have been infected with over 300,000 deaths globally. Billions of people are in various stages of 'lockdown'. ▪ New Zealand was at the highest alert level (Level 4) through April, with only 'essential services' operating. For lifeline utilities, this means all staff worked from from home apart from operation of critical facilities (such as network operating centres) and responding to urgent requests (service failures). ▪ The country dropped to Level 3 in May, allowing lifeline utilties to resume most activities, so long as social distancing rules are maintained and all staff work from home if they can. ▪ As at June 2020, NZ is at Level 1.
Infrastructure Impacts	Lifeline utilities have individually and collectively planned for a pandemic event, with many conducting or participating in exercises at an organisational, lifelines group and CDEM Group level. Also, most lifeline utilities have well tested business continuity plans that specifically cover pandemic events, or at least the key components of pandemic response planning. This includes understanding what critical functions and people need to continue operating in a constrained environment and knowledge of supply chains and backup arrangements. Indeed, many lifelines implemented these plans early in March, pre-empting formal government directions. All lifeline utility services have, to date, continued normal services to customers. However, there have been some challenges to be addressed on the way. These include: ▪ Concern about worker safety (lack of personal, protective equipment, or PPE) which has the potential to impact supply restorations and capital programmes if front-line workers do not have access. ▪ Delayed maintenance of infrastructure, with potential impacts on service reliability. ▪ Delays to delivery of major equipment and travel by international experts required to support major capital projects. ▪ Over-supply in the liquid fuel and gas sectors – while these have been managed, there is potentially longer-term impacts on how gas and fuel production storage occur in NZ. ▪ Stockpiling at ports, particularly during Level 4 when only essential goods were being distributed. ▪ Financial impacts challenging business viability, particularly in the air and fuel sectors.
Learnings	In due course there will be time for reflection and identifying learnings through debriefs. An initial request for feedback from lifeline utilities identified the following learnings to date: ▪ Lifeline utilities recognised the significant benefits from business continuity, emergency response planning, capability building and testing. ▪ The coordination and communication around PPE requirements were confusing with disconnects between messaging from some agencies. ▪ Past lifelines pandemic planning and exercising has been under a NEMA lifelines coordination structure. The establishment of new MBIE infrastructure coordination processes and systems at the beginning of the event was seen as frustrating and time-consuming for some lifeline utilities (should have been in place beforehand).

Rural (Wild) Fires

The frequency and extent of major rural fires (bush fires) has increased in recent years, and this trend is expected to continue due to the influence of climate change. Both the Port Hills, Christchurch fire in 2017 and the Nelson fire in 2019 covered extensive areas and directly impacted urban areas.

The most direct impact on infrastructure networks typically involves the overhead assets of electricity networks. However, the 2019 North Dunedin fire highlighted the potential second order impacts, with the chemicals used to fight the fire inadvertently contaminating the drinking water held in an open reservoir, a key component of the city's water supply.

The difference between the regional risk ratings for rural fire in Section 5.1(and the lack of a rating for the many regions) indicates that the risk to both the community and infrastructure systems requires further specific consideration.

A research programme being led by the Scion Rural Fire Research Group "Resilience to Wildfires" is, amongst other things, mapping wildfire prone areas with a high potential to affect people and property (the rural-urban interface). This will provide hazard information to support lifelines risk assessments.

Fires following Hawkes Bay Earthquakes 1931 (Source Hawkes Bay Emergency Management: hbemergency.govt.nz)

Port Hills Fire, 2017 (Source StarNews Canterbury)

Global Navigation Satellite Systems

All lifelines sectors use the Global Positioning System (GPS) to some extent. GPS is one of a number of satellite-based positioning systems collectively known as the Global Navigation Satellite System (GNSS).

GNSS provides the positioning, navigation and importantly the timing of data exchange between/to users worldwide and is now used extensively in many of New Zealand's critical infrastructure sectors (e.g., transport and information and communications technology (ICT) networks). It is also a key component in many of the modern conveniences that people rely on or interact with on a daily basis, including banking financial services, aviation, maritime navigation and surveillance, surveying and vehicle navigation systems.

Water, electricity, transportation, ICT, and energy networks are particularly vulnerable to a GNSS disruption and this reliance continues to grow as the sectors become more technologically dependent.

GNSS disruption can come from a variety of unintentional or intentional sources, including space weather events, radio spectrum encroachment (radio emissions matching GNSS frequencies), 'jamming' devices that intentionally block GNSS signals, or 'spoofing' devices which intentionally replace true GNSS signals to manipulate the computed position or time. New Zealand's increasing dependency on the GNSS, particularly for data exchanges with little or no backup services, leaves users potentially vulnerable to these disruptions.

Current risk reduction initiatives include:

- Advances in receiver and antenna design will reduce the impacts of space weather events,
- multiple GNSS constellations to reduce the incidence of ‘jamming’ or ‘spoofing’,
- advisory notices on the ‘health’ of systems/networks that rely on GNSS,
- upgrades if necessary,
- awareness raising, and
- inclusion in business continuity plans for at-risk businesses

Future treatment options include implementation of a Satellite-Based Augmentation System (SBAS) and alternative timing being led by Land Information New Zealand (LINZ) in collaboration with Australia.

Space Weather

Space weather events are rare and well monitored by international agencies. Overseas studies show that the other unintentional or intentional ‘jamming’ or ‘spoofing’ of GNSS signals may be more prevalent than expected, and in some countries, show that it is happening on a daily basis over limited areas (e.g., the blocking of signals from vehicle navigation systems to prevent the location of a vehicle being known).

There are now several documented cases of major airports worldwide being closed and air traffic being diverted due to GNSS disruptions from ‘jamming’ devices being used adjacent to the airport. There is currently no monitoring of ‘jamming’ or ‘spoofing’ devices in New Zealand.

Cyber Security

Our increasing reliance on networked technology and information communication systems poses a cyber security risk. Protection of New Zealand’s infrastructure in order to avoid vulnerabilities and disruptions to service, including cyber risks, will be increasingly important. Cyber security work led by the National Cyber Policy Office (NCPO) in the Department of Prime Minister and Cabinet (DPMC) and Government Communications Security Bureau (GCSB), to ensure that New Zealand’s most significant information infrastructure, both public and private, are protected from cyber risks. This includes critical national infrastructure.

6. Building Resilience in NZ's Infrastructure

Section 6 presents a summary of the key regulatory and funding agencies for lifeline utilities that have a role in contributing to infrastructure resilience. It includes information on proposed initiatives to improve resilience by individual lifeline utilities, regional lifeline utility groups, and national research and assessment programmes.

6.1 Regulation and Funding Drivers

Business Models

Lifeline utility services operate under a range of regulatory frameworks and market models; these were discussed for each sector in Section 3. Some lifelines services are competitive (electricity generation, gas supply, liquid fuel supply and telecommunications), some are natural monopolies (electricity and gas transmission and distribution and Airways Corporation) and some are run as public services funded through taxes, levies or rates (roads and water supply).

These different business models give rise to different approaches to resilience investment. Investment decisions in some sectors are made on a purely commercial basis (will the investment provide financial gain?) which may not necessarily reflect the best community outcomes. All sectors operate with some level of financial constraint, and resilience projects compete with many others for funding.

Regulating and Funding Agencies

Regulation and funding bodies specific to each sector are discussed in Section 3 and summarised in Table 6-1.

Agency	**Role** (in relation to funding, regulation or policy relating to infrastructure resilience)
Civil Aviation Authority	Aviation safety and security regulator.
Commerce Commission	Enforce competition, fair trading and consumer credit contracts laws. Have regulatory responsibilities in the electricity lines, gas pipelines, telecommunications, dairy and airport sectors.
Climate Change Commission	Established in 2019 to provide independent, evidence-based advice to Government to help Aotearoa-NZ transition to a low-emissions and climate-resilient economy. One of their tasks is to undertake regular national climate-change risk assessments.
Electricity Authority	Promote and regulate reliability in the electricity industry (except where regulated by the Commerce Commission), including security of supply and resilience. Provides support to the Security and Reliability Council and acts on their advice.
EQC	A Crown entity that invests in natural disaster research and education as well as providing natural disaster insurance to residential property owners.
Infrastructure Commission	Infracom was established in 2019 to advise the Government on infrastructure delivery and planning at a strategic level to improve New Zealand's long-term economic performance and social wellbeing.
MBIE	Policy setting across telecommunications, electricity, gas, and building sectors.
Ministry for the Environment	The Climate Change Response Act empowers the Minister for Climate Change and Climate Change Commission to request information from lifelines utilities about their climate change adaptation plans.
Ministry of Transport	Policy setting for the transport sector.
NEMA	National Emergency Management Agency - National emergency management through the 4R's of reduction, readiness, recovery and response.
NZ Transport Agency	Standards and funding across State Highway network, part funding for local roads; regulation of rail.

Agency	**Role** (in relation to funding, regulation or policy relating to infrastructure resilience)
Treasury	Government funding and oversight of the Infrastructure Commission.

Table 6-1: Agencies with Infrastructure Resilience Regulation or Funding Roles

Regulating and Funding Legislation

The CDEM Act 2002 has a requirement for lifeline utilities to *"function to the fullest possible extent"* following an emergency. The CDEM Act 2002 gives effect to the National Civil Defence Emergency Management Plan 2015, which sets out the roles and responsibilities of lifelines (and others) in reducing risks and preparing for, responding to and recovering from emergencies. However, while the CDEM Act 2002 and National CDEM Plan 2015 may be used by utilities to support investment decisions, there has been no real compliance monitoring of this legislation to date.

Other relevant regulation common to many sectors includes:

- The Building Act, which sets standards for building quality and resilience, with higher standards for important sites.
- Some sites, such as fuel terminals, are regulated with respect to safety through the Health and Safety at Work Act (Major Hazard Facilities) which requires operators to identify and eliminate / minimise risks and hazards.
- Consenting requirements under the RMA also consider risk mitigation in the location and design of infrastructure sites.
- The RMA which now recognises the management of significant risks from natural hazards as a new matter of national importance.

6.2 Lifeline Utilities Investment Programmes

New Zealand's infrastructure networks have all been designed to be resilient to varying degrees. Technical resilience is inherent in many networks through redundancy (multiple paths of supply) and robustness (design codes for strength). However geographical constraints and the size of our population makes redundancy in all networks impractical and unaffordable.

Most lifeline utilities have in place asset/activity management plans with medium to long term investment programmes to renew and improve the networks.

While recognising major infrastructure investment is ongoing, there is no national picture of required and planned investment specifically focussed at improving infrastructure resilience. For this edition of the report, NZLC attempted to compile information on significant resilience programmes and projects to provide this national picture. However, most organisations either did not have specific resilience categories in their investment programmes or noted that major resilience projects (without other drivers such as growth) fail to pass benefit-cost thresholds under current funding models.

Discussion Topic: A Strategic Governance Framework for Critical National Infrastructure

The current governance, regulation and funding arrangements have been broadly described in this report.

There are examples in other countries where governments have taken a more strategic governance and coordination framework for critical infrastructure management. The intention being to enhance critical infrastructure resilience, in both the short-term and the longer term.

In the short-term, this could start by agreeing a common definition of critical infrastructure and developing a list of nationally critical infrastructure sectors (the existing CDEM Act definition of lifeline utilities is sometimes quoted but has a much narrower focus than other international definitions).

In the longer term, individual agencies and private sector organisations can continue to progress separate pieces of work as part of business-as-usual in their existing areas of responsibility. However, another option is for government to lead the development of a national approach to critical infrastructure resilience. This could include development of a national strategy for critical infrastructure resilience and establishing legal frameworks and formal arrangements to support outcomes.

There are also no nationally consistent standards for resilience applied to New Zealand's critical infrastructure, and little clarity on what acceptable levels of service are following different event scenarios.

Growth in some parts of New Zealand is both contributing to and reducing resilience. Growth has been a major driver for several investment programmes which will also add to network redundancy and resilience. However, it also reduces the spare capacity of existing infrastructure.

6.3 Regional Lifelines Group Initiatives

The first Lifelines Project was initiated in Wellington in the late 1980s. This was followed by the commencement of projects in Christchurch (1993) and Auckland (1995) with similar projects following in several cities and regions over the following decade. Each project typically culminated in the establishment of a Lifelines Group to progress and monitor recommendations arising from the Lifelines Projects.

The work that Regional Lifelines Groups undertake provides a collective layer of risk management and resilience planning that builds upon and links across the work undertaken by individual lifeline utilities. Regional Lifelines Groups include representatives from lifeline utilities, CDEM Groups, emergency services and local councils in the region and typically aim to:

- Encourage and support the work of all lifeline utility organisations in identifying hazards and mitigating the effects of hazards on lifeline utilities.
- Facilitate communication between all lifeline utility organisations and other organisations involved in mitigating the effects of hazards on lifelines, to increase awareness and understanding of interdependencies between utilities and organisations.
- Coordinate lifeline utilities input into Civil Defence Emergency Management (CDEM) planning activities.
- Create and maintain awareness of the importance of lifelines, and of reducing the vulnerability of lifelines, to the various communities reliant on lifelines services.

Regional lifelines projects typically produce a summary of impacts and recovery times following scenario hazards, but the progression of mitigation work is left solely to the individual lifeline utility. A recent exception is the Wellington Lifelines Group Programme Business Case which compiled a coordinated and prioritised programme of infrastructure works to mitigate the region's vulnerability to earthquake and other hazards (a case study is presented in Section 5.2).

6.4 National Collaborative Initiatives

Outside of regional lifelines projects, there are other major programmes underway seeking to improve New Zealand's infrastructure resilience, both by individual lifelines (such as NZTA's resilience programme) and through other forums. Case studies on major programmes were included in Section 5. Other initiatives include:

- The 'Built Environment Leaders Forum – Summary of Findings June 2017' has a range of actions to build a more resilient built environment. It covers a wide range of areas such as governance, leadership, decision making, public engagement and the evidence base.
- The National Disaster Resilience Strategy (NEMA), which identified a key objective as *"Address the capacity and adequacy of critical infrastructure systems, and upgrade them as practicable, according to risks identified."*
- Treasury's 2015 National Infrastructure Plan identified a number of key actions, including providing mandate and support for lifelines group activity. The Plan identified shortcomings in all sectors between the level of resilience that can be expected from a national perspective and identified a number of priority areas including three waters, ports, rail and national roads.
- The National Asset Management Support Group (a committee of the Institute of Public Works Engineering Australia continues to develop guidance and build industry capability in asset/infrastructure management of public infrastructure. Managing risk and resilience is an important component of this work.

- The National Science Challenges (mainly "Resilience to Nature's Challenges", "Better Homes, Towns and Cities", and "Deep South" (Climate Change)) are substantial multi-organisation research programmes including programmes of work aimed at infrastructure resilience.
- The Transport System Strategic Resilience project across all agencies of land, air and marine transport.
- The Ministry for the Environment National Climate Change Risk Assessment Framework, the risk assessment itself underway and the subsequent National Adaptation Plan will follow. Future national climate change risk assessments will be undertaken by the Climate Change Commission at up to 6-yearly cycles.
- Many other university research programmes including Quake Centre, QuakeCoRE, Resilient Organisations and others.

6.5 Lifeline Utility Organisational Resilience

It is important to recognise that resilience does not just apply to the physical lifeline networks – the organisations themselves need to be resilient. This brings many other aspects into consideration such as financial resilience, leadership, the ability to adapt and customer awareness.

The organisational resilience of infrastructure service providers is increasingly recognised as a key ingredient to overall resilience improvement. The guidance, tools and products of Resilient Organisations (www.resorgs.org.nz) are strongly founded on advice and experience with infrastructure providers.

Associated with Resilient Organisations, GNS Science and Market Economics is the MERIT (Measuring the Economics of Resilient Infrastructure) tool which offers considerable opportunity to better represent the impacts on communities and the considerable benefits to be gained by increased infrastructure resilience. The input from Resilient Organisations enables consideration of impacts on businesses over time of prolonged outage and incorporates adaptation strategies, often leading to lesser economic impacts than direct analysis would indicate. The MERIT tool is in a state of continual improvement and development but is being applied by NZTA, potentially electricity sector transmission and distribution entities, ports, local authorities and others.

6.6 Research Initiatives

The research sector is a major contributor to our understanding of hazards, impacts of hazards on infrastructure and potential risk mitigation strategies. Many of these are collaborative initiatives with government and stakeholder agencies, such as major hazard-specific programmes described in previous sections. A significant amount of work is being undertaken through the National Science Challenge.

The proposed areas of future work are summarised in Attachment 3.

7. Next Steps

This section identifies gaps in our understanding of critical lifelines and community infrastructure, their vulnerability to hazards and knowledge of the hazards themselves. Areas of further work are recommended to close these gaps – many of these are well beyond the resources of Lifelines alone but are considered nationally important to guide infrastructure investment to meet community needs and expectations.

7.1 Knowledge Gaps

The following knowledge gaps and opportunities have been developed through engagement with NZLC members and stakeholders in the development of this report.

Knowledge of Critical Lifelines and Community Impacts

Gaps identified in the knowledge of critical lifelines and community impacts include:

- 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.

Understanding of Impacts of Hazards on Lifelines Infrastructure

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 and volcanic ash posters.
- Further work on earthquake and cascading impacts on electricity (e.g., landslides / hydro lakes).
- Inclusion of other hazards – rural fires, disruptive technologies, cyber-attack, space weather, other malicious acts.
- 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)

Hazards

There are a number of national hazard datasets/maps to support vulnerability assessments. Potential areas for further work identified during this assessment include:

- National volcanic ashfall modelling scenarios.
- Updated tsunami inundation modelling supported by high resolution bathymetry and topographic data (while there are a number of initiatives underway none have national reach and are largely local to regional scale).
- Probabilistic seismic hazard modelling and associated landslide and liquefaction hazard.

7.2 Next Steps

This report represents a strategic overview of nationally significant infrastructure and its vulnerability to hazards drawing largely on existing documented information and advice from lifelines organisations. There are many areas of further work that can be progressed by a range of agencies, including:

Improve Understanding of Risk

1. Further analysis of national critical infrastructure asset failure impacts and vulnerabilities, including across the supply chains.
2. Better engagement with the 'critical community' sectors identified in Section 4.2 to understand their critical sites and supply chains, the impacts of failure of lifelines services and extent of backup arrangements, as well as raise their readiness to loss of service.
3. Development of a clearer national level understanding of acceptable risk/service levels for nationally significant infrastructure. This could include establishing target resilience goals at local, regional, and national levels to which infrastructure providers work towards (potentially leading to a national code).
4. Modelling economic impacts of nationally significant infrastructure failures (and cost/benefit of mitigation programmes).
5. Draw on further risk assessment outputs from major regional and hazard-based projects/programmes as they progress.
6. Encourage understanding of lifeline utility organisational resilience, through the application of evaluation tools.

Action Planning

7. Develop an action plan to address strategic issues and gaps, aligned to the Built Environment Leaders Forum Findings, the National Disaster Resilience Strategy, and the National Infrastructure Plan, together with new work of the Infrastructure Commission, the Climate Commission, the Commerce Commission, and the Water Services Regulator.
8. Work with others to maintain a national view of future resilience investment programmes.

Addressing Knowledge Gaps

9. Review and map knowledge gaps identified in Section 7.1 against existing research programmes to identify which are and are not being addressed.
10. Develop maps of nationally significant infrastructure for each sector (possibly overlaid with national hazard datasets where practical).
11. Inclusion of more national overview information on the resilience of wastewater, stormwater, flood protection and solid waste services.
12. Expand the range of hazards and risks covered in Section 6 (e.g. technology failure, cyber-attack, urban encroachment) and the cumulative gradual-onset impacts and implications of climate change on infrastructure and levels of service (e.g. more frequent hazard events).

13. Include further analysis and information of the impact of new technologies as both resilience opportunities and challenges.
14. Working with others, extend to all regions in New Zealand the "Resilience Programme Business Case" approach, to confirm regional vulnerabilities, consider infrastructure interdependencies, raise awareness of service outage durations, take a community wellbeing perspective and assess the relative merits of various infrastructure investment options.

7.3 Recommendations and Actions

To progress the potential actions identified above, it is recommended that:

1. The New Zealand Lifelines Council (NZLC) continue work with its own members, government agencies, the business community, infrastructure service providers, peak bodies and others, to act as a conduit to achieving improved community outcomes from infrastructure services.
2. Lifeline Utilities use the information in this report to review and update their own risk mitigation and preparedness programmes.
3. The NZLC specifically engage with new stakeholders such as the Infrastructure Commission, the Climate Commission and the Water Services Regulator.
4. The NZLC work with the research sector to identify which knowledge gaps are being addressed in current research programmes and where there are opportunities to progress remaining gaps.

The strongest recommendation with the greatest value proposition is:

5. That a national investment be made in regional resilience business cases, to take a community and critical customer perspective, to recognise infrastructure interdependencies and prioritise across all infrastructure.

Attachment 1: List of Acronyms

AVF	Auckland Volcanic Field
CDEM	Civil Defence Emergency Management
CAA	Civil Aviation Authority
FMCG	Fast Moving Consumer Goods
DEVORA	Determining Volcanic Risk in Auckland
GNSS	Global Navigation Satellite System
LiDAR	Light Detection and Ranging
LPG	Liquid Petroleum Gas
MBIE	Ministry of Business, Innovation & Employment
MfE	Ministry for the Environment
NEMA	National Emergency Management Agency
NZLC	New Zealand Lifelines Council
NZTA	Waka Kotahi The New Zealand Transport Agency
RMA	Resource Management Act
TCF	Telecommunications Forum
UFB	Ultra-fast broadband

Attachment 2: Glossary

Term	Definition
Asset	The physical hardware (e.g., pipes, wires), software and systems to own, operate and manage Lifelines Utilities (energy, transport, telecommunications, water). In the broadest sense this includes utility business owners, operators and contractors.
Asset Management Plan	A document that specifies the activities, resources and timescales required for an individual asset, or a group of assets, to achieve the utility's asset management objectives.[7] *Note:* May extend to information on funding plans.
Business Continuity Planning	An organisational activity to build its ability to maintain its internal systems and operations, in order to promote service continuity to customers.
Consequence	The impact of a supply outage on direct customers, usually extending to include the downstream impacts of the outage on society as a whole.
Critical Assets (Sites / Facilities / Routes)	Assets that have a high consequence of failure with potentially significant consequences to societal wellbeing. *Note:* Both Infrastructure and community sites/facilities will generally feature in regional lifelines group critical sites / facilities lists.[8] A broad criticality rating of *Nationally Significant, Regionally Significant and Locally Significant* has been used.
Critical Customer	An organisation that provides services deemed critical to the functioning of communities and that rely on lifelines services to function. For this report, these include emergency services, health, banking, Fast Moving Consumer Goods and Corrections services, as well as the lifeline utilities themselves.
Emergency .	A situation that • is the result of any happening, whether natural or otherwise, including natural hazard, technological failure, failure of or disruption to an emergency service or a lifeline utility; and • causes or may cause loss of life, injury, illness or distress, or endangers the safety of the public or property; and • cannot be dealt with by emergency services, or otherwise requires a significant and co-ordinated response under the Civil Defence Emergency Management Act 2002. *Paraphrased from the Civil Defence Emergency Management Act 2002*
Event	An occurrence that results in, or may contribute substantially to, a utility supply outage (i.e. an inability to continue service delivery). *Notes:* This informal term is often used by lifeline utilities to refer to the onset of a hazard or an emergency. Events can be 'external', i.e. something that happens to the utility, or 'internal', i.e. a breakdown within the utility.
Exposure	The extent to which an asset is potentially exposed to a hazard.
Four R's	Categories that form a framework for emergency planning and post-event actions. New Zealand's civil defence emergency management framework breaks down into four such categories: *Reduction, Readiness, Response and Recovery*. • *Reduction* means identifying and analysing risks to life and property from hazards, taking steps to eliminate risks if practicable, and, if not, reducing the magnitude of their impact and/or the likelihood of occurrence

7 Based on the definition in the ISO Asset Management Standard.

8 A list in *The Guide to the National CDEM Plan* identifies these and other sectors and areas that should be prioritised in *response* and *recovery.*

Term	Definition
	• *Readiness* means developing systems and capabilities before an *event* happens to deal with *risks* remaining after *reduction* possibilities have been put in place, including self-help and response programmes for the general public and specific programmes for *lifeline utilities,* emergency services and other agencies. The term *preparation* is sometimes used • *Response* means actions taken immediately before, during, or directly after an *event* to save life and property and to help communities begin to recover • *Recovery* means efforts and processes to bring about the immediate, medium-term, and long-term holistic regeneration and enhancement of a community after an *event.* *Paraphrased from the National CDEM Plan*
Global Navigation Satellite Systems (GNSS)	GNSS provides the positioning, navigation and the timing (PNT) of data exchange between/to users worldwide and is now used extensively in many of New Zealand's critical infrastructure sectors (e.g., transport and information and communications technology (ICT) networks).
Hazard	Something that may cause, or contribute substantially to the cause of, a utility performance failure. *Adapted from the CDEM Act 2002.*
Hotspot	Place where especially significant assets of different infrastructure utilities or sectors are co-located. *Notes: It is envisaged that the 'location' will be 'tight' – the underlying principle is 'if a hazard strikes here, several asset-types will be affected'. Bridges often offer good examples. There doesn't need to be a 'supply' relationship between the assets for a hotspot to exist. Simple co-location is the test.*
Interdependence	Relationship between infrastructure types characterised by one's need for supply from another in order for their service to function.
Lifeline Utility	Lifeline utilities own and operate the assets and systems that provide foundational services enabling commercial and household functioning. *Notes:* Lifeline utilities are defined formally in the CDEM Act to include those operating in the following sectors: electricity, gas, petroleum, telecommunications, broadcast media organisations, ports, airports, roads, rail, water, and wastewater. The term 'critical infrastructure' is sometimes used.
Lifelines Groups	Regional collaborations, typically bringing together representatives of utilities, the science community, emergency managers, emergency services and other relevant professionals, with the objectives of improving the resilience of the region's lifeline utilities. Lifelines Groups focus on the first two of CDEM's *Four R's*: *Reduction* and *Readiness*.
Likelihood	The probability that an event will occur. *Note:* Depending on the context, 'likelihood' can be applied either to natural hazard return periods (e.g.,1:100 year flood) irrespective of whether a supply outage results, and to *events* (essentially, outage-causing occurrences whatever the cause).
Locally Significant	An asset or facility that, if it failed, would cause a loss of service of local impact (broadly, loss of service to more than 2,000-5,000 customers, or partial loss of service across the country). *Note:* The threshold for 'locally significant' used in regional lifelines projects has varied.
Mitigation	The asset-related or operations related steps of a utility to reduce or eliminate supply outages.
Nationally Significant	An asset or facility that, if it failed, would cause a loss of service of national impact (broadly, loss of service to more than 100,000 customers, or partial loss of service across the country).

Term	Definition
Pinchpoint	Utility asset or site where a satisfactory alternative is not available, and which is therefore essential to service delivery. *Note: Pinchpoint* is equivalent to a 'single point of failure' (a term sometimes used in telecommunications) or 'bottleneck' (a term often used in road transport).
Resilience	The state of being able to avoid utility supply outages, or maintain or quickly restore service delivery, when *events* occur. *Notes: It is sometimes helpful to distinguish:* • *'technical' or 'asset-related' resilience: i.e. the ability of physical system(s) to perform to an acceptable/desired level (and beyond the design event to prevent catastrophic failure) when subject to a hazard event* • *'organisational' resilience: i.e. the capacity of an organisation to make decisions and take actions to plan, manage and respond to a hazard event in order to achieve the desired resilient outcomes. Adaptation by the utility following an outage-threatening event can be an important aspect of resilience.* *Similarly, the broad 'service delivery' resilience focus adopted in this glossary draws attention to three components adopted by the New Zealand Lifelines Council):* • *Robust assets (bringing in the engineering perspective)* • *Effective coordination pre-event and during response and recovery (participation in Lifelines Groups and sector coordination entities assist here)* • *Realistic end-user expectations (utilities have roles in fostering an appreciation that occasional outages will occur)* *The National Infrastructure Unit's (NIU's) description of resilience (one of its six 'guiding principles') is 'national infrastructure networks are able to deal with significant disruption and changing circumstances'. The extension to 'changing circumstances' broadens the interest to include pressures other than outage events.*
Regionally Significant	An asset or facility that, if it failed, would cause a loss of service of regional impact (broadly, loss of service to more than 20,000 customers, or partial loss of service across the region). *Note:* The threshold for 'regionally significant' used in regional lifelines projects has varied.
Risk	The effect of uncertainty in meeting objectives. Usually described as the combination of *likelihood* and *consequence*.
Risk Management	A **s**ystematic process to identify, analyse, evaluate, treat, monitor, and review *risks* that cannot be reduced. *Notes: Risk management has an 'event-specific' emphasis, i.e. typically addressing identified risks – likely to be those where the likelihood and consequence are greatest. In common with business continuity planning, risk management may be undertaken both by utilities and by organisations that depend on infrastructure services.*
Vulnerability	The utility state of being susceptible to loss of utility service delivery/outages when *events* occur and being unable to recover quickly. *Notes: The serviceability loss could arise from a failure of the utility's assets or systems, or from any external event. Vulnerability and resilience can be regarded as opposite ends of a continuum.*
Vulnerability Study	A review of and report on utility *vulnerability*, generally undertaken at regional level by Lifeline Groups. *Notes: Vulnerability studies generally include description of interdependencies and may also identify hotspots and pinchpoints.*

New Zealand Lifelines Council

Attachment 3: Major Research Programmes

Programme	Future Work
AF8	Next phase being scoped for further funding.
Deep South Science Challenge	Next phase being scoped for further funding.
DEVORA	Major project supported by EQC and Auckland funding, with co-funding from a number of additional organisations: ▪ Governance around unrest and eruption (PhD shared with RNC2); ▪ Crustal structure for clarity around magma ascent (PhD); ▪ Novel monitoring opportunities for earlier magma detection and reduced uncertainty (working group); ▪ Unrest and eruption decision support for emergency management (PhD); ▪ Eruption gas dispersion and impacts (MSc/PhD); ▪ Calculation of risk and loss from Auckland eruption scenarios, and initiation of probabilistic approach (PhD).
DIA	Cross-government Community Resilience to Natural Hazards and Climate Change Work Programme. The aim is to support decision makers at all levels to identify and choose risk treatment strategies that support community resilience. At the request of LGNZ this group is currently focussing on flooding hazards and climate change impacts.
ECLIPSE	ECLIPSE is working with CDEM, Lifelines and local Iwi to co-produce: ▪ A decision support and planning framework for unrest and eruptions. ▪ Unrest and eruption scenarios for the area from Taupo to Tarawera. ▪ Impacts (including to infrastructure) from both unrest (earthquakes, tremor, ground deformation, geothermal changes, landslides) and the wide range of eruption hazards in the central Taupo Volcanic Zone caldera complex area. ▪ A wide range of physical science related to the magma systems and interaction with fault-lines and earthquakes to reduce uncertainty in the next unrest episode.
EQC	▪ Upgrading RiskScape (with GNS and NIWA) - (further details below) ▪ Member of the MBIE-led governance group overseeing the update to the National Seismic Hazard Model (NSHM). ▪ Supporting DEVORA, It's Our Fault and QuakeCentre programmes including infrastructure, buildings, land performance and hazards work. ▪ Supporting several local councils to identify and map liquefaction hazards and recently transferred its automated groundwater monitoring network of around 250 with high-tech sensors to the Christchurch City Council. ▪ Supporting a 2-3 year project led by MBIE on updating the National seismic hazard model – working with GNS and other govt agencies. This update will in time feed into design loading standards. ▪ Supporting NZSEE in Phase 1 of developing a think piece for building design for the 21st century.
GNS	Major projects supported through MBIE's Strategic Science Investment Fund: ▪ A multi-year project is on-going to develop an end-to-end framework demonstrating various aspects of hazards and risk management including impact, recovery, risk communication and risk governance. The research supports scientifically advanced models for regional cascading hazard and impacts on physical/social/economic environment from a Hikurangi subduction event. ▪ Current research on infrastructure networks: A computational platform in the form of a decision support system (DSS) is being developed to analyse infrastructure networks including their interdependencies to determine service disruptions and recovery time after a hazard event for regional scale networks. The DSS can link with RiskScape damage models and generates outputs required

Programme	Future Work
	for socio-economic modelling. DSS provides user-friendly platform to run several 'what-if' scenarios required for decision making. ▪ Research is underway to apply probabilistic methods to assess and generate heatmaps of potential impacts in regional networks. The research is supported by GIS platform and associated tools.
Hikurangi Subduction Zone	East Coast Life at the Boundary (East Coast LAB) is a collaborative programme that brings stakeholders together across the East Coast to foster well connected research to increase understanding of the plate boundary and associated natural hazards, e.g. earthquakes & tsunami. Upcoming is: ▪ Publication of the Hikurangi Response Planning Toolbox (from the Hikurangi Response Planning project), to help inform and advance response planning for a large Hikurangi subduction zone earthquake and tsunami. ▪ Building on the Hikurangi Response Planning project, research is proposed with EQC and GNS improving tsunami loss modelling capability in programs like RiskScape by building a set of scenarios. ▪ Proposed recovery research through Massey University to ensure councils make adequate provisions for the costs of a potential disaster in terms of the recovery process, and development of a framework to improve the economic resilience and recovery of businesses after large disasters.
NIWA	▪ RiskScape: continual development of a multi-hazard risk modelling software application. Current development focuses on deterministic and probabilistic modelling functions, compatible with all infrastructure network components. ▪ Hazard Vulnerability and Impacts: post-event investigations of flood (fluvial and coastal) and tsunami hazard impacts for building and infrastructure component vulnerability function development. National and local level assessments of hazard exposure and impacts from flood and tsunami hazards under current and future climate scenarios. ▪ Adaptation to coastal change: guidance on adaptive design of infrastructure, serious games for decision-making under climate uncertainty, updated sea-level rise trends and projections (with the NZ SeaRise Programme, Victoria University of Wellington): https://www.searise.nz/ ▪ Flood hazards: national flood (river/rainfall) model and implications of climate change (MBIE Endeavour proposal and ongoing strategic science funding) ▪ High Intensity Rainfall Design System (HIRDS v4): ongoing development of the tool for estimating future rainfall intensities for different rainfall durations (1 to 120 hours) for different average recurrence intervals: https://niwa.co.nz/information-services/hirds/help ▪ Versatile adaptation of coastal roads (Resilience Science Challenge with University of Auckland Civil and Environmental Engineering) – development of more adaptive and versatile response options for coastal roads arising from ongoing sea-level rise and wave/storm surge overtopping. ▪ Coastal flooding (storm-tide and wave overtopping) forecast tools for low-lying coastal areas, connected to operational weather, wave and storm surge forecasting system EcoConnect. First pilot is being trialled in Christchurch.
Resilience Science Challenge – Built Environment	Recently completed and upcoming projects summarised in a wiki page that is regularly updated - link.
TTVF	Current major programme of work underway to improve understanding of impacts and regional recovery options following a significant eruption.

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