Aotearoa New Zealand's Critical Infrastructure

A National Vulnerability Assessment

PART C: INFRASTRUCTURE SECTORS AND HAZARDS ASSESSMENT

2023 Edition






New Zealand Lifelines Council

Prepared By:

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New Zealand Lifelines Council Members

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This document is an easy-to-read summary of the considerable effort and findings contained in the more detailed "New Zealand Critical Lifelines Infrastructure National Vulnerability Assessment, 2020 Edition" available online on several websites.

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PART C:

INFRASTRUCTURE SECTORS AND HAZARDS ASSESSMENT

PART A: SUMMARY

Section 1: Summary

- For those with limited time - provides cross-reference into the main report for detail.
- Summarises the report purpose and context.
- Provides background to critical customers and communities, critical national infrastructure.
- Summarises key sector vulnerabilities.
- Outlines proposed next steps.

PART B: MAIN REPORT - INFRASTRUCTURE RESILIENCE IN NEW ZEALAND

Section 2: Introduction

- NZ Lifelines sector, report purpose, approach and content.

Section 3: Infrastructure Serving Communities

- Critical customers, critical infrastructure and their dependencies and interdependencies, plus national infrastructure 'hotspots'.

Section 4: National Resilience Drivers and Initiatives

- Regulation and funding for lifeline utility resilience and major lifeline utility resilience initiatives.

Section 5: Next Steps

- Potential areas of further work are identified to close gaps identified during this update.

PART C: INFRASTRUCTURE SECTORS AND HAZARDS ASSESSMENT

Section 6: New Zealand's Critical Infrastructure

- An overview of New Zealand's lifeline utility networks, critical infrastructure, vulnerabilities to hazards and resilience improvement programmes.

Section 7: Vulnerability to Hazards

- An overview of major hazards to New Zealand's infrastructure, plus an assessment of impacts to lifelines infrastructure arising from that hazard.

Contents

6. Critical Infrastructure Sectors

Section 6 provides an overview of New Zealand's critical infrastructure networks, services and assets. 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.

6.1 Electricity

2023 Update

A stormy start to 2023 again highlighted a key resilience issue for overhead electricity lines: tree management. In high-wind storms, vegetation often causes the vast majority of power losses, and the sector hopes a long-awaited review of the 'Tree Regulations' will provide more asset protection.

In a bad news-good news story, Cyclone Gabrielle's destructive path has raised government's attention as to why known resilience issues hadn't been addressed (an ongoing challenge in this price-regulated sector). Many damaged critical assets, such as Transpower's Redclyffe substation, had been identified as been at risk but mitigations had not been prioritised for funding.

Alongside this, a drier South Island has triggered warnings of another 'tight' winter for electricity generation. The government continues to look at possible interventions in the electricity generation market to provide more seasonal security as it decommissions non-renewable sources, though the $30B+ Lake Onslow 'battery' project may be getting priced out of contention. The market is delivering a plenitude of small-medium renewable energy generation sources, but bigger solutions may be needed for the 'dry winter' problem.

Since the previous National Vulnerability Assessment, work has been done to develop and refine the definition of critical infrastructure, illustrated in Table 4-1. This is expected to support government prioritisation of resilience and recovery funding into the future.

Criticality	Critical Infrastructure Entities	Critical Assets	Critical Infrastructure Thresholds
National	System Operator (Transpower) Major Generators National Grid Owner (Transpower)	Core Grid Infrastructure, inc. communications, data centres and control. Generation Infrastructure, inc. civil and structural Multi-regional distribution of infrastructure	Dependent community populations in excess of 200k Infrastructure serves >200MW of demand. Has a "Black Start" or stability role. Economic Losses of failure >$200M.
Regional	Grid Connected Generation National Grid Owner Lines Companies	Generation infrastructure 50kV+, non-core-grid and sub-transmission electricity infrastructure Distribution communication and control Automatic demand management systems	Dependent community populations >50k. Infrastructure serves >50MW of demand. Economic Losses of failure >$50M.
Local	Lines Companies Embedded and Co-Generation Cos	All other critical electrical assets (33kV and below) Generation Infrastructure Demand management systems	Dependent community populations >10k Infrastructure serves <>0MW of demand Economic Losses of failure >$10M

Table 6-1: Defining Critical Infrastructure – Electricity Sector

Network Overview

New Zealand's electricity network broadly comprises:

- generation stations
- national transmission grid – connecting generation stations to distribution networks (and in some cases, directly to large consumers)
- distribution networks - connecting the national grid to customers
- generation and transmission system operation (managed by Transpower)
- electricity retailers - which buy wholesale electricity and sell to customers

The transmission grid, generation sources and main load centres are illustrated in Figure 4-1. The figure highlights the distance between major demand nodes (blue circles) and generation supply sites (red circles), and the importance of the transmission networks that connect them.

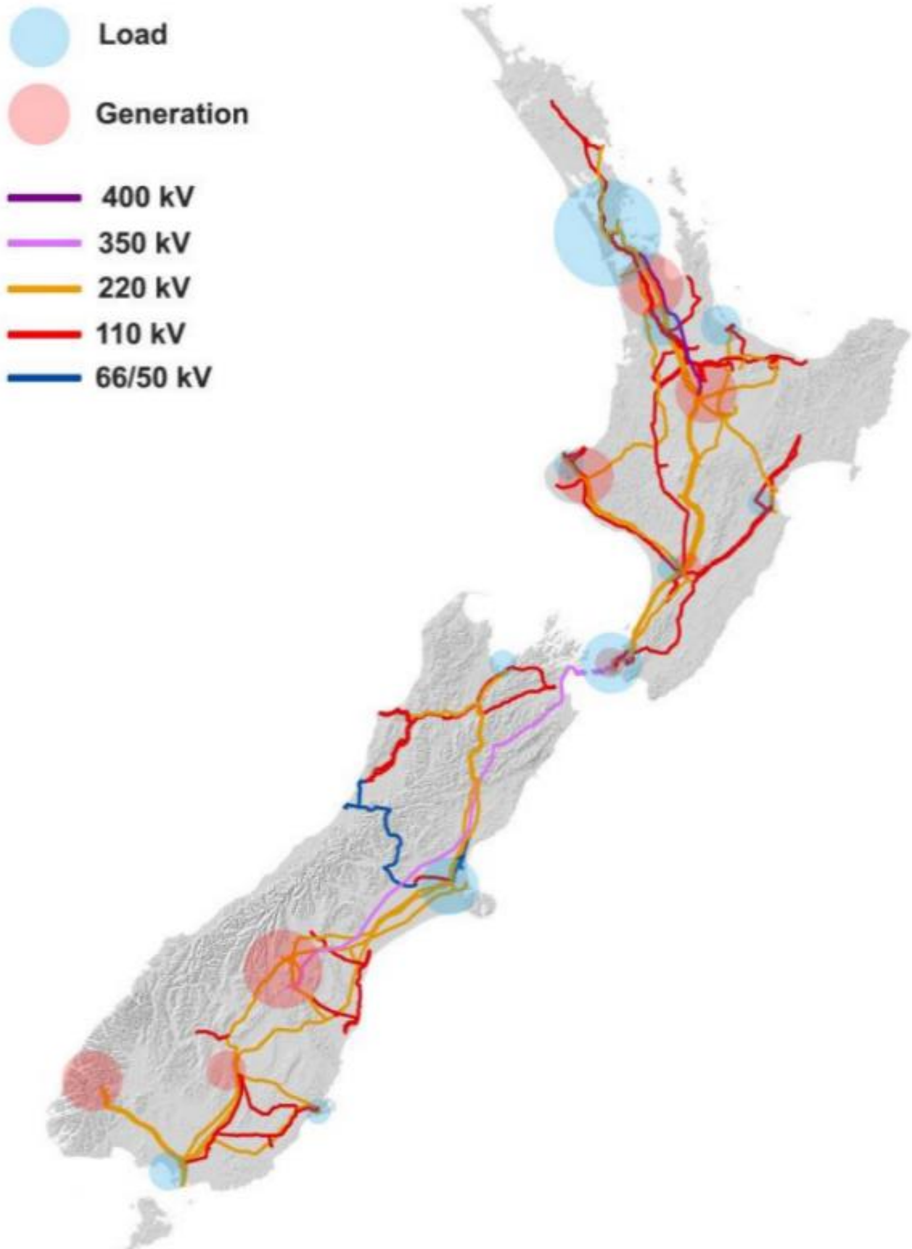


Figure 6-1: The National Grid (Transpower Transmission Planning Report, 2022)

Electricity Generation

The quantity of electricity supplied from each generation site varies by time and season; this is managed by Transpower as the System Operator. The varied source types (refer Figure 6-3) provide some redundancy against source-specific hazards, such as South Island droughts impacting hydro generation and disruptions to Taranaki gas fields.

The major generation schemes are critical to New Zealand's electricity supply and would have security of supply impacts if there was a major failure. The largest capacity sites/systems include:

- The South Island, home to the majority of New Zealand's hydro generation capacity, meeting 38-48% of New Zealand's electricity; including Manapouri (840MW capacity), Benmore (540MW), Clyde (432MW) and Roxburgh (320MW). *Depending on hydrology and water storage factors, actual generation can vary considerably.*
- The Waikato River hydro schemes - operating at maximum capacity all sources in the Waikato region (including Huntly, 954MW capacity, the largest capacity generator after Manapouri) can potentially meet 50% of New Zealand'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.

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). The Electricity Demand and Generation Scenarios prepared by the Ministry of Business, Innovation and Employment (MBIE) indicate further coal and gas retirements of 2700MW by 2050. The sector has seen an increase in the development of grid scale solar, geothermal and wind generation in the last few years.

Increasingly generation is further away from demand centres, with the top half of the North Island representing approximately half of New Zealand's population.

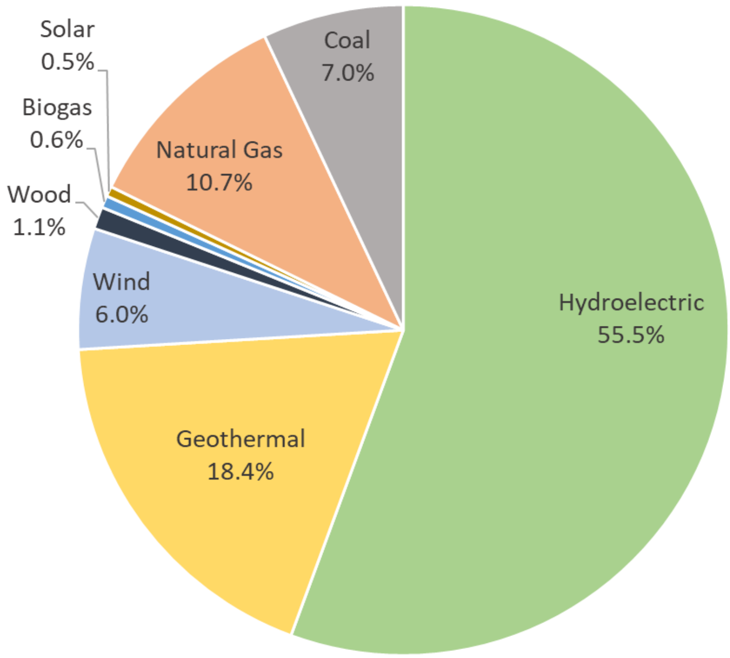


Figure 6-2: New Zealand's Electricity Generation by Type, 2021 (MBIE website)

Going Carbon Neutral

Replacing coal and gas-fired generation with renewable sources and reducing reliance on imported fuel will create new resilience challenges.

The country's dependence on electricity will increase, as will the risk associated with 'dry years' and societal expectations of a reliable electricity supply. The future closure of the Huntly Power Station, and other non-renewable sources, will need to be carefully managed.

Increased distributed generation by consumers (e.g., solar PV) is supplementing grid scale generation, but solar and wind are still weather-dependent.

Along with changing types of electricity generation, Transpower estimates a 72 per cent increase in required electricity generation to meet forecast 2050 demand, even with demand-side efficiency gains.

This concentration of risk must be reflected in market and policy settings to incentivise and reward investment in a reliable and resilient electricity sector.

Options to mitigate supply risks in dry years are currently being investigated by MBIE's New Zealand Battery Project.

Another potential strategic resilience issue is the timing of the closure of both the coal capable generation plant at Huntly Power Station and the Tiwai Smelter. Tiwai accounts for about 13% of demand in New Zealand whilst Huntly accounts for 13% generation. Without Huntly there are implications for national electricity supply during an extended period of low hydro inflows and for supply security in the upper North Island. Without the Tiwai load more generation, but not all, can be sent north via the high-voltage direct current (HVDC) inter island link.

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 4-3) which over the next decade will be:

1. **Supply to Marsden Point fuel facilities** – despite changing to be fuel storage and transfer only, the Marsden Point site still remains important for supply of fuels into Auckland. However, with increasing electrification of transport over the next decades the importance of Marsden will decline.
2. **The highest capacity transmission line in New Zealand, the 610km, 1200MW, 350kV HVDC 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 can generate sufficient capacity to meet demand within the island, however there are likely to be constraints in the North Island at peak loads or for sustained periods. 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 and the surrounding region.
4. **Bunnythorpe substation**, a key switching point between South Island generation and North Island demand (and sometimes vice versa), as are the transmission lines from Bunnythorpe to Haywards substation.
5. **Whakamaru and Wairakei substations** including the associated transmission lines are critical infrastructure supplying the Hawkes Bay, Bay of Plenty, Waikato, Auckland and Northland regions. They also connect around 800MW of hydro and almost 1000MW of geothermal generation from the Waikato region north to Auckland.
6. **Benmore substation** is a major hub linking the South Island generation and the 1200MW HVDC transmission line to Haywards (Wellington) and the North Island.
7. The **Roxburgh and Clyde substations** adjacent to the Clutha River.
8. **Pakuranga and Otahuhu substations** are critical infrastructure for Auckland and Northland regions and they each provide some resiliency via diversity and redundancy for each other. Otahuhu continues to be a critical node to the core grid.
9. Several of Auckland's grid exit point (GXPs) substations service greater than 50,000 connections, including **Pakuranga, Mt Roskill, Henderson, Penrose and Albany GXPs**. These equate to dependant populations and communities exceeding 150,000 for most of these substations. Penrose supplies an estimated 200,000+ community population.
10. **South Island transmission lines from Islington substation into Kikiwa and Stoke substations** (supplying the upper South Island). Islington is an important substation supplying Christchurch and surrounding districts, as well as a hub for lines connecting the lower and upper South Island.

11. A number of regions in New Zealand are dependent on a single transmission line for supply. Examples include Queenstown (transmission lines through Kawarau Gorge with 2 circuits), the double circuit transmission line from Wairakei to the Hawkes Bay and circuits from Stratford to Opunake and New Plymouth which also service the critical onshore gas fields (with a mutual dependency for electricity generation).

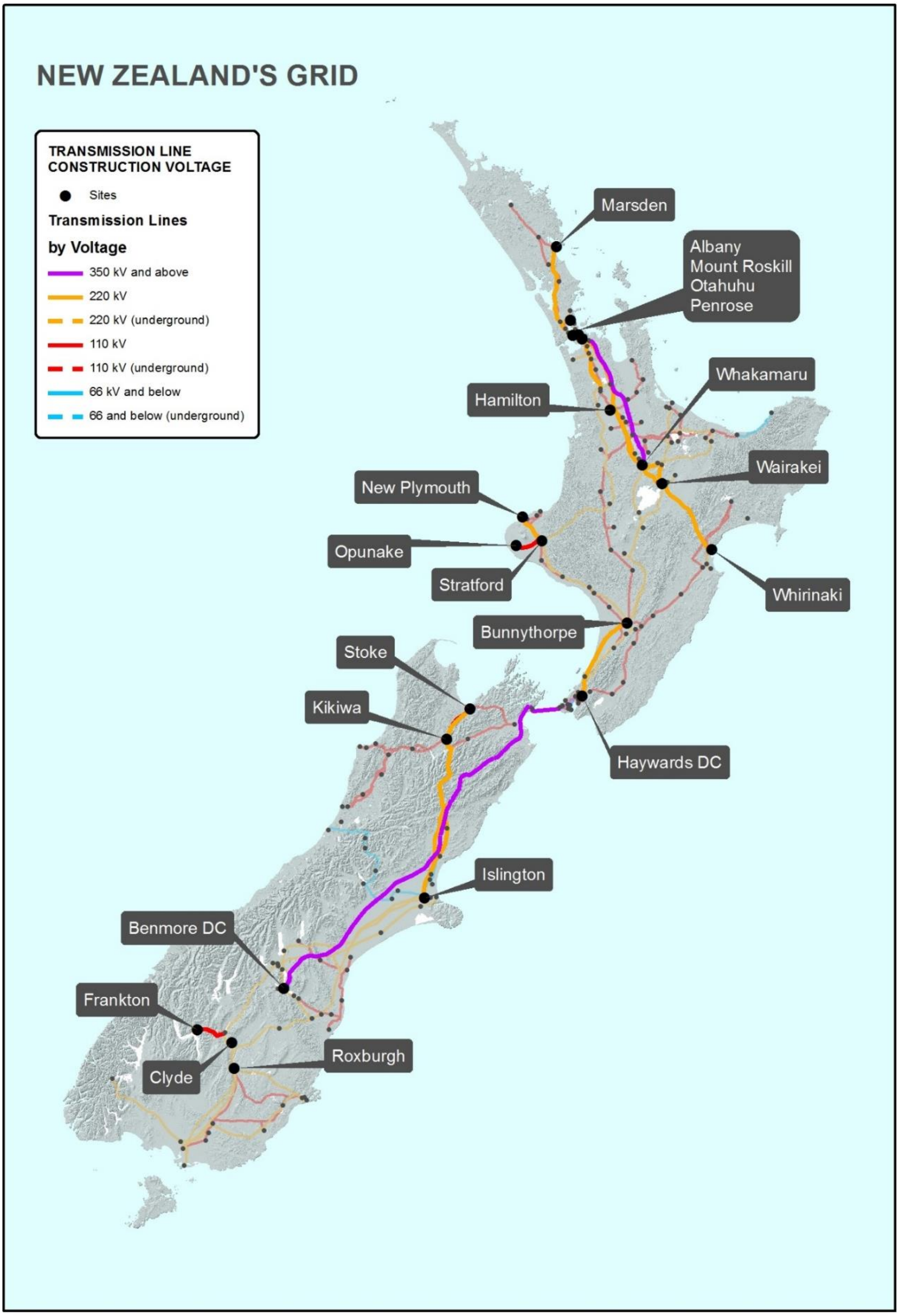


Figure 6-3: Critical National Infrastructure Assets in the National Grid (as also recognised in regional lifelines studies)

System Operation

As well as managing the national grid, Transpower is the national "System Operator", responsible for managing the power system in real-time. In this role it aims to balance supply and demand and meet system security criteria. As a last resort, to avoid system-wide blackouts, it can respond to major imbalances through mechanisms such as Automated Under Frequency Load Shedding (AUFLS). 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 and distribute them to customers via a network of substations, cables, and lines.

Critical National distribution assets are generally those that supply other critical sites dependant on electricity, such as national hospitals and major city water treatment plants. 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 backup electricity supplies.

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

Providing a resilient electricity supply

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.

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.

The onshore gas processing sites in Taranaki are extremely critical and 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 3.

Vulnerability to Hazards

The national grid passes through areas vulnerable to all New Zealand's major natural hazards. Most of the South Island's generation sources have proximity to the Alpine Fault. Some major substations such as Bream Bay and Marsden (supplying Northland) are in tsunami inundation zones, though these have been assessed by Transpower as having an acceptable risk level. Critical transmission lines pass through many areas of slip-prone terrain or are susceptible to hydrological scouring from flooding.

Physical network resilience

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. As noted earlier, most of the network can be supplied from more than one source (though sometimes the second circuit is on the same tower).

The smaller distribution networks are a combination of overhead lines and underground cables – the former tend to be more resilient to seismic activity and overhead line 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 higher design standards and are likely to survive an earthquake or at least be repairable. Distribution substation design is more variable, however the loads they supply are usually designed to a lower standard again. Impacts of tsunami and volcano scenarios are summarised in the box to right.

Wildfires not only impact structures and lines directly but can also impact the ability to operate electricity lines. With climate changes this is an increasing risk.

Dry winters

Hydro generation is vulnerable to low rainfall and drought conditions with potential impacts on security of supply.

Space Weather

Research over the last decade, such as MBIE Solar Tsunami project, has provided increased understanding and greater awareness of New Zealand-specific generation and transmission exposure to space weather events. Transpower is involved with the Solar Tsunami project to identify the location, understand the magnitude of effects, and to identify possible mitigation options for their assets and the power system more widely.

Malicious Attack

Electricity networks are critically dependent on communication and control systems, which are vulnerable to cyber-attack with strict counter-measures in place. Malicious damage to electricity assets is a known risk.

New Zealand's Major Natural Hazard Programmes: Electricity

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 Fault

- 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).

Central North Island Volcanic Zone

- Loss of central North Island generation sites, and ash disruption to transmission lines and substations, would severely constrain electricity supply to the upper North Island.
- Probabilistic models are now available.

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.

National Seismic Hazard Model, 2022

- Peak acceleration for seismic design has increased and this will have flow on impacts for electricity infrastructure resilience and design.

Climate Change – Slips/Flooding

- Increasing risk of extreme rainfall events that can cause flood damage of infrastructure and cause extended outages.
- Increased land stability issues with extreme rainfall that can undermine infrastructure.

Assets in Vulnerable Buildings

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 the 2016 Kaikōura earthquake. Even buildings with lesser damage may be inaccessible due to adjacent structures' safety issues.

Regulation and Funding

While most parts of the electricity supply chain operate as a commercial business, resilience is also influenced by sector regulation. 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.

The Commerce Commission regulates maximum revenues for 17 distribution businesses (of 29 in total), incorporating incentives for them to maintain or improve reliability. However, in general, distributors make their own investment decisions about resilience levels. Under the "information disclosure" regulations, the distribution businesses produce a summary of this information and 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 2004.

New Zealand's National Adaptation Plan has provided clearer direction on climate change, including the requirement for Transpower to develop and deliver an Adaptation Plan on how it will address exposed assets and invest in infrastructure to adapt to climate change. The treatment of resilience investments in the price regulation is currently under review by the Commerce Commission.

Transpower's publication TP Whakamana i Te Mauri Hiko.pdf (transpower.co.nz) outlines the strategic changes in the industry and their proposed responses.

The Commerce Commission is reviewing its price regulation to consider how climate change adaptation and resilience investments be best incorporated in the future.

Resilience Investment Programmes

Electricity distributors outline their capital investment programmes in their Asset Management Plans. These include projects 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 invests in national grid resilience mostly through the renewal and replacement investments, grid upgrades and 'building back better' after an event. A more proactive resilience program is planned for the 2025 – 2030 investment period, which will increase funding for risk reduction and readiness for the transmission system across a range of hazards. In addition, transmission upgrades are actively being planned for with the Net Zero Grid Pathways program that is responding to the growing number of electrification projects and renewable generation.

While there are opportunities to provide more redundancy to regions that have limited points of supply (such as Northland, West Coast, Southern Lakes and Hawkes Bay), many of these may not 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.

6.2 Fuel

2023 Update

Before it was decommissioned in 2022, the Marsden Refinery refined imported raw fuel, providing around ½ - ¾ of the country's demand. In April 2022, following its decommissioning, Refining New Zealand was re-named Channel Infrastructure in April 2022 (publicly listed, with fuel companies Z, BP, and Mobil holding around 35% ownership). The company continues to operate the Marsden Point site as a fuel import terminal only and the Marsden Point to Auckland pipeline. The two coastal ships that previously loaded fuel at Marsden and shipped it to ports around New Zealand have been returned to their owners.

A contaminated fuel issue on a fuel import ship in late 2022 threatened supply and triggered jet fuel rationing measures (though in the end, flights were not disrupted). The event seemingly validated concerns by some parties that a fuel supply network without the Marsden refining and raw fuel storage facility was less resilient. While there is still no definitive answer on this, the government is implementing regulation to mandate minimum storage of specific fuel types.

Fuel supply disruptions in Cyclone Gabrielle were mainly due to road damage hindering deliveries and fuel stations unable to operate without power/telecommunication and electronic payment systems. Continued work on regional and local fuel planning is needed to ensure priority fuel stations can provide continuous supply critical customers.

Since the previous National Vulnerability Assessment, work has been done to develop and refine the definition of critical infrastructure, illustrated in Table 4-2. This is expected to support government prioritisation of resilience and recovery funding in the future.

Criticality	Critical Infrastructure Entities	Critical Functions	Critical Assets	Critical Infrastructure Thresholds
National	Fuel Importers ('big 3') National Distributors (e.g., Allied)	Importing Fuel Pipelines supplying national airports.	Bulk Fuel Wharves / Terminals (Marsden, Wiri, Tauranga, Centreport, Lyttelton). Major fuel pipelines (Marsden-Wiri, Wellington, Christchurch port to city).	Specific thresholds may be developed, e.g., ▪ Fuel import > (x) l/day ▪ Tank storage volumes > (x) m3 ▪ CDEM-Priority 1 Fuel Stations Tank storage volumes > x m3
Regional	Other Major Fuel Retailers and Distributors.	Tank storage at national ports.	Bulk Fuel Storage Tanks at other ports/wharves (New Plymouth, Dunedin, Bluff).	
Local	All Retailers and Distributors.	Regional Priority Fuel Stations.	All assets – retail outlets, storage.	

Table 6-2: Defining Critical Infrastructure – Fuel Sector (In development)

New Zealand's National Fuel Supply System

New Zealand imports its fuel requirements by ship to coastal fuel terminals around the country, with the main importers currently being BP, Mobil, Z, Gull and Tasman Fuels. Each company manages its own refined fuel imports and storage, liaising with port/terminal companies around scheduling and stock requirements, however there is some co-mingling of fuel in shared tanks at some ports.

Distributor wholesalers are independent companies under the Fuel Industry Act 2020 which distribute fuel from ports to customer supply points, including fuel retail outlets and direct to major consumers. The location of the major fuel terminals and normal direction of internal distribution is shown in Figure 4-4.

Taranaki is an important region for the extraction of crude oil, gas and condensates, and the production of methanol. All of the crude oil and condensate production is exported.

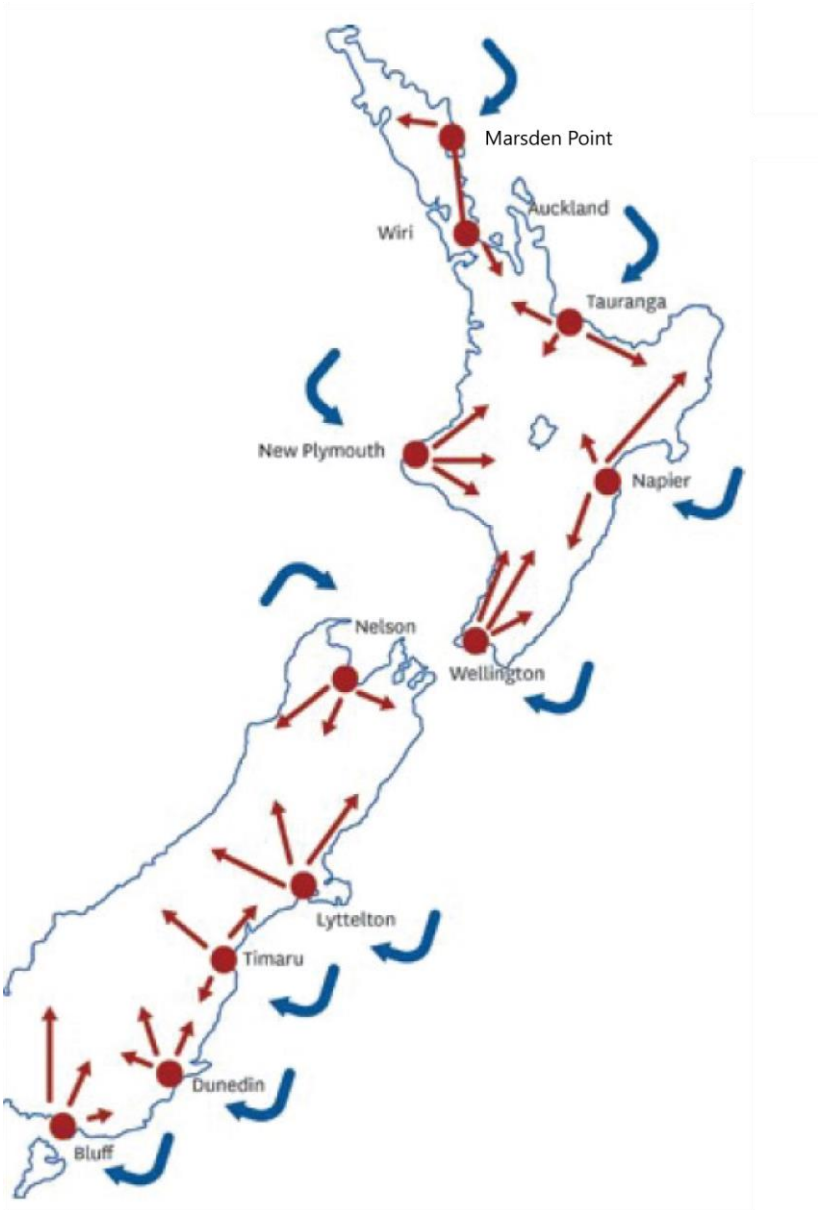


Figure 6-4: National Fuel Supply

Supply Chain Vulnerabilities

Marsden Point

The Marsden Point Terminal and jetty are critical points in the national fuel supply chain, as they supply Northland and Auckland as well as being the only supply route for Auckland Airport's jet fuel requirements. Major, prolonged disruption to these facilities would likely cause fuel supply disruptions in the North Island, with trucking from other terminals (such as Tauranga) unlikely to meet full, normal demand.

Fuel Terminals 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. The availability of suitable trucks, drivers and a functional road network to distribute fuel are the key constraints in the ability to supply areas from other ports.

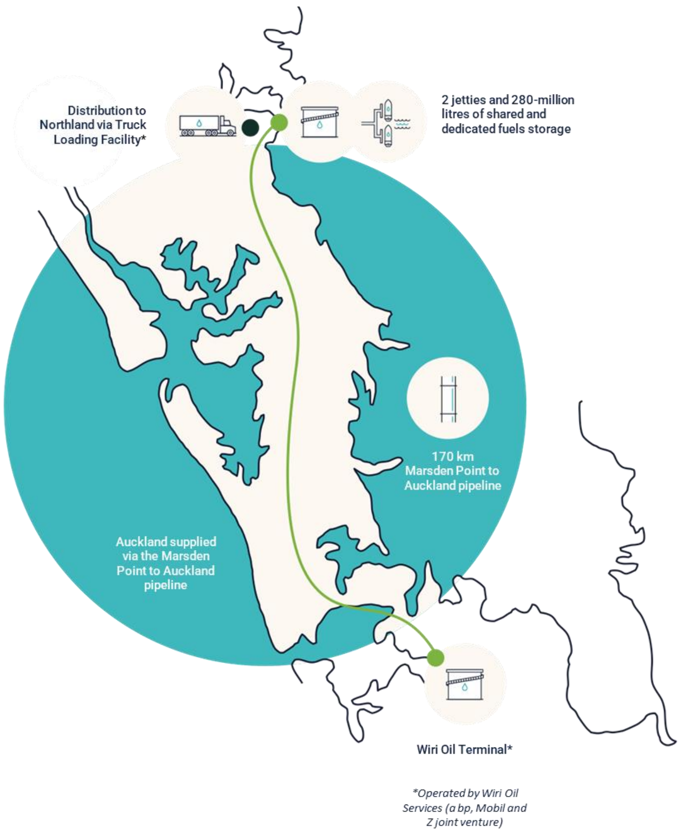


Figure 6-5: Fuel Supply to Auckland/Northland (Channel Infrastructure)

The Wiri Oil Terminal and the Marsden-Wiri Auckland Pipeline are critical facilities in New Zealand in terms of numbers of customers potentially affected by outages.

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.

In the pre-COVID-19 years, jet fuel demand and Auckland regional fuel demand increased significantly, increasing the fuel shortage risks associated with a pipeline or refinery failure. Pipeline capacity has been increased to mitigate this risk to some extent. In 2019 there was typically 6 days' supply at Wiri terminal and 2 days of Jet A1 at Auckland Airport. However, the COVID-19 demand reduction has significantly increased the days cover of jet fuel storage in New Zealand. Pipeline throughput is around 30% and there remains significant capacity in the system.

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

The major fuel 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 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:

- Most fuel terminals are in potential tsunami inundation zones, and even where they are not directly at risk, they rely on wharves being accessible. Sea level rise will exacerbate coastal hazards.
- The Marsden Point Terminal is dependent on electricity supply (which is, in itself, vulnerable to hazards), with backup generation only sufficient to ensure a safe shutdown.

Other terminals are also dependent on electricity supply though some have generator backups. Other general risks include:

- 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.
- Availability of appropriate fuel loading and unloading facilities can also prove challenging when covering for contingency events.

> **Fuel Supply and Tsunami**
>
> In 2016 a national CDEM Exercise, 'Exercise Tangaroa' tested the nation's ability to respond to a tsunami event. The event was an earthquake near the Kermadec Trench which generated waves on the New Zealand coast of up to around 10m.
>
> Exercise Tangaroa highlighted New Zealand's fuel supply vulnerability to coastal hazards. The majority of bulk fuel storage is at ports and wharves along the east coast, many in tsunami inundation areas. Damage to wharves, jetties and fuel tanks are likely to cause disruption to many points of supply.
>
> Modelling of tsunami risk at Marsden Point has shown that the jetties are largely protected by landmass, the underground pipeline should not be impacted, but the terminal tanks could suffer some damage.
>
> While there are two jetties at Marsden Point, both capable of all fuel imports, and 280 million litres of fuel storage spread across over 25 tanks, there are currently no viable plans to get fuel to shore at Marsden Point if there is complete / major damage to both jetties or all tanks.

Road Distribution Network

The primary fuel distribution points all rely on roads to connect to supply points. These are vulnerable to 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. 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 National Fuel Plan 2020 identified an area for future work is developing/identifying (JF) 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.

Customer Supply Points

Fuel is delivered and stored for supply at retail outlets. Some of these retail outlets are oil company owned and managed, but many are independently owned and manage - such as NPD, which has a big presence in the South Island, and Waitomo in the central North Island. The re-fuelling rates and the stock levels at retail outlets varies 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, and internet connection to process payments. Only a few fuel stations in New Zealand have on-site standby generation, however an increasing number have 'plug in' generator capability. The number of retail sites which rely on the internet to dispense fuel is increasing (e.g., unmanned sites).

If there is a widespread electricity outage, the number of generators available for hire in New Zealand would cover the fuel stations in one region and not much else (this is prior to considering likely substantial demand for generators for other purposes). Furthermore, most fuel tankers are gravity drop only and cannot fill above ground tanks – those with pumping gear are likely to be in high demand. The identification of 'priority fuel retail outlets', prioritising supply to critical customers, is an important response to this issue (National Fuel Plan 2020).

Many farms and industries also have their own diesel storage, though there is no national picture of such stockholdings and there is 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 Telecommuncations 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.

New Zealand's Major Natural Hazard Programmes: Fuel

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.

As a member of the International Energy Agency (IEA) 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 onshore stockholdings fall short of this, the Government makes up the shortage with 'ticket' contracts (an option to purchase stock in an IEA declared emergency).

Resilience Investment Programmes

There have been several reviews into whether the fuel storage volume in New Zealand is sufficient to ensure the right level of resilience, given possible supply disruption 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 New Zealand 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, though it is no longer available for that purpose. *As noted earlier, COVID-19 demand disruptions have eased this jet fuel storage issue, with uncertainty as to when demand will return to pre-COVID levels.*
- 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. Other low-cost contingency measures were also recommended, such as preparatory investment in mobile skids that could be deployed on any wharf to discharge fuel products into fuel tankers.
- The Wellington Lifelines Group Resilience Project raised concerns about the vulnerability of the Seaview (Lower Hutt) 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 improvement 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.

The onshore fuel storage resilience issue has arguably been exacerbated by the removal of raw fuel storage at Marsden, previously holding crude stocks and intermediate products on average equivalent to 17 days fuel cover for New Zealand. However, a Hale and Twomey report in 2020[1] concluded that this will not have a major impact on fuel security because:

- Much of the stock that will no longer be held was required to operate the refinery and the related distribution system (coastal shipping), so was not immediately available for disruptive events;
- New Zealand's stock in transit from international sources will still be a similar volume and, as 100% finished product, provides a very flexible response measure to disruptions; and
- In most domestic disruption events, the resupply constraint is set by available tanker trucks and drivers.

MBIE undertook a national fuel stockholding review in 2022, which proposed that:

- The government will enter a long-term lease agreement to store at least 70 million litres of diesel, which is the equivalent to about 7 days of normal use.
- Fuel importers and wholesalers with bulk storage facilities will be required to hold at least 28 days' cover for petrol, 24 days' cover for jet fuel, and 21 days' cover for diesel (regulations will be developed in 2023).

[1] https://www.mbie.govt.nz/dmsdocument/15257-fuel-security-and-fuel-stockholding-costs-and-benefits-2020

6.3 Gas

2023 Update

The New Zealand Government's Climate Action Plan requires transformation of the sector as it transitions out of fossil fuels as a major energy source. A Gas Transmission Plan is required by the end of 2023 to achieve the goals of the Climate Action Plan.

With increasing intermittent renewables such as wind and solar, the role of gas in energy storage and peaking generation has been highlighted as crucial in a range of independent reports. FirstGas (and others) have plans to commence blending biomethane and hydrogen fuel in with existing product within the next 12 months. Both natural gas and LPG industries are closely monitoring international developments of bio alternatives.

Since the previous National Vulnerability Assessment, work has been done to develop and refine the definition of critical infrastructure, illustrated in the table below.

Criticality	Critical Infrastructure Entities	Critical Assets	Critical Infrastructure Thresholds
National	Major Gas Producers Gas Transmission Owner	Major Production Facilities North-South Transmission Line (to Auckland, Wellington)	Supplies > 500,000 customers, or > tj demand *this takes into account large, nationally significant customers.*
Regional	Gas Transmission Owner	Other transmission lines Bulk gas storage terminals.	Supplies > 100,000 customers, or > … demand *this takes into account large 'regionally significant' customers.*
Local	Gas Distribution Owner	Gas distribution lines feeding critical customers. Bottled gas storage centres.	Supplies > 20,000 customers, or > … demand *this takes into account large 'locally significant' customers.*

Table 6-3: Defining Critical Infrastructure-Gas Sector (In development)

Natural Gas

Production

Natural gas in New Zealand is sourced from approximately 15 gas fields in the Taranaki region, 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 or trucked to Tank Farms for shipping to offshore refineries. The natural gas produced is injected into the North Island Gas Transmission system.

The Maui pipeline, Port Taranaki and Omata Tank Farm are all considered critical national infrastructure.

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. Figure 4-6 shows that, over the past 20 years, New Zealand has maintained proven and probable 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 1991, which allows for offshore existing permits to be extended or amended on their merits. 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 liquefied natural gas (LNG).

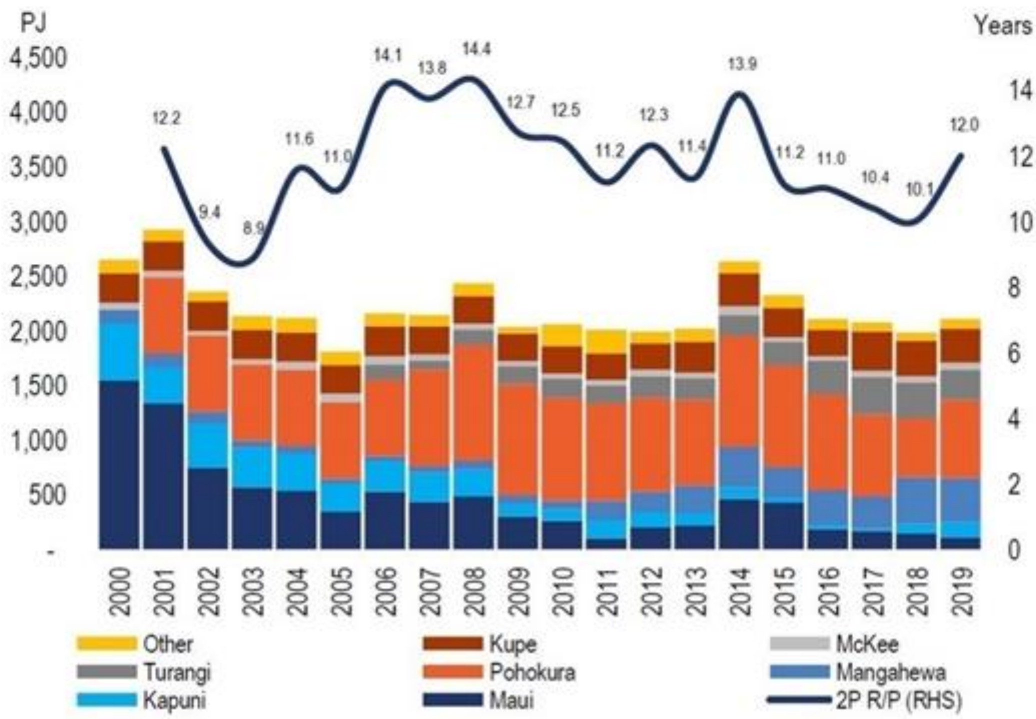


Figure 6-6: Gas Reserves and Reserves to Production Ratio (Source: Enerlytica)

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 4-7. The main north-south line, on the west side of the North Island, supplies Auckland, Hamilton and Wellington and is considered a critical national asset.

There is little loop redundancy in the transmission pipeline network. 'Line-pack' in the system, with the high operating pressure of the network, can cover very short duration disruptions, but generally a pipeline system disruption - due to physical pipeline damage for example - is likely to lead to downstream gas shortage and the need for urgent demand curtailments. The Gas Governance (Critical Contingency Management) Regulations 2008 set out how the system is managed in the event of a Critical Contingency (a shortage of gas in a specific part of the network or all of the network) in order to maintain gas supply to associated lower pressure distribution networks around towns and cities. Details for critical contingency operation can be found at www.cco.org.nz.

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.

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

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. Threats 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.

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)*.

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

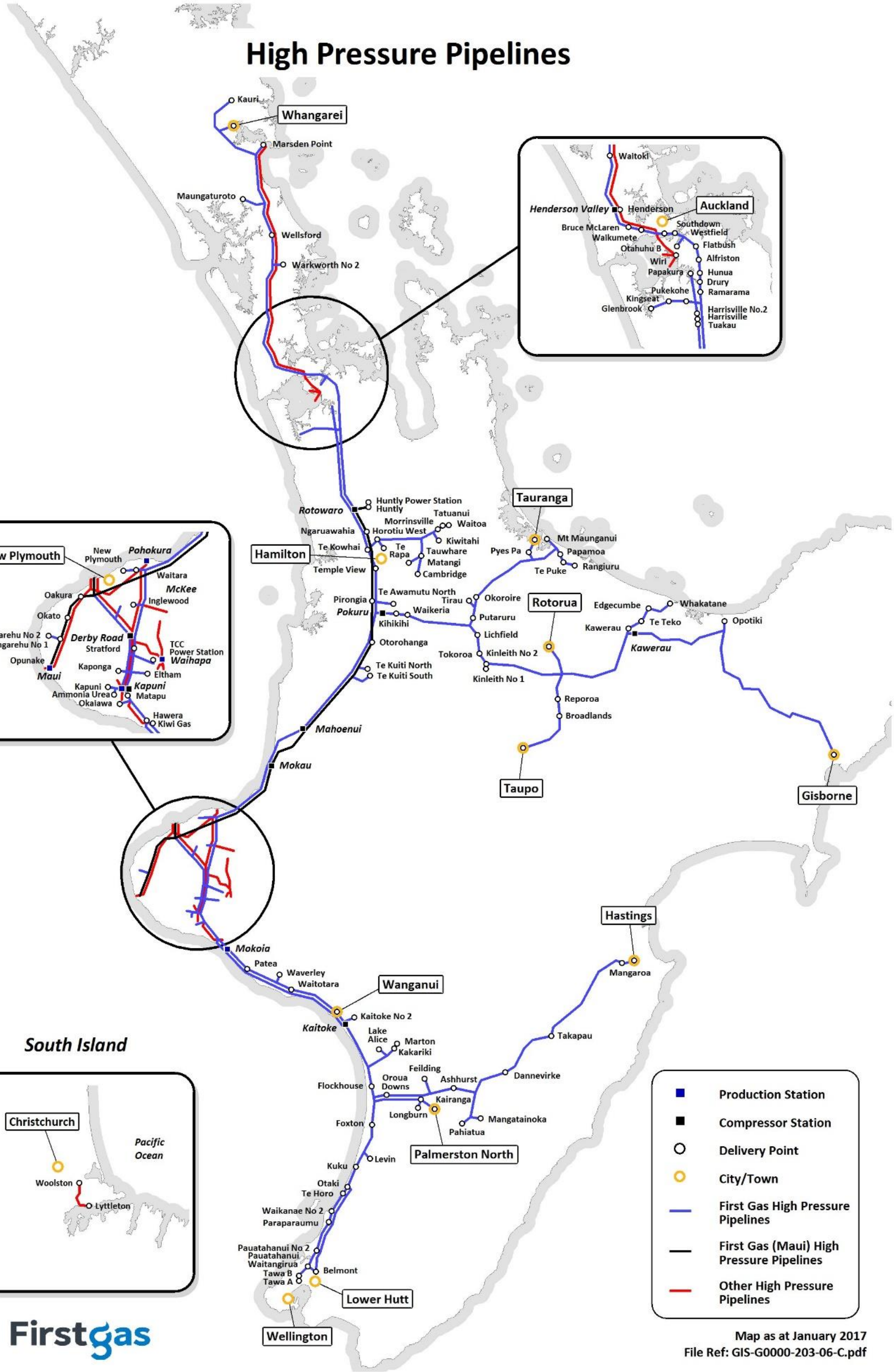


Figure 6-7: Gas Transmission in the North Island

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 which have gas as their primary source of heating and cooking.

Vulnerability to Hazards

The box on the following page summarises key hazard risks. In a natural hazard event, damage to the gas network could present its own challenges as it could be a fuel source for fire.

As with other lifeline utilities, the gas network is also at risk of malicious attack – physical asset damage and cyber-attacks.

Liquefied Petroleum Gas (LPG)

LPG is supplied from Taranaki and off-shore – a combination of imports and New Zealand 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 tankers, from where it is distributed by pipes 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.

New Zealand's Major Natural Hazards: Gas

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 of 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).

Third party damage

- In the event of a major natural disaster, it is likely that urgent response and recovery works in urban areas will cause third party damage to gas distribution networks, thus creating further hazards for rescuers and general public.

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. Distribution of LPG has a very high dependence on road access.

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 3.

Resilience Investment Programmes

First Gas, as the transmission system owner, routinely reviews the risks to pipeline operations and prioritises programs of work to ensure that the resiliency of the transmission system is sufficient. Current ongoing programs of work include:

- Inline inspection programs on all 'piggable' lines (those that can have inspection "pigs" inserted), including strain detection tools to monitor for geohazard development and pipeline movement.
- Implementing pigging improvement projects to be able to inspect pipelines which are currently "unpiggable" and unable to have an inline inspection completed.
- Major upgrades to the transmission control systems (SCADA) to ensure these are reliable and secure.
- Upgrading compression units to improve reliability and resiliency, alongside efficiency and emissions improvements.

A summary of gas transmission risks and investment plans is provided in First Gas' Asset Management Plan: https://firstgas.co.nz/about-us/regulatory/transmission/

6.4 Transport – Roads

2023 Update

A wet year in the north created sodden ground conditions, with a massive number of landslips during Cyclone Gabrielle and road managers on edge with each heavy rain warning. Many communities in Northland, Coromandel and Hawke's Bay were isolated by road for days, even weeks for some smaller rural communities.

Gabrielle also raised awareness of risks around scour damage to bridges and the viability of local road alternatives to state highways – these have been a key focus area for Waka Kotahi and local road authorities for some years, however resilience funding to start to tackle these issues has been inadequate. The silver lining of Cyclone Gabrielle is the significant step up in government funding for recovery and resilience programmes.

Climate change conditions, with the increased frequency and intensity of storms, are forcing decisions on the viability of some of the worst hit state highways in the Far North and Coromandel.

Since the previous National Vulnerability Assessment, work has been done to develop and refine the definition of critical infrastructure, illustrated in the table below.

Criticality	Critical Infrastructure Entities	Critical Assets	Critical Infrastructure Thresholds
National	NZTA-Waka Kotahi	State Highways (national) State Highways (regional) long detour times	ONRC = National ONF M1, long detour
Regional	NZTA-Waka Kotahi, local authorities	State Highways (regional) Local roads servicing critical national customers.	ONRC = Regional ONF M1 ONF M2, long detour
Local	NZTA-Waka Kotahi, local authorities	Local roads servicing critical regional customers.	ONRC = Arterial

Table 6-4: Defining Critical Infrastructure – Road Sector

Critical National Infrastructure Assets

The purpose and function of roads varies from a national perspective, with the importance and purpose reflected in a classification schema. New Zealand road authorities are moving to use the One Network Framework (ONF) system, which divides New Zealand's roads into twelve categories related to both movement and place functions. The categorisation is based on factors such as the level of use by different modes and the adjacent land uses.

This classification provides a useful baseline for criticality assessments for lifelines vulnerabilities studies. However, Road Controlling Authorities participating in regional lifelines projects have, in some cases, classified roads as nationally or regionally significant - particularly from an emergency management perspective - that appear at odds to the ONF classification. These situations can be resolved via local moderation of 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

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

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

Low lying coastal roads are vulnerable to inundation from tsunami, high water tables (with salt intrusion) and storm surges, as well as wave over-topping and coastal erosion.

Other vulnerabilities on roads include snow and ice (with associated rock fall hazards), avalanche, wildfires and traffic incidents, such as bridge strikes by trucks.

Critical national road vulnerabilities identified in regional vulnerability studies are shown in Table 4-5. For many of these roads the alternate routes are also prone to the same hazards. A further resource for State Highway risks is the Waka Kotahi National Resilience Programme Business Case 2020 - https://www.nzta.govt.nz/roads-and-rail/highways-information-portal/technical-disciplines/resilience/national-resilience-programme-business-case/.

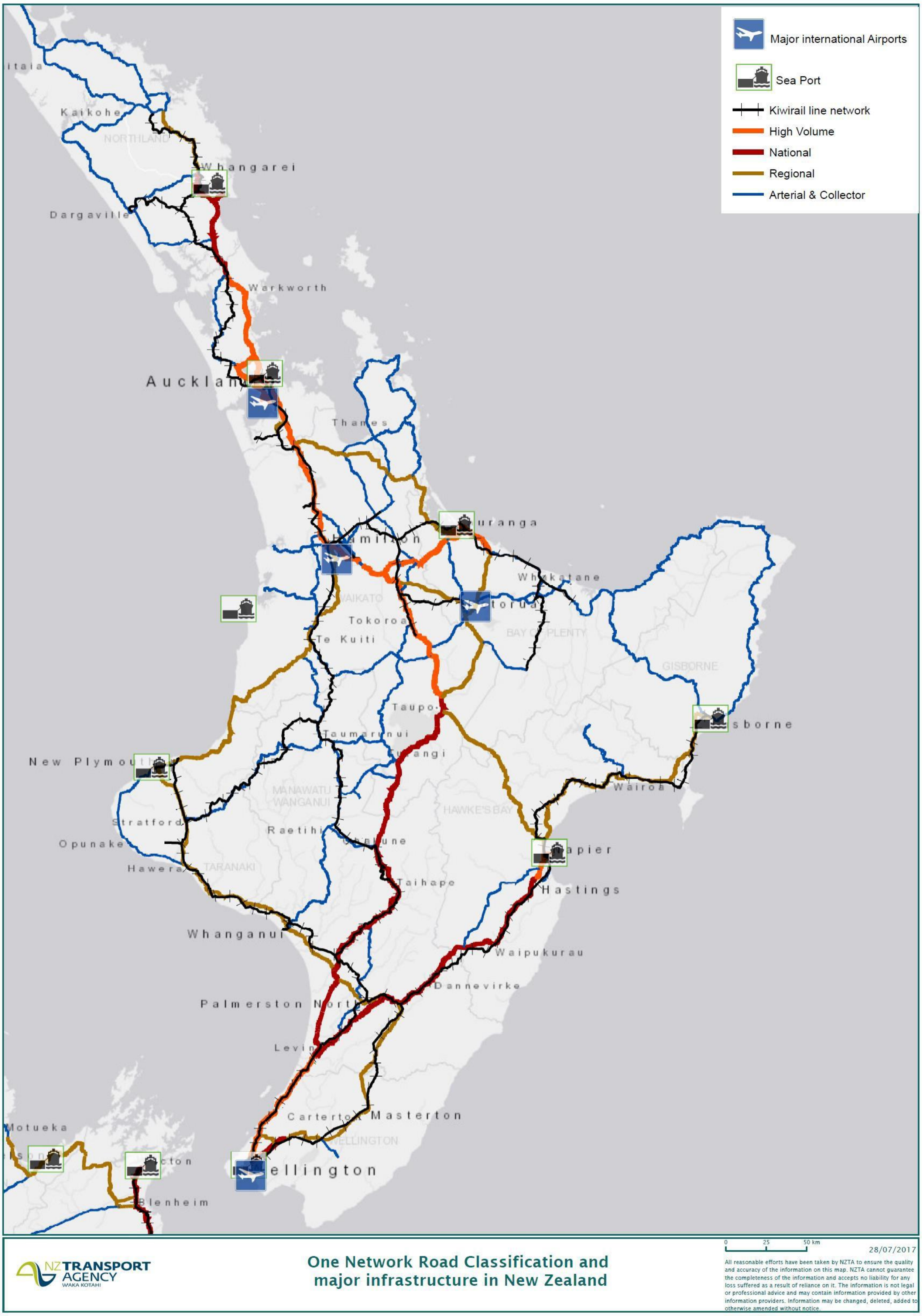


Figure 6-8: North Island Transport Infrastructure

Figure 6-9: South Island Transport Infrastructure

Regulation and Funding

Waka Kotahi allocates funding from the National Land Transport Fund on behalf of the government, for both State Highways and local roads, using an Investment Decision-Making Framework (IDMF) model. The funding allocation model is guided by the Government Policy Statement on Land Transport 2021, which includes Climate Change as a Strategic Priority. 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 ONF Level of Service and benefit measures provide some broad standards and indicators for resilience that could be referenced in funding applications.

Other general regulation and funding constraints for lifelines are discussed in Section 3.

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
SH2, 25, 35, Waikato, Bay of Plenty, Tairawhiti several locations.	Vulnerable to tsunami along several stretches.	
SH 1 Desert Road.	Volcanic and snow/ice.	
SH5, Taupō-Hawkes Bay	Landslips. Snow/ice.	Main road to Hawkes Bay.
SH 3 Taranaki North.	Volcanic and flooding/slips.	Important freight and evacuation route
SH 1 and 2 into Wellington.	Seismic and flooding/slips.	Long detours, key access to interisland ferries
SH 1 Kaikōura Corridor.	Landslips (rain and earthquake), inundation, tsunami.	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/rock fall.	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.
SH88, Dunedin	Tsunami / coastal flooding	Link to Port Chalmers
In addition, roads to critical national transport links such as major ports and airports.		

Table 6-5: Nationally Significant Roads with Hazard Exposure

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

Resilience Investment Programmes

There are several sources of funding being used in Transport Resilience Improvement Programmes, such as: the National Land Transport Fund/Plan (NLTP), New Zealand Upgrade Programme, Provincial Growth Fund, and local authority rates. The NLTP is the largest source of funding for Transport Resilience improvements.

Although the NLTP has many transport projects, which have multiple drivers, there is no exclusive 'resilience' budget allocation or activity class. Of these projects, ones that are primarily targeted at resilience improvements are prioritised against all other improvement project types and often do not receive a high priority (due to inability to demonstrate a good return on investment). Minor resilience works (<$2M) are undertaken through a separate Low Cost/Low Risk budget category. Response and recovery repair work occurs through the emergency works programme (currently over $80M pa).

Recent and current major projects providing a significant 'resilience' benefit (by providing alternate routes for high-risk highways) include Transmission Gully, Manawatu Gorge/Te Ahu a Turanga and Auckland-Whangarei highway upgrades, Waikato Expressway and the Petone-Ngauranga Path (Te Ara Tupua).

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.

Waka Kotahi has reviewed its exposure to sea level rise, but this is unlikely to drive significant capital projects in the short-medium term, other than driven through their renewals programme. The most immediate priorities are likely to be in the Hauraki Plains, Coromandel, East Cape, Petone-Ngauranga and the motorway north of the Auckland Harbour Bridge.

Waka Kotahi is reviewing the adequacy of State highway alternate routes and its recovery processes as part of Emergency Works. These may identify resilience process and asset upgrades to address deficiencies along alternate routes and vulnerable areas to natural hazard impacts.

New Zealand's Major Natural Hazard Programmes: Roads

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) accessed through alpine passes or steep valleys near 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

- 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).

6.5 Transport – Air

2023 Update:

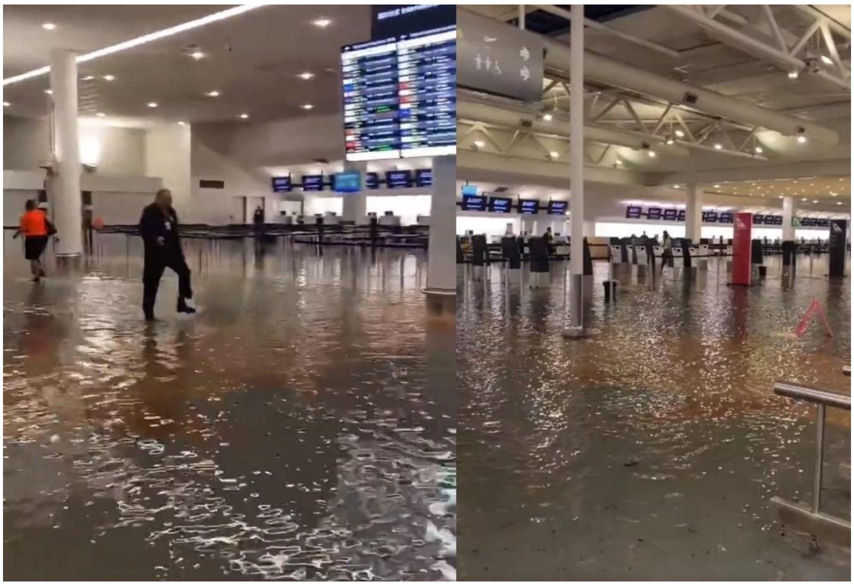
Coming out a hard few 'Covid' years, which massively disrupted the air industry and created staff shortages that continue to be a significant issue, the last year has highlighted many other key resilience issues for the sector.

Contaminated fuel on a fuel import ship in late 2022 was a reminder of the limited fuel stock in New Zealand, particularly jet fuel for Auckland Airport, and contingency arrangements to conserve jet fuel were implemented (without service disruption).

The February Auckland flooding event closed Auckland Airport for over a day, raising questions about adequacy of stormwater network, and flights were cancelled for another day during Cyclone Gabrielle.

Power outages and flooding in Cyclone Gabrielle closed regional airports in Hawkes Bay, a reminder of interdependency risks for this sector.

Since the previous National Vulnerability Assessment, work has been done to develop and refine the definition of critical infrastructure, illustrated in Table 4-6.



Criticality	Critical Infrastructure Entities	Critical Assets	Critical Infrastructure Thresholds
National	Major Airport Owners, Airways New Zealand	International Airports – runway, terminal. Navigation Aids International Airports National Control Centres	Auckland, Wellington, Christchurch, Queenstown. Ohakea Christchurch, Auckland.
Regional	Airport Owners Airways New Zealand	Regional and Strategic Airports – runway, terminal Navigation Aids Regional Airports	Dunedin, West Coast, all other regional airports.
Local	Airport Owners	Airports	All airports with sealed runway.

Table 6-6: Defining Critical Infrastructure – Air Transport

Critical National Infrastructure

There are 5 public international airports plus the Royal New Zealand Air Force (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 Urban Search and Rescue (USAR) assistance. Clearly, the closure of Auckland, Christchurch or Wellington airports would cause the most significant air travel disruption both nationally and internationally.

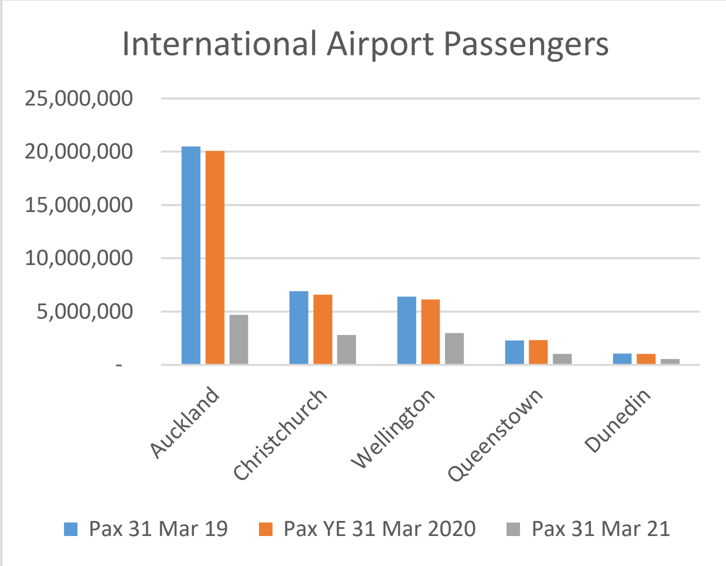


Figure 6-10: Passenger Numbers (New Zealand Airports Association)

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, Wanaka and Milford Airports could be extremely important in the evacuation of tourists (and other people) and for bringing in emergency supplies and responders. *The Queenstown Airport only holds 3-5 days of jet fuel, which has to be transported by road from Dunedin or Christchurch).* Kaikōura Airport and Rangiora Airfield became critical infrastructure following the 2016 Kaikōura earthquake for moving supplies and evacuating people.

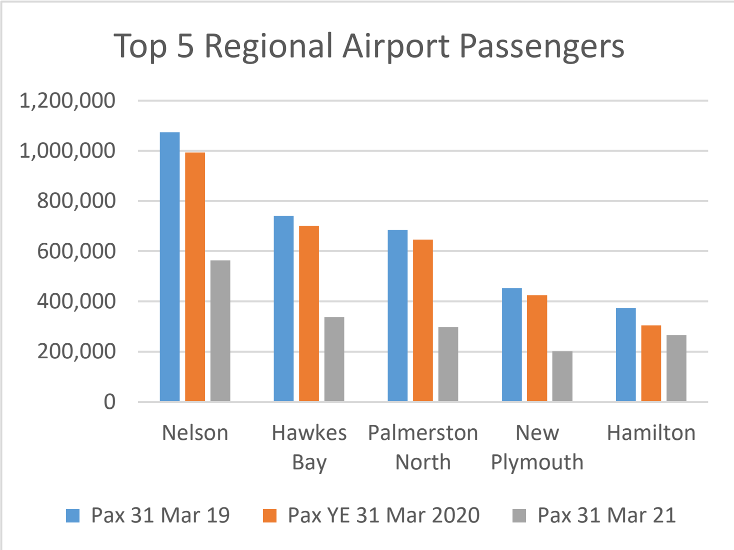


Figure 6-11: Passenger Numbers (New Zealand Airports Association).

The national air navigation service provider, Airways New Zealand, provides national air traffic control infrastructure for airports and aircraft operating in New Zealand. Critical national infrastructure assets include:

- The Airways centre in Christchurch, which monitors all the air traffic in New Zealand and the Oceanic Control Centre in Auckland which monitors traffic to and from New Zealand (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 significantly slows down, but does not necessarily halt, air transport. There are robust and extensive backup plans for the failure of all these assets.

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 system is likewise necessary.

The Air Traffic Management System requires other Instructure Landing Systems and three main sensor systems – radar, multi-lateration, and ADS-B (aircraft surveillance system). The latter uses a distributed network of sensors that can cope with a localised outage, although it is also heavily reliant on both global positioning system (GPS) and the telecommunications network.

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. GBNAs are maintained by Airways New Zealand at all airports with air traffic control services, as well as at Kaitaia, Hokitika and the Chatham Islands (which are uncontrolled airports). 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.

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 traffic control or navigation 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 controllers has the potential to impact services.
- Dependence on jet fuel. The loss of jet fuel supply to Auckland or Christchurch Airports 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.

New Zealand's Major Natural Hazard Programmes: Air

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 New Zealand 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).*

Aircraft accident (of many causes).

- Low lying airports near the coast vulnerable to tsunami or storm surge. Sea level rise associated with climate change will exacerbate those hazards. 13 of the 28 domestic and international airports in New Zealand will face higher risks from a 1m 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.

Regulation and Funding

Air transport services are privately funded through airlines charging passengers and freight handlers, and the airlines are in turn are charged by airports and Airways for their services.

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

The Ministry of Transport sets policy and contributes some ‘public good' 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 4.

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 resilient radar centres built to importance level 4 (IL4) standards in Auckland and Christchurch are due to be operational in 2023.

Capital investments in airport infrastructure are being driven by future growth in demand, rather than any specific ‘resilience’ improvements. Modern airports are already designed to withstand major hazards such as earthquakes and rainfall events.

6.6 Rail

2023 Update

The rail network suffered major damage during Cyclone Gabrielle, disrupting supply chains from Napier to Gisborne ports. Several disruptions to metro networks, from weather events and technological issues, have also been causing frustrations for both rail and road commuters (as disrupted passengers turn to road-based transport).

KiwiRail has a major resilience investment programme in progress, and government recovery and resilience funding announced in 2023 will help progress this work. A new National Control Centre in Upper Hutt and a planned new control centre in Ellerslie, Auckland are key parts of this programme (reliance on a single National Control Centre having been a significant resilience concern in the past).

Another key aspect of building resilience is enhancing multi-modal connections to enable rapid shifts between rail, road and sea transport, with a major planned multi-modal transport hub in Palmerston North.

Since the previous National Vulnerability Assessment, work has been done to develop and refine the definition of critical infrastructure, illustrated in Table 4-7. This is expected to support government prioritisation of resilience and recovery funding both for recent and future.

Criticality	Critical Infrastructure Entities	Critical Assets	Critical Infrastructure Thresholds
National	KiwiRail Auckland Transport GWRC	National trunk lines (inc. inter-island) Rail to major national ports (Tauranga, Auckland, Hamilton, Wellington, Picton). Wellington, Auckland metro lines and Hub stations National Control Centre	To be developed, e.g., > (x) tonnes freight per day > (x) Passengers per day
Regional	KiwiRail Auckland Transport GWRC	Rail to regional ports. Train stations on metro lines	
Local			

Table 6-7: Defining Critical Infrastructure – Rail Sector (In development)

The national rail network moves around 13% of New Zealand's total freight - measured by net-tonne kilometres (KiwiRail Integrated Report 2022) – and, at pre-covid levels, carries around 1 million tourists and 35million commuters each year (*KiwiRail Asset Management Plan AMP 2020*).

Rail plays a vital role in New Zealand by reducing transport emissions and relieving road congestion, transporting millions of people annually on Auckland and Wellington commuter services. With rail having significantly fewer carbon emissions per tonne compared to road freight, increasing rail freight volumes is seen as a crucial strategy for reducing emissions in the transportation sector.

Critical National Infrastructure

The rail network is illustrated in Figure 4-12; of note is New Zealand's predominantly single-track configuration, which poses significant challenges when confronted with natural hazards. Effectively the road and marine network become alternative routes for freight movement and commuter travel if parts of rail corridor are closed. Any disruption or required maintenance work on a single track can have a severe impact on train operations, with the entire railway line needing to be suspended - leading to delays and congestion due to constraints in train frequency and traffic volume. Single track railways heavily rely on signalling systems, making them vulnerable to disruptions and delays if signalling infrastructure fails or sustains damage. Additionally, the limited passing opportunities for trains traveling in opposite directions can further impede schedules and travel times.

Critical national infrastructure assets in the network, based on lines with the highest percent of freight and commuter traffic include: the North-South trunk line in the North Island; the Auckland-Tauranga line which, with the inclusion of Hamilton, is referred to as the 'golden triangle' - due to its importance in servicing significant freight volumes contributing to gross domestic product (GDP) and connection of these population bases; the inter-island rail route (owned and operated by KiwiRail); and the Wellington and Auckland metro lines. KiwiRail's Asset Management Plan identifies other 'very high' criticality lines as the Picton to Christchurch line and the Christchurch metro. The Kaimai Rail Tunnel on the East Coast Mainline represents a key singular infrastructure component on the Auckland – Tauranga line.

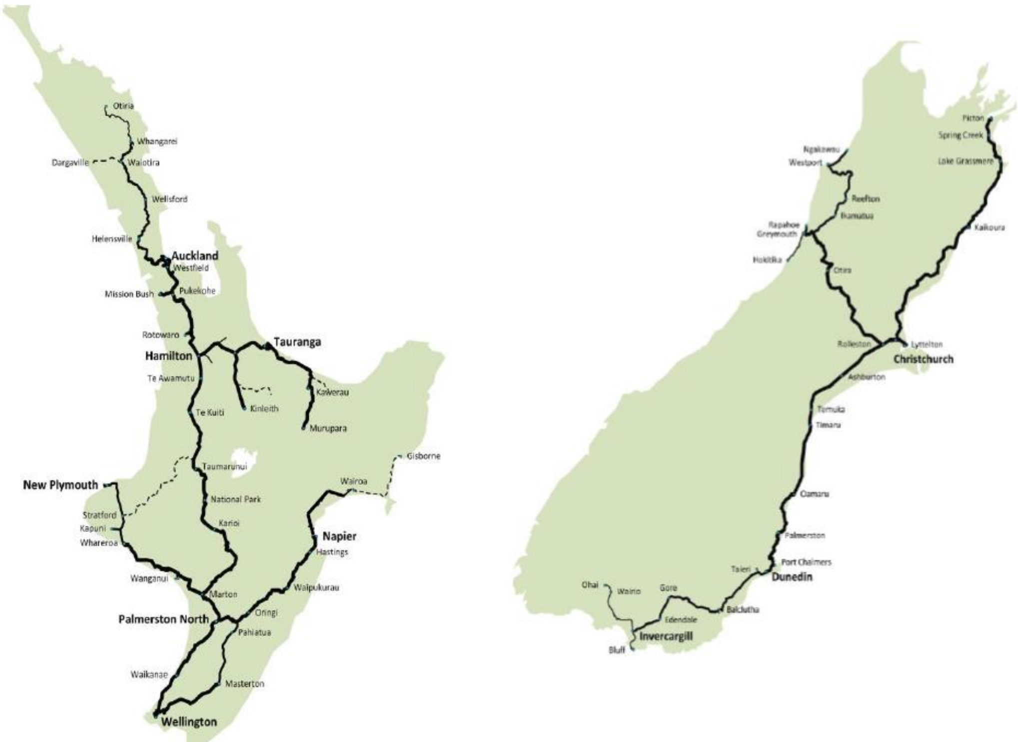


Figure 6-12: National Rail Network

A new National Control Centre in Upper Hutt has recently opened which, combined with an additional control centre under construction in Ellerslie in Auckland, significantly improves resilience for national train operations compared with the previous arrangement of a single aging control centre in central Wellington.

Key planned improvements to mechanical workshop facilities include major refurbishment to Hutt Workshops and a new facility at Waltham in Christchurch. Demolition of Hillside Workshops in Dunedin in 2021/22 has allowed for new construction of facilities on that site for local assembly of wagons. KiwiRail is also planning an intermodal freight hub in Palmerston North, which is seen as a crucial for transport of domestic and export goods in the lower North Island, serving various regions. The hub aims to enhance rail and road transport integration, boost the regional economy, and align with growth plans of Horizons and Palmerston North City Council.

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, after the 2016 earthquake, the movement of freight by road following the closure of the Kaikōura Corridor caused immediate issues on the inland road between Picton and Christchurch. In response, KiwiRail entered the coastal shipping freight market - with a New Zealand 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, had the added benefits of reducing truck congestion from already busier-than-usual, alternative roads.

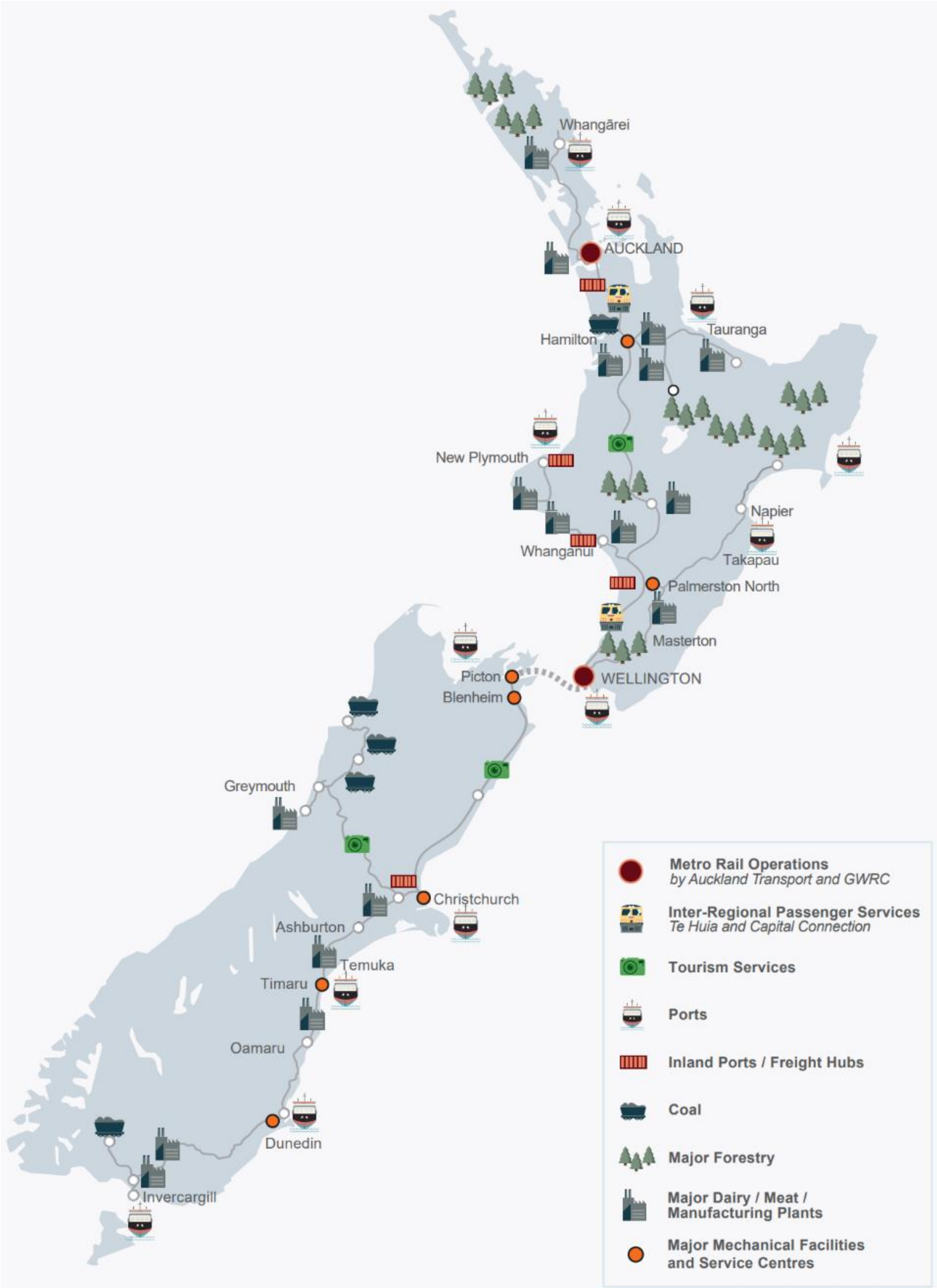


Figure 6-13: Key Infrastructure and Industry Railway Connection Map (figure from KiwiRail Integrated Report 2022)

Vulnerability to Hazards

Vulnerabilities in the rail network are similar to those discussed for roads. These hazards are summarised below. The box to the right presents a summary of findings from national scenario-based research programmes as to the impacts of major natural hazards on the rail network.

Flooding: Railway lines located near rivers, coastal areas, or low-lying regions are susceptible to flooding. Heavy rainfall or storm surges can lead to water overflow, causing track damage, erosion of embankments, and washouts. Floodwaters can also impact signalling systems and electrical equipment.

Landslides: Railways passing through hilly or mountainous terrains are at risk of landslides. Slopes weakened by heavy rain, seismic activity, or soil erosion can result in debris and rocks falling onto the tracks, obstructing train movement and causing infrastructure damage.

Earthquakes: Seismic events can impact railways by causing track misalignment, foundation settlement, and damage to bridges, tunnels, and other structures. Ground shaking can also lead to soil liquefaction, which weakens the stability of tracks and embankments.

Cyclones and Extreme Weather: Strong winds associated with cyclones and extreme weather can cause trees, branches, and other debris to fall onto tracks, potentially damaging infrastructure. Storm surges can also inundate coastal rail lines, leading to erosion and undermining of track foundations.

Volcanic Eruptions: Ashfall can disrupt railways by accumulating on tracks, reducing traction and potentially damaging the infrastructure. Volcanic flow hazards, such as lahars, can erode or bury railway tracks, leading to structural instability and operational disruptions.

Extreme Heat: High temperatures can cause rail tracks to expand, leading to track buckling. This can result in track deformities, requiring immediate repairs to ensure safe train operations.

Winter Weather: Cold temperatures, snowfall, and ice accumulation can create challenges for railways. Frozen switches may hinder train movement, ice buildup on overhead lines can disrupt power supply, and snowdrifts can obstruct tracks, requiring snow removal operations.

New Zealand's Major Natural Hazard Programmes: Rail

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.
- The existing and proposed Kaiwharawhara Interislander ferry terminals are both directly on/near the fault line meaning the ferry rail link would likely be affected.
- Opening of the new Upper Hutt National Control Centre mitigates the risk of nationwide operational issues that existed with the previous control centre located in central Wellington. Risk of disruption will be further mitigated with the additional control centre in Ellerslie.

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.
- Risk of damage to infrastructure due to lahars.

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).

Wildfires: Railways passing through forested areas are at risk of wildfires. Burning vegetation and timber can damage tracks, bridges, and other infrastructure elements, affecting train operations and safety.

Regulation and Funding

KiwiRail is registered as a State-Owned Enterprise (SOE) and operates within the policy and regulatory frameworks of the SOE Act 1986. As an SOE, it seeks to self-fund its freight operations, with additional Government funding sought for new initiatives and investments. Note that KiwiRail also holds responsibility for operating the Cook Straight Interislander ferries, for which there is a programme to replace the Interislander fleet with two new purpose-built ships, along with new terminal facilities in Picton and Wellington. The first of these ships will arrive in 2025, and the second a year later.

Rail has a prominent focus as an enabler of economic development, which links New Zealand's regions and ports to export markets overseas. The Rail Network Investment Programme (RNIP), approved by the Minister of Transport on 29 June 2021, represents a significant change in the planning and funding of New Zealand's rail network. It sets out the planned maintenance, management, renewal, and improvement work for the national rail network over the next three years and provides a forecast for potential investment over the coming decade. The RNIP is a key component of the government's 10-year vision for rail - as outlined in the New Zealand Rail Plan - and for KiwiRail, each RNIP creates a three-year pipeline of work, facilitating more effective investment decision-making and providing certainty to both the company and its customers. This new approach includes funding network infrastructure through the National Land Transport Fund (NLTF), marking a significant shift from previous practices.

Waka Kotahi 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

To achieve the government's goals for rail, it is essential that tracks, bridges, and other rail infrastructure across the country are brought up to standard. The inaugural RNIP sought to address the historical underinvestment in rail infrastructure and improve the network to a "resilient and reliable" level.

The RNIP also emphasizes investing in metropolitan rail to support productivity and growth in New Zealand's largest cities. This includes completing programs aligned with the Auckland Transport Alignment Project and the Regional Land Transport Plans (RLTPs), as well as enhancing regional services, such as the Hamilton to Auckland and Palmerston North to Wellington services.

The country's largest transport project is progressing with the development of the Auckland CityRail Link, which will double the capacity of the Auckland rail network. It will create flexibility and resilience in the network by changing Britomart (downtown Auckland) from a terminus 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. KiwiRail is progressing key programmes of work such as the North Auckland Line (north of Auckland to Whangarei), investments in the Auckland and Wellington metropolitan areas; and investment in rolling stock.

6.7 Sea Transport (Ports)

2023 Update:

The country's remote position and reliance on shipping and ports was highlighted vividly during the Covid pandemic, with supply chains continuing to be disrupted.

Coastal shipping is likely to become even more important over the next few years, to our nation and economy, as:

- *the shift continues to a fully integrated multi-mode transport network.*
- *part of the national strategy to achieve carbon zero goals.*
- *coastal shipping is increasingly recognised as an alternative emergency supply chain when roads and rail are damaged.*

Since the previous National Vulnerability Assessment, work has been done to develop and refine the definition of critical infrastructure, illustrated in Table 4-7. This is expected to support government prioritisation of resilience and recovery funding into the future.

Criticality	Critical Infrastructure Entities	Critical Assets	Critical Infrastructure Thresholds
National	National Port Owners (Port of Tauranga, Auckland Council, Channel Infrastructure (Marsden), GWRC / CentrePort, Port of Marlborough.	Wharves / cranes: Interisland rail/road: Port Marlborough and Cenreport.	To be developed, e.g., > (x) tonnes freight per day > (x) Passengers per day
Regional	Lyttelton Port Northport South Port (Bluff) PrimePort Timaru Port Nelson Port of Napier Port Taranaki Inland ports (Hubs): Wiri (south-west Auckland), Metroport at Penrose (west Auckland), Ruakura (Waikato), Bunnythorpe (Manawatu) and Rolleston (Canterbury).	Wharves / cranes: Deep water: Northport Storage open and covered Specialised, dedicated facilities Mode transfer	
Local	All other public port/wharf facilities	Wharves / cranes: other ports / wharves with local economic or emergency management significance (e.g., evacuation point).	

Table 6-8: Defining Critical Infrastructure – Ports (In development)

Overview

New Zealand ports provide vital public benefits in both their commercial and social role. Efficient port function is integral to the movement of freight both in terms of imports and exports, and the movement of goods around New Zealand, in the form of Coastal Shipping. This movement of freight underpins the New Zealand economy. Ports facilitate tourism through the cruise industry.

Increasingly important is the role of inland ports providing import, export and warehouse functions, and linking to rail, road and air services. Ports and inland ports provide important biosecurity, customs and border protection services.

In regions at risk of being isolated by road for extended periods, such as Wellington, Taranaki and the West Coast, ports become critical for evacuations and transport of emergency supplies.

Critical National Infrastructure

Ports play a central role in the New Zealand supply chain. In 2020, 99% of New Zealand's exports and imports (by volume) pass through these ports. Coastal (domestic) shipping is also essential and is an important growth area identified by the Government under the Emissions Reduction Plan. With New Zealand determined to respond to the challenges posed by climate change, the port sector is destined to become even more important for the economy. Ports have potential to play a vital role in support of new technology in response to climate change, e.g., offshore wind farms, low carbon sea transport options and movement of people via sea gliders.

New Zealand is fortunate in having a network of ports around the country. One of the strengths of the ports system has been its resilience. Recent large earthquakes and commercial disruptions have shown how quickly the system can readjust, adapt and reset. There have been two recent examples when New Zealand ports have been unable to operate for extended periods - Lyttelton and Wellington post-earthquakes. The market responded within 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 events occur.

However Tauranga, as by far the largest export port, 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.

Of specific importance is Wellington and Picton as part of the inter-island ferry crossing service and essentially a key component in the road and rail network of New Zealand.

Most ports in New Zealand co-exist with major communities with competing interests across amenity, noise, emissions and value. This proves a challenging land use planning environment that generally assigns little value to the strategic importance of ports and the necessity to protect existing and future access and egress routes (e.g., rail widening, road widening, grade separation, etc). Some examples of this would include: Council Unitary / District Plans do little to protect routes from intensification / reverse sensitivity issues / conversion to cycle lanes / congestion, etc, and Council Unitary / District Plans often prevent 24/7 operation (e.g.,b ans on nighttime deliveries or onerous noise controls). This has implications for both business-as-usual activities as well as recovery from events.

Government is a major player in the sector. Central Government as a major funder / decision maker in the road and rail sectors has recently acted to stimulate coastal shipping activity. Local Government is involved to varying degrees in the ownership of our ports.

Judging by decisions taken over the past two years by international shipping lines to order new ships, it seems likely the trend towards increased ship size will continue. This could well increase pressure for international ship calls to New Zealand ports and the development of more of a hub and spoke system. If this happens this will be gradual. Coastal shipping is likely to benefit substantially from such a trend, as evidenced by recent investment by major players in coastal shipping. Recent decisions around coastal shipping could see a number of ports that have essentially ceased freight operations resuming this function.

Ports operate in an uncertain international trading environment and therefore must be inherently adaptable. International trade policy, international politics and the response to current and future human and animal health emergencies, as well as domestic trade requirements, can quickly or incrementally shift demands on the ports system. Two current examples are the increase in coastal shipping and the closure of the Marsden Point Refinery.

With the refinery closing, liquid fuel shipping patterns have changed markedly. There are likely to be many more ship movements of refined product direct from international sources to regional ports using appropriately sized vessels, plus a tendency to part off-load at deeper ports before proceeding to shallower ports.

Freight and Supply Chains

Tauranga accounts for about 45% of exports by value, while Auckland accounts for 50% of imports by value. Tauranga is the fastest growing port.

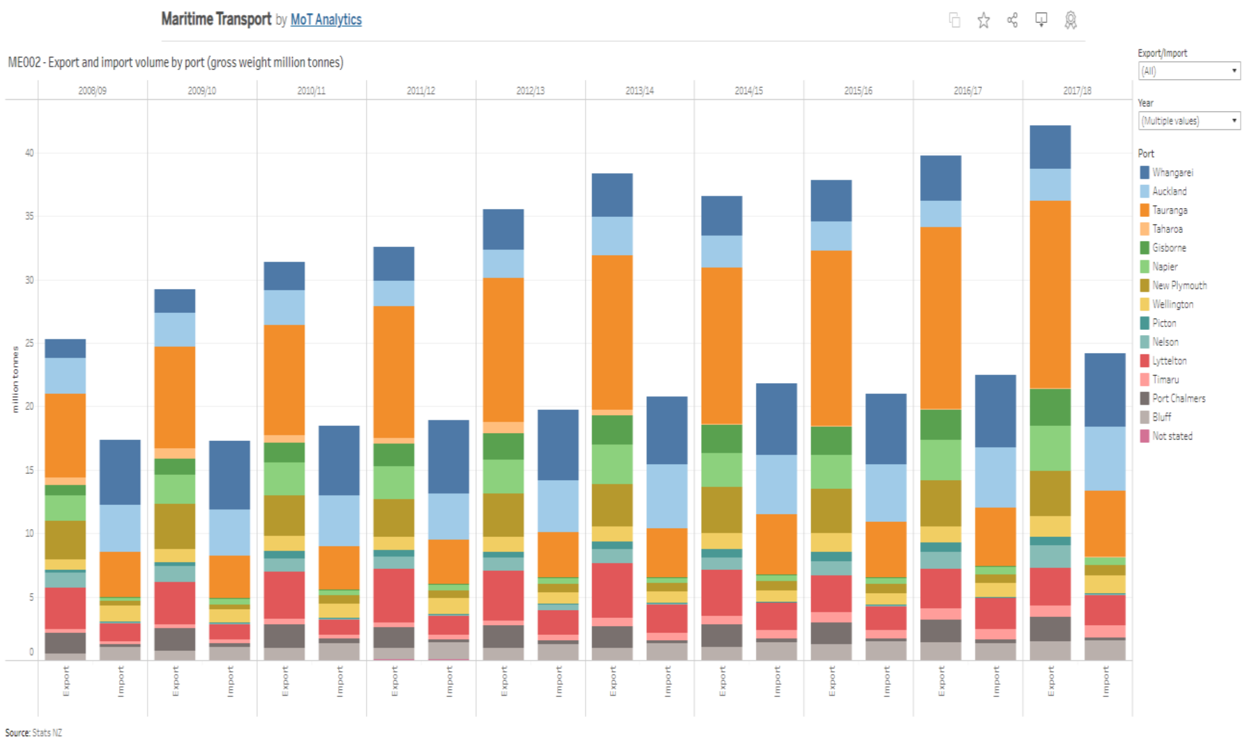


Figure 6-14: Sea Export and Export Tonnage (https://www.transport.govt.nz)

To demonstrate the importance and potential effects should events occur to impact on the operations of ports, it is useful to assess the top 5 export commodities and their trends over time. This is presented in Figure 4-15.

Inland ports are increasingly important for freight and supply chain management, being strategically located to better match supply and demand for importers and exporters, as well as for distribution within

New Zealand. Current inland ports exist at Wiri (south-west Auckland), Metroport at Penrose (west Auckland), Ruakura (Waikato), Bunnythorpe (Manawatu) and Rolleston (Canterbury).

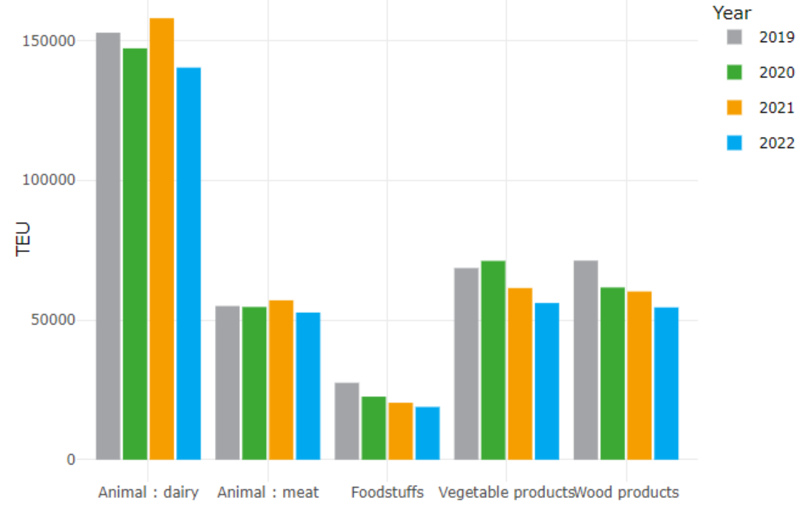


Figure 6-15: Top 5 Expert Commodities (TEU) by year (cumulative YTD to July)

Source: FIGS Data https://www.transport.govt.nz/statistics-and-insights/freight-and-logistics/
FIGS refers to the Freight Information Gathering System. The information contains data from New Zealand's largest container ports: Ports of Auckland, Port of Tauranga, Port of Napier, Port Nelson, CentrePort, Lyttelton Port, PrimePort Timaru, Port Otago and South Port

The Ministry of Transport is currently leading the development of the New Zealand freight and supply chain strategy which seeks to identify what is needed to optimize the system in the coming decades. This is referred to as "Te mekameka anamata tuku atu ki Aotearoa | New Zealand's supply chain into the future": Resilience is one of the identified drivers for change.

Vulnerability to Hazards

A study carried out by the University of Auckland in 2012 is still considered current (*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. 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 seismic intensities 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 7 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.

New Zealand's Major Natural Hazards: Ports

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.

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

A research paper accepted in January 2021 "An assessment of subduction zone-generated tsunami hazards in New Zealand Ports" provides more recent detail of the tsunami hazard to the ports system.

With ports located along coastlines having similar exposure to tsunami hazards, multiple facilities could experience structural damage and operational disruption during a single event. Tsunami effects were evaluated in terms of water levels and current speeds at 13 ports, as caused by both local and distant source subduction zone earthquakes. The results suggest that while the tsunami hazard varies between ports, it is generally highest along the eastern coastline due to its exposure to tsunami generated along the Southern Kermadec, Hikurangi and South American Subduction Zones. While a Hikurangi earthquake has the potential to generate the most devastating impacts at individual ports, an earthquake off the Peruvian coastline has the potential to impact operations and infrastructure at the largest number of ports. Such an event could affect international trade capacity, regional recovery and domestic inter-island transport. Due to the potential for damage and disruption at multiple ports in a single event, this study highlights the importance of a broader national and international transport system perspective to inform potential resilience investments.

This paper also usefully summarises the trading characteristics and facilities of each port.

Regulation and Funding

Port facilities in New Zealand 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 3.

Various peak bodies act to coordinate across the sector. These include:

- New Zealand Council of Cargo Owners
- New Zealand Port Company CEO Group
- New Zealand Shipping Federation
- Ports Industry Association

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. A further example is Wellington and the Seaview Energy Resilience Project.

The Wellington Lifelines Regional Resilience Project identified a Preferred Investment Programme including seismic strengthening of the Seaview Wharf.

Upgrades to the wharf and the pipeline are necessary to ensure that they are as resilient as possible during an event such as an earthquake and to ensure they are future fit for lower carbon fuel types, such as biofuels, and different types of ships. The upgrade work must also meet international standards for ship berthing and bulk fuel discharge. To ensure uninterrupted fuel supply the work is being undertaken in sections.

CentrePort is working with Z Energy on behalf of the fuel industry to future-proof this critical asset in three stages over three to five years.

Stage 1 of the project is the replacement of the fuel pipeline along the Seaview Marina foreshore, which began in February 2021 with construction work continuing under the management of contracting partner, Downer Group.

Stage 2 consents were obtained in August 2021 and main wharf work started early in 2022. A construction compound and a staging wharf have been set up near the head of the wharf at Point Howard.

Every effort is being taken to ensure minimal community disruption. While land at Point Howard is being used for the construction compound, public access for walking and cycling through the site has been retained. Potential issues such as traffic safety, noise, lighting and impacts on the marine environment have been carefully considered and specific management plans prepared. These plans, which include public complaint procedures, are available via a dedicated website.

Stage 3 will replace the required sections of onshore pipelines to the respective fuel storage terminals. The wharfline will be predominantly buried within the Seaview Business Area.

6.8 Telecommunications

2023 Update

The telecommunications sector continues to evolve rapidly, both in terms of technology and structure, for example:

- *One and Spark have both recently sold their mobile sites to Fortysouth and Connexa respectively.*
- *The last of the copper cable services continue to be removed as fibre become available in these areas.*
- *The advancing cellular 5G technology provides greater data speeds and lower latency but requires a higher density of cell sites to cover the same geographical area due to its shorter range per site.*
- *Satellite services continue to grow to meet demand in areas without broadband; these provided an important backup service during Cyclone Gabrielle.*
- *Additional international cable connections continue to be built to meet growing demand – while all cables currently 'land' in the North Island, the next proposed cable 'Hawaiki Nui' will connect Invercargill, Dunedin and Christchurch directly to Melbourne and Sydney.*

Gabrielle and many other recent storm events have again highlighted the vulnerability of the telco network to power failures, at both the telco and customer end. Risks to cables on low bridges over rivers reminded lifeline utilities of the physical co-dependencies in the infrastructure system.

The sector continues to collaborate effectively in emergency preparedness and response, with the development of a Telecommunications Emergency Response Plan underway. The industry is also working on a resiliency investment plan, with government, which will look at Cyclone Gabrielle recovery actions and future infrastructure investment.

Since the previous National Vulnerability Assessment, work has been done to develop and refine the definition of critical infrastructure, illustrated in Table 4-7. This is expected to support government prioritisation of resilience and recovery funding in the future.

Criticality	Critical Infrastructure Entities	Critical Functions	Critical Assets	Critical Infrastructure Thresholds
National	Southern Cross Cable, Hawaiki, Chorus, Spark, Vodafone, 2degrees	111 Services. Emergency Service channels.	International cables / landing points / cable stations. Core trunk fibre network Major exchanges / POIs	To be developed, e.g., Supplies > (x) customers.
Regional	Chorus, Spark, Vodafone, 2degrees, Tua Tahi Fibre		Core trunk fibre network Major exchanges / POIs	
Local				

Table 6-9: Defining Critical Infrastructure – Telecommunications Sector

Overview

The telecommunications sector is one of the most complex utility frameworks in New Zealand. It encompasses a blend of commercial and competitive interests. Telecommunications technology is always changing and requires a high level of interconnectedness between the various providers who share parts of the network to exchange data.

As technology changes so too does consumer demand, with the shift towards more efficient and high-capacity broadband technologies supported by the expanding coverage of fibre and alternative technologies across the country. This has resulted in marked changes to the telecommunications landscape, such as satellite services becoming accessible to mass market and Chorus signalling its intention to retire the copper network within the next ten years to become an all-fibre company among other initiatives.

For fixed line services, there is one copper network operator and four fibre network operators, a number of fibre wholesale service providers and over 80 fibre retail service providers.

There are three mobile network operators and the Rural Connectivity Group (RCG) and four mobile virtual network operators (MVNOs).

Wireless services are delivered by a range of companies including more than 20 Wireless ISPs (WISPs). The satellite sector is represented by various participants, from traditional geosynchronous satellite operators like Inmarsat through to new low-earth orbit (LEO) operators like Starlink.

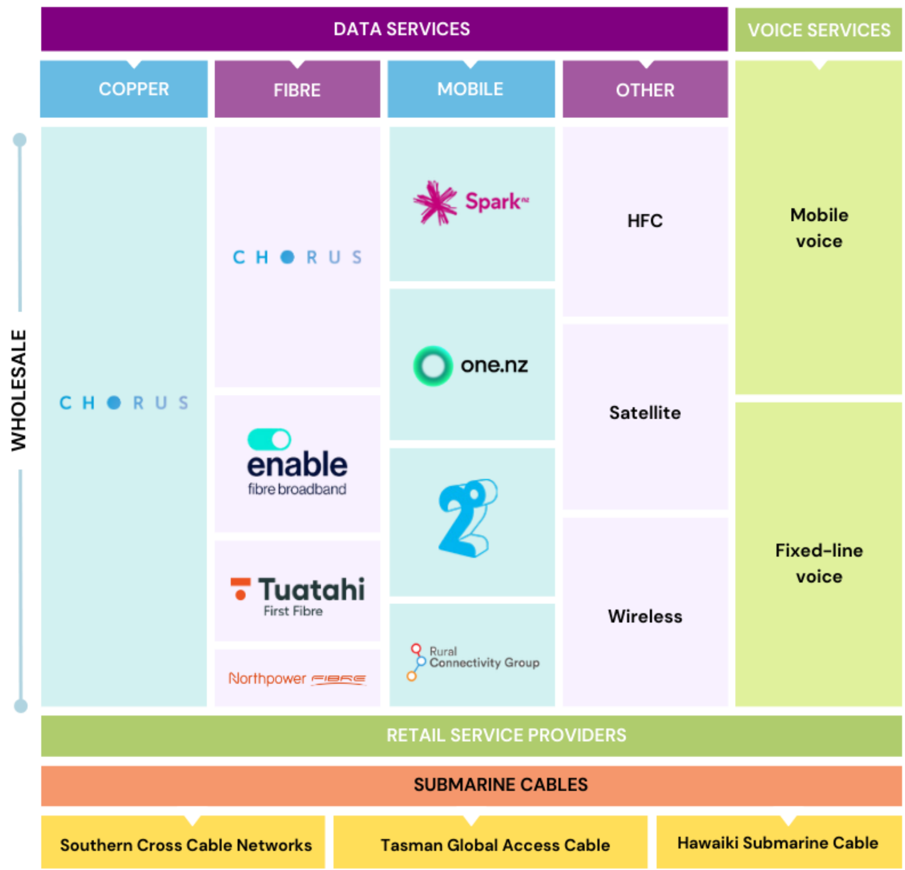


Figure 6-16: Sector Overview

Regulatory and Policy Environment

The sector includes a number of privately-owned companies, however, government-led investment in the fibre-to-the-home Ultrafast Broadband (UFB) network and the Rural Broadband Initiative (RBI) combines public funding with private capital to deliver infrastructure throughout the country.

MBIE is responsible for regulation, including fibre regulation, Telecommunications Service Obligations (TSO) and policy objectives for 111 Emergency Service Calling, while MBIE provides policy advice and guidance to the minister. It also oversees radio spectrum management as required under the Radiocommunications Act 1989.

The Commerce Commission enforces the regulatory framework under the Telecommunications Act 1989 which has recently been updated to include a section on retail service quality.

The New Zealand Telecommunications Forum (the TCF) is the industry association charged with producing the codes that govern the sector. This quasi-regulatory role allows the Commerce Commission to set the regulatory agenda, while the TCF works with the industry to deliver the detail.

TCF codes set the minimum standards required for a number of key elements - ranging from number portability to emergency calling, customer service obligations and vulnerable end-users, through to requirements for marketing of services. The aim is to provide a level playing field for providers of both fixed and mobile services for the benefit of consumers. The TCF also coordinates sector responses to regulatory matters. For more information visit: www.tcf.org.nz.

The Telecommunications (Interception Capability and Security) Act 2023 has aspects relating to management of network security.

Fixed Line Networks

Core Networks

Forming the backbone of an operator's national network, core or transport networks serve the entire country with inter–region communications. There are multiple core network operators who collectively use a combination of land-based fibre and radio systems, each having varying degrees of geographic penetration throughout New Zealand. These include 2degrees, Chorus, Spark, One New Zealand, Transpower and Kordia.

Core network operators generally run a meshed / ladder network using a combination of geographical fibre route diversity and geo-redundancy of equipment sites. These are often thought of as loops that provide at least two paths to any destination. This means that equipment nodes (exchanges / data centres) can deliver a "self-healing" function by redirecting digital traffic away from a failed link into those that are still operational. In most cases for a single route failure, it's possible to fully restore services "round the other way" - even if those services take a longer route than they are normally programmed to take.

Figure 6-18 shows the geographical disposition of a typical "core transport" network, showing the geographically diverse routes that contribute to its robustness.

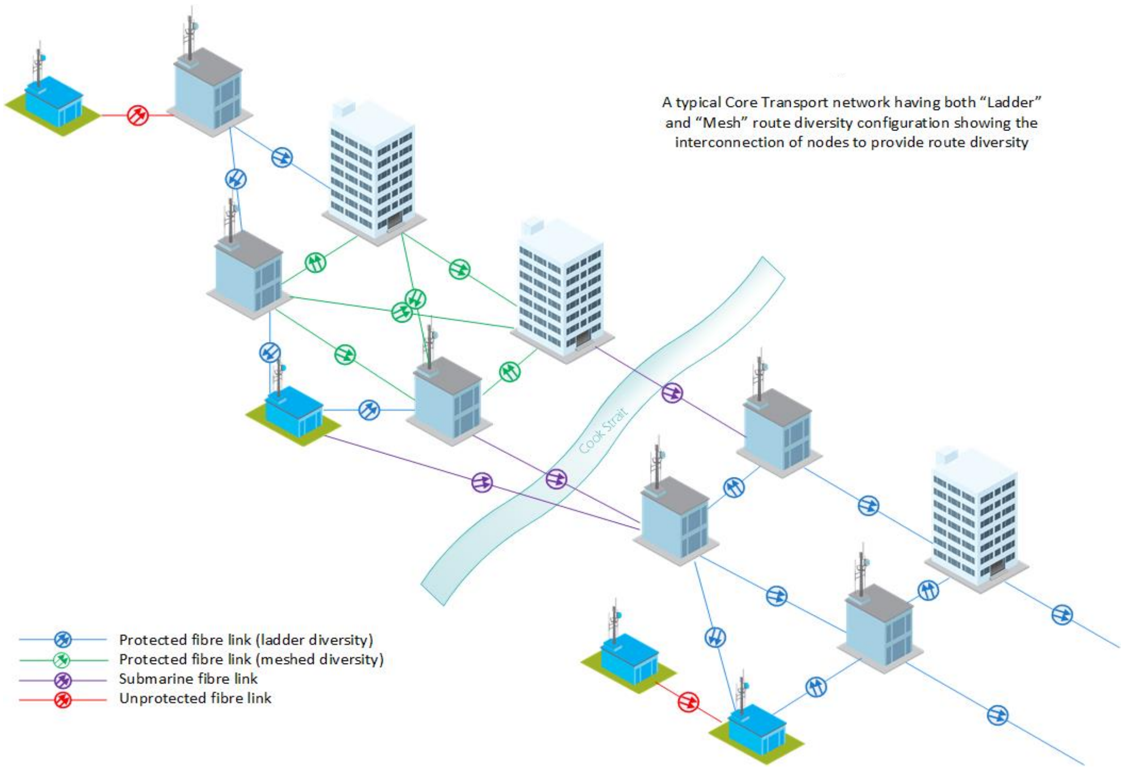


Figure 6-17: A Typical Core (Telecommunications) Transport Network

Figure 6-18: Geographical Routes Core Transport Network

Access networks

Access networks are responsible for providing connectivity between an exchange or data centre to delivering services to a local customer base. Historically that was over copper cable but now is predominantly by fibre and fixed wireless delivery. Chorus, Northpower, Tuatahi Fibre, Unison Fibre, Enable Networks (Fibre) and Spark, One New Zealand and 2degrees all provide this retail connection over various technologies. Radio based solutions for this include cellular service (as in RBI), WISPs and a range of satellite services.

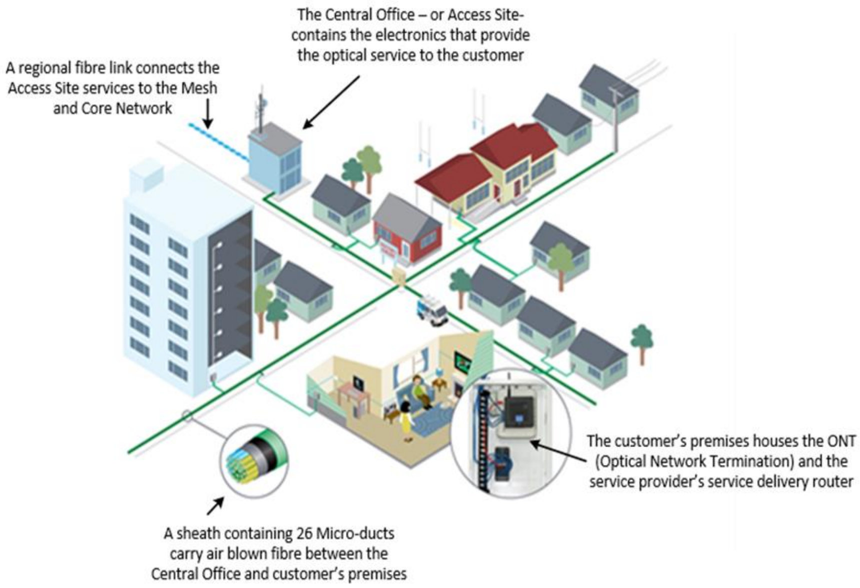


Figure 6-19: Fibre Network

Access networks are generally the most vulnerable components of the overall telecommunications environment as they cannot be equipped with redundancy features such as those found in self-healing regional and core networks.

Resilience and reliability

A buried optical fibre cable is inherently more robust than its copper counterpart. In the case of UFB, either the fibre bundle or the conduit carrying the fibre is made of High Density Poly-Ethylene (HDPE). UFB networks also consist of aerial networks, where fibre cable is suspended on (for example) power poles. Aerial fibre is rated for different conditions than ducted fibre, taking into account the different exposure conditions that apply. Although ducted fibre is typically more resilient, aerial fibre is easier to access and repair (reducing reinstatement times).

Optical fibre is also immune to the electrical interference and induction that was always an issue to be managed with copper lines, as cables that accumulated moisture due to sheath cracks and nicks were susceptible to inducing noise into the signal. This impacted the customer's service performance both in terms of voice quality and especially that of high-speed digital subscriber line/loop (DSL) services.

By comparison to a copper network, the UFB network and its associated blown fibre units are immune to the effects of water and will continue to carry its signal even while submerged under water.

One of the best features of the UFB service delivery is that the majority of the UFB network between the Central Office and the customer's premises is entirely a passive optical fibre. The only intervening cabinet or fibre flexibility point that may be part of the service delivery is an optical splitter which is also passive.

The fibre network requires that the customer provides a reliable power source at their premises to maintain not only the Optical Network Termination (ONT) but also to any attached service delivery device, such as a modem/router. This is in contrast to the older copper network where power was fed initially from the exchange and, more recently, from cabinets in the network. Power outages at the exchange or cabinet level were mitigated through the use of batteries which can run for up to eight hours, although this varies dramatically based on the number of customers connected to any given cabinet.

There are battery backup options available for consumers that will sustain a broadband modem or ONT for a range of times. There are also industry consumer protections for vulnerable consumers who have a particular need that may require access to 111 calling, these are set out in the Commerce Commission's 111 Contact Calling Code.

There is an acute dependency on power for the telecommunications network. To protect the network against a widespread power outage, providers go to great lengths to make sure that their central offices and exchanges, cabinets and cell sites have power backup facilities. During an extensive power outage ongoing power backup is dependent on fuel and access to site. From a customer's perspective, if there is a power outage at the customer's premises and they do not have a power backup facility for their telecommunications service, they will be unable to consume the service.

Wireless Access Networks

Wireless Internet Service

There are ~37 wireless internet service providers nationally affiliated with the Wireless Internet Service Providers Association (WISPA) New Zealand, and an additional small number who operate independently of this. These networks deliver internet services principally in rural New Zealand.

Traditionally WISPs have been focused on radio-only delivery, but recently larger WISPs have started to provide buried fibre access to larger rural community clusters that are distant from, but in some instances over-build, the local fibre company's reticulation.

Fixed Wireless access (Cell Site derived)

The three national cellular mobile providers in New Zealand (2degrees, One New Zealand, Spark) offer a fixed wireless service. This service can be delivered from any cell site to any residence that is within coverage of that cell site and is available in both urban and rural environments.

Fixed wireless service is used as a component of the RBI to deliver services to customers where the installation of fibre to their premises is not feasible.

Resilience and reliability

Cellular derived fixed wireless services have a similar or slightly better reliability than mobile services delivered from the same cell site(s), because the fixed services use a different network platform and offers greater reliability because of physically static equipment. Reliability of the radio link component (such as may be encountered in some rural situations) can be improved by the addition of an external antenna on the premises.

Due to the service using shared radio linking frequencies and the technology employed at the cell site, there may be some service level reduction (Internet connection speed) during busy times of the day, usually in the evening, where multiple users are connected to the same cell site.

Mobile Access Networks

Cellular Networks

Spark, One New Zealand and 2degrees, and the RCG operate cellular networks in New Zealand. The general principle of their operation is one of radio coverage "cells" that integrate to form a coverage zone. The cell site provides the local coverage, and a mobile handset will connect to the cell site with the strongest signal, usually, but not always the nearest cell site.

Cell sites are only wireless for the connection to the customer's handset – backhaul from each cell site to the core network is typically provided by fibre or Digital Microwave Radio (DMR). Individual cell sites cannot operate independently of the core network and are unable to provide stand-alone local service if the link to the cell site is broken. Connectivity into the core network and power are essential for all services to operate.

The principal cellular technologies delivery throughout New Zealand are 3G, 4G and 5G (3rd Generation, 4th Generation and 5th Generation). Each advance of generation is able to provide greater data speeds and lower latency. The topology for 5G requires a higher density of cell sites to provide the same geographical coverage area as earlier generations of cellular networking due to its shorter range per site.

Figure 6-20: Typical Cellular Service Coverage across New Zealand

Resilience and reliability

Cellular networks offer a fail-over capability for emergency calls. If the customer's network is not available, the call will be routed automatically by whatever network the device can see, whether owned by a competitor or not. Thus, 111 calls can often be made even when the phone or tablet shows no service is available.

In addition to battery backup, cell sites may also have either a permanently installed generator or the ability to connect to a rapidly deployed generator, and some have been equipped with solar panel arrays to provide power during daylight hours.

Cellular operators have (or have access to) sufficient portable generation resources to support a limited number of battery-only sites if there is an extended commercial mains outage. During a widespread telecommunication outage, the restoration of mobile services becomes a priority as it restores widespread service delivery of a service that is predominantly accessed by battery powered handsets and other cellular connected devices.
All cell site installations are inherently physically robust, proven during the recent Cyclone Gabrielle where only two sites had storm damage out of over 1600 across the four affected regions.

Figure 6-21: Vital's LMN coverage

Digital Mobile Radio (DMR) Land Mobile Networks (LMN)

A land mobile radio system (LMRS) is a person-to-person voice communication system consisting of two-way radio transceivers (an audio transmitter and receiver in one unit) which can be stationary (base station units), mobile (installed in vehicles), or portable (handheld transceivers e.g., "walkie-talkies"). Public land mobile radio systems are made for use exclusively by public safety organisations such as Police, Fire and Emergency New Zealand (FENZ) and ambulance services, and other governmental organisations, and use special frequencies reserved for these services. DMR is a digital radio standard for voice and data transmission in non-public radio networks.

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 mission critical communications one to one or one to many, within a workplace or region, nationally across New Zealand, outside mobile coverage, or when the mobile networks are congested or fail.

Vital is the major provider of critical communications services with nationwide analogue and digital mobile radio networks. It provides services to a number of lifeline utilities and emergency services in the region such as Hato Hone St John and FENZ, MBIE, utility companies such as Wellington Electricity, PowerCo, Unison, First Gas, Manawa, Genesis, health authorities, Regional and District Councils, and CDEM.

Vital's land mobile radio networks run in both public or private modes, in VHF and ultra-high frequency (UHF), analogue and digital radio formats. These networks are interconnected with fibre and the company's DMR network. This allows the network to operate in national disasters, as it is not reliant on underground fibre networks and have backups to reticulated power. Vital sites are built to be resilient, with some sites hardened to 72 hours of battery backup, beyond mains and generators.

Vital's Land Mobile Networks allows calling to landline and mobiles, can integrate with mobile networks for better data performance, has GPS location alerts and monitoring for "lone worker" and "man down" functions. Additionally, there is a cloud-based voice recording capability for certain use cases.

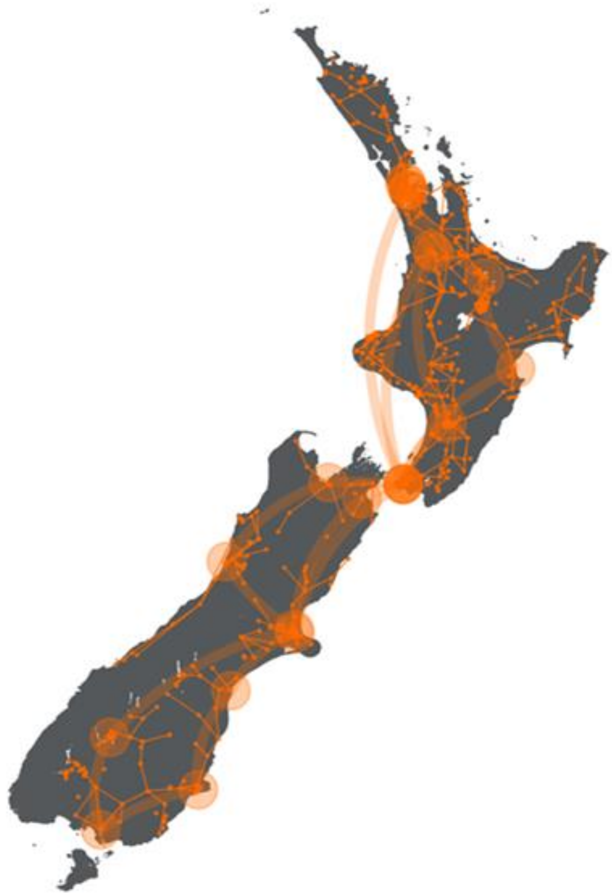


Figure 6-22: Vital's High Speed Microwave Network / Fibre Nodes and Connections.

Radio based Transport Networks

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

Kordia has invested significantly in resiliency by way of geographical and technological diversity (fibre and radio) into their sites and centres. Kordia's sites, network and power backup systems are provisioned to a high level of robustness and the infrastructure is dimensioned to match the role of a specific installation, especially high sites such as those that house the high elevation Digital Microwave repeater sites.

Most sites are unmanned and are monitored 24/7 from the Network Operations Centre (NOC), located in Avalon. The NOC is duplicated in Auckland for redundancy. Kordia provides a managed environment with associated towers for others to locate their transmission equipment - such as Police and other emergency services, Airways, Transpower, One New Zealand, Spark, 2degrees 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.

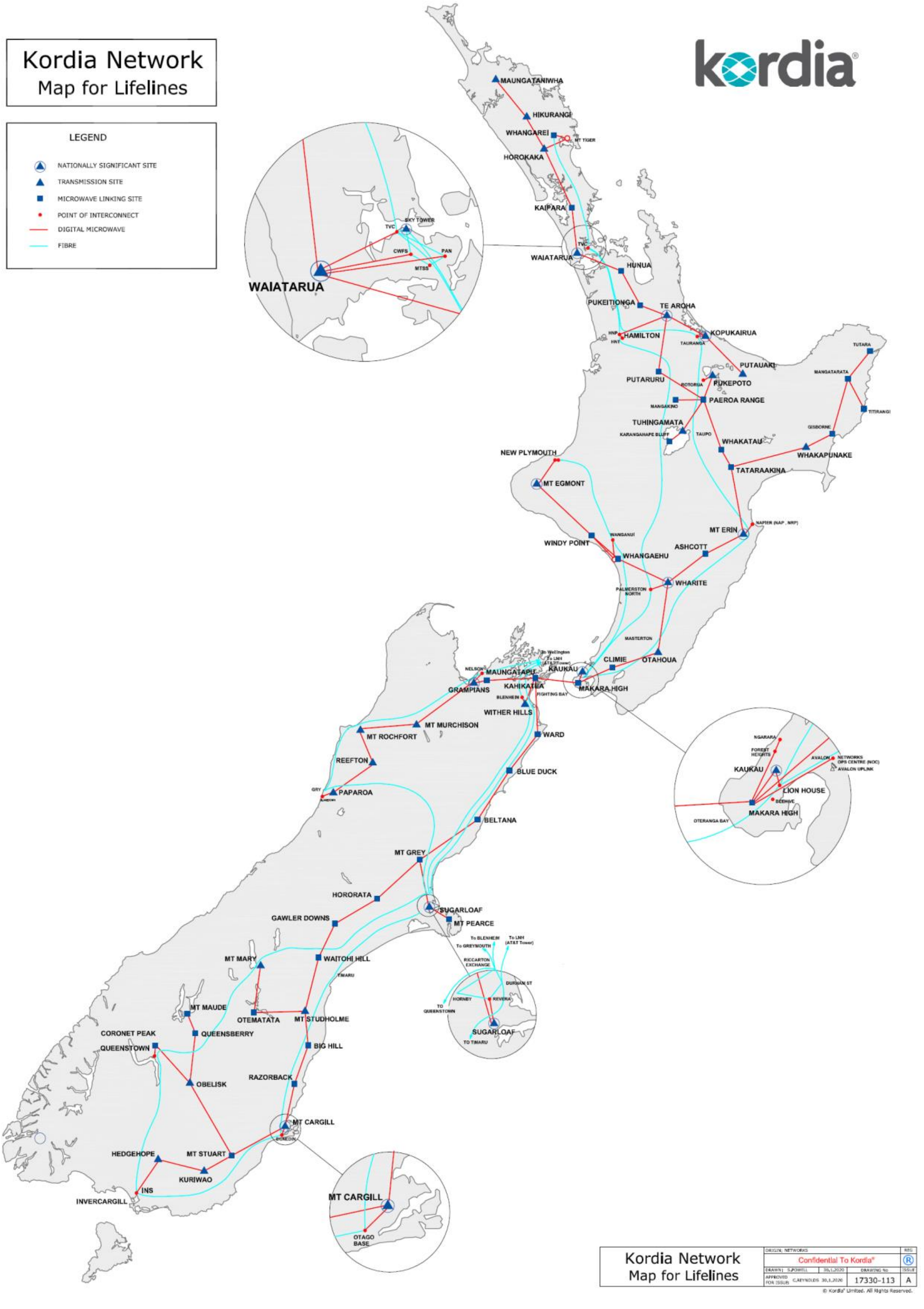


Figure 6-23: Kordia's Transmission Network

Satellite Networks

There are two main types of satellite in use over New Zealand – geo-stationary satellites (GEO) and LEO. GEO satellites operate at much higher altitudes than LEO and cover a set area of the planet below, while LEO satellites are much smaller and closer and are constantly circling the globe, requiring customers to constantly align their receiving equipment with the satellite to maintain a link.

Geostationary satellite with fixed satellite earth installations

There remain very few services from New Zealand being delivered by this means. The remaining Satellite Earth Station (SES) is located at Warkworth and is owned by Spark International.

The permanent services still delivered by this installation to New Zealand interests are:

- Chatham Islands – principally to provide backhaul for the Island's telephone exchange. The island's telecommunications, upgraded as part of the RBI programme, providing satellite derived island wide 4G Cellular coverage from five cell sites on the islands.
- Scott Base Antarctica – a satellite Earth station positioned at Arrival Heights feeds a limited digital capacity to Scott Base via a 4km surface laid fibre link. Due to Scott Base's proximity to the USA McMurdo base the fallback option is to use their satellite capacity and vice versa.
- Pacific Island nations - a number of Pacific Island destinations.

Satellite for the provision of consumer internet

Satellite-based services are available to provide services that support terrestrial telecommunication in New Zealand. Satellite services can either be a customer's main connectivity with the rest of the world (as in the case of a remote rural environment), or it can be installed as a backup to protect their normal terrestrial services.

Increasingly, this role is played by LEO satellites that are being launched around the world. Starlink is one such example, with the company launching around 4000 satellites over the past few years and with plans to launch thousands more.

Because of the relatively short distance between the low-earth orbit and the customer below, these connections tend to be faster than GEO satellite connections and have lower latency. However, most services on LEO satellites tend to be best efforts and are considered consumer grade at best. Customers will find their service is contended (that is, more customers per satellite means a slower speed for all) and in some parts of New Zealand the service is unable to be sold due to overloading.

Other satellite operators are: Globalstar, Kacifica, OneWeb.

Resilience and reliability

While satellite-based services are an excellent alternative delivery method, especially for those customers that are unable to connect to land-based services, they do have radio propagation issues (signal fading) during times of high rainfall and heavy cloud cover. Higher speed services use radio frequencies that are higher on the spectrum, but this is more affected by signal fade.

Lower speed services are available, and are less prone to signal fade, but their data speeds are lower. High speed satellite services are a useful adjunct to those services being delivered over terrestrial networks and can serve those customers who are removed from the existing networks. There are limitations to the quality of the services but for those users who are in remote parts of the country, they may provide exactly the solution that suits their needs.

However, there is a place for satellite during an emergency event to help service emergency services and provide backhaul to mobile cell sites, as was the case in Tairāwhiti during Cyclone Gabrielle.

International Networks

Submarine cable providers

New Zealand is served by three submarine cable operators that land five individual cable ends in the upper North Island. These provide service to numerous international points of presence located predominantly in Australia and the USA. The more recently installed cables (Southern Cross NEXT and Hawaiki) also provide service spurs to several Pacific nations including Fiji, Tokelau, New Caledonia and American Samoa, refer to figure 8 below.

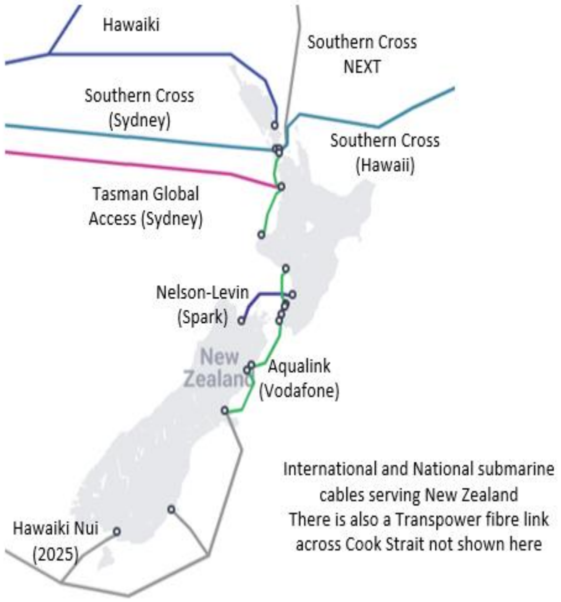


Figure 6-24: International and National Submarine Cables

- Southern Cross Cable Network – Pacific sector – which lands at Takapuna and Hawaii
- Southern Cross Cable Network – Tasman sector – which lands at Whenuapai and Sydney
- Tasman Global Access (TGA) – Tasman – which lands at Raglan and Sydney
- Hawaiki – a New Zealand spur off the Sydney – Hawaii link – which lands at Mangawai
- Southern Cross NEXT – a submarine cable system connecting New Zealand, Sydney and Los Angeles; link lands at Takapuna

All of these cables land on the upper North Island. A proposed new cable, Hawaiki Nui, has a planned commissioning date of 2025 and will connect three South Island cities (Invercargill, Dunedin and Christchurch) from a spur of the Melbourne – Sydney sector of the cable.

Telecommunications as a Lifeline Utility

Telecommunications is a Lifeline Utility under the CDEM Act 2002 and, as such, there is an increasing focus on the resiliency of core assets to deliver services for consumers and has become as much an essential service as electricity or fuel. When there is a serious threat to the network, the industry comes together to deliver operational unity where a collaborative approach is taken to protect the telecommunication imperatives of New Zealanders.

There is an expectation that telecommunication services are always available and, like any key infrastructure, it can and is affected during an emergency event. The aim of the industry is always to ensure any disruption to a customer's telecommunication service is minimised and that outages are repaired as quickly as the situation allows. Building resiliency into the network, to minimise the impact and maximise the ability to restore and repair, is an important part of the sector's business operations and strategy.

There are various factors that contribute to the telecommunications sector's resiliency, including investment models, regulatory mechanisms, competition and collaboration that underlies network operations.
Although these factors are never static it is important to ensure they remain in balance to ensure the best response and outcomes during an emergency event. The challenge for the industry is in pre-emptively

mitigating emergency events, particularly when it comes to natural hazards. When an event does occur no two are the same and time to repair equipment and restore services relies on a number of factors, some of which will be specific to the type of event but some of which are other factors, such as availability of electricity, fuel and transport.

Resilience Investment Programmes

Currently the sector is focussed on the following:

1. Development of a Telecommunications Emergency Response Plan.
2. Identify additional network infrastructure investment - the telecommunications industry has an ongoing programme of investment with a number of initiatives to expand regional connectivity and significant industry investment in more resilient infrastructure - such as new access fibre handovers, national transport fibre routes, highly resilient data centres and service "cores", and international connectivity. The industry is now working on a resiliency investment plan, with government, which will look at Cyclone Gabrielle recovery actions and future infrastructure investment.

Collaboration

The Telecommunications Emergency Forum (TEF) is a well-established group of over 21 members and provides an intra-industry forum that is convened when the industry needs to collaborate and have a unified focus on restoring telecommunication services during times of disruption. From a CDEM perspective, the TEF is the Sector Coordinating Entity (SCE) and links into NEMA through the Senior Emergency Management Advisor (National Lifelines Utility Coordinator) based in the National Crisis Management Centre (NCMC) Wellington. The TEF is coordinated by the TCF.

The sector has demonstrated that it is not only able to work collaboratively but is also able to foster links with allied utilities, such as power companies, and coordinate with them during a crisis. This inter-connection between other SCEs is incredibly important during an emergency event that requires the restoration of the network. Telecommunications infrastructure needs power to operate as well as access and transport to sites and fuel for generator backup. The sector's physical presence in the NCMC (the sub-basement of the Beehive) adds an additional dimension in the inter-sector cooperation - as the decision making is done at a level that authorises a greater immediacy of actions on the ground and enables more than one sector (e.g., power, telecommunications, transport) to coordinate a mutually beneficial response. Fostering a close ongoing relationship with NEMA and other SCEs, both regionally and nationally, ensures protocols and response plans can continue to be fine-tuned and any response via the coordination channels are quickly established during an emergency event.

Critical National Infrastructure

Major Telecommunication Nodes (Exchanges)

Both Spark and One New Zealand's main exchanges are in Auckland, Wellington, Christchurch, and Hamilton. Spark also has another critical exchange in Porirua which acts as 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. Mobile provider 2degrees has its major exchange for mobile in Auckland and Wellington, with a disaster recovery site in Hamilton. For fixed broadband 2degrees' major exchange is in Christchurch with disaster recovery in Auckland and Hamilton being built up.

Telco Cooperation – Cyclone Gabrielle 2023

Cyclone Gabrielle was a severe tropical cyclone that devastated the North Island of New Zealand between 12 – 16th February 2023, causing significant damage to homes, infrastructure, and livelihoods across northern and eastern regions of the North Island.

The major impacts to telecommunications occurred over the 13-14th February period as the cyclone moved from the Northland Region to Auckland then across the Bay of Plenty and into the Hawke's Bay and Gisborne regions.

Fixed line services were affected due to loss of power and flooding. Major fibre transport routes were impacted by slips and bridge washouts. Mobile services were severely impacted due to the loss of power to cell sites and multiple cuts across the fibre transport routes. Across the four regions (Northland, Auckland, Hawke's Bay and Gisborne) there are a total of 1645 cell sites and although only two cell sites were damaged, some 20% of cell sites were offline at the peak. The worst hit region was Gisborne, where for two days (14 / 15th February) 90% of cell sites were offline.

Restoring the mobile network was given the highest priority, and field teams equipped with generators were deployed into the affected areas to re-establish power supply and fix fibre backhaul. Satellite units provided limited backhaul capacity for those sites that couldn't be immediately reconnected to fibre.

The TEF facilitated the coordination of resources and equipment between the network operators (2degrees, Chorus, One New Zealand and Spark) and SCEs - in particular fuel and transport sectors. Coordination with local power companies, and network engineering company Downers on the ground, enabled fibre cable restoration across damaged bridges and prioritisation of power to key telecommunications core hubs.

DOWN BUT NOT OUT: Hikuwai Bridge No 1 collapsed in Cyclone Gabrielle in February, taking with it critical fibre connection for the East Coast. A fibre bypass has been completed. Picture by Rory O'Sullivan, Chorus

Core Transport Network

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

The shared Chorus core fibre network, refer to Figure 3, 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 critical national infrastructure 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 One New Zealand, Spark and 2degrees have their own networks, generally on high-capacity routes such as inter-city core backhaul networks.

Vital's fibre network was recently undergrounded and upgraded in Wellington. The network is extensively used by Retail Service Providers for connectivity to and within Wellington and Auckland. These assets are of national significance as they interconnect and provide network redundancy for the following government agencies; Parliamentary Services, Treasury, Defence, NEMA, MSD, MBIE, Police and FENZ. These fibre assets do not use the historical telephone exchanges thus providing their customers a level of redundancy. 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 Hato Hone 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 – national public radio network that is used by a significant number of utility companies, power generators, lines companies and nationally critical pipeline companies

New Zealand's Major Natural Hazards: Telco

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 backup 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

- Severe weather events are increasing due to climate change. These events could impact a region or multiple regions at the same time e.g., Cyclone Gabrielle.

Typical impacts:

- Copper networks are susceptible to water damage caused by flooding.
- Fibre is predominantly installed along common transport routes which can be damaged by slips and broken roads and bridges.
- Loss of power which will impact mobile cell sites and key interconnect points like exchanges.
- Telecommunication sites were not included in the *DSCC Coastal Flooding Exposure under Sea Level Rise*. No quantitative information about coastal exposure is available.

4. Dedicated Radio Networks – 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 – nationwide microwave network to provide redundancy of fibre cuts, for example providing the redundant voice network for the NCMC at the Beehive provided by Vital and the Maritime Safety Sea Network provided by Kordia.

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 or a break in a core transport fibre link. These sites are designed to 'fail over' to the remaining sites or links if one fails though there are some limitations.

Spark's Mayoral Drive exchange (and nearby Airedale) is possibly the country's most significant telecommunications 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 One New Zealand Exchange and the Sky Tower (a major telecommunications hub) in the vicinity.

There are other key nodes exposed to risks such as flood inundation, tsunami and fire.

As a sector, the networks are most vulnerable to electricity outage. Backup arrangements were described previously, but batteries have limited operating time before re-charging is required and generators need fuel. In a major, prolonged electricity outage, as experienced in the Hawke's Bay region during Cyclone Gabrielle, 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 – therefore, once power on the grid is restored, faults caused by the event or isolated power outages can leave a customer without internet services.

The other major hazards are seismic activity and flooding, land displacement and slips which can snap fibre cables and cause damage to bridges carrying cables. Copper networks are susceptible to water damage whereas fibre cables are more resilient. Equipment and exchanges also require air conditioning systems to keep equipment cool, which can be affected by fire and volcanic ash. Building vulnerability housing telecommunications equipment is another risk to be considered. Access maybe required to ensure generator or battery backup continues.

Smaller traditional switching exchanges (such as Whataroa) are progressively being shut down. 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 New Zealand failed, 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.

Customers are increasingly moving to cellular service rather than landlines. This increases the importance and prioritisation of restoring cellular services during an event. Almost all calls to 111 are made from a mobile device these days.

Increasing the resiliency of communities that could be isolated during an event is becoming more important, therefore it is critical to ensure communities have emergency plans in place and are prepared for telecommunications services to be unavailable for a period of time. Satellite and radio services will have their place in the immediate aftermath of an event to ensure that communities can communicate to CDEM and emergency services.

6.9 Water and Wastewater

2023 Update

Arguably the hardest-hit sector in the weather-events of early 2023, several water and wastewater treatment plants, single-supply water mains, water sources and wastewater disposal assets were heavily damage. The focus has been on restoring basic water supply services and minimising public health and environmental impacts of wastewater spills, but the full recovery will take years.

Alongside these events, major sector reforms have been progressing, including the establishment of a Drinking Water Regulator (Taumata Arowai) in 2018 and legislation to establish Water Service Entities in 2022. There has been significant opposition by certain stakeholder groups and portions of the general public. The rebranding to the 'Affordable Water Reforms' in 2023 saw a shift from a proposed four large Water Service Entities to ten, largely regionally based Entities, with some covering 2 regions (refer Figure 4-25).

Since the previous National Vulnerability Assessment, work has been done to develop and refine the definition of critical infrastructure, illustrated in Table 4-7. This is expected to support government prioritisation of resilience and recovery funding into the future.

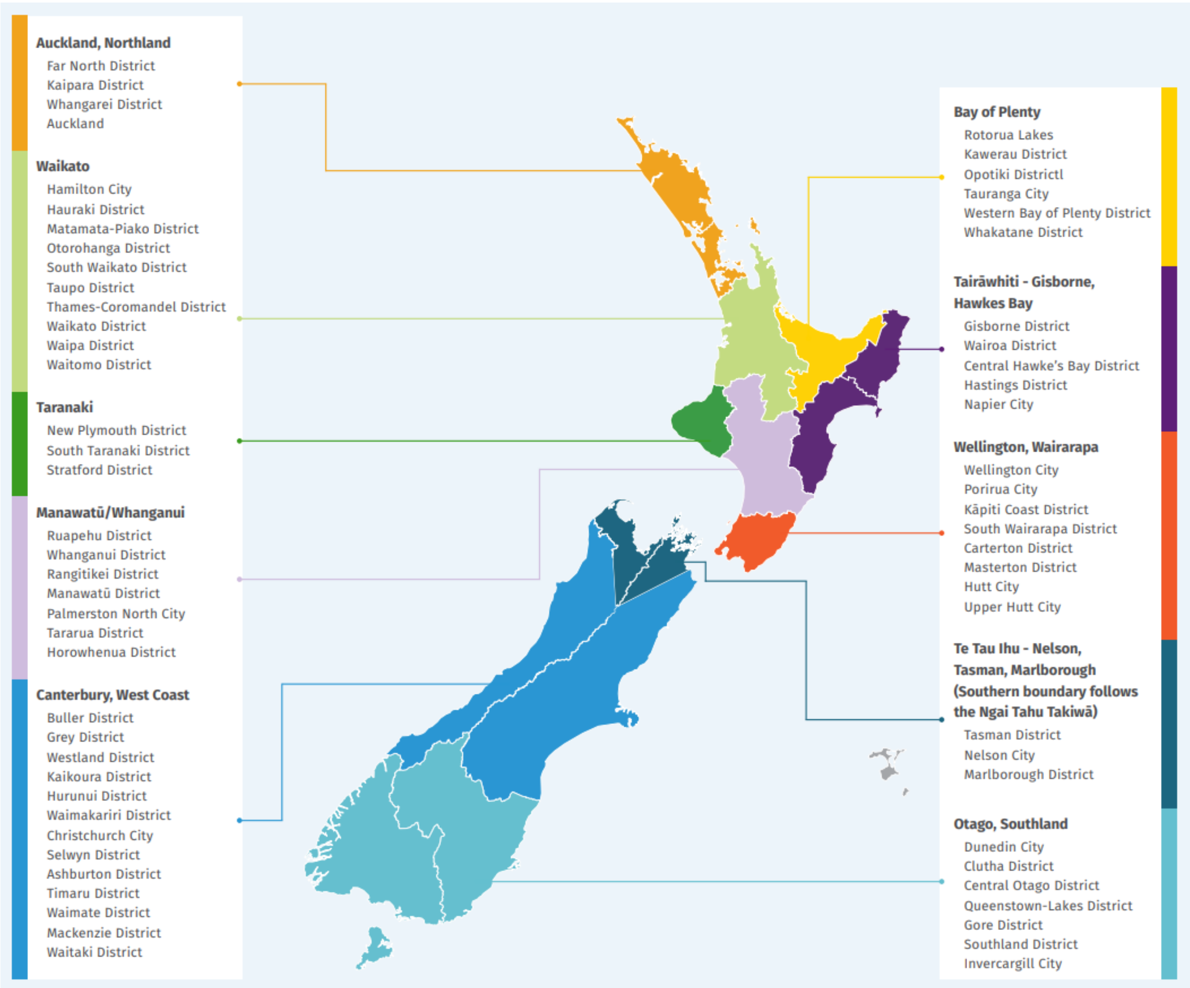


Figure 6-25: Map of Proposed Water Service Entity Areas

Sector	Criticality	Critical Assets	Critical Infrastructure Thresholds
Water Supply	National	Major sources, treatment plants, trunk mains with limited redundancy.	Supplies > 100,000 customers
Water Supply	Regional	Major sources, treatment plants, trunk mains	Supplies > 20,000 customers or critical (national) customer
Water Supply	Local	Source / treatment / storage / trunk main assets with limited redundancy.	Supplies > 2,000 customers or critical (regional) customer
Wastewater	National	City treatment plants, limited redundancy.	Supplies > 1M customers
Wastewater	Regional	City treatment plants with limited treatment / disposal options, pump stations, bulk mains.	Supplies > 100,000 customers
Wastewater	Local	Large town treatment plants with limited treatment / disposal options, pump stations, bulk mains.	Supplies > 10,000 customers

Table 6-10: Defining Critical Infrastructure – Water Supply and Wastewater

Overview

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. Even where weather events aren't damaging, water supply

Three Waters Reforms

A water quality incident in Havelock North in 2016 caused thousands of illnesses, hundreds of hospitalisations and (an estimated) four deaths. The subsequent Government Inquiry 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.

In particular, there were concerns about the ability of local government to fund and deliver basic maintenance and renewal programmes whilst also delivering resilience improvements and providing for rapid growth in some areas.

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).

Changes to the reforms programme in 2023 saw a shift from a proposed four large Water Service Entities to ten, largely regionally based with some covering 2 regions. A staggered rollout programme from 1 July 2024 to 2026 is proposed.

turbidity and quality issues following heavy rain in catchments are common, (example, Hunua Dam, 2016).

A brief discussion on the water supply for the four largest cities follows.

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).

Some components of Auckland's water supply are considered critical national infrastructure, as their failure could cause 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 Hunua's highlighting catchment protection and activity risks.

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

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 earthquake 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. 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).

New Zealand Lifelines Council

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

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 critical national infrastructure 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).

Regulation and Funding

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

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 New Zealand 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).

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 New Zealand'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.

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.

Other general regulation and funding constraints for lifelines are discussed in Section 3.

Resilience Investment Programmes

The ability to fund 'improvement' projects, such as those with resilience enhancements, is highly constrained in the sector – one of the many drivers for Sector reforms.

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.

The Department of Internal Affairs (DIA) National Transition Unit overseeing the reforms is compiling investment programmes as part of the development of the first draft Entity Asset Management Plans (AMPs), though information was not available for this report.

New Zealand's Major Natural Hazard Programmes: Water

AF8 / Alpine Fault

- Damage to 3-waters networks throughout 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.

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 processes can be disrupted, and equipment damaged. Also, ash ingress into wastewater networks (particularly combined systems).

Mt Taranaki

- 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

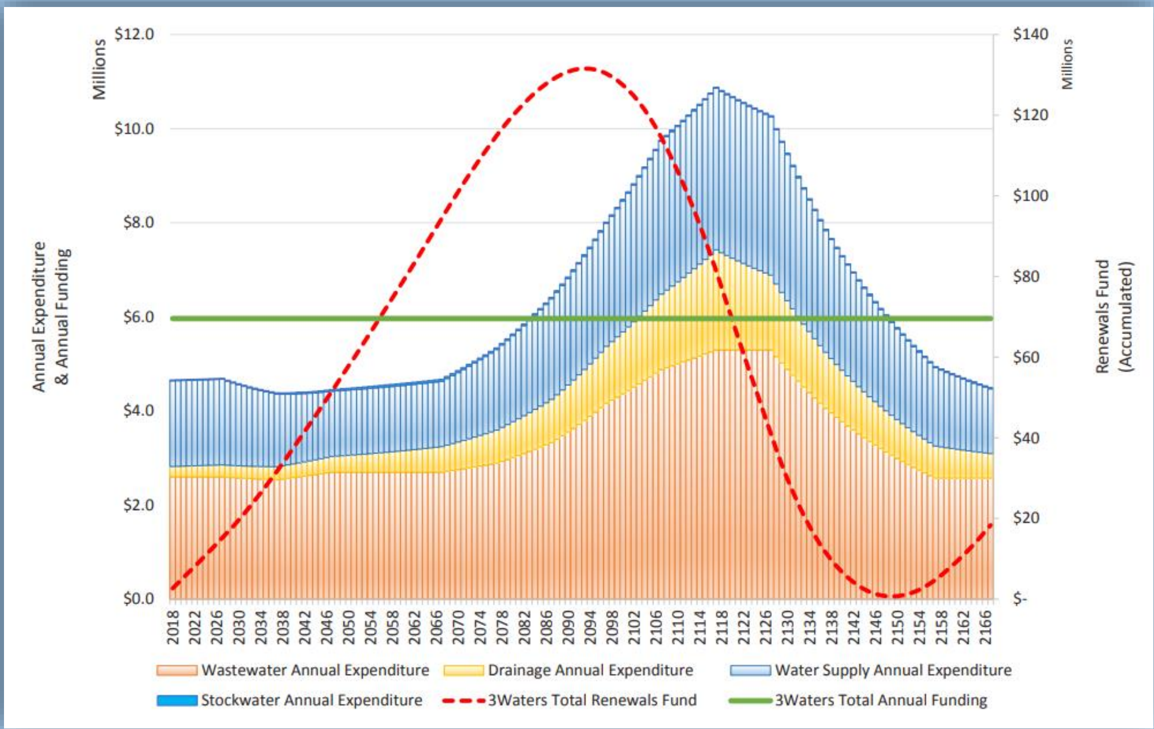
- Coastal wastewater treatment plants and stormwater outlets will be impacted by sea level rise.
- Increasing drought conditions will impact many New Zealand water supplies.

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 Vulnerability		
	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.
Consequence: Criticality Rating	Consequence			
AA, A	High	Default	0.85	0.75
B, C	Low	Default	Default	0.95

6.10 Stormwater and Flood Protection

2023 Update

As debate continued around whether to include stormwater and flood protection as Critical (Lifeline Utilities) infrastructure for this report, Cyclone Gabrielle made its own point. Stopbank breaches caused not only community property flooding but damage to other critical infrastructure.

There was an estimated 3-5 km of cumulative breach, and gate control equipment at some flood detention dams could not be accessed when the dam is full. MBIE has oversight of impending dam safety regulations coming into effect in 2024, which will affect a large number of stormwater detention and flood control dams across the country.

Again, this catastrophic event highlighted what was already well known in the Sector. 1) that the current flood protection levels provided by many flood control and stormwater schemes is inadequate. 2) that the actual level of current and future protection is not even known for many schemes, and 3) that funding for this sector is notoriously low (except for short periods following major flood events).

Since the previous National Vulnerability Assessment, work has been done to develop and refine the definition of critical infrastructure, illustrated in Table 4-7. This is expected to support government prioritisation of resilience and recovery funding both for recent and future.

Criticality	Critical Infrastructure Entities	Critical Assets	Critical Infrastructure Thresholds	Specific Asset Examples
National	Local authorities	Stopbanks protecting major urban populations.	Protects > x Dwellings Protects > y $land	Examples: Hutt Valley, Christchurch
Regional	Regional / Local Councils	Stopbanks protecting urban populations and significant economic activity.	Protects > x Dwellings Protects > y $land	
Local	Regional / Local Councils	Stopbanks protecting small urban areas or large mixed-use areas or high value cultural areas	Protects > x Dwellings Protects > y $land	

Table 6-11: Critical Infrastructure Thresholds

Overview

Flooding is New Zealand's most frequent natural hazard and is responsible for the highest number of declared civil defence emergencies. With over a hundred cities and towns located on flood plains, New Zealand has a long history of flooding events.

Climate change is increasing both the intensity and likelihood of future flooding events. Many communities and critical infrastructure networks rely on physical flood protection and other mitigation measures to reduce flood risk.

A 2022 report from the River Managers Special Interest Group called for urgent action to meet flood hazard risks arising from climate change.
002-Central-Government-Co-Investment-in-Flood-Protection-January-2022_ADVANCED-COPY-EMBARGOED-3PM-6-APR-22.pdf (lgnz.co.nz)

Urban stormwater networks and rural land drainage networks are not generally considered as critical as water and wastewater services. There are no critical national stormwater assets identified in regional lifelines assessments. However, attention is certainly given to stormwater management at a regional and local level.

Major flood protection schemes along rivers and flood plains are common, and generally include a wider range of measures:

1. Structural ('hard') measures - flood protection infrastructure such as stopbanks, floodways and spillways and floodgates
2. Non-structural ('soft') engineering approaches, land development exclusions, meteorological and hydrological forecasting and emergency management and insurance planning.

Stopbanks

Stopbanks are critical infrastructure protecting valuable property and enabling social and economic activity by containing floodwaters within a channel created by the stopbank. They are generally raised earth embankments that have been developed over the last 100 or so years to both protect existing built assets that are in flood prone areas, and to enable development or higher levels of productivity from protected land.

Each region manages their own flood protection schemes based on available resources and priorities, though at various points in time government funding has been injected (see 'Shovel Ready' case study).

The regional nature of stopbank management means that asset information is held in various formats and often is out-of-date or incomplete. This includes information on both the assets themselves, the level of protection they provide and the consequence of stopbank failure.

The New Zealand Inventory of Stopbanks (NZIS) provides the only geospatial overview of New Zealand's stopbank network. The inventory shows a total stopbank length of around 5,000 km across the country, with two thirds located in five regions (Canterbury, Waikato, Southland, Manawatū-Whanganui and Bay of Plenty). These regions are each characterised by relatively large land areas and major river systems.

Vulnerability to Hazards

Flooding

Flooding events causing stopbank overtopping and breaches have occurred often, examples include:

- **March 2016:** The Waiho River, near Franz Josef on the West Coast, burst its banks, resulting in evacuation of residents as well as sewerage flow into the river. Existing stopbanks had been washed away in previous flooding events, and replacement banks were deemed too expensive to repair.
- **April 2017:** Remnants of two tropical cyclones passed over New Zealand within a week of each other, resulting in significant flooding in many areas along the East Coast. A section of river stopbank in Edgecumbe failed, forcing the immediate evacuation of around 2000 people from the town.
- **August 2022:** A repaired stopbank near Harihari on the West Coast was severely damaged, causing flooding in both Westport and South Westland. The stopbank had already been extensively rebuilt following flooding events in February of the same year.

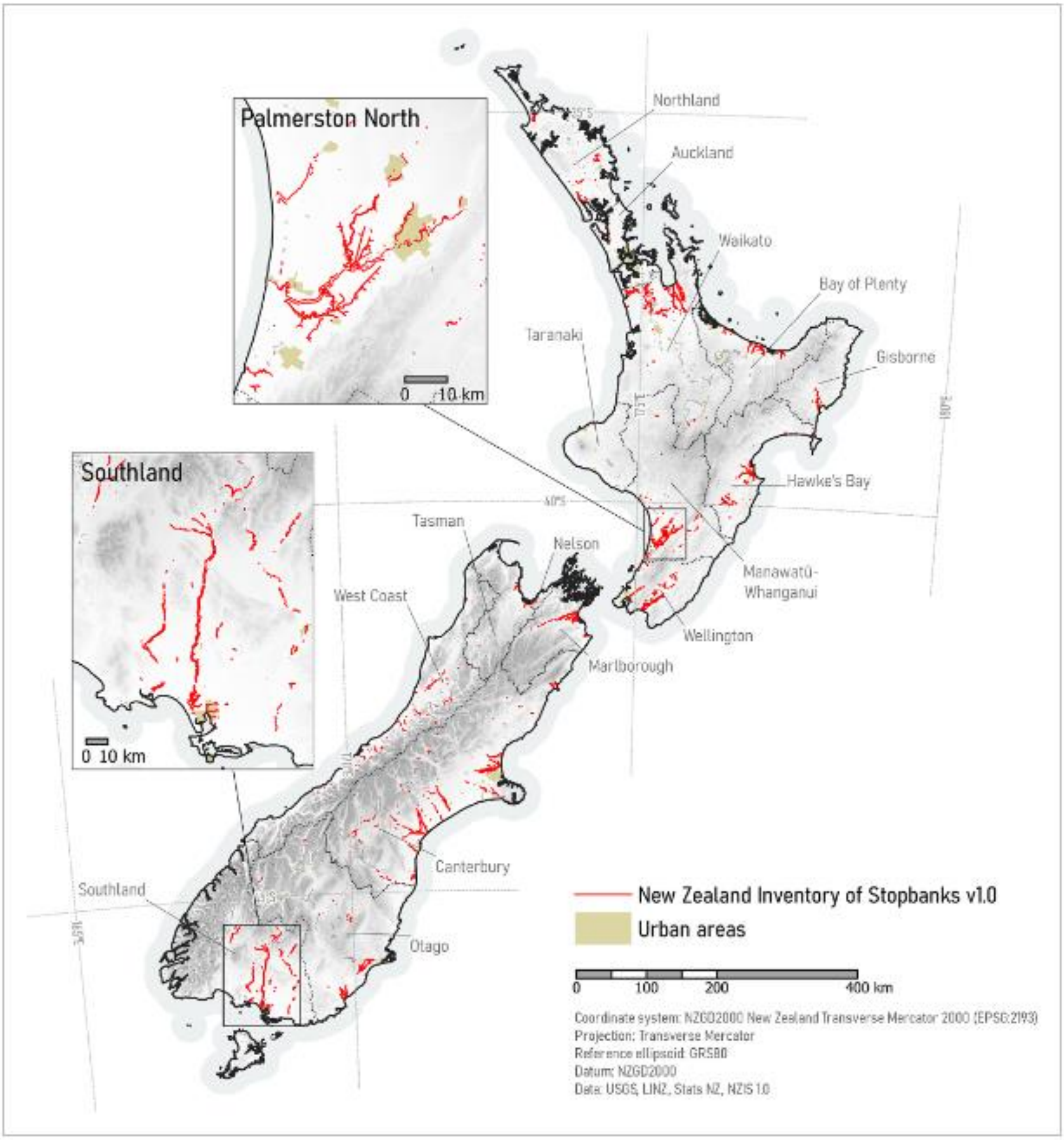


Figure 6-26: Length of Stopbanks Catalogued in the NZIS

Seismic

Seismic activity can cause settlement, slumping and slipping of stopbanks, as occurred in the 2010–2011 Canterbury Earthquake Sequence and November 2016 Kaikōura earthquake. Stopbanks by their nature are often in areas of liquefiable soils, with around 80% of stopbanks in areas with either 'very high' or 'high' liquefaction susceptibility. Other information from the NZIS includes:

- Around 60km, or 1%, of national stopbanks are within 100m of a known active fault, with a higher number of these in Bay of Plenty, Otago and Wellington regions.
- Over 85% of stopbanks in New Zealand are potentially exposed to ground shaking, with the highest number of stopbanks exposed to strong ground shaking intensities being in Manawatū-Whanganui, Wellington, Bay of Plenty and Hawkes Bay.

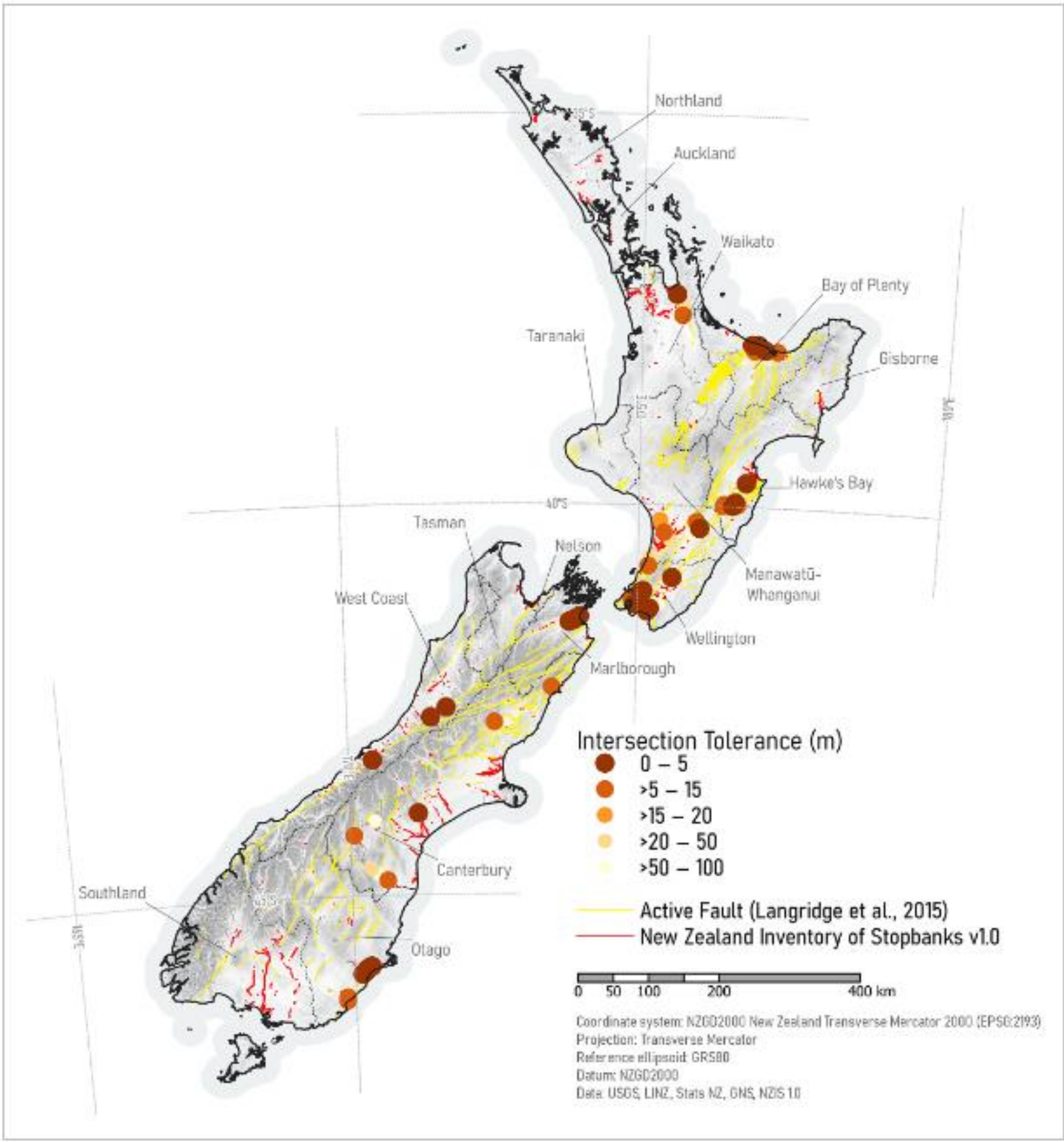


Figure 6-27 Locations where stopbanks are in close vicinity to known active faults across New Zealand (taken from NZIS)

The DIA has carried out analysis to provide national level information on the scale of vulnerable communities' exposure to flood hazard. The report (*August 2022, Report: Vulnerable Communities Exposed to Flood Hazard*) identified 44 communities across 7 territorial authorities that are exposed to a flood hazard, are not planning to build flood protection infrastructure, and that have a high level of socio-economic vulnerability. The seven territorial authorities are South Waikato, Waitomo, Buller, Gisborne, Opotiki, Rotorua, and the Far North.

Regulation and Funding

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 2004 requires new houses and habitable buildings to be designed with the floor level above the 50-year Annual Recurrence Interval (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.

Activities on stopbanks are generally governed by the RMA 1991 and maintenance is governed by the Local Government Act 2002.

Due to the regional nature of the stopbank system, investment and funding is set by each Local Authority and differs significantly across regions. Councils fund and prioritise flood protection infrastructure differently. Examples of investment into this infrastructure in recent years includes:

- Christchurch recently completed a $40 million upgrade of a stopbank system to protect the city from the Waimakariri River.
- $2.5 million was in Ashburton to build stopbanks on either side of the town's river.
- Over $23 million by Environment Southland and Invercargill City Council in 2020 to upgrade the region's flood protection infrastructure, as part of the Government's shovel-ready infrastructure initiative.

Case Study: 'Shovel-ready' projects

Funding for climate resilience flood protection infrastructure projects

In 2020, six regions received $210M funding for climate resilience and flood protection from the $3B allocated to infrastructure projects from the Government's COVID-19 Response and Recovery Fund.
The following regions received funding:

- Tairāwhiti – 1 project, $7.5m: Waipaoa River Flood Control Scheme – construction of stopbanks to protect valuable horticulture land
- Waikato – 10 projects, $23.8m: Stopbanks, pump stations, erosion protection with a number of these in the Hauraki Plains and along the Piako and Waikato Rivers.
- Hawke's Bay – 4 projects, $19.2m on upgrades to the Heretaunga Plains, Wairoa River and Upper Tukituki Flood control schemes.
- Manawatu-Whanganui – 5 projects, $26.9m mitigation flooding to Foxton, Palmerston North plus 25km of stopbank upgrades on the Lower Manawatu River.
- Wellington – 3 projects, $10.8m upgrading the Hutt River and Ruamahanga River schemes.
- Canterbury – 6 projects, $15.5m, multiple river protection, berm planting and stopbank upgrades.

6.11 Solid Waste

2023 Update:

Solid waste management is new addition to the (Lifeline Utility) Infrastructure sectors in this report. While not previously included as a lifeline utility in the CDEM Act 2002, the Canterbury earthquakes in 2010/11 confirmed this as a critical part of the interdependent infrastructure system. Clearing disaster debris from roads became a key response priority, to enable access and re-construction of infrastructure and to prevent public health impacts from rotting refuse. Several damaging disasters since then have reinforced the importance of this sector.

More recently, managing the millions of tonnes of silt debris following Cyclone Gabrielle required a dedicated silt disposal facility to be established (photo below), and the thousands of damaged homes and properties in the February 2023 Auckland floods led to a massive cleanup exercise.

Solid waste perhaps has been seen as a less asset-intensive activity than other lifeline utilities, but the shift in recent decades from undesigned local 'dumps' to heavily engineered, centralised landfills supported by a network of transfer stations has changed that picture. While the individual modern waste management sites are generally much more resilient, the impacts of disruption to a major regional landfill are much higher.

Since the previous National Vulnerability Assessment, work has been done to develop and refine the definition of critical infrastructure, illustrated in Table 4-7. This is expected to support government prioritisation of resilience and recovery funding in the future.

Criticality	Critical Infrastructure Entities	Critical Assets	Critical Infrastructure Thresholds
National	Large city councils and waste management operators	Large city landfills with long drive to alternate disposal.	To be developed. e.g.,> ..m3 waste disposed / day
Regional	Large district councils and waste management operators	Other large regional landfills with long drive to alternate disposal.	
Local	Councils and waste management operators.	Operating landfills and major transfer stations.	

Figure 6-28- Defining Critical Infrastructure – Solid Waste Sector

Overview

Waste management services comprise disposal, treatment, recycling and collection of waste from households and other sites to refuse transfer stations and landfill. There are generally two main waste streams: municipal solid waste (including residential, commercial, institutional, construction & demolition), and industrial waste (including agricultural, mining).

Waste management services are essential for human and environmental health but are also a significant economic enabler and 'lifeline'. All other infrastructure providers generate waste to build and operate their networks. Waste management becomes even more critical following natural hazards which can generate significant volumes of additional waste.

Landfilling is the most common method of solid waste disposal in New Zealand; an estimated 17.5 million tonnes of waste is generated annually with around 75% sent to legal landfill sites. These include Municipal landfills (household and other wastes), Managed landfills, construction/demolition landfills, 'cleanfills' and industrial landfills for specific waste types. As environmental standards have increased, the old Municipal landfill 'dumps', where people brought waste to a largely unmanaged sites, have been replaced with a smaller number of larger, engineered landfills where negative effects such as leachate, pests, traffic and air pollution are managed under stringent consent conditions. Transfer stations provide convenient local disposal locations from where waste is transported in bulk to these landfills.

District and city councils manage 87%of the landfills in New Zealand, typically operated through medium to long term contracts. There are a large number of private companies involved across the waste management system.

Since the 1990s, huge efforts have been put into reducing the volume of waste to landfill, with kerbside recycling in most larger urban areas and food waste collection starting in a number of regions. Landfilled rubbish is a significant contributor to New Zealand's greenhouse gas emissions (4% of total).

Critical National Infrastructure

There has been an ongoing reduction in the number of landfills across New Zealand and the number continues to decline; there are now less than 100 landfills operating in New Zealand, one third of the number in the 1990s. Landfills in some urban areas are reaching capacity and the availability of new space is limited by local opposition and environmental standards.
https://en.wikipedia.org/wiki/Waste_in_New_Zealand - cite_note-14

The trend to centralised, larger landfills, means that many can be considered critical national infrastructure - with long detours to the next available landfill if access to a landfill is disrupted. There is no national picture of landfill assets and the following table was compiled through regional lifelines groups (not complete).

Region	Major Landfills
Northland	Northland Regional Landfill (Puwera)
Auckland	Redvale, Albany, Whitford, Auckland
Waikato	North Waikato Landfill, (Hampton Power and Resource Recovery Centre)
Bay of Plenty	
Manawatu-Whanganui	Bonny Glen Landfill
Taranaki	To Bonny Glen (some materials required to go to Hampton). A South Taranaki landfill has been planned and constructed but is not operational.
Wellington	Southern Landfill
Nelson-Tasman	
Marlborough	
Canterbury	Kate Valley, Canterbury
Otago	Victoria Flats (Queenstown). Green Island, Dunedin
Southland	

Table 6-12: New Zealand's Major Landfills

Vulnerability to Hazards

Flooding / inundation

Many older and closed landfills are in coastal or flood-prone areas, vulnerable to flooding/inundation which can contribute to formation and release of toxic leachate from the sites.

According to a Local Government New Zealand report, there are 100 North Island and two South Island landfills exposed to sea level rise (refer Figure 6-29). These are mostly old, closed landfills but there are some operational landfills at risk (Otago, Canterbury).

Figure 6-29: Closed Landfills Adjacent to River/Coast

Seismic

Earthquakes may cause damage to the landfill liner, potentially contaminating natural water sources below or downstream of the landfill. Road access to landfills may be disrupted by slips.

Lifelines Dependence

Most transfer stations and landfills rely on electricity and fuel powered plant and equipment. Access to transfer stations and landfills for waste disposal is reliant on the roading network, and disruption to this network may slow the removal of waste from impacted sites to landfill. It is possible that access to landfill sites may be cut off for some weeks in a major disruption scenario, for example following a major earthquake or flooding.

Disaster Waste

Natural hazards often generate large volumes of debris and waste and may overwhelm waste management capacity. The waste can block access for response activities, hinder lifeline provision and are often contaminated with toxic or hazardous matter.

Some regional councils have disaster waste disposal and management plans, and there is a national Disaster Waste Management Plan template that has been developed to assist planning. Interim waste storage sites may be set-up following a disaster to manage waste volumes if the permanent landfill structures are not operational and/or accessible.

Regulation and Funding

Landfills are consented under the RMA 1991 and regulated through the Waste Minimisation Act 2008. There are also Hazardous Substances (Disposal) Regulations 2001 that set out the disposal regulations for hazardous waste material.

Resilience Investment Programmes

New landfill sites are strategically selected to ensure minimal risk to the public, environment, and exposure to hazards. Facilities are designed with lining systems typically made of low permeability clay that remove the risk of contaminated liquid escaping before it is captured and treated. Modern landfills are located away from the coast and major waterways and have protections to keep them safe from flooding.

6.12 Financial Payments and Cash Systems

2023 Update

The Financial Payments and Cash Systems is a new addition to the (Lifeline Utility) Infrastructure sectors in this report and is not currently recognised as a 'lifeline utility' service in the CDEM Act 2002. However, the service is critical to the functioning of many other lifelines services, for example to enable payment for food, fuel, flights and waste disposal.

The Financial Payments System needs power and telecommunications to function, and while core parts of the system have backup arrangements, most ATMs and retail outlets (such as fuel stations) cannot operate without these supplies. During Cyclone Gabrielle, there were issues around recognition of this sector, and associated companies such as Cash-in-Transit companies, being Essential Services and getting priority access through restricted roads.

The sector is in many ways becoming less resilient. As communities become more cashless and banks retreat from 'physical presence', there are less local options for securing cash, reducing this as an alternative means of payment in emergencies.

There are many critical sites within the Financial Payments System, such as major onshore holdings (regional vaults) that should be on critical customer lists. The table below (work in progress) will assist in identifying critical sites for inclusion on these lists.

Criticality	Critical Infrastructure Entities	Critical Assets	Critical Infrastructure Thresholds
National	Reserve Bank. Major Banks. Major ATM, point of sale and cash handling equipment providers and maintainers. Cash in Transit Industry. Payments industry service providers.	Wholesale and retail payments systems. Cash storage and processing infrastructure. Special purpose vehicles.	To be developed
Regional	Second tier banks.	Regional cash storage and processing infrastructure. Special purpose vehicles.	
Local		Bank branches ATMs (and associated equipment.	

Table 6-13: Defining Critical Infrastructure – Financial Payments Sector (In development)

Financial Services

The security and resilience of the Financial Services Sector depends on close collaboration between a broad set of partners. New Zealand's Financial Services Sector includes banks, non-bank lenders, licensed insurers and financial market infrastructures. New Zealand currently has 27 registered banks, including four large Australian-owned banks (ANZ, ASB, BNZ and Westpac).

Financial systems face a broad range of risks that could impair their functioning. In particular, the failure of the support structures that underlie the financial system - Financial Markets Infrastructure (FMI) – would have serious consequences across Aotearoa. FMI provides the systems and channels for clearing, settling, and recording financial transactions across New Zealand and internationally. Well-managed and well-operated FMI is of critical importance to the daily functioning of New Zealand, as it plays a key role in the sector, and disruption or failure could cause significant adverse impacts on financial markets, businesses, and consumers. All participants and financial systems discussed below have active risk management practices and mutual obligations, including for extensive business continuity and resilience contingencies.

In New Zealand, there are four types of FMIs:

- payment systems — a set of instruments, procedures and rules for the transfer of funds between or among participants
- securities settlement systems — enable securities to be transferred and settled by book entry according to a set of predetermined multilateral rules
- central securities depositories — provide securities accounts, central safekeeping services and asset services
- central counterparties — interpose themselves between counterparties to contracts traded in 1 or more markets.

The New Zealand FMI landscape is detailed in Figure 1.

There are three high-value wholesale payments FMIs in New Zealand:

- Exchange Settlement Account Systems (ESAS) - Provides real-time gross settlement of interbank transactions across the exchange settlement accounts held with us.
- High Value Clearing System (HVCS) - A set of rules for customer-to-customer real-time payments and for high-value payments between participating financial institutions. Settlement occurs in ESAS.
- Continuous Linked Settlement (CLS) - Provides payment versus payment settlement of foreign exchange transactions.

Payment systems facilitate the circulation of money in a country and are fundamental to the functioning of all monetary economies.

New Zealand's main retail payment systems are:

- Settlement Before Interchange (SBI) - Arrangements for the progressive exchange during the day of retail payment instructions (direct debits and credits, automatic payments, ATM settlement transactions, internet banking and phone banking). Payments are exchanged using Society for Worldwide Interbank Financial Telecommunication (SWIFT) and settlement of net interbank positions occurs in ESAS.
- Worldline New Zealand Limited - Provides a network for the interchange of point-of-sale card transactions.

- **EFTPOS New Zealand Limited** - Provides a network for the interchange of point-of-sale card transactions.

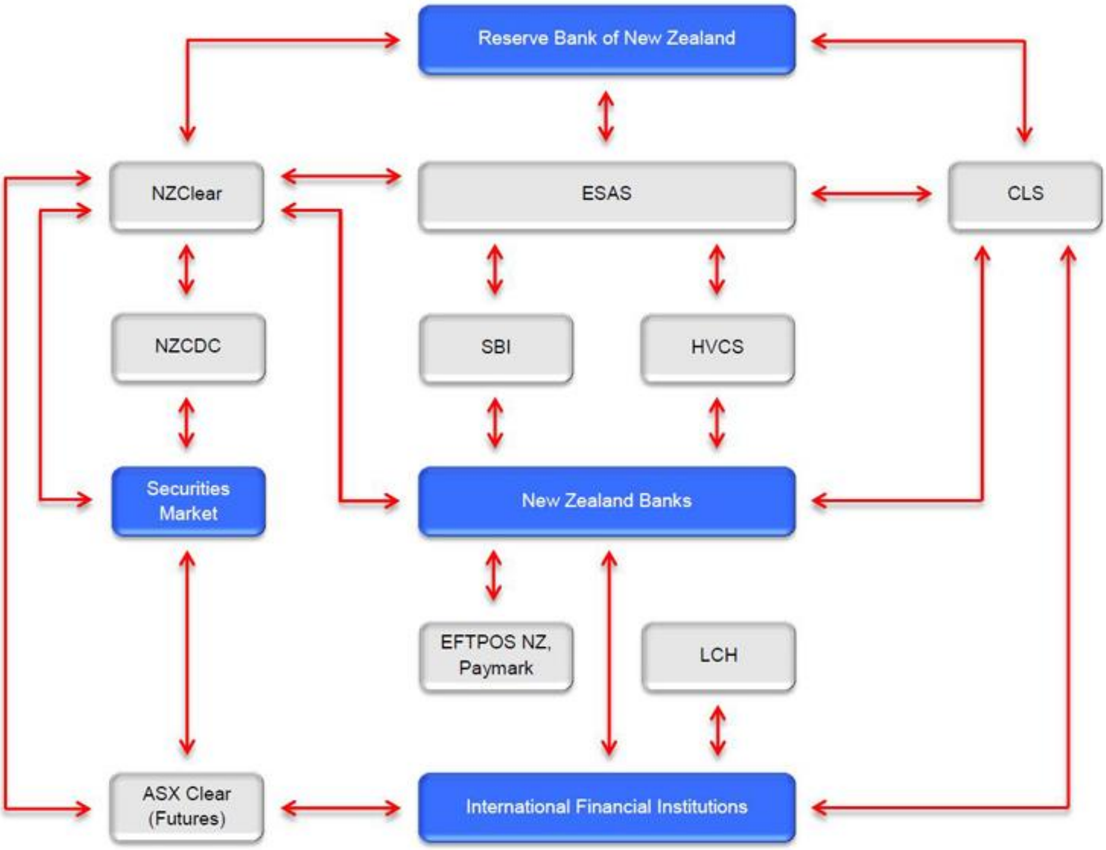


Figure 6-30: The New Zealand financial market infrastructure landscape

Vulnerabilities and Mitigations

As an FMI, payment systems are critical to the functioning of New Zealand before, during and after emergencies. All FMI is highly reliant on telecommunications and electricity services to function. FMIs and the wider financial sector are linked through a network of electronic systems, and failure of these systems could have detrimental effects on the entire economy. Additionally, the system is particularly vulnerable to cybersecurity risks, adding an additional layer of interdependency.

FMIs have layers of practiced redundancy and fallback systems (both technical and geographic) should a disruption event occur. There are varying degrees of regulatory supervision for FMIs based on their organisational form, role and risk profiles.

The headquarters of the major banks are in Auckland and considered to be critical national infrastructure assets. Due to Auckland's vulnerability to a range of natural hazards, banks require strong business continuity plans to minimise disruption. To reduce the risk associated with natural hazards, the Financial Services Sector continuously assesses its risk profile by understanding its vulnerabilities, critical assets and key mitigations required to minimise disruption. This includes understanding the organisational dependencies that financial services have on other lifelines. Further, the financial services sector should have recovery plans in place for potential disruption events.

This section has focussed on Financial Payments – additional information on the Cash Payments system will be included in future editions.

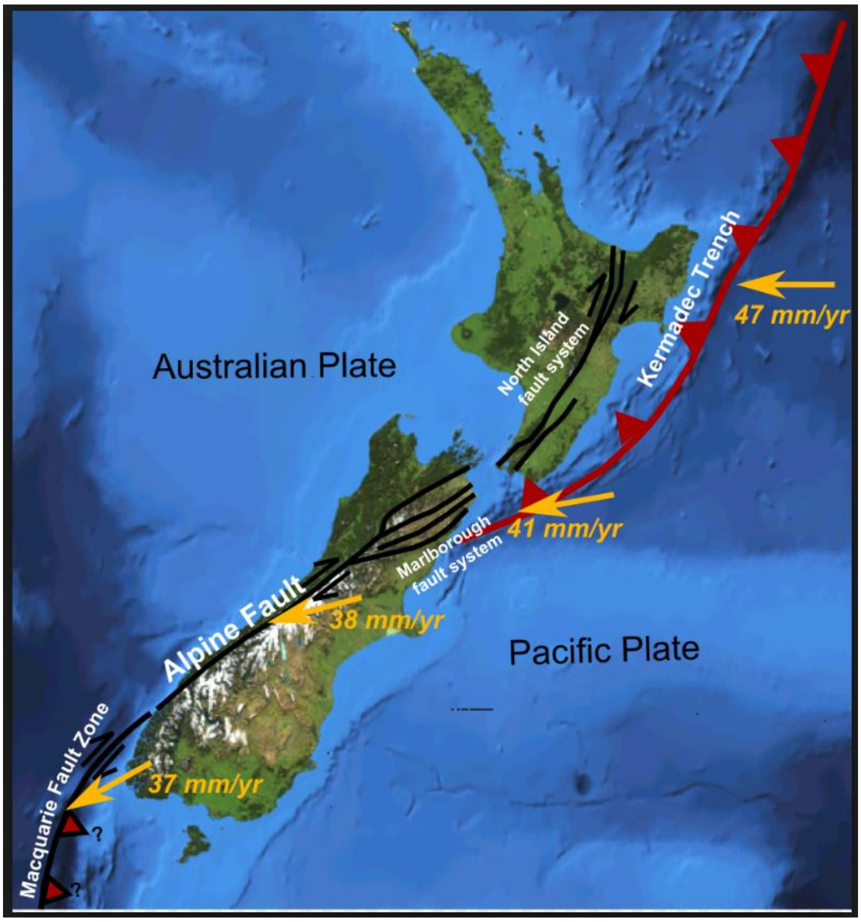
7. Infrastructure Vulnerability to Hazards

Section 7 presents an overview of major hazards to New Zealand's infrastructure, including earthquakes, volcanoes, tsunami, severe weather, 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.

7.1 New Zealand's Hazardscape

New Zealand's hazardscape reflects the country's position in the Pacific Ocean, on the collision zone between the Pacific and Australian plates. The country has high earthquake, landslide, storm and flood, tsunami and volcanic risk, and climate change is exacerbating many of these hazards.

Figure 7-1: Major faults and tectonic plates in and around New Zealand



There are several features of natural hazards that make them challenging to plan for.

The ***composite, cascading, cumulative*** nature of hazards is not always well understood. The focus is often on direct impacts such as earthquake shaking damage and landslides, not necessarily the cascading impacts such as increased flood risk arising from ground subsidence (as occurred in the 2011 Christchurch earthquake).
An example of cumulative impacts is when a light rain accompanies volcanic ashfall increasing 'flashover' risks on electrical systems.

There is a limited hazard event history within our living memory and an even smaller history of impacts on the impact on modern infrastructure of low frequency events. Geological hazards occur on geological (not human) timeframes, meaning most large magnitude events haves not been observed. There is also limited understanding of the frequency of small to moderate volcanic events as these events geological deposits are relatively thin and are largely may not have been preserved in the geological record.

Availability of national hazard and risk data. For some hazards there are national datasets such as active faults, earthquakes (GeoNet), tsunami and soil types. For others, hazard and risk 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 a usable form / product for practice, studies such as in lifelines projects.

Damage impacts cannot be accurately forecasted. There are a huge range of contributing factors and forecasted damage / loss assessments are likely to have large uncertainties at individual asset scale. Vulnerability and fragility of structures cannot necessarily be used from international examples, where construction practices may be quite different, and so we are reliant primarily on relatively limited experiences from New Zealand.

The impact of different hazard types are often assessed on different return periods, making it difficult to compare hazard risks. For various reasons, floods are typically analysed for much higher frequency events (1:100 year) 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 year coastal flooding event will become a 1 :1 year event with only modest rises in sea-level of 30-40 cm).

The following sections summarise information on the 'big four' natural hazards that are most commonly the focus of regional lifelines studies: earthquake, volcano, tsunami, and severe weather.

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

7.2 Earthquake

The Hazard

The Alpine Fault, the Wellington Fault and Hikurangi Subduction Zone are three major faults 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, located along the east coast of the North Island, can cause major earthquake shaking impacts and also has an associated high risk of generating a tsunami.

However, there are hundreds of other known active faults and many unknown faults both on and offshore.

Knowledge of Hazard

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

Figure 7-2: Active Fault Database (GNS)

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

New Zealand's major known faults are mapped in the **Active Faults Database**. This provides a nationwide map of onshore faults that have ruptured during the last 125,000 years. It is being continually updated as more information becomes available.

The **National Seismic Hazard Model** (NSHM) provides probabilistic estimates of the strength of earthquake shaking that can be expected according to a user-defined time period. A revision of the NSHM was completed in October 2022 which showed that seismic hazard increases almost everywhere across the country compared to what we knew previously.

This is not unexpected, because:

- We now know a lot more about earthquake behaviour due to better global understanding, more sophisticated science, and more than a decade of advancements in technical computing.
- We now have an improved model of the variability in shaking from potential earthquakes that could rupture in any single location. One significant contributor is the Hikurangi Subduction Zone, another is the Alpine Fault. These are important sources, but we also model the likelihood for earthquakes on unknown (hidden) faults and how shaking can affect regions far from the epicentre.
- We can model low probability but potentially high impact events affecting New Zealand, by understanding how faults can link together.

An initiative born out of the Canterbury earthquakes is the New Zealand Geotechnical Database which aims to collect and make available geotechnical investigations from all sources. While originating in Canterbury, it is now a full national data repository.

Auckland Council and Toka Tū Ake EQC have established the New Zealand Landslides Database which provides a central repository to catalogue landslide information from councils, Crown entities and geotechnical consultants.

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

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.

Fires were 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. However, there were very few instances of fires in Canterbury following the 2010/11 earthquakes, largely due to the limited extent of the 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.

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

Mitigation of the risk in New Zealand 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. Access to and use of water from the harbour is a key element of San Francisco's planning for firefighting following a major earthquake.

Impacts on Lifelines Infrastructure

Seismic and co-seismic hazards that have the potential to damage and disrupt infrastructure include:

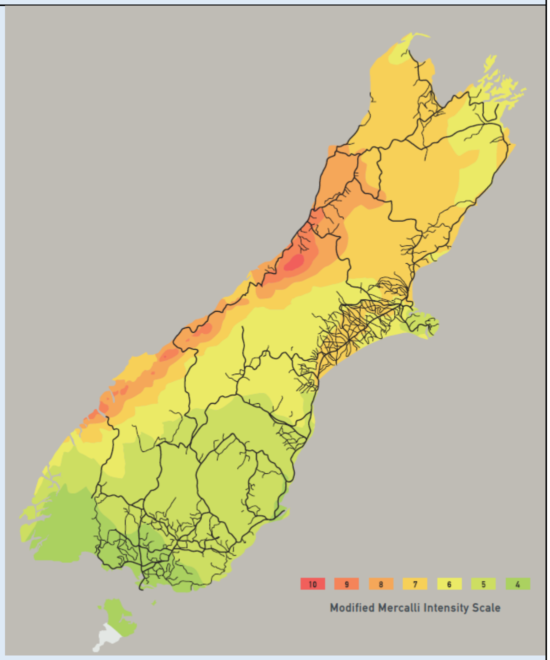
- Surface fault rupture – can range in length from a few metres to hundreds of kilometres and with horizontal and/or vertical ground displacements of several metres possible. Shearing and vertical offset of assets can result where ground displacements occur.
- Tectonic land movement – in a moderate to large earthquake the ground in nearby areas may be uplifted, dropped or tilted. Ground displacement can be several metres, as experienced in the Edgecumbe 1987 earthquake (where a large part of the ground in the Rangitaiki Plain dropped by up to 2m) and more recently in Kaikōura (2016).
- Strong shaking can cause damage to structures – the extent of structural damage that results in life safety risk can be reduced through modern seismic design.
- Fault rupture and ground shaking can produce secondary effects including rockfall / landslides, tsunami, ground settlement and liquefaction. All of these hazards are expected to become more severe with climate change. Liquefaction was shown in the Canterbury earthquakes to be particularly devastating to underground, brittle assets due to the associated vertical ground movement and horizontal movement due to 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.

Damage from liquefaction and ground movement, Canterbury Earthquake, February 2011.

Case Study: Alpine Fault (AF8 Research Programme)



Scenario and Context	▪ The Alpine Fault has a high probability (estimated at 75%) of rupturing in the next 50 years - and there is an 82% chance that this rupture will be a magnitude 8 earthquake. ▪ The Maximum Credible Event developed for AF8 initiates in Fiordland, propagating North East 400km to Lake Kaniere (inland from Hokitika). ▪ 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. ▪ 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 not expected due to the onland nature of the fault, but could occur if offshore faults rupture, and coastal populations should self-evacuate following a long or strong 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 South Island/Te Waipounamu Alpine Fault Earthquake Response (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 earthquake. https://af8.org.nz/safer-framework/

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 10% probability of occurrence within the next 100 years[2]. ▪ 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 Airports / Ports Water Electricity Telecomms FMCG Fuel Gas	▪ Major landslides will likely isolate Wellington by road. While Transmission Gully mitigates this risk by providing some redundancy, that route may also be impacted by landslides. Wellington is likely to be fractured by slips, fault rupture and other impacts, with links between these areas 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. ▪ 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. These assumptions are being questioned as optimistic. ▪ Palmerston North, Ohakea, Kapiti Coast (Paraparaumu), Masterton, Nelson and Blenheim airports will potentially be damaged or disrupted. ▪ Wellington regional potable water, stormwater and wastewater networks are highly likely to be severely disrupted, taking months to restore in some areas. Water/wastewater systems across the rest of the affected area may be disrupted or damaged. ▪ 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. Cook Strait cables could be broken, meaning north and south islands operating as separate grids. ▪ Traditional telecommunications networks are likely to be inoperable, overloaded or degraded, between Palmerston North and the Hurunui District. ▪ FMCG distribution system into the Wellington, Nelson, Tasman and Marlborough region will be inoperable via normal methods, due to road and port closures. ▪ 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 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 a resilience programme with a capital cost of $3.9B which are estimated to reduce economic impacts by $6B (refer Figure 53).

[2] New research suggests that larger earthquakes are possible on the Wellington Fault and also that significant seismic hazard is presented by many other faults in the region, especially the Hikurangi Subduction Zone.

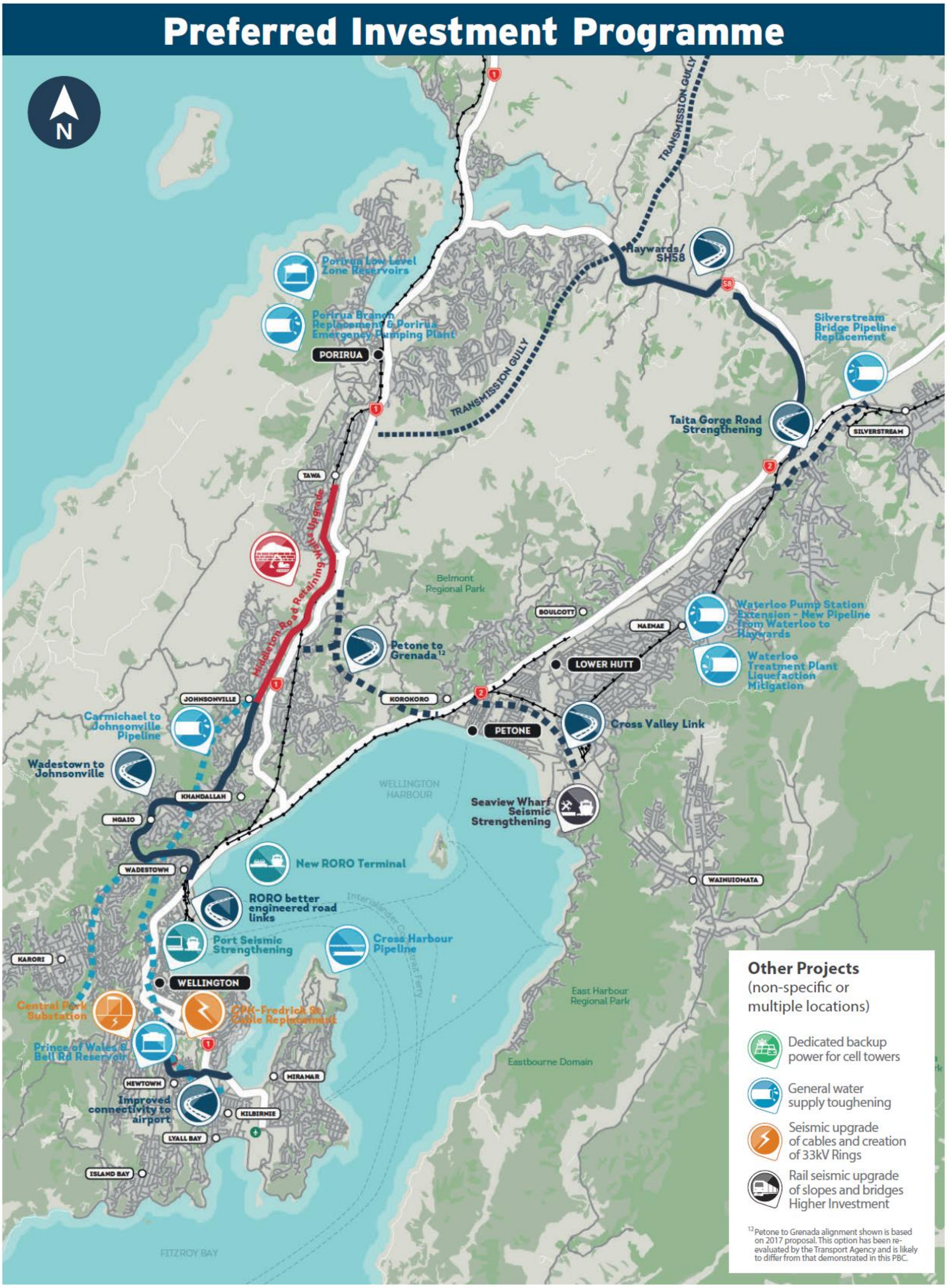


Figure 7-3: Wellington Lifelines Group Programme Business Case

7.3 Volcano

Volcanic hazards can cause extensive direct and systemic impacts to critical infrastructure and have the potential to impact large areas for potentially years to decades. New Zealand is one of the most volcanically active regions globally, with active volcanoes located on and offshore the North Island. Though we have relatively little lived experience of eruptions and their impacts, oral histories, historical and geological records, indicate our volcanoes are highly active in their eruptive histories. The volcanoes can broadly be classified into 3 main types: volcanic fields (e.g., the Auckland Volcanic Field), stratovolcanoes/cone volcanoes (e.g., Taranaki) and calderas (e.g., Taupō), that each have unique risk management challenges. Substantial advances have been made recently in volcanic hazard and risk management in New Zealand, and we are considered to be a global leader in this field, but volcanic risk is often not considered by critical infrastructure operators or regulators.

The Hazards

Volcanoes are complex and produce multiple hazards during both periods of unrest and eruption (e.g., volcanic earthquakes, subsidence, landslides, ash, pyroclastic density currents, lava flows, lahars and gases). Volcanic activity varies in intensity, style (which influences the type, sequence and extent of hazards) and duration.

The impact severity of each volcanic hazard and how these impacts compound (and cascade) can be complex. Generally the most destructive hazards occur close to the eruptive vent (e.g.,<20km) and more widespread hazards tend to be disruptive instead of destructive (such as volcanic ashfall, volcanic gas). However, lahars can travel tens to hundreds of kilometres from volcanoes and can be highly destructive to critical infrastructure. Lahars can also occur many years after a volcanic eruption ends.

Environmental conditions can influence volcanic hazards. For example, weather can influence volcanic ash dispersion, and the presence of water at the eruption vent (e.g., crater lake, snow, ice), and/or precipitation, can remobilise volcanic deposits (e.g., ash) in the form of lahars. Volcanic gas emissions are an often overlooked far-reaching

New Zealand's Volcanic Science Advice Panels

- **NZVSAP** (New Zealand Volcanic Science Advisory Panel): national-level multi-agency panel for coordination of science advice for volcanic preparedness and response.
- **VISG** (Volcanic Impacts Study Group): hosted by Auckland Lifelines Group, is a multidisciplinary and multi-institution consortium of volcanic risk scientists and critical infrastructure practitioners which provides a national focal point for volcanic impacts work on critical infrastructure.
- **CPVAG** (Central Plateau Volcanic Advisory Group), **TSVAG** (Taranaki Seismic and Volcanic Advisory Group), **CAG** (Caldera Advisory Group) **and AEM** (Auckland Emergency Management): regional-level multi-agency groups for collective planning, readiness activities and coordination of science advice for volcanic risks.

New Zealand's Volcanic Research Programmes

- **RNC** (Resilience to Nature's Challenges) Volcano, Rural and MRM (Multi-hazard Risk Model) themes, 2019-2024: research programmes that both coordinate national volcanic research and develop novel multi-hazard risk assessment methodologies.
- **NVHRM** (National Volcanic Hazard and Risk Model), 2022 – 2024: research programme that aims to develop a national framework for the quantification of volcanic hazard and risk.
- **GNS Science SSIF** (Strategic Science Investment Fund, 2010 – present: strategic funding to support New Zealand volcanic hazard and risk research.
- **DEVORA** (DEtermining VOlcanic Risk in Auckland), 2008 – present: research programme that aims to develop a much-improved assessment of volcanic hazard and risk in the Auckland metropolitan area and provide a strategy and rationale for appropriate risk mitigation.
- **He Mounga Puia (Transitioning Taranaki to a Volcanic Future)**, 2019 – 2024: research programme that aims to demonstrate how robust decisions can reduce risk and mitigate impacts for future Taranaki Mounga volcanism.
- **ECLIPSE** (Eruption or Catastrophe: Learning to Implement Preparedness for future Supervolcano Eruptions), 2017 - 2023: research programme that aims to reduce uncertainty surrounding the hazard and impact of future Taupō and Okataina caldera unrest episodes and eruptive activity.
- **Beneath the Waves,** 2021 – 2026: a research programme that aims to build resilience to hazards from Aotearoa New Zealand's near-shore volcanoes (Tuhua/Mayor Island and Whakaari/White Island).

volcanic hazard. Large gas plumes are possible from any New Zealand volcano, and will include acidic, corrosive gases such as sulphur dioxide (SO_2). Climate change is exacerbating many volcanic hazards, in particular making landslides and lahars more common.

Volcanic Unrest

Volcanic hazards and associated impacts are not limited to occurring only during eruptions. Volcanic unrest is characterised as a change from 'normal' behaviour at a given volcano, which generally indicates changes in magma dynamics in the subsurface. Volcanic unrest may or may not lead to an eruption. Volcanic unrest hazards include hydrothermal systems, gases, earthquakes, and ground deformation. Volcanic unrest can have considerable implications for infrastructure services, including direct damage, preventative shutdowns, exclusion zones and unpredictable societal responses (e.g.,self-evacuations).

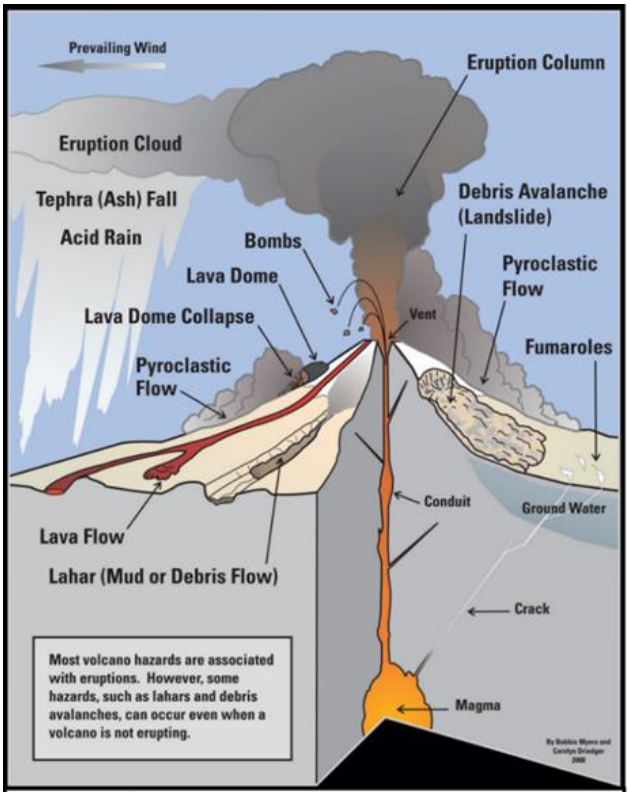


Figure 7-4: Geological hazards present at volcanoes (USGS 2008[i]).

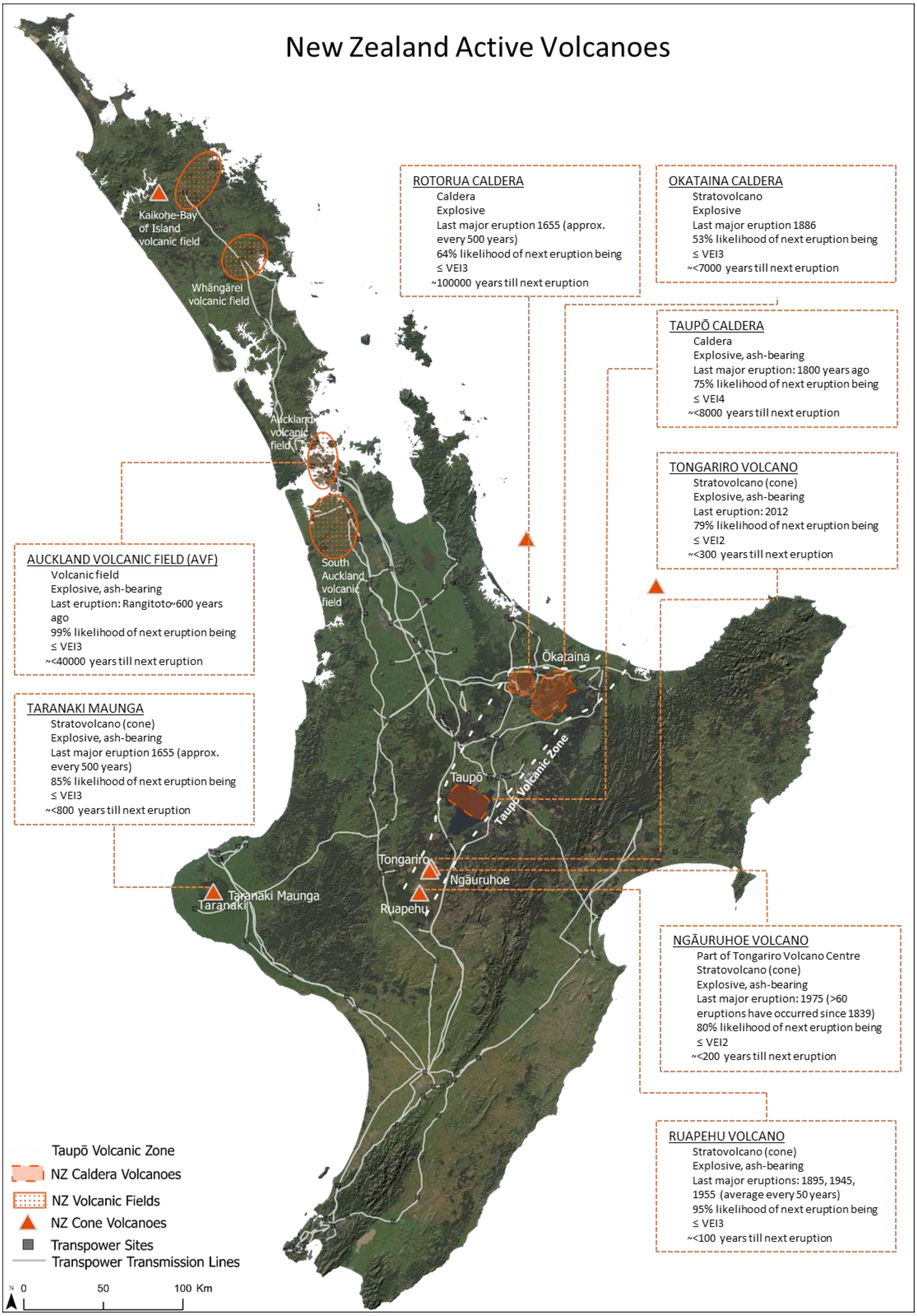
Knowledge of Hazards

Volcanic Eruption Probabilities

There has been a sustained, substantive effort to understand the likelihood of volcanic activity at each volcano in New Zealand (Table 52). These studies are typically informed by a range of data, including geological deposits of past eruptions, volcanic monitoring data (such as geophysical, geodetic and geochemical observations), observations from historic eruptions, observations or measurements from analogous volcanoes globally, and expert knowledge. Eruption magnitude is generally measured by the volume of material erupted, measured using the Volcanic Explosivity Index (VEI), which ranges from VEI 0 to VEI 8 (VEI 8 being the largest known eruptions in Earth's geological history). New Zealand volcanoes have produced eruptions ranging from VEI 0 to VEI 8, with Taupō producing some of the largest known eruptions in Earth's history.

Table 7-1: The likelihood of future eruption magnitudes at active volcanic centres in Aotearoa. Values show the probability of the next eruption being of a certain magnitude (measured by the Volcanic Explosivity Index (VEI)), and the time to the next eruption (Bebbington et al. 2018).

Volcano	VEI probabilities for next eruption								*Time to next eruption (years from 2018 (study publication date))*		
	VEI ≤2	VEI 3	VEI ≤ 3	VEI 4	VEI 5	VEI ≥6	VEI 6	VEI ≥7	*10% quantile*	*median*	*90% quantile*
Auckland Volcanic Field (AVF)	0.77	0.22	-	0.006	0.003	0.004	-	-	*35*	*2450*	*36400*
Rotorua	-	-	0.47	0.17	0.14	-	0.13	0.09	*1850*	*>100000*	*>100000*
Okataina	0.46	0.073	-	0.16	0.16	0.15	-	-	*4*	*150*	*6460*
Taupō	-	-	0.29	0.46	0.17	-	0.068	0.016	*49*	*1040*	*7510*
Ruapehu	0.68	0.27	-	0.039	0.015	0.003	-	-	*0.58*	*9.9*	*52*
Ngauruhoe	0.8	0.14	-	0.046	0.005	0.004	-	-	*0.72*	*17*	*162*
Tongariro	0.79	0.15	-	0.035	0.017	0.004	-	-	*0.84*	*19*	*227*
Taranaki	0.095	0.76	-	0.13	0.01	0.003	-	-	*4.5*	*82*	*619*


New Zealand Active Volcanoes
ROTORUA CALDERA
Caldera
Explosive
Last major eruption 1655 (approx. every 500 years)
64% likelihood of next eruption being ≤ VEI3
~100000 years till next eruption
OKATAINA CALDERA
Stratovolcano
Explosive
Last major eruption 1886
53% likelihood of next eruption being ≤ VEI3
~<7000 years till next eruption
TAUPŌ CALDERA
Caldera
Explosive, ash-bearing
Last major eruption: 1800 years ago
75% likelihood of next eruption being ≤ VEI4
~<8000 years till next eruption
TONGARIRO VOLCANO
Stratovolcano (cone)
Explosive, ash-bearing
Last eruption: 2012
79% likelihood of next eruption being ≤ VEI2
~<300 years till next eruption
AUCKLAND VOLCANIC FIELD (AVF)
Volcanic field
Explosive, ash-bearing
Last eruption: Rangitoto~600 years ago
99% likelihood of next eruption being ≤ VEI3
~<40000 years till next eruption
TARANAKI MAUNGA
Stratovolcano (cone)
Explosive, ash-bearing
Last major eruption 1655 (approx. every 500 years)
85% likelihood of next eruption being ≤ VEI3
~<800 years till next eruption
NGĀURUHOE VOLCANO
Part of Tongariro Volcano Centre
Stratovolcano (cone)
Explosive, ash-bearing
Last major eruption: 1975 (>60 eruptions have occurred since 1839)
80% likelihood of next eruption being ≤ VEI2
~<200 years till next eruption
RUAPEHU VOLCANO
Stratovolcano (cone)
Explosive, ash-bearing
Last major eruptions: 1895, 1945, 1955 (average every 50 years)
95% likelihood of next eruption being ≤ VEI3
~<100 years till next eruption
Kaikohe-Bay of Island volcanic field
Whāngārei volcanic field
Auckland volcanic field
South Auckland volcanic field
Ōkataina
Taupō
Taupō Volcanic Zone
Tongariro
Ngāuruhoe
Ruapehu
Taranaki Maunga
Taranaki
Taupō Volcanic Zone
NZ Caldera Volcanoes
NZ Volcanic Fields
NZ Cone Volcanoes
Transpower Sites
Transpower Transmission Lines
N
0
50
100 Km

Our understanding of the likelihood of volcanic activity underpins the development of scenarios and hazard assessments. It is important to note that these probabilities can shift drastically following activity in the volcano. Eruption forecasting is regularly examined and updated by the science advisory panels, research groups and programmes.

Volcanic Hazard Assessment

All active volcanoes in New Zealand are capable of producing large, spatially-extensive volcanic ash hazard. As such, probabilistic volcanic ash hazard assessment is relatively well-developed, and several studies have produced national-scale probabilistic ash hazard maps. Most recently, Wilson et al. (2023) conducted a probabilistic ash hazard assessment for electricity transmission assets in the North Island, discussed further in the proceeding section. Since there is wide diversity in eruption probabilities, frequency/magnitude relationships, potential eruption styles, intensities, durations and conditions at the surface during eruptions, there is considerable uncertainty in the development of volcanic hazard assessments for New Zealand volcanoes, particularly when assessing hazard and risk at a national scale. To reduce some of the complexity, Wilson et al. (2023) developed a 'screening step' for New Zealand volcanoes, which rapidly identifies higher hazard areas to direct research priorities for a hazard and risk assessment for national electricity transmission assets. This 'screening step' eliminated some volcanoes and/or some hazards, from further consideration in the study. The resultant map (Figure 57) is a qualitative output that has utility beyond the study, for other infrastructure sectors, at national and regional scales (Wilson et al. 2023).

Probabilistic hazard modelling is time-, labour- and computationally-intensive, and requires considerable development of input parameters for analytical models. Accordingly, surface flow hazards, such as pyroclastic flows and lahars, have not been robustly probabilistically assessed for New Zealand volcanoes, which is an identified priority for future volcanic research in New Zealand. Toka Tū Ake EQC is currently funding a project working on the development of a whole-country National Volcanic Hazard and Risk Model that aims to characterise and begin to address these knowledge gaps.

Figure 7-5: Active volcanoes in Aotearoa. There are broadly three types of volcanoes: stratovolcanoes (cone volcanoes), volcanic fields, and calderas. Volcano type, common eruptive style, last known eruption and the likely future eruption intensity of active and well-studied volcanoes are detailed in the text boxes. Figure from Wilson et al. (2023).[ii]

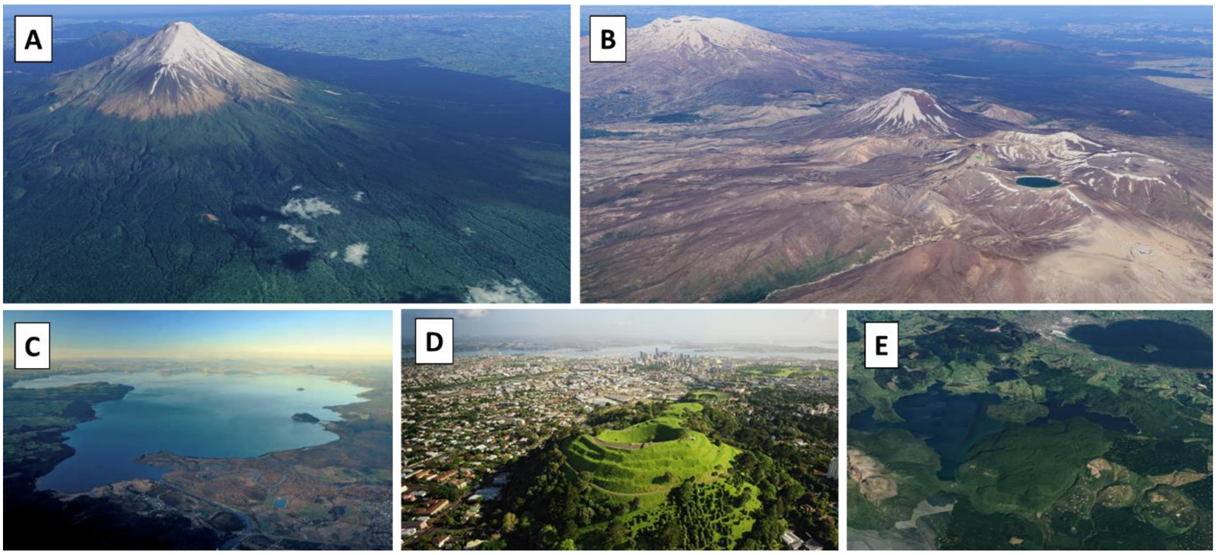


Figure 7-6: A) Taranaki (Google Maps); B) Tongariro National Park with (left to right) Mt. Ruapehu, Mt. Ngauruhoe and the other eruptive centres of Tongariro volcanic centre (Google Maps); C) Taupō volcano showing Lake Taupō (Dougal Townsend, GNS); D) Mt Eden, part of the Auckland Volcanic Field (GNS Science); E) Okataina caldera showing Mt. Tarawera (bottom left) with Rotorua Caldera (upper right) (Google Maps). Figure from Wilson et al. (2023).

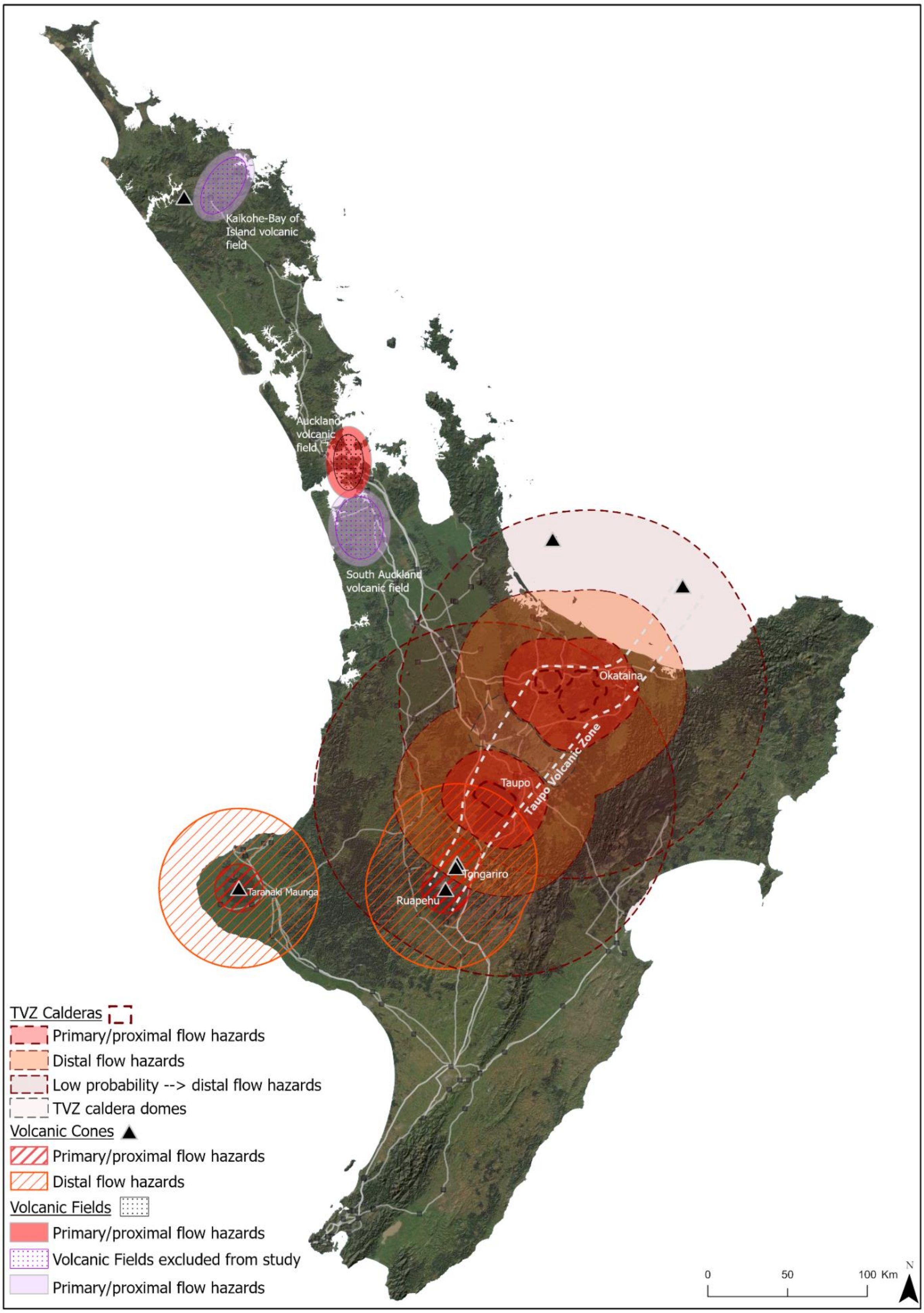


Figure 7-7: Volcanic hazard identification for high-energy surface flow hazards from active volcanoes in the North Island. Volcanic ashfall hazard is ubiquitous and therefore not spatially mapped. Figure from Wilson et al. (2023).

Probabilistic Volcanic Ash Hazard

Volcanic ash (tephra <2mm particle diameter) is a spatially-extensive volcanic hazard that can occur frequently throughout eruptive episodes. Volcanic ash impacts vary from destructive to nuisance-inducing and is a particular challenge for volcanic clean-up operations. Volcanic eruptions can last mere seconds up to multiple decades, during which time the wind direction and speed can vary greatly, introducing considerable uncertainty when planning for volcanic ash hazard.

Wilson et al. (2023) developed a probabilistic volcanic ash hazard assessment for New Zealand volcanoes. Probabilistic ashfall modelling is the statistical representation of ash hazard, often over vast spatio-temporal scales. Probabilistic hazard modelling allows the exploration of two values of relevance for infrastructure planning: 1) the AEP, which is the probability of an event occurring in any given year, such as exceeding 3mm of ashfall, and 2) the Average Return Period (ARP), which is the average duration of time between events. The AEP and ARP for 3mm of volcanic ash deposition (a threshold for infrastructure disruption and damage for several infrastructure sectors) across the North Island is presented in Figure 58 and Figure 59 respectively. Other ashfall thickness thresholds can be readily extracted from the probabilistic model (Wilson et al. 2023).

Impacts on Lifelines Infrastructure

Volcanic hazard impacts to critical infrastructure range from damaging to disruptive. Volcanic ash is generally disruptive and manageable during an eruption, though thick ashfall deposits can cause damage to large span buildings. However, volcanic flows (e.g., lahars, pyroclastic density currents and lava) can cause severe damage to exposed assets.

Although pyroclastic density currents, debris flows, lava, lahars and ballistic projectiles are the most destructive and life-threatening volcanic hazards, volcanic ash is by far the most widely distributed eruptive product (Wilson et al. 2014a). Ash rarely endangers human life directly, however, threats to public health and disruption to critical infrastructure services can lead to considerable societal impacts (Wilson et al. 2014a). Even relatively small eruptions can cause widespread disruption, damage and economic loss due to ash. Ash can cause heavy disruption, and repeated deposition or remobilisation by wind, vehicle movement and entrainment in water can cause repeated issues over months to decades. Past eruptions illustrate the vulnerability of urban areas to only a few mm of ash, as this thickness is sufficient to cause disruption of critical infrastructure systems. However, if affected only by thin ash fall (<50 mm), most infrastructure can be restored within a few days to weeks.

The Volcanic Impacts Study Group (VISG; https://www.alg.org.nz/volcanic-impacts/), in partnership with the Auckland Lifelines Group, have developed volcanic impact and preparedness resources for critical infrastructure. Much of this work is summarised by the **Volcanic Ashfall Preparedness Poster Series,** available at: https://www.gns.cri.nz/our-science/natural-hazards-and-risks/volcanoes/ash . An example of a poster output from this work is shown in Figure 7-10.

Considerable challenges remain in understanding multi-hazard impacts to infrastructure assets. Volcanic activity produces multiple hazards that can cascade, compound and interact to provoke damage and disruption to critical infrastructure networks. Limited domestic and overseas evidence makes it challenging to disentangle multi-hazard interactions and impacts, but research efforts are underway to address these challenges. Another notable challenge is understanding how volcanic unrest episodes cause disruption (and damage) to infrastructure. Caldera volcanoes in particular can undergo prolonged periods of unrest, often not resulting in an eruption. Research programmes underway in Aotearoa and overseas are actively exploring the impact of volcanic unrest on exposed elements and wider society.

Volcanic impacts are complex and diverse. However, relative to other facets of risk (e.g., societal, cultural and economic impacts), volcanic impacts to critical infrastructure are well-understood, or at least well-identified. Volcanic impacts, especially from volcanic ashfall, can be mitigated, managed and tolerated. A high-level summary of the key impacts of volcanic hazards to critical infrastructure is provided on the following page, with a list of resources for further reading in *Attachment 5: References*.

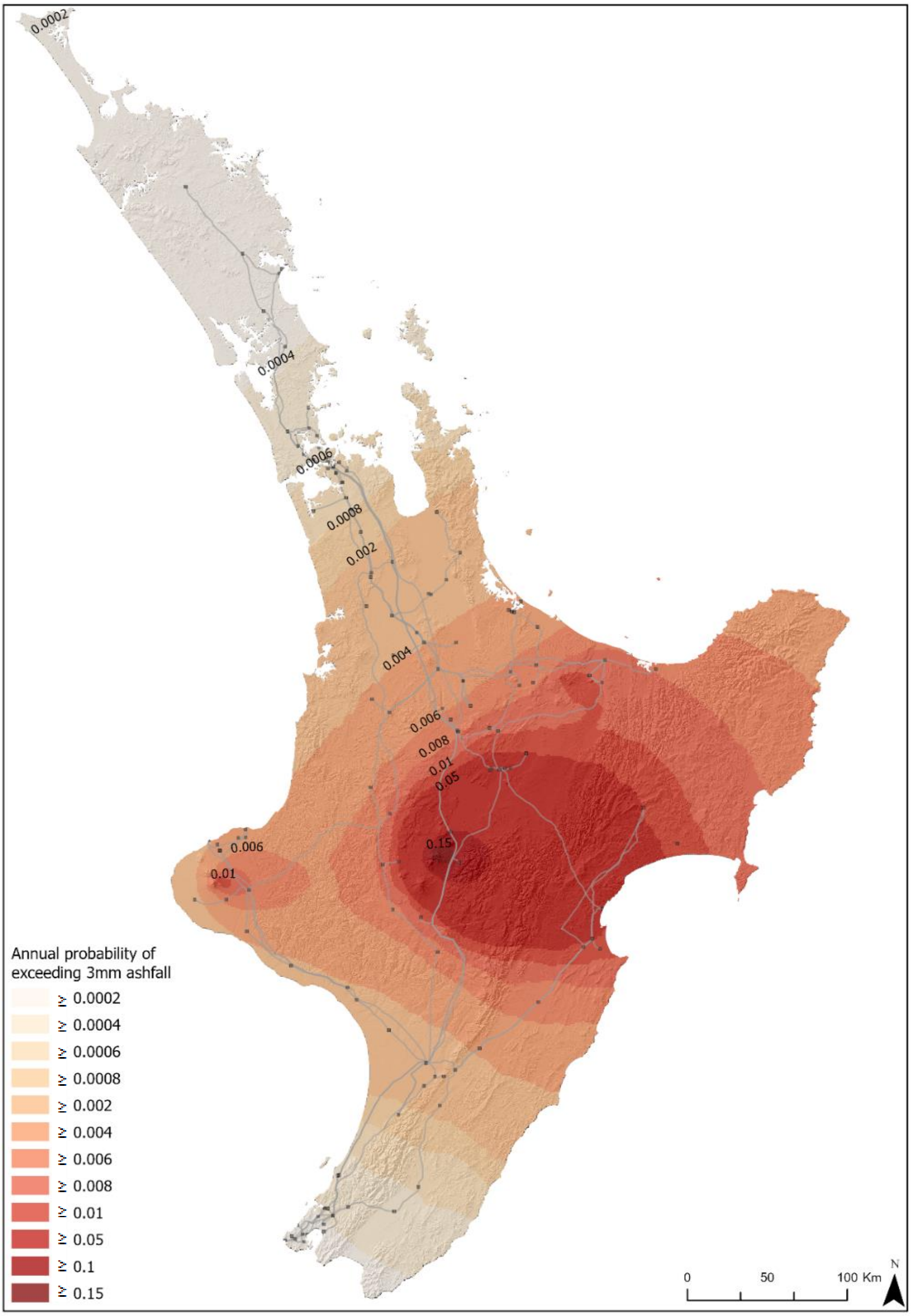


Figure 7-8: The probability of exceeding 200mm of volcanic ashfall from New Zealand volcanoes in any given year. Due to low eruption probabilities, the Auckland Volcanic Field (AVF) and Taupō volcano make relatively little contribution to the ashfall exceedance probability. The downwind location of high probability areas is indicative of the westerly prevailing wind direction at Taranaki and the Taupō Volcanic Zone (TVZ). Probabilistic ashfall model developed by Dr. Christina Magill (GNS Science) using data from Bebbington et al. 2018 Transpower's high-voltage transmission lines and sites are shown for context. Figure from Wilson et al. (2023).

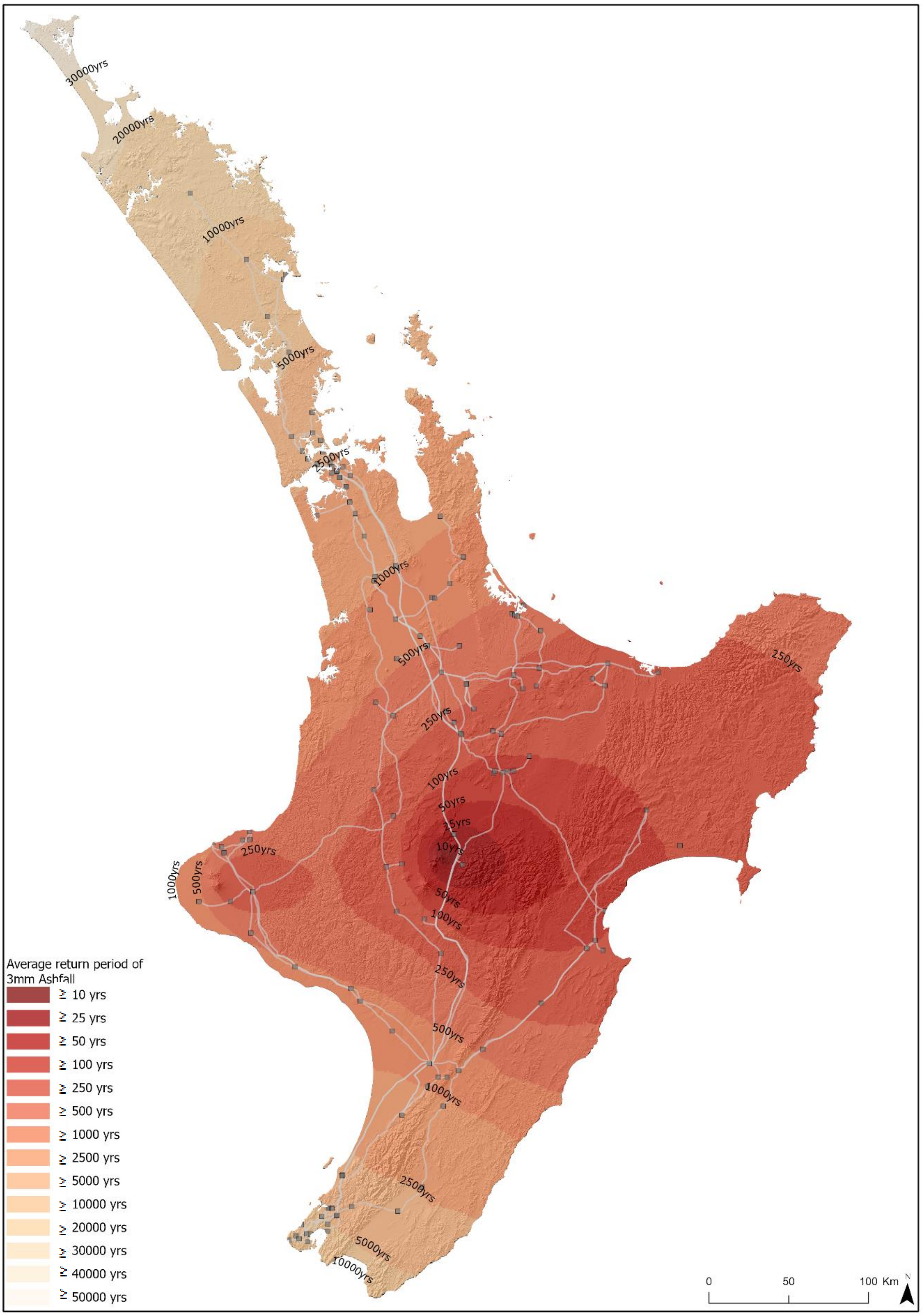
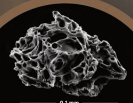


Figure 7-9: The average return period (ARP) for 3mm of ashfall from New Zealand volcanoes (the estimated average time between 3mm ashfall deposition events). Due to relatively long average return periods, the Auckland Volcanic Field (AVF) and Taupō volcano make relatively little contribution to the map symbology. Probabilistic ashfall model developed by Dr. Christina Magill (GNS Science) using data from Bebbington et al. (2018). Transpower's high-voltage transmission lines and sites are shown for context. Figure from Wilson et al. (2023).

High-level summary of key volcanic impacts on lifelines infrastructure

*Table 7-2 Summary table of documented volcanic impacts to critical infrastructure grouped by decade indicating the prevalence and occurrence of impacts over time. Symbols are: × Pre 1980s; # 1980s; * 1990s; § 2000s; and + 2010s (Wilson et al. 2014a).*

Sector	Damage	Tephra falls	PDCs	Lava flows	Lahars
Electrical supply					
	Flashover	# * § +			
	Abrasion – dry	# +			
	Abrasion – wet	*			*
	Corrosion	+			
	Gravel contamination	+			
	Physical damage to lines	§	§	× §	§
Water supply network					
	Pump, motor abrasion	# * +			
	Pipe, channel blockage	× # * +			× *
	Pipe ruptures		* §	× §	§
	Intake & filter blockages	× * +			×
	Water quality decrease	× # § +		§	
	Water shortages	× *			
Wastewater network					
	Pump, motor abrasion	× #			
	Pipe blockage	× # §			
	Infill of tanks	§ +			
	Filter blockage	§			
	Treatment disruption	# §			
Transportation					
	Road damage		# §	× # §	# * +
	Road burial/closure	* § +	§	# §	+
	Vehicle damage	# * § +	# *	#	× #
	Traction/visibility reduction	# * § +		#	
	Airport closure or damage	× # * +	*	§	§
	Aircraft damage	× # * +			
	Railway closure or damage	× # +		× #	× #
	Port closure or damage	× +		×	
	Ship damage	§	×		
Communications					
	Physical damage	# §	*		
	Signal interference	# * § +			
Buildings					
	Lateral impact damage		× # * § +	× # * §	# * § +
	Roof damage/ collapse	* § +	#		
	Fire		× * +	# §	
	Corrosion	*			
	Gutter damage	* §			
	Burial	× §	# §	× # §	# *
Critical components					
	Computer damage	# §			+
	HVAC damage	*			



VOLCANIC ASH IS: HARD, HIGHLY ABRASIVE, MILDLY CORROSIVE & CONDUCTIVE WHEN WET.

VOLCANIC ASHFALL

ADVICE FOR **WASTEWATER MANAGERS**

Impacts On Wastewater Collection And Treatment Systems

VOLCANIC ASH CAN CAUSE SERIOUS DAMAGE TO WASTEWATER COLLECTION AND TREATMENT SYSTEMS

- Cities with combined wastewater and stormwater sewers are particularly vulnerable.
- Ash can also enter sewer networks via inflow and infiltration (e.g. through illegal connections, cross-connections, gully-traps, manhole covers, cracks in sewer pipework).

SYSTEM COMPONENT	IMPACTS OF VOLCANIC ASHFALL
Wastewater network	• Ash may enter wastewater networks if there are combined sewers, or through inflow and infiltration. • Once in wastewater networks, ash may form unpumpable masses which may cause wastewater overflows. • Ash-laden wastewater will cause accelerated damage to pump impellers (pitting and thinning of metal).
Pre-treatment	• Mechanically-cleaned screens are highly vulnerable to damage as ash can abrade moving parts and block screens which may lead to motor and gearbox damage. • Fine screens are more vulnerable than coarse screens. • Ash may damage comminutors.
Primary treatment	• Ash may damage grit classifiers. • Ash will increase the volume of sludge for disposal, and will increase the inorganic content of sludge.
Secondary treatment	• Ash can enter open-air biological reactor tanks both through airfall and via influent. • The main effect is likely to be reduced capacity (due to ash accumulation on tank floors) rather than interference with bacterial processes. pH control may help prevent 'toxic shock' to bacterial populations. • Ash may damage biofilms in trickling filters.
Tertiary treatment	• Any residual very fine ash may increase suspended solid load of effluent, which may interfere with disinfection.
Sludge treatment	• Expect an increased volume of sludge with an increased inorganic content.
General impacts	• Airborne ash may clog aeration pump filters, requiring them to be changed more frequently. • Ashfalls may affect road networks, which may affect staff access and deliveries of supplies. • Ashfalls can cause electrical power outages. • Expect increased maintenance.

Recommended Actions

WHERE TO FIND WARNING INFORMATION

See **www.geonet.org.nz** for ashfall forecasts in the event of a volcanic eruption.

HOW TO PREPARE

At-risk wastewater treatment plants should develop operational plans for ashfall events, including site clean-up. Plans should include provision for:

- Incorporating up-to-date information from GeoNet into operational decisions.
- Monitoring the presence of ash in raw wastewater.
- Monitoring torque on motor-driven equipment.
- Shutting down non-essential equipment.
- Covering exposed equipment such as HVAC systems, switchboards, and electric motors to protect them from airborne ash.
- Limiting the ingress of ash into buildings.
- Equipment and labour requirements for increased maintenance and site cleanup.
- Ensure that staff working outdoors are supplied with adequate personal protective equipment (long-sleeved clothing, heavy footwear, fitted goggles and properly-fitted P2 or N95 dust masks).
- Coordination with local and regional emergency plans.

Review stocks of essential items as an ashfall may affect road and air transport.

Ensure access to back-up power generation, particularly for pumping stations.

HOW TO RESPOND

Work with local authorities to limit ingress of ash into stormwater drains and sewer lines.

Step up preventive maintenance.

Consider bypassing pumping stations and treatment plants as a protective measure to avoid severe and costly damage.

Ash-laden wastewater will cause accelerated damage to pump impellers (metal pitting and thinning).

FURTHER RESOURCES:

http://www.geonet.org.nz (volcano monitoring information)

http://www.gns.cri.nz/volcano (general information on volcanic hazards)

http://volcanoes.usgs.gov/volcanic_ash (volcanic ash impacts and mitigation encyclopedia)

http://www.ivhhn.org (information on volcanic health hazards)

CONTENT BY CAROL STEWART AND TOM WILSON

DESIGNED BY DARREN D'CRUZ

Version 3, June 2018

Case Study: City Of Yakima, Washington State, USA

VOLCANIC ASH CAN CAUSE SERIOUS DAMAGE TO WASTEWATER TREATMENT PLANTS.

The City of Yakima, Washington State, USA, sustained US$4 million (1980 value) damage to its plant following the 1980 eruption of Mt St Helens volcano which deposited approximately 10 mm of sand-sized ash on the city. This was primarily due to damage to the mechanically-cleaned bar screen and grit classifier.

Biological reactors at the municipal wastewater treatment plant at San Martin de los Andes, Argentina, continued to function without problems despite receiving 2 cm of ashfall from the 2015 eruption of Calbuco volcano, 165 km away in Chile. This was partially because the town's storm drains and sewers are well separated, so very little ash entered the plant in raw wastewater. Photo credit: Daniel Blake

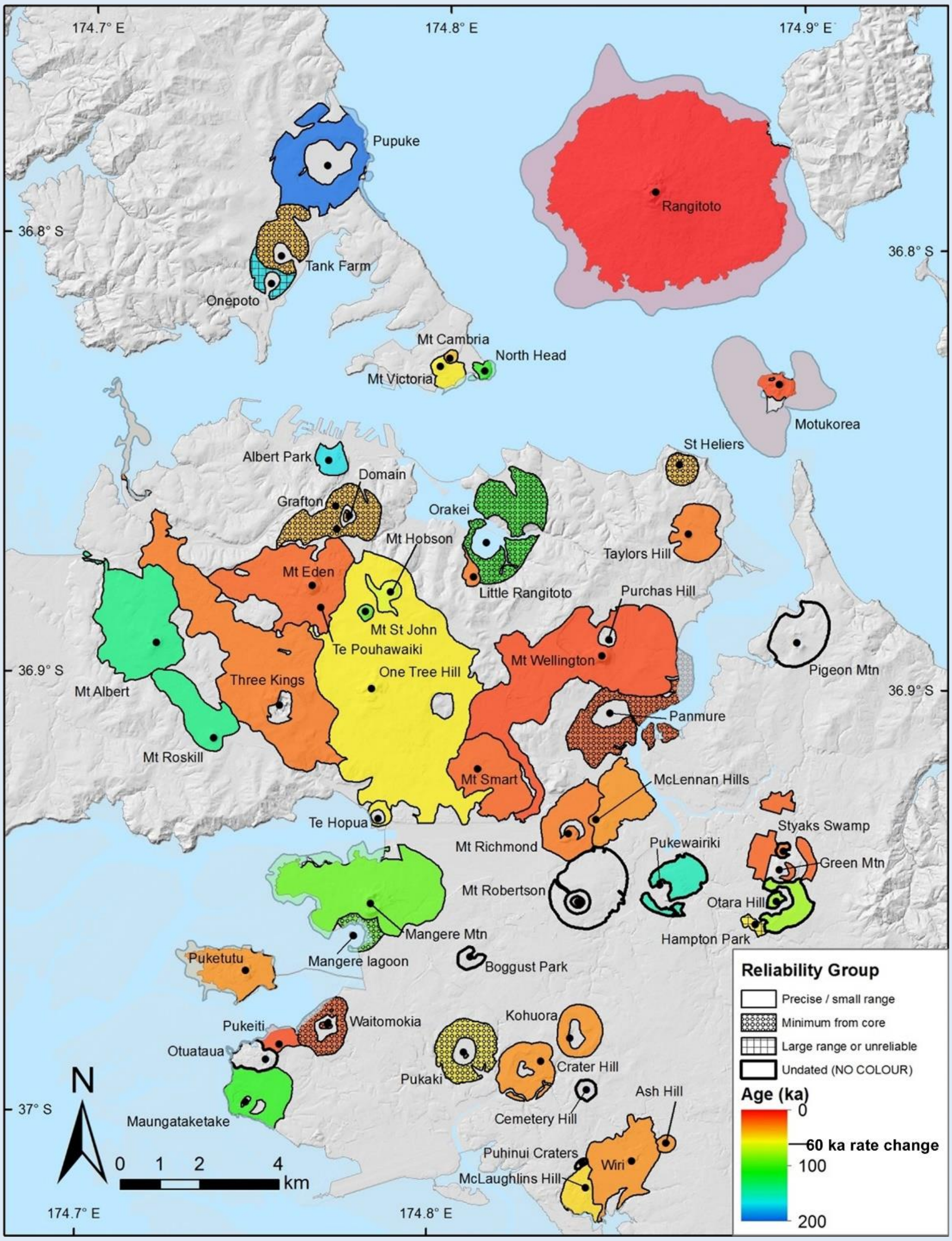
UC University of Canterbury · Auckland Lifelines · Massey University · EQC Earthquake Commission · DEVORA · VISG Volcanic Impact Study Group · GNS Science

Figure 7-10: Example of a Volcanic Ashfall Preparedness Poster (Auckland Lifelines Group, Volcanic Impacts Study Group). https://www.gns.cri.nz/our-science/natural-hazards-and-risks/volcanoes/ash/

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

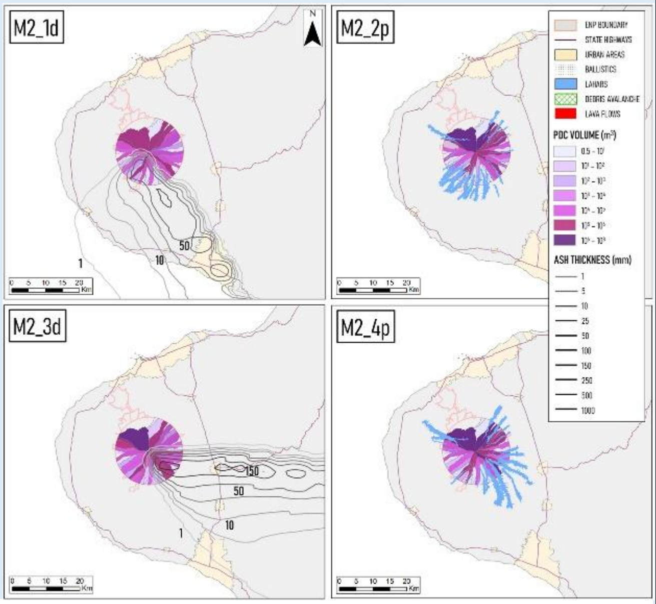
Scenario and Context

- 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 markings and 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. This would have substantial impacts on international travel, as international travel to New Zealand must have an alternate landing site, and New Zealand only has two airports capable of landing the largest international planes – Auckland and Christchurch.
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: Taranaki	
Scenario and Context	▪ 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 – 1.3 % probability of eruption in any one year (Cronin et al. 2021[iii]). ▪ 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.  *Figure 7-11: An eruption scenario for Taranaki Mounga. The scenario ('Medium 2' or M2) is one of an available suite of nine scenarios that have multiple phases (1d, 2p, 3d, 4p) and occur over long-durations (Weir et al. 2022).* ▪ A major study (*He Mounga Puia | 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.
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 significantly 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 water supply inlets, uncovered treatment plants, and uncovered reservoirs. Increased turbidity or contamination of water sources can limit supply through tactical shutdown of operations.
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 (Central-Taupō Volcanic Zone Calderas)	
Scenario and Context	▪ This programme is investigating how New Zealand can be more prepared for future unrest and eruptions by the Taupō to Okataina supervolcano complex. It is being led by a team of New Zealand 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.

7.4 Tsunami

New Zealand's tsunami hazard

A tsunami is a series of powerful waves with strong currents. They are mostly caused by underwater coastal earthquakes, and sometimes by underwater landslides, volcanic eruptions, and meteorite impacts.

Tsunami hazards to New Zealand are broadly categorised as:

1. Distant source; more than 3 hours travel time to New Zealand from sources mostly within the ring of subduction zones around the Pacific Ocean, such as South America, Japan, Solomon Islands, Cascadia (North America) and the Aleutian Islands.
2. Regional source; 1-3 hours travel time to New Zealand from sources such as the Puysegur trench and the Tonga-Kermadec trenches.
3. Local Source; less than an hour travel time to the nearest New Zealand coast. Seismic activity on the southern end of the Tonga-Kermadec trench can cause tsunami to reach northern New Zealand within an hour. Tsunami waves generated by an earthquake from the adjacent Hikurangi Subduction Zone along eastern North Island could arrive at the coast within minutes. There are many off-shore and shore-cutting faults around NZ capable of generating tsunami, such as those that ruptured during the 2016 Kaikōura earthquake event. Other sources include submarine landslides or a slump in the continental shelf.

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 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 has been significantly improved through the NZ Government funding the establishment of a network of twelve Deep-ocean Assessment and Reporting of Tsunami (DART) buoys to detect tsunami close to New Zealand and in the Pacific.

The data from the DART buoys supports more accurate tsunami warnings and also more rapid confirmation of no threat.

NEMA's 24/7 Monitoring Alerting and Reporting Centre are informed by the National Geohazards Monitoring Centre and provide warnings.

Figure 7-12: Tsunami Origin Locations (Source: NEMA Tsunami Advisory and Warning Plan (SP 01/20)

Tsunami risk to New Zealand

New Zealand has had over 80 recorded tsunamis between 1835-2011, many of which were generated by distant sources. More recently, New Zealand has been impacted by several tsunami events including the 2016 Kaikōura earthquake and tsunami, the 2021 Hikurangi and Kermadec Islands earthquake and tsunami sequence and the 2022 Hunga Tonga-Hunga Ha'apai volcano tsunami. GNS Science estimates that New Zealand has experienced six tsunamis that were over five metres high.

GNS Science has recently completed an update to New Zealand's National Tsunami Hazard Model. This dataset provides estimates of the maximum tsunami height to be expected at New Zealand's coast within specific time periods and confidence levels. There is also a tsunami hazard risk model, which uses probabilistic assessment (considering all likely future events and examining their size, frequency and impacts) to calculate tsunami risk for New Zealand.

Tsunami evacuation zones are a key tool for mitigating tsunami risk in New Zealand. They have been mapped for much of New Zealand's coastline in accordance with the Director's Guideline for Tsunami Evacuation Zones [08/16]. Evacuation zones represent an envelope around all possible inundation from all known tsunami sources, considering how each of those sources may generate a tsunami (and therefore no single event is expected to inundate all of the region's zones). The modelling used to calculate the tsunami evacuation zones varies by region across the country. The zones have a significant factor of safety applied, reflecting the accuracy of the relatively simplistic empirical approach.

The availability of Light Detection and Ranging (LiDAR) datasets is a key enabler of accurate tsunami inundation modelling. Funding has been made available through the Provincial Growth Fund for councils to collect new land base LiDAR. Land Information New Zealand (LINZ) has coordinated this work which is seeing improved elevation data coverage over much of New Zealand. LINZ is also seeking to source improved elevation data in the coastal zone, considered not only important for tsunami forecasting but important as we adapt to changing climate.

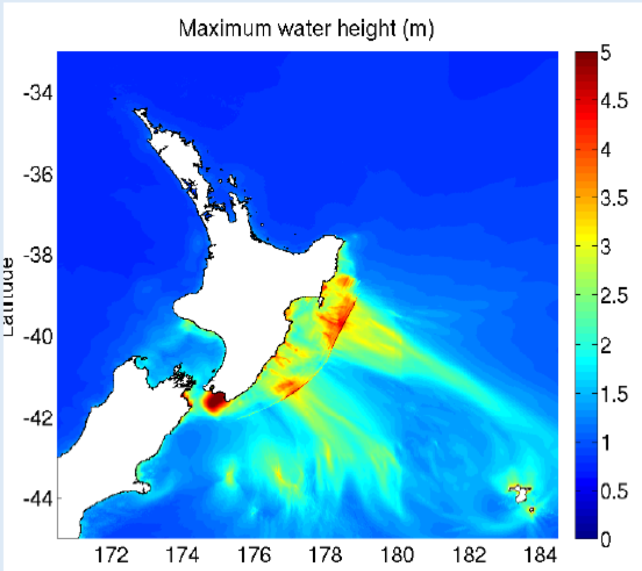
Sea level rise, resulting from climate change, will increase the inundation extent of tsunami.

Impacts on Lifelines Infrastructure

The Auckland and Wellington Lifelines Groups collaborated on a project in 2015/16 to review knowledge of tsunami impacts on infrastructure drawing from research on recent events[iv]. 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.
- Backup 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 lifelines services located on them.

- Major ports can be damaged through tsunami waves, tsunami have potential to significantly disrupt ship movements and damage ships and docks (e.g., ships pulling moorings).

Case Study: Hikurangi Subduction Zone – Earthquake and Tsunami	
Scenario and Context	▪ The Hikurangi plate boundary, located off the East Coast of the North Island, is where the Pacific tectonic plate subducts beneath 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 (Figure to right).
Infrastructure and Human Impacts	▪ 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 Marlborough is closed by slips. Airports and ports around the country will be coping with additional flights and ships diverted from their original locations.
Identified Mitigations	▪ Wellington Lifelines Group Programme Business Case (developed around the Wellington Fault) is a general reference for that region.

7.5 Severe Weather and Climate Change

Hazard Overview

New Zealand's climate and meteorological hazards vary by location and geography. In the north, ex-tropical cyclones produce intense rainfall and/or high winds occur every few years. Further south, along with intense rainfall 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, is exacerbating existing risks and the potential impacts of severe weather hazard events. Infrastructure and communities are vulnerable to sea level rise, drought, and climate change exacerbating the impacts of other hazards. At approximately 1°C of warming, New Zealand is already experiencing higher sea levels and more volatile weather patterns. As rates of global emissions put New Zealand on track to experience between 3°C and 5°C of warming by 2100, increasingly severe natural hazard events will increasingly disrupt lifelines infrastructure, putting communities at increasing risk.

There are three key 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). New Zealand will experience more frequent and/or more extreme floods and droughts, extreme temperatures and storms.
- **Ocean warming adds energy to ocean weather systems, especially cyclones:** Ex-tropical cyclones, which create many of New Zealand'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 and water table rise increasingly impacts natural and built environments**: Sea level around New Zealand 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).

Figure 7-13: A broadcasting tower (continuing to function in ice / snow conditions)

February 2023 Weather Events

In February 2023, a National State of Emergency was declared, the third time this has occurred in New Zealand's history and the first time that climate was part of the root cause.

Climate scientists have consistently projected more frequent and intense storm and heavy rainfall events, suggesting that recent events are not one-off aberrations but rather an indicator of permanent trend changes in weather patterns. Tropical cyclones are coming further south more frequently and are likely to have increased wind intensity and rain rates, causing more damage.

Hazard Knowledge

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

A lot of climate-related hazard information 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, higher impact events (most are limited to 1:100 year events).

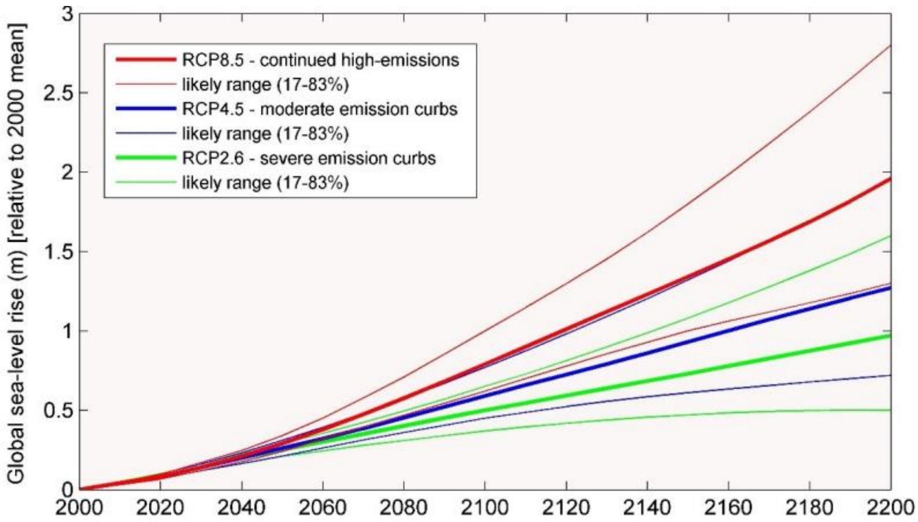
'Mā te haumaru ō nga puna wai ō Rākaihautū ka ora mo ake tonu: Increasing flood resilience across Aotearoa' is a five-year NIWA-led research programme aims to develop a system to map flood hazard consistently across Aotearoa New Zealand. It will also reveal how our flood risk may change over the next 100 years because of changes to rainfall and sea level from climate change, as well as due to land-use changes.

The Deep South Challenge (DSCC) is a National Science Challenge that aims to enable New Zealanders to adapt, manage risk and thrive in a changing climate. One of the research projects within the programme is focused on coastal flooding exposure under future sea level rise, summarised in the case study later in this section. 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 New Zealand that will be realised 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 Ministry for the Environment (MfE) Guidance for Local Government 'Coastal Hazards and Climate Change' produced four sea level rise scenarios to support climate change planning and stress-test response options or designs (refer Figure 5-14). coastal-hazards-guide-final.pdf (environment.govt.nz)

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). This work concluded with the National Adaptation Plan and Emissions Reduction Plan. national-adaptation-plan-and-emissions-reduction-plan-guidance-note.pdf (environment.govt.nz).

Standards New Zealand have committed to supporting and promoting the integration of climate change adaptation and mitigation in new and revised standards commissioned by third parties. For example, incorporating the MfE projections on rain and wind increases associated with climate change into the structural design "Wind actions" standard.



Heavy line = median, thin lines, the likely range (17th–83rd percentile) for projection ensembles generated by the probabilistic modelling approach.

Figure 7-14: Range of projections of global mean sea level rise to 2200 for three representative concentration pathways, relative to 2000 from Kopp et al (2014)

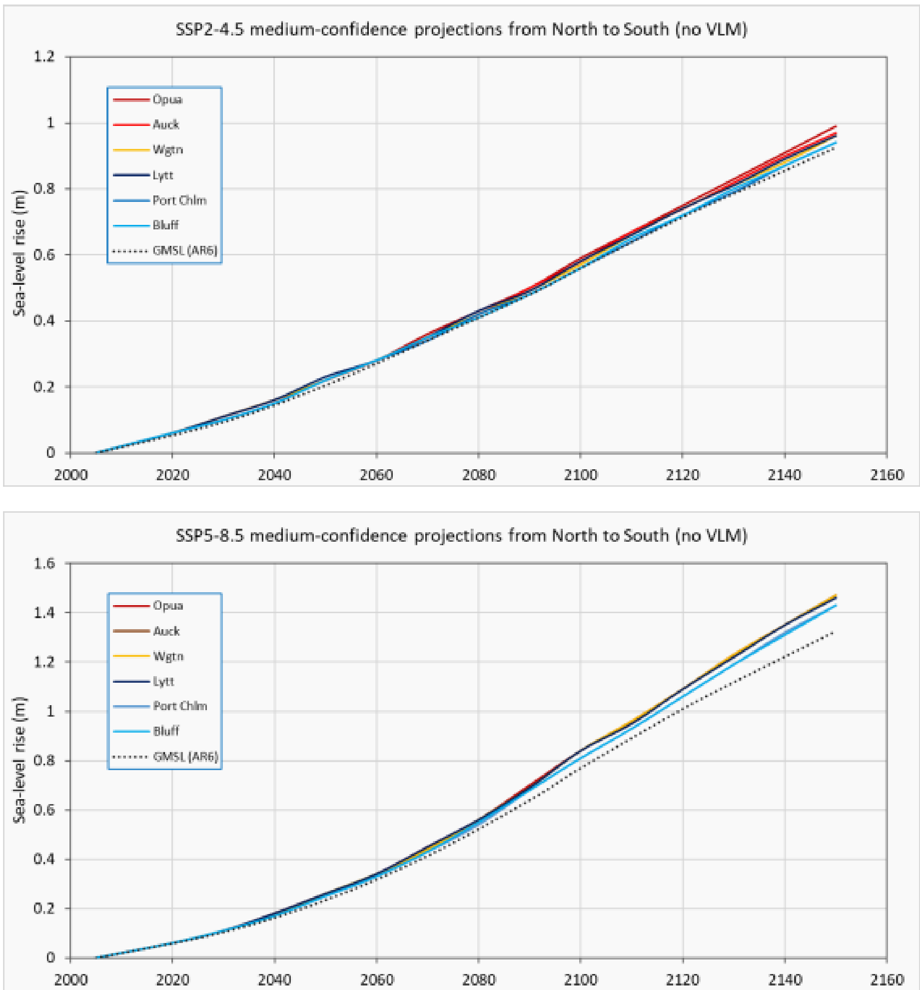


Figure 7-15: Comparison of the new NZSeaRise projections (excluding VLM) for SSP2-4.5 M and SSP5- 8.5 M for six locations with the equivalent global average GMSL from IPCC AR6 (Source MfE Interim Guidance on the use of new sea-level rise projections).

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
- 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 DSCC 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.
- Experts from Te Herenga Waka: Victoria University of Wellington, GNS Science, NIWA, the University of Otago, and the Antarctic Science Platform worked together to provide improved predictions of sea-level rise in New Zealand, in a programme called NZ SeaRise. In May 2022, NZ SeaRise released location specific sea-level rise projections through to 2300 for every two kilometres of the coast of New Zealand, available at www.searise.nz.

Impacts on Lifelines Infrastructure

Several regional lifelines studies have looked at the risk from infrastructure exposed to flooding. While these have not identified any critical national infrastructure vulnerable to floods, the low-lying Dunedin CBD area does contain several regionally important infrastructure sites. The DIA Report: *Vulnerable Communities Exposed to Flood Hazard, August 2022* identified 44 communities most vulnerable to flooding.

Beyond these specific studies, the impacts on lifelines infrastructure resulting from climate change are:

- 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.
- 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 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). Coastal saltwater flooding can impact low-lying control or electrical systems or advance corrosion.
- 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.
- 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 increased temperature and electricity outages.

Knowledge gaps

- A national picture of assets at risk, and their replacement value.
- The consequential and cascading impacts of assets at risk (GDP and impacts on wellbeing).

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 (under a DAPP approach).
- Some utilities have modified design codes which require new infrastructure to be built with consideration of sea level rise and higher flooding frequencies.
- An important project was 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 medium term, and allow further raising of the road longer term, by providing sufficient footprint and ground treatment up front.
- Transpower and Waka Kotahi's resilience programmes have both identified mitigations associated with flood risk at critical sites/routes.

7.6 Other Hazards: Cyber Attack, Pandemic, Fire, Space Weather and Malicious Attacks

This report does not aim to exhaustively cover all potential causes of disruptions to lifeline utility services. The hazards dealt with in Sections 7.1 to 7.5 are natural hazards that have been well studied in New Zealand and are considered to have potentially highly damaging impacts on lifelines infrastructure.

This section broadens attention to a range of hazards beyond just natural hazards and includes cyber-attack, pandemic, fire, space weather and failure of satellite-based global positioning systems.

Cyber Attack

Critical infrastructure has become reliant on networked technology and information communication systems to deliver modern, resilient and scalable services. Cyber security incidents can cause significant disruption to New Zealand's lifeline utility services through disabling critical online control systems, exhausting digital infrastructure capacity, isolating parts of critical systems or making data unavailable through techniques such as encryption or destruction.

In addition to reliance on network technology, there is also an increasing sophistication in the capabilities of state-sponsored and criminal actors to conduct cyber operations directly against critical infrastructure providers and their suppliers.

Cyber security work led by the National Cyber Security Centre (NCSC) within the Government Communications Security Bureau (GCSB) supports nationally significant organisations, both public and private, to improve their cyber resilience and respond to advanced threats through:

- publishing reports about specific vulnerabilities, mitigations and cyber security best practice
- facilitating sector-based information exchanges where participants can discuss cyber-security challenges in a confidential and trusted environment
- offering cyber defensive capabilities to consenting organisations, including Malware Free Networks, a threat detection and disruption service tailored to the New Zealand threat environment
- helping nationally significant organisations respond to, and recover from, high-impact cyber security incidents.

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.

The COVID-19 pandemic had wide-reaching global impacts but New Zealand lifeline utilities' followed business continuity plans and maintained normal services, even while there were some 'close calls' in disruptions to important supplies such as chemicals. Key issues included:

- Concern about worker safety (lack of personal protective equipment) 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 New Zealand.
- 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 sector.

(Wild) Fires

The frequency and extent of major wild 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.

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 several 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 daily, 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.

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.

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 LINZ in collaboration with Australia.

Space Weather

Space weather refers to the variations in the natural electromagnetic and particle radiation environment in space, primarily caused by solar activity. While space weather events are not as widely recognized as other natural hazards like earthquakes or hurricanes, they can pose significant risks to modern infrastructure systems, particularly those reliant on advanced technology and electronic components. Some potential space weather hazards for infrastructure systems include:

Geomagnetic Storms: Geomagnetic storms are caused by solar flares and coronal mass ejections from the sun. These storms can induce electric currents in power lines, pipelines, and communication cables, leading to disruptions or damage to power grids and communication networks. Transformers and other electrical components can be affected, potentially leading to widespread power outages and communication breakdowns.

Satellite Operations: Space weather can impact satellite operations by causing increased drag on satellites in low Earth orbit, leading to a degradation in their orbits or even re-entry into the Earth's atmosphere. Solar radiation can also degrade solar panels and electronic components on satellites, affecting their functionality and lifespan.

GPS and Navigation Systems: GPS and other satellite-based navigation systems can experience disruptions due to ionospheric disturbances caused by space weather events. This can affect various sectors, including aviation, maritime navigation, transportation, and precision agriculture.

Aviation: Space weather can impact high-frequency radio communication used for air traffic control and navigation. Polar routes can be particularly vulnerable to increased radiation exposure for passengers and crew during solar storms.

Power Grids: Geomagnetically induced currents can flow through power lines, transformers, and other components of power grids, potentially damaging equipment and causing power outages. Vulnerable regions near high latitudes are at greater risk.

Communication Networks: High-frequency radio communication used for long-distance communication, such as shortwave radio and amateur radio, can be severely disrupted during geomagnetic storms.

Data Centers: Space weather events can lead to power fluctuations, equipment damage, and data corruption in data centers, affecting digital infrastructure and data storage.

Source: [Space Weather Infrastructure Risks (openai.com)]

Theft and Malicious Attacks

Conspiracy theories escalated during the 'COVID years', with arson and other attacks on telecommunications infrastructure.

During Cyclone Gabrielle, and many other events requiring deployment of portable generators, theft of generators, batteries and fuel were common, amongst other items. GPS tracking and security cameras are being increasingly used but do not thwart all criminals. Additional security such as security fencing around locations where portable generators and fuel are stored are increasingly being used.

Further Work

In future editions, NZLC will continue to look across the infrastructure hazardscape to identify further information on the above risks and look to identify other key risk areas, including for example:

- Heatwaves – potential infrastructure disruptions from severe heat and drought.
- Unmanned Aerial Vehicle (UAV's) or drones - an emerging threat for overhead line networks, and aviation.

End Notes

[i] https://www.usgs.gov/publications/geologic-hazards-volcanoes

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[iii] Weir, A. M., Mead, S., Bebbington, M. S., Wilson, T. M., Beaven, S., Gordon, T., Campbell-Smart, C. A modular framework for the development of multi-hazard, multi-phase volcanic eruption scenario suites, Journal of Volcanology and Geothermal Research, 427, 2022, 107557, https://doi.org/10.1016/j.jvolgeores.2022.107557. (https://www.sciencedirect.com/science/article/pii/S0377027322000889)

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