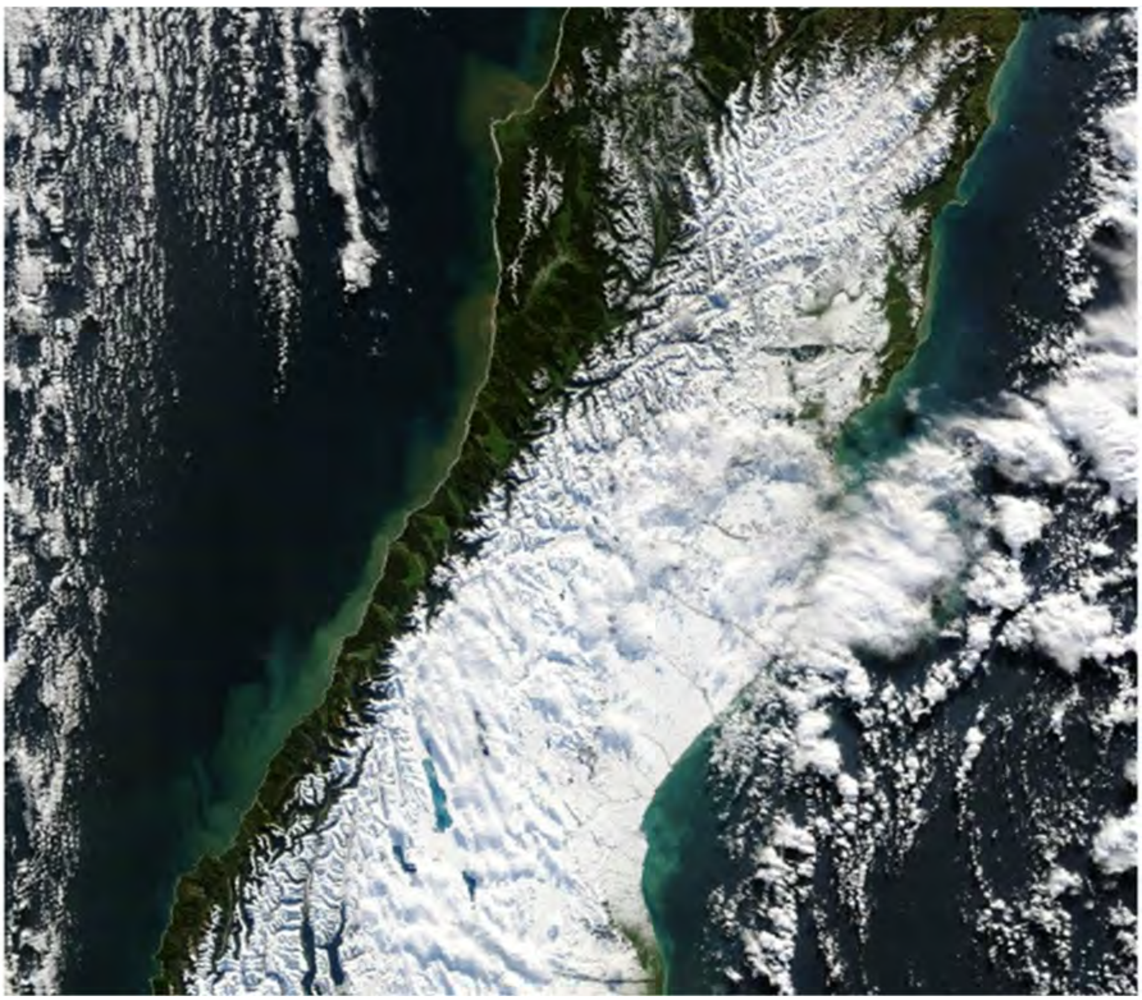
Risks and Resilience

Advancing the Maturity of Infrastructure Vulnerability and Resilience Investment Business Case Assessments

Scanning Stocktake Report

Canterbury Civil Defence Emergency Management Group



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1.0 Introduction

1.1 Background

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

Through the New Zealand Lifelines Council (NZLC) and 15 Regional Lifelines Groups, New Zealand's lifeline utility organisations work together on projects to understand and identify ways to mitigate the impacts of hazards on lifelines infrastructure.

Many significant national research programmes are improving our national understanding of hazard risks; the Alpine Fault, Wellington Fault, Hikurangi Subduction Zone, Climate Change, Auckland and Taupo Volcanic areas and Mount Taranaki, are all the subject of ongoing major studies.

Source: New Zealand Critical Lifelines Infrastructure, National Vulnerability Assessment (New Zealand Lifelines Council, 2020).

1.2 Project Summary

This project is intended to "connect the dots" in relation to tools, resources, knowledge, and practice in use throughout New Zealand, with the aim of facilitating informed, up-to-date, and efficient vulnerability and resilience assessments using a lifelines GIS portal. A standardised maturity-based approach is to be developed along with an agreed data schema for lifeline utilities that can be nationally applied.

It includes engagement with the lifelines sector, universities, research agencies as well as a wide range of stakeholders and Iwi, drawing on research outputs such as Resilience to Natures Challenges and tools such as MERIT and RiskScape. It is intended to develop an "intermediate" level approach that lies between the current methodology for vulnerability assessments and the more comprehensive "Wellington business case" approach.

From a Canterbury perspective, this "intermediate" approach is expected to make tangible progress on Phase 2 of the Risks & Resilience project, utilising the GIS portal and information documented in Phase 1 (Vulnerability Assessment). The intent is to identify and evaluate potential social, economic and cultural impacts arising from both hazard events and climate change, including the use of MERIT. It is anticipated that this work will be valuable to the wider lifelines sector in improving resilience outcomes elsewhere.

1.3 Task Summary

This report summarises the outcomes of the Scanning Stocktake, Tasks 1-3 of the NEMA Resilience Fund application, being:

- **Task 1:** Scanning stocktake of approaches in use or planned throughout the country in relation to vulnerability assessments and business cases for investment similar to that recently completed by the Wellington Lifelines Group.
- **Task 2**: Scanning stocktake of economic, social and cultural stakeholders to identify what locations and facilities should be considered in impacts analysis within Canterbury. Includes key "community sites" such as emergency services, hospitals, marae, industry, commercial, rural advisory groups, etc.
- **Task 3**: Scanning stocktake of relevant tools, resources and knowledge used in lifelines risk reduction planning – what they are, how they are being used, who owns them, what are the barriers, how they could be used. Engage with science community and universities.
- **MILESTONE 1 - Task 4**: Produce report on the scanning process and findings from tasks 1-3 above.

2.0 Regional Lifeline Vulnerability and Resilience Assessment Projects

This section draws from content in the New Zealand Critical Lifelines Infrastructure, National Vulnerability Assessment (New Zealand Lifelines Council, 2020) and the Taranaki Lifelines Vulnerability Study, October 2018).

2.1 General Approach (Core Practice)

Over the last 25 years, lifelines projects have been carried out in many regions in New Zealand. The typically stated purpose of 'vulnerability assessments' is to: *Identify the potential impacts from major natural hazard events on critical infrastructure in the region and potential measures to improve resilience to hazards.*

The term vulnerability, in the context of lifelines projects, is used to refer to the susceptibility of lifelines networks to service outages when events occur and the inability to recover quickly. Vulnerability and resilience can be regarded as opposite ends of a continuum. Some lifelines vulnerability projects are titled 'Regional Infrastructure Resilience Project' or similar, the latter term is now encouraged.

Most regional lifelines vulnerability assessment projects in the last decade have broadly followed a similar methodology, illustrated in Figure 2-1, with each step described briefly below.

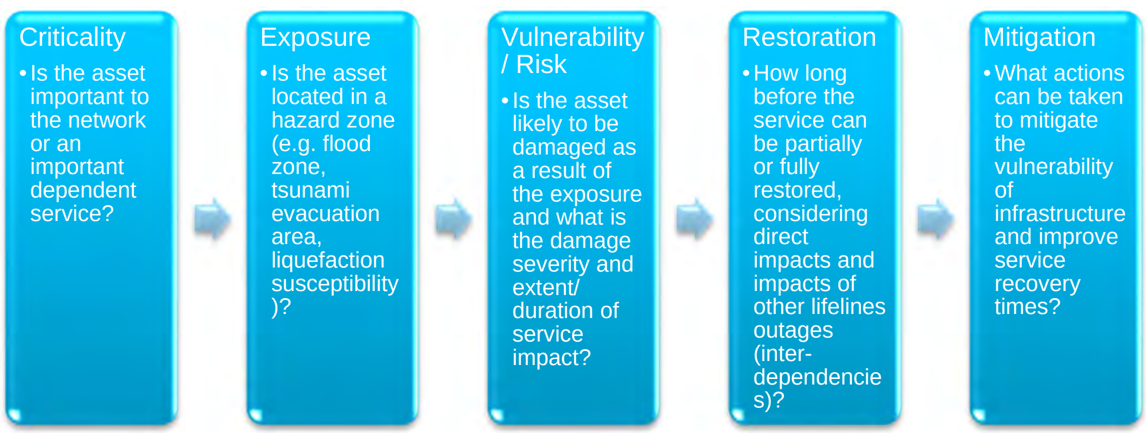


Figure 2-1 Overview of Lifelines Vulnerability Assessment Process

2.2 Identifying Critical Assets and Critical Customer Sites

Lifelines projects usually start with identifying critical infrastructure in the region and focussing on assets that are likely to have the highest consequences of failure for communities. This is for the purpose of managing the scale of the assessment and prioritising efforts in the area of highest impact.

2.2.1 Standard National Approach

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

General principles in applying the methodology:

a) Criticality is defined only in terms of the consequence of failure such as the numbers and types of customers affected. The likelihood of failure is not relevant (e.g.: just because it is in a flood prone area does not make it critical).

b) If alternative arrangements can be put in place before serious financial and/or social problems emerge, either:
- by the utility themselves, through network reconfiguration, or
- by critical customers with alternative supplies on-site such as generators or water tanks then reduce the criticality rating down one rank. As part of this step, make a broad assessment of how long users can function using their own alternative supplies (if it is less than 2 days, that should not be considered to provide sufficient redundancy).

Brief assumptions should be stated as to how 'sufficient redundancy' can be provided.

c) In determining the criticality level, assume that general demand is sustained (i.e. at this stage consider failure of that asset alone rather than the broader consequences of a larger disaster).

Recognising that the model is a simplistic and a somewhat blunt tool, NZLC worked with Treasury in 2020 on potential enhancements (refer Figure 2-3, source NVA 2020), however this has not been used in lifelines projects at this stage.

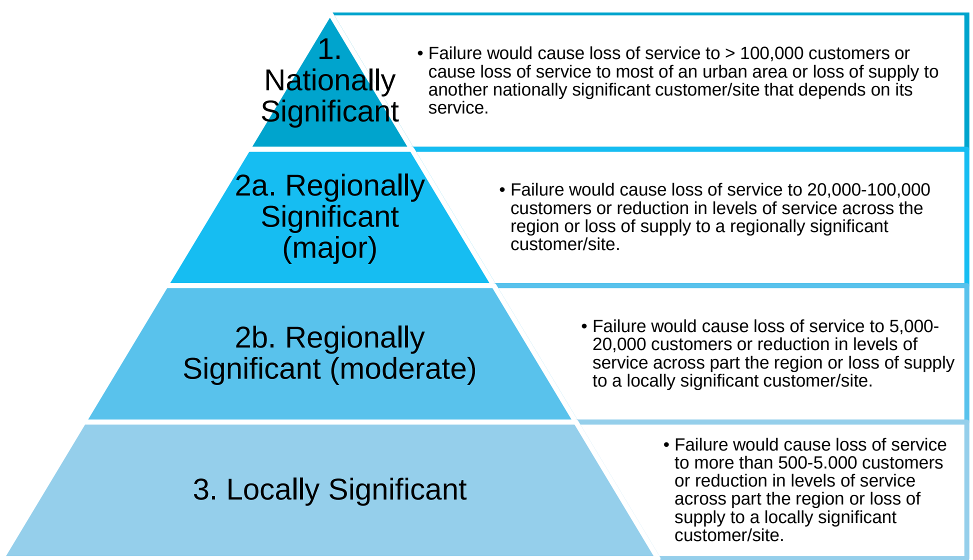


Figure 2-2 Assessing Infrastructure Asset Criticality

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

Figure 2-3 Draft Treasury Criticality Model, 2020

2.2.2 Critical Customer Sites

The criticality rating shown in Figure 2-2 depends on both the numbers of customers impacted and the criticality of those customers (e.g. other lifelines sites, hospitals, etc.) to reflect the overall consequence of the asset failing. The criticality assessment process therefore requires an understanding of the critical customers of lifeline utilities; including other lifeline utilities that depend on their service to function.

In order for lifeline utilities to determine whether an asset is critical because it supplies a critical customer, it needs to understand where the service is required. These are sites that are important to the critical customer for the provision of their essential functions, examples include:

- Corrections: Corrections facilities.
- Emergency Services: Major communication facilities, headquarters, major ambulance depots.
- NZDF: Defence Bases.
- Fast Moving Consumer Goods (FMCG): Distribution centres, major food production facilities.

An example format for capturing critical sites information from critical customers is shown in Figure 2-4.

There are variances by region in the level of information captured, for example more rural regions with isolated communities may include major supermarkets and health clinics as 'locally significant' (criticality 3) sites. Whereas the most recent Auckland project only covered 'criticality 1 and 2' assets to manage the scale of the assessment.

Organisation	Site Name	Street Address	NZTM - Easting	NZTA - Northing	Criticality	On Site Generator	On Site Battery	Gen Plug	Gensize if required	Fuel stored on site	Water stored on site
Fire and Emergency NZ	Chartwell Fire station	Crosby Road Chartwell	-37.75444	175.28883	1	Yes	No	Yes		No	No
Matamata-Piako DC	MPDC EOC 1	35 Kenrick Street, Te Aroha	-37.54422	175.71101	3	Yes	No	No		1 day	No
NZ Police	*Hamilton Central Police Station*	*12 Anzac Parade HAMILTON*	-37.79292	175.28750	*1*	*Yes*	*Yes*	*N/A*		*None stored*	20L
St John	*Cambridge*	*16 Fort Street*	-37.89557	175.47369	2b	*No*	No	No	25	No	No
Waikato DHB	Tokoroa Hospital	75 Maraetai Street, Tokoroa	-38.23058	175.86147	2a	Yes	No	No		Yes	Yes
Taupo DC	Great Lake Centre (Welfare Centre)	*5 Story Place, Taupō*	38°41'11.1"S	176°04'07.4"	*3*	*Yes*	*Yes*	*Yes*	*400kVA*	*1000 litres diesel, 4-5 days usage*	*n/a **
Taupo DC	*Taupō Events Centre*	*26 AC Baths Avenue, Taupō*	38°40'39.5"S	176°05'37.1	*3*	*Yes*	*Yes*	*Yes*	*400kVA*	*1000 litres diesel, 4-5*	*n/a **
Taupo DC	*Taupō EOC*	*9 Rifle Range Road, Taupō*	38°41'35.0"S	176°04'38.6"	*3*	*Yes*	*Yes*	*Yes*	*400kVA*	*1000 litres diesel, 4-5 days usage*	*n/a **
Hamilton CC	Claudelands Event Centre	Heaphy Terrace, Claudelands	-37.4648	175.1719	2b	NO	NO	NO	*kVA*	*Unknown*	*Unknown*
Hamilton CC	FMG Stadium	Seddon Road,	-37.4652	175.1606	2b	NO	NO	NO	*unknown*	*Unknown*	*Unknown*
Hamilton CC	City Parks, HCC Alternate EOC	Duke Street	-37.4808	175.1539	3	NO	NO	YES	*unknown*	*unknown*	*unknown*
Hamilton CC	HCC EOC	Genesis Building, Level 2, 94 Bryce Street	-37.4712	175.1636		YES	YES	*unknown*	*unknown*	*Diesel*	*Yes Quantity Unknown*

Figure 2-4 Example Format for Capturing Critical Customer Sites Information (Source, draft Waikato Infrastructure Resilience Project, 2021)

Lifelines vulnerability assessment projects typically involve 'critical customers' to help identify and categorise the importance of their sites.

Other ways in which critical customers are commonly engaged with lifelines projects include:

1. Involvement in impact assessment workshops, if there is an objective to consider the impacts of natural hazards on those sectors (not just lifeline utilities).
2. Involvement in presentations / workshops to share information on lifeline utility vulnerabilities, to support the business continuity planning by critical customers.

2.2.3 Mapping Critical Infrastructure Assets

Most recent vulnerability assessment projects have mapped the region's critical assets in geospatial applications (e.g. ArcGIS), to support the spatial assessment of exposure to hazards, as shown in the example below.

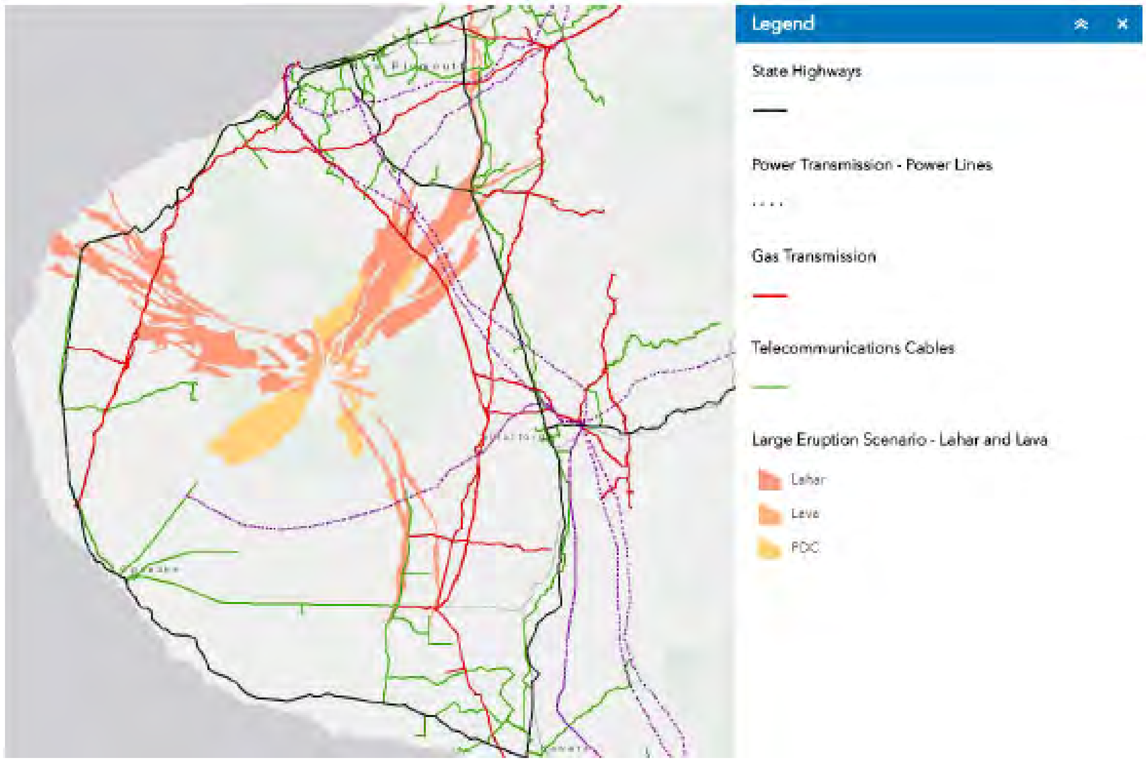


Figure 2-5 Example of critical asset mapping (source Taranaki Lifelines Vulnerability Assessment 2018)

Information is collected as GIS shape files, or, where lifeline utilities are not using GIS, then asset information is provided in Excel spreadsheet (with GIS coordinates for each site) or Google Earth.

The minimum data attributes typically sought for asset mapping include assets as points, lines or polygons with the following data:

- The organisation's unique asset ID
- Asset name
- Asset owner (organisation)
- Asset type (pipe, cable, pump station, etc)
- Lifeline's criticality (1-3)
- Own organisation's criticality rating (commonly a 1-5 rating)
- Data source

In the 2021 Waikato Lifelines Resilience Project, the following data structure was used (refer Table 2-1 below).

ASSET_OWNER	SECTOR_CATEGORY1	SECTOR_CATEGORY2	ASSET_TYPE1	ASSET_TYPE2	ASSET_NAME	CRITICALITY_LIFELINES	CRITICALITY_SOURCE	CAPACITY	DEPENDENCIES	NOTES	DATA_SOURCE	DATA_SUPPLIED	SUPPLIED_ID	OBJECTID
Organisation name	Energy	Electricity	e.g. OH line, UG line, tower, pole, GXP, generation site, substation	allow user-specified entry (unlikely to be consistent amongst all organisations)		This is the 1-3 'lifelines' rating	this is the organisation's criticality rating system	e.g. Voltage	This is the service that the site is dependent on, e.g. electricity, water. Option to capture additional data attributes, e.g. Genset on site, fuel stored on site, water stored on site.	Free entry comments from organisation	Organisation name, or public website if sourced online	Date of data supply	Owning Org Unique ID	Host Org GIS ID
		Gas	e.g. Pipe (transmission), pipe (distribution), gate, valve.											
		Fuel	e.g. Terminal, retail site											
	Telecommunication	Telecommunications	e.g. Fibre cable, cellsite, exchange, aggregation node											
		Broadcasting	e.g. Tower											
	Water / Waste	Water Supply	eg. Pipe, Treatment Plant, Pump Station, source, intake, Reservoir											
		Wastewater	eg. Pipe, Treatment Plant, Pump Station											
		Stormwater	eg. Pipe, Treatment Plant, Pump Station											
		Flood Protection	e.g. Stopbank, floodgate											
		Solid Waste	e.g. Transfer station, landfill											
	Transport	Roads	e.g. Road, bridge, tunnel											
		Rail	e.g. Railline, bridge, tunnel											
		Airports	Airport											
		Ports	Port											
		Public Transport	e.g. Bus / ferry terminal											

Table 2-1 Waikato Lifelines Project Data Attributes

2.3 Identifying Hazards for Assessment

2.3.1 Selecting Hazards for Assessment

The scope of hazards covered in Lifelines projects typically include:

- A multi-hazard assessment covering the major natural hazard risks (commonly earthquake, tsunami, volcano and severe weather).
- A multi-hazard assessment covering all the hazards in the region, for example, as listed in the regional CDEM Group Plan. This might include hazards such as pandemic, cyber-attack and technological failure.
- A single-hazard assessment.

This section describes the type of hazard information typically used in current lifelines resilience projects.

2.3.2 National datasets

The following information on available spatial natural hazard datasets is sourced from the *National Vulnerability Assessment 2020.*

Data	Description
Seismic Hazard Model	Provides probabilistic estimates of the strength of earthquake shaking that can be expected according to a user-defined time period and probability. Currently under major review (due 2022).
NZ Landslide Database	Holds data on historical major landslides including information such as triggering event and damage (GeoNet).
Active Faults Database	Noted limitations in its usefulness due to the inconsistent nature of how earthquake magnitude has been historically recorded.
Active Volcanic Areas	Geonet

Table 2-2 National Hazard Datasets

2.3.3 Regional and local datasets

Most regional councils provide spatial hazard information in a publicly accessible GIS viewer, providing ready access to this information for lifelines projects.

Data	Description
Tsunami – Evacuation Zones	Tsunami evacuation zones have been mapped for much of NZ's coastline in accordance with the Director's Guideline *MCDEM DGL 08-16* based on a 'level 2' rule-based methodology. Evacuation zones are not intended to be used to model inundation risk but have been in some projects due to lack of inundation models.
Tsunami – Inundation areas	Areas with good LiDAR information are able to undertake more accurate tsunami inundation modelling.
River flooding	Regional councils have mapped flooding extents from major historic events as well as predicted 100year or other return period river flooding extents from hydrological models.
Urban flooding	Hydrological and hydraulic stormwater models are in place for many urban catchments, but there are often challenges that the information is developed using various methodologies and outputs aren't often easily accessible as a GIS layer.

Data	Description
Liquefaction prone / seismic vulnerability	Geologically-based seismic risk is often available as a GIS layer, based on an association between soil type and seismic risk. More detailed liquefaction studies are sometimes available, using additional information and analysis such as ground water depth.
Landslides	May be available, often recording historic landslide areas, or where land movement is occurring. Less commonly available is land stability risk information based on analysis of soil type and slope.
Volcanic ash – scenarios	Various ash depth contour maps have been developed for all volcanic areas, primarily by the research sector – GNS and universities. Each depends on modelled inputs such as volume of eruption and wind direction and speed.
Volcanic ash – probabilistic	These show cumulative depth of ashfall over defined return periods. Most recent maps for the North Island produced by Hurst, 2010 (ref), currently being fully redeveloped by GNS and University of Canterbury for Transpower project (due 2022).
Volcanic hazards – all	Various maps have been developed, primarily by the research sector – GNS and universities. Maps available through major volcanic research programmes include DEVORA, ECLIPSE, TTVIF (one page summaries of these programmes available in the NVA 2020).
Dam Break	Dam break modelling is required by owners of large dams and is usually held by the regional council.

Table 2-3 Regional and Local Datasets

Note that the following data is often not available as a spatial GIS dataset but may be included in lifelines risk assessments.

Hazard Data	Description
Drought	Spatial datasets of drought risk areas not typically available; but water authorities have knowledge of which schemes have historically required water restrictions and forecasted capacity issues in asset management plans.
Wildfire	Not currently easy to source wildfire risk maps in GIS format, though FENZ, Department of Conservation and Scion are all doing work in this space.
Snow	Again, not commonly available as a single GIS layer, though most road authorities have information on snow-prone roads and simple altitude-based rules can be used to provide broad indications of snow risk areas.
Pandemic	Assumptions may be sourced from national and regional pandemic plans.
Cyber-attack	Usually rely on lifeline utility assessment of risk.
Technological / infrastructure failure	A catch-all covering any scenario that might cause a major asset failure, e.g. condition failure, third party damage, site fire.
Space Weather	Transpower has done some work in this area.
Fire following earthquake	

Table 2-4 Other Hazard Datasets

2.4 Exposure and Vulnerability Assessment

2.4.1 Evolution of Practice

The extent to which quantitative risk scoring systems are used in regional lifelines projects varies; some earlier studies used detailed asset lists, spreadsheets and multi-criteria analysis to rank asset risks based on criticality and exposure to hazards. More recent projects have undertaken a higher-level lifelines project approach which provides a more strategic , sector-based view of the potential infrastructure impacts from natural hazards rather than an asset-by-asset assessment.

2.4.2 Subject Matter Expert Assessment

Most recent vulnerability assessment projects have provided information in the form of GIS asset and hazard overlays to support vulnerability assessments by lifeline utility subject matter experts (SMEs).

Table 2-5 illustrates the damage and service rating scale used in several recent lifelines projects, with an example output shown in Figure 2-6.

Damage Impact Rating	Service Impact Rating
1) Unlikely to cause damage.	1) Minimal impact (<500)
2) Possible damage, short term disruption.	2) Localised failure (500-5,000)
3) Possible damage, longer term repairs (weeks/months).	3) Regional loss (5-20,000)
4) Complete failure, partial or full reconstruction required, days / weeks.	4) Regional loss (20-100,000)
5) Complete failure, full reconstruction required, several months / years	5) National (>100,000 customers)

Table 2-5 Damage and Service Rating Scale

Earthquake		Damage Impact	Service Impact
Wastewater	Liquefaction	2	4
	Ground shaking	3	3
	Landslip	3	3
Water Supply	Liquefaction	3	3
	Ground shaking	3	3
	Landslip	2	3
Electricity	Liquefaction	3	3
	Ground shaking	3	3
	Landslip	3	3
Gas	Liquefaction	1	2
	Ground shaking	3	1
	Landslip	3	5
Stormwater	Liquefaction	2	4
	Ground shaking	2	2
	Landslip	3	3
Roads	Liquefaction	3	2
	Ground shaking	3	2
	Landslip	3	2
Airport	Liquefaction	3	5
	Ground shaking	3	5
	Landslip	1	5
Port	Liquefaction	2	5
	Ground shaking	3	5
	Landslip	1	5
Rail	Liquefaction	3	2
	Ground shaking	3	2
	Landslip	3	2
Telco	Liquefaction	3	3
	Ground shaking	2	3
	Landslip	3	3

Figure 2-6 Vulnerability Assessment

2.4.3 GIS Analysis – Exposure and Vulnerability Assessment

The GIS-based approach provides the ability to undertake quantitative asset exposure analysis – e.g. how many assets are exposed to different hazard scenarios. Most recently, this has been used in the Bay of Plenty Lifeline Utilities Climate Change Assessment, with an example output in Figure 2-7 showing the number of assets exposed to sea level rise under current and future climate change scenarios.

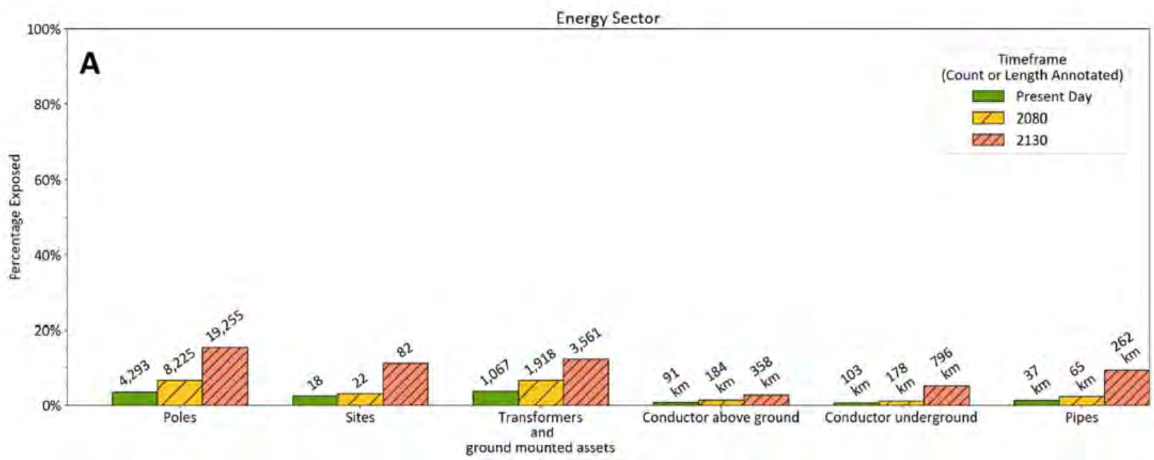


Figure 2-7 Bay of Plenty Lifeline Utilities Climate Change Assessment *(Ref Bay of Plenty Regional Climate Change Risk Assessment, T+T July 2021)*

The GIS data compiled for the Bay of Plenty project also included criticality and vulnerability data to identify the highest risk assets exposed to climate hazards.

2.4.4 Fragility Modelling

The Wellington Lifelines Group Regional Resilience Project modelled infrastructure losses using RiskScape, risk analysis software that calculates the consequences of hazard to infrastructure (amongst other things). Refer also to Sections 2.7 and 3.3.4.

Such applications require the definition of fragility curves for different asset types (e.g. pipe material type) that describe the probability of different damage states across a range of hazard intensities, such as the example in Figure 2-8. Each curve represents a different damage state for a particular asset type, with the horizontal axis representing the depth of water – this could be tsunami or river flooding for example.

Damage states then need to be translated to service disruptions, generally through expert elicitation.

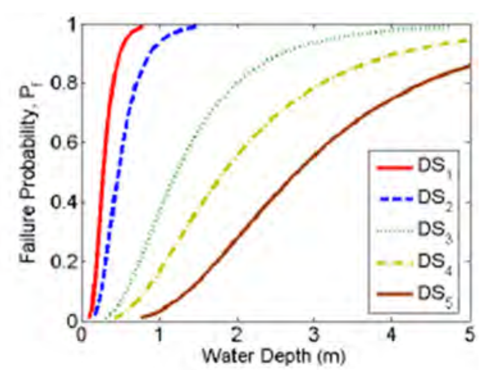


Figure 2-8 Fragility Curves

2.5 Dependencies and Interdependencies

2.5.1 Conventional Lifelines Practice

The term ‘interdependencies’ is commonly used in the NZ lifelines sector, however it is noted that more correctly most of these are actually one-way dependencies; i.e. most sectors rely on electricity to function but electricity does not need all other lifelines services to function.

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

In a major event dependencies can change significantly and understanding how the sequencing of infrastructure restoration will best enable recovery can help to inform criticality assessments and pre-event mitigation. For example, in a Wellington Fault event, predicted road damage is likely to make port a critical access route for fuel and plant that will enable roads to reopen and provide access to other infrastructure assets.

Lifelines projects usually capture interdependencies at an asset, system and/or sector level:

- At an asset level, where dependency on lifelines services are recorded in a spreadsheet (and also in the GIS if the critical sites are mapped). *An example was presented in Figure 2-4.*
- At a system level, where each utility’s network system dependency on other lifelines networks is recorded in matrix format.
- At a sector level, similar to the above, but grouped into a sector level summary.

The degree to which the utilities listed to the right are dependent on the utilities listed below	STDC water	SDC water	NPDC water	Wastewater - all	Telecomms	Roads	Airport	Port	Powerco Gas	FirstGas	Trans power	Rail	Fuel	Contact	Trust power	Kupe (gas/ LPG)	Kordia	Nova Gas	Comments
Electricity	2	3	2	3	3	2	2	2	1	2	3	1	3	3	3	3	2	3	All utilities are dependant on electricity to function (except roads which only affects traffic lights). Where backup generation enables the majority of the service to function, the rating is a 2 instead of a 3.
Gas	1	1	3	2	1	1	1	1	3	3	1	1	1	3	1	3	1	3	Gas fired electricity generation sites are most dependant. There is also dependencies within the network - transmission/gas require production sites to be operational.
Fuel (if power out)	3	3	3	3	3	3	3	3	3	3	3	3		1	1	2	3	1	The '3's reflect sectors that rely on backup generators in a power failure.
Fuel (power on)	2	2	2	2	2	3	3	3	2	2	2	3		2	2	2	2	2	Most are rated as '2' reflecting the need for fuel to operate vehicles during response. Roads, airport, rail and the port are more critically reliant on fuel to operate.
Roads	3	3	3	3	3	3	3	3	3	3	2	2	3	3	2	2	2	2	The port and airport require vehicle access to operate. In a response, roads become critical for access to sites. Those rated a '2' consider helicopter access to be feasible (lower number of sites to access
Rail	1	1	1	1	1	1	1	2	1	1	1		1	1	1	2	1	1	Required to bring some products to the Port and to distribute LPG to the South Island.
Airport	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	Could become critical for bringing in emergency resources and evacuation, but not critical to the operation of other lifelines.
Port	1	1	1	1	1	1	1		1	1	1	1	3	1	1	3	1	1	Port operations are important for bringing in fuel for regional use and exporting petroleum and LPG.
Water Supply				3	2	1	2	2	1	1	1	1	1	2	1	1	1	1	Required for fire fighting (at Port and Airport) though there is storage on site amd cooling (eg: NP telephone exchange). Important for staff, but bottled water can be provided.
Wastewater	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Not essential for other utilities to function.
Telecommunications - landline	1	1	2	2		1	1	1	1	1	0	1	1	1	1	2	1	1	Important for some remote monitoring/control processes, but otherwise dependency is reduced (unless cellular networks are down).
Telecommunications - cellular	2	2	2	2		3	3	3	2	2	2	2	2	2	2	2	2	2	In a disaster, important for coordinating communications, however most rate as a '2' assuming that other comms methods are available.
Telecommunications – internet	1	1	2	2		2	2	2	2	1	1	1	1	1	1		1	2	Becoming increasingly important as part of monitoring and communication processes.
Telecomms - broadcasting	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1		1	Obviously important in a major disaster for public communications, for other lifelines, may be important for key public health messaging around water supply

Figure 4-1: Interdependency Matrix – During / Post Disaster Event

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

Figure 2-9 Interdependencies between Sectors (Source, Taranaki Lifelines 2018)

2.5.2 Canterbury Lifelines Interdependencies Trial

The Canterbury Lifelines Group trialled an interdependency assessment approach in 2008/09 using a spreadsheet based cascade failure tool in a workshop-based "speed dating" process and developed multiple-level interdependency ratings. The pilot was located in the Waimakariri District and included representatives from lifeline utilities, banking, and the fast moving consumer goods (FMCG) sectors.

The method was based on the application of a "Dependency Score", this being derived from two-way conversations between each participant in the workshop and multiplied up through the cascade levels. Dependency scores were rated from 1 Little Dependence to 3 Highly Dependent.

Noted in the development of this tool was the possibility of incorporating an "Importance Score", with an overall rating being based on *Dependency(D) x Importance (I)*. This was a potential refinement, however, following the 2010-2011 Canterbury earthquakes development of the method was not further progressed.

The approach is illustrated in the following diagrams.

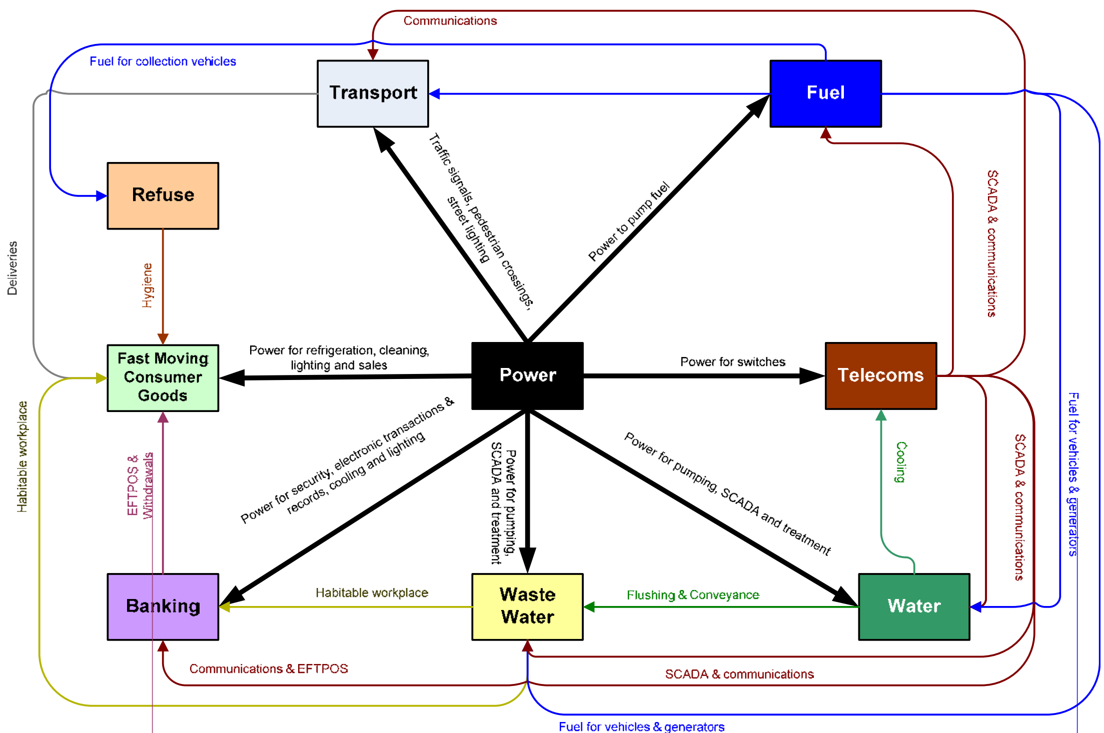


Figure 2-10 2-level Interdependency Diagram – Power (Source, Canterbury Lifelines 2010)

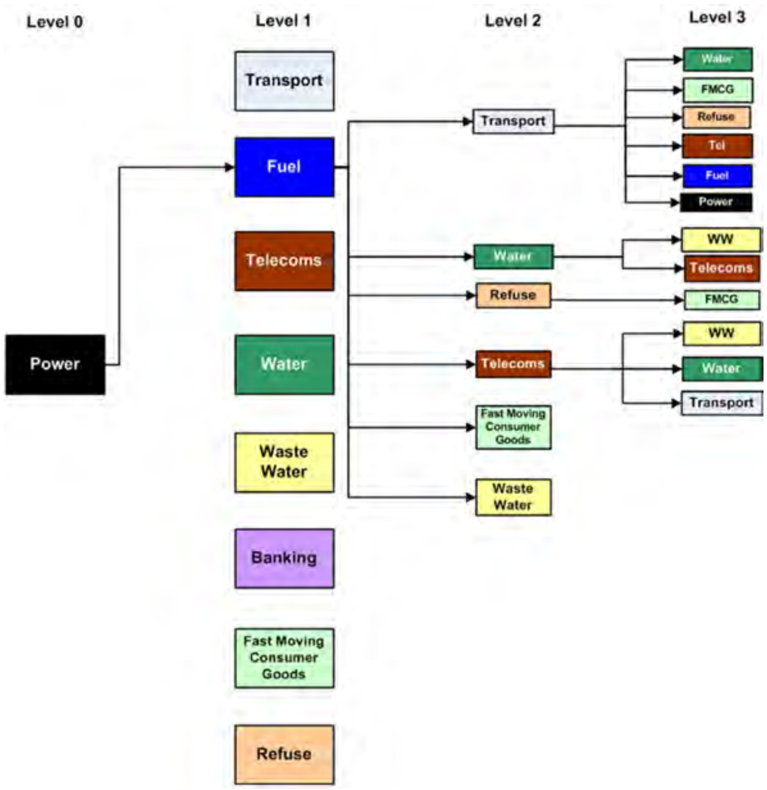
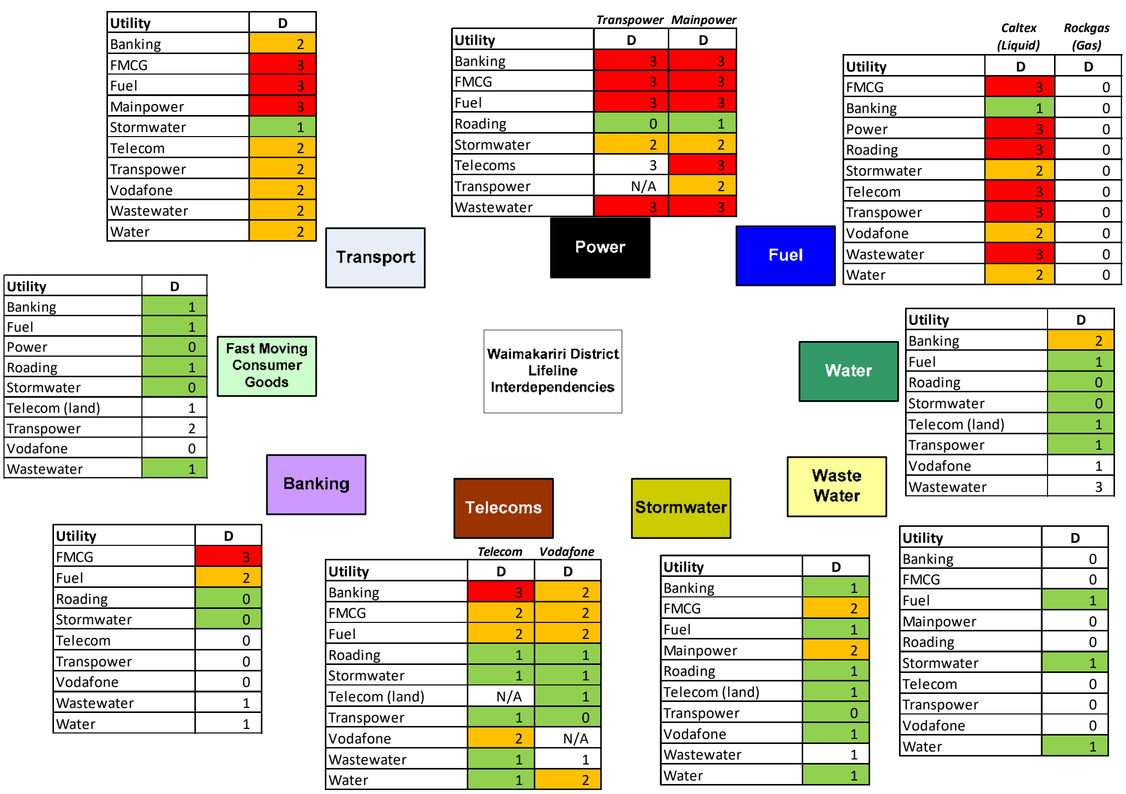


Figure 2-11 3 Level Linear Interdependency Diagram – Power-Fuel Cascade (Source, Canterbury Lifelines 2010)



Transport

Utility	D
Banking	2
FMCG	3
Fuel	3
Mainpower	3
Stormwater	1
Telecom	2
Transpower	2
Vodafone	2
Wastewater	2
Water	2

Power

	Transpower	*Mainpower*
Utility	D	D
Banking	3	3
FMCG	3	3
Fuel	3	3
Roading	0	1
Stormwater	2	2
Telecoms	3	3
Transpower	N/A	2
Wastewater	3	3

Fuel

	Caltex (Liquid)	*Rockgas (Gas)*
Utility	D	D
FMCG	3	0
Banking	1	0
Power	3	0
Roading	3	0
Stormwater	2	0
Telecom	3	0
Transpower	3	0
Vodafone	2	0
Wastewater	3	0
Water	2	0

Fast Moving Consumer Goods

Utility	D
Banking	1
Fuel	1
Power	0
Roading	1
Stormwater	0
Telecom (land)	1
Transpower	2
Vodafone	0
Wastewater	1

Water

Utility	D
Banking	2
Fuel	1
Roading	0
Stormwater	0
Telecom (land)	1
Transpower	1
Vodafone	1
Wastewater	3

Banking

Utility	D
FMCG	3
Fuel	2
Roading	0
Stormwater	0
Telecom	0
Transpower	0
Vodafone	0
Wastewater	1
Water	1

Telecoms

	Telecom	*Vodafone*
Utility	D	D
Banking	3	2
FMCG	2	2
Fuel	2	2
Roading	1	1
Stormwater	1	1
Telecom (land)	N/A	1
Transpower	1	0
Vodafone	2	N/A
Wastewater	1	1
Water	1	2

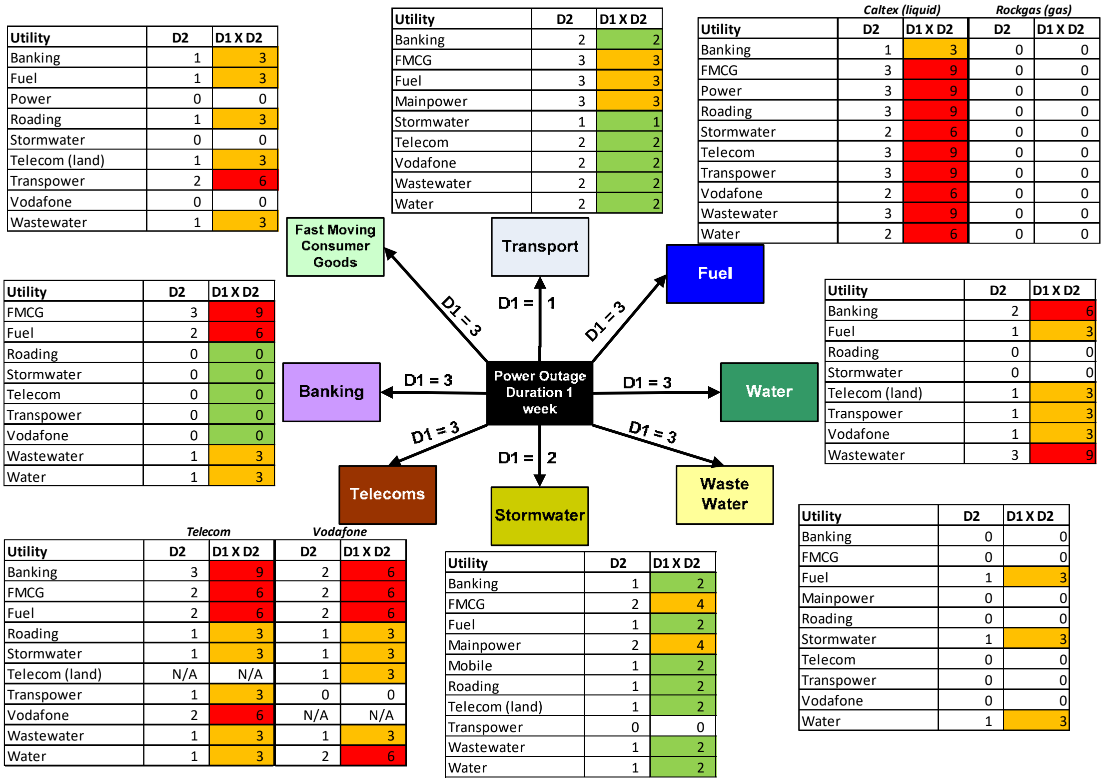
Stormwater

Utility	D
Banking	1
FMCG	2
Fuel	1
Mainpower	2
Roading	1
Telecom (land)	1
Transpower	0
Vodafone	1
Wastewater	1
Water	1

Waste Water

Utility	D
Banking	0
FMCG	0
Fuel	1
Mainpower	0
Roading	0
Stormwater	1
Telecom	0
Transpower	0
Vodafone	0
Water	1

Figure 2-12 Single Level Dependency Ratings (Source, Canterbury Lifelines 2010)



Utility	D2	D1 X D2
Banking	1	3
Fuel	1	3
Power	0	0
Roading	1	3
Stormwater	0	0
Telecom (land)	1	3
Transpower	2	6
Vodafone	0	0
Wastewater	1	3

Utility	D2	D1 X D2
Banking	2	2
FMCG	3	3
Fuel	3	3
Mainpower	3	3
Stormwater	1	1
Telecom	2	2
Vodafone	2	2
Wastewater	2	2
Water	2	2

	Caltex (liquid)		Rockgas (gas)	
Utility	D2	D1 X D2	D2	D1 X D2
Banking	1	3	0	0
FMCG	3	9	0	0
Power	3	9	0	0
Roading	3	9	0	0
Stormwater	2	6	0	0
Telecom	3	9	0	0
Transpower	3	9	0	0
Vodafone	2	6	0	0
Wastewater	3	9	0	0
Water	2	6	0	0

Utility	D2	D1 X D2
FMCG	3	9
Fuel	2	6
Roading	0	0
Stormwater	0	0
Telecom	0	0
Transpower	0	0
Vodafone	0	0
Wastewater	1	3
Water	1	3

Utility	D2	D1 X D2
Banking	2	6
Fuel	1	3
Roading	0	0
Stormwater	0	0
Telecom (land)	1	3
Transpower	1	3
Vodafone	1	3
Wastewater	3	9

	Telecom		Vodafone	
Utility	D2	D1 X D2	D2	D1 X D2
Banking	3	9	2	6
FMCG	2	6	2	6
Fuel	2	6	2	6
Roading	1	3	1	3
Stormwater	1	3	1	3
Telecom (land)	N/A	N/A	1	3
Transpower	1	3	0	0
Vodafone	2	6	N/A	N/A
Wastewater	1	3	1	3
Water	1	3	2	6

Utility	D2	D1 X D2
Banking	1	2
FMCG	2	4
Fuel	1	2
Mainpower	2	4
Mobile	1	2
Roading	1	2
Telecom (land)	1	2
Transpower	0	0
Wastewater	1	2
Water	1	2

Utility	D2	D1 X D2
Banking	0	0
FMCG	0	0
Fuel	1	3
Mainpower	0	0
Roading	0	0
Stormwater	1	3
Telecom	0	0
Transpower	0	0
Vodafone	0	0
Water	1	3

Figure 2-13 Power Failure Scenario – Level 0 to Level 2 (Source, Canterbury Lifelines 2010)

2.5.3 Waka Kotahi NZTA Transport Interdependencies

More recently, Waka Kotahi NZ Transport Agency commissioned a research project[1] that studied how New Zealand's transport network infrastructure interdependencies could be better understood and assessed. This identified two key types of interdependency, geographic and physical / digital, and three interdependency attributes, strength, order, and directionality

It looked at several international approaches, including the University of Auckland (UoA) Infrastructure Interdependency Model described in Section 3.3.4, and proposed a series of modules and methodologies for assessment, as shown below.

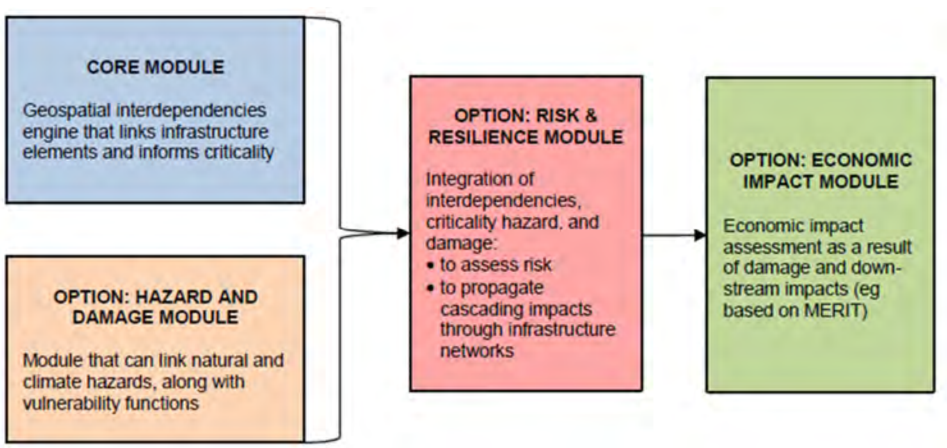


Figure 2-14 Proposed Interdependency Framework (Source, NZTA Research Report 671)

[1] Hughes, Wild & Muzyk (2020), *Developing a Method for Quantifying Transport Interdependencies*, NZTA Research Report 671

The proposed approach is similar to the Canterbury pilot above (importance and dependency parameters), in that the Core Module proposes a causal chain scored in terms of infrastructure “criticality” and dependency “strength”. It also considers important community assets such as Hospitals. Extracts from the report are shown below:

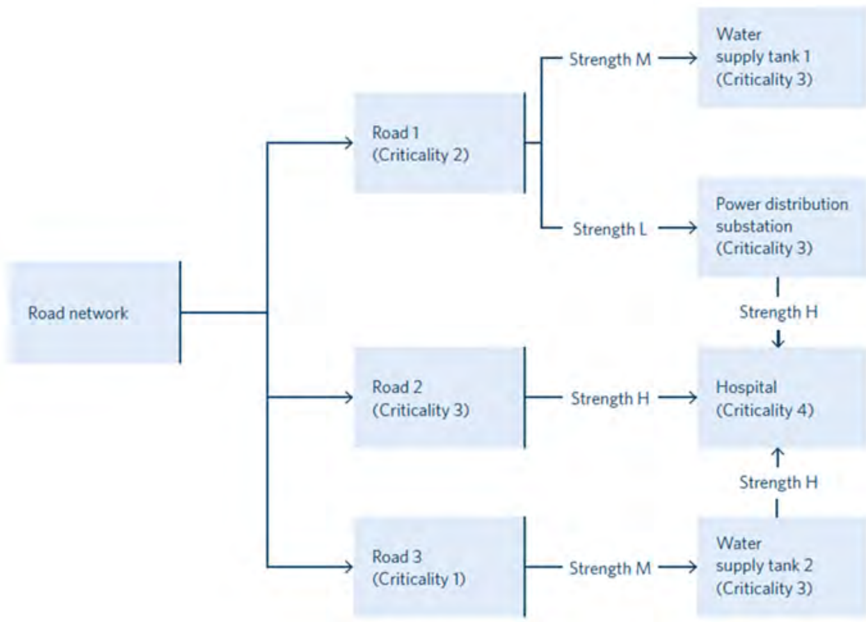


Figure 2-15 Example Infrastructure Dependency Network as a Causal Chain (Source, NZTA Research Report 671)

Upstream infrastructure (base criticality rating)	Downstream infrastructure (base criticality rating)	Order from road network	Strength	Comment regarding strength
Road 1 (C2)	Water supply tank 1 (C3)	1st	Medium	Road access is sometimes required for staff to conduct maintenance.
Road 1 (C2)	Power distribution (C3)	1st	Low	Road access is rarely required for staff to conduct maintenance.
Road 2 (C3)	Hospital (C4)	1st	High	Road required for hospital access and operation.
Road 3 (C1)	Water supply tank 2 (C3)	1st	Medium	Road access is sometimes required for staff to conduct maintenance.
Power distribution (C3)	Hospital (C4)	2nd	High	Essential for operation.
Water supply tank 2 (C3)	Hospital (C4)	2nd	High	Essential for operation.

Figure 2-16 Example Infrastructure Dependency Relationship Dimensions (Source, NZTA Research Report 671)

The output of the assessment is a “modified criticality” rating for infrastructure elements within the transport network. This can then be used as part of a risk assessment by integrating it with specific hazard and vulnerability information to develop a “risk rating”, which in turn can be used to prioritise risk treatment options or resilience improvements.

To demonstrate application, a GIS-based pilot geographic assessment was conducted in Queenstown, this included roads, power, water supply, and wastewater infrastructure and developed modified criticality ratings based on ONRC road classes, QLDC’s criticality ratings, and numbers of infrastructure assets present.

A key recommendation was to evaluate whether the proposed approach could be incorporated within the existing UoA model. This would require the inclusion of additional parameters such as strength and modified criticality.

2.6 Hotspots Analysis

Infrastructure interdependence increases the overall risk and consequence of a potential failure of a single infrastructure type. Co-location of critical infrastructure assets also increases the risks of a damaging event at a single site, both in terms of the direct impact of a number of critical assets simultaneously failing (e.g. a major landslide) and in terms of the potential hazards that some assets pose to others (e.g. a major water main failure could wash away other assets in the area). These areas are termed ‘hotspots’ – where a number of critical infrastructure assets from different sectors converge in a single area. *Source NVA 2020.*

It is important to note that this term does not represent a relationship between assets/networks, just some representation of co-location. Identifying co-location is a function of the analysis approach, and the assets may actually be far enough away that they do not affect each other.

The Auckland Hotspots Project in 2007 (updated in 2015) and the Waikato Vulnerability Assessment Project (2013, being updated in 2021) used *Kernel Density Analysis* function in GIS to identify areas of infrastructure density (example output, Figure 2-18). Other lifeline projects have identified hotpots based on a visual assessment of overlaid sector maps (Otago, Manawatu Whanganui, Nelson-Tasman, Wellington).

The Auckland Hotspots project then carried out more specific risk analysis at those sites to identify the highest risk hotspots summarised as follows:

- Impact (consequence) of failure was a multiple of the *service failure impact* based on numbers of customers affected (broadly aligned to criticality rating), *level of service impact* (whether the service loss is complete or partial), *infrastructure importance* (higher weightings for roads, electricity, water and telecommunications).
- Likelihood of failure, from all assets, rated from high to low.
- Risk was a weighted calculation of the above inputs.

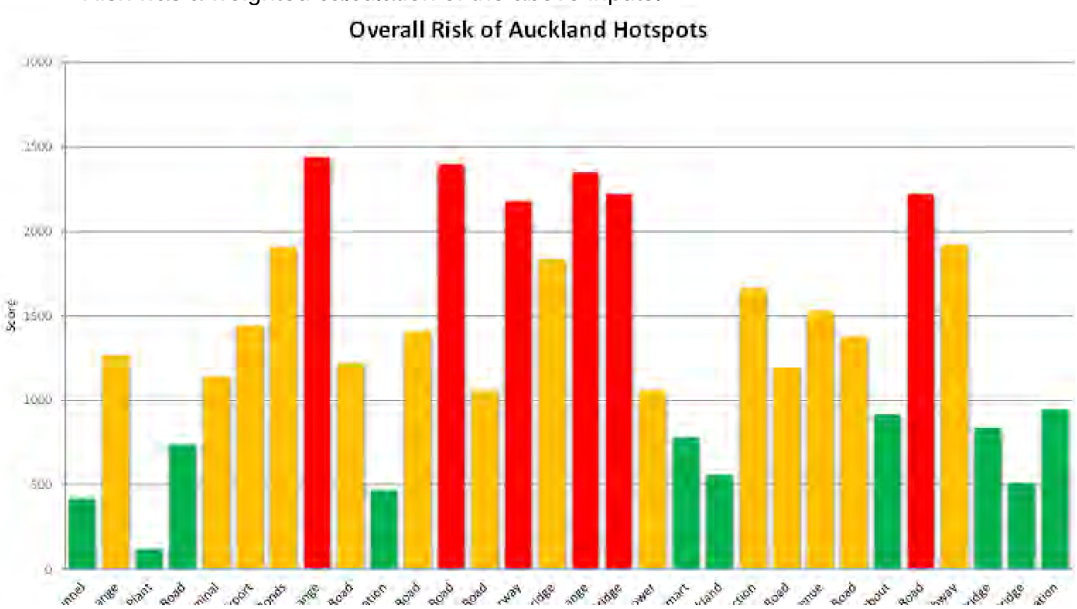


Figure 2-17 Risk Rating for Infrastructure Hotspots (labels deliberately omitted)

The intended use of these outputs is for lifeline utilities to:

1. Incorporate hotspots maps into emergency response planning arrangements, so that staff who respond to failures at these sites can be aware of the significance of other utilities at the site.
2. Consider re-location as an option during planning of future upgrades, if the risks warrant this.
3. Carry out their own risk assessment at each site and identify appropriate mitigation actions.

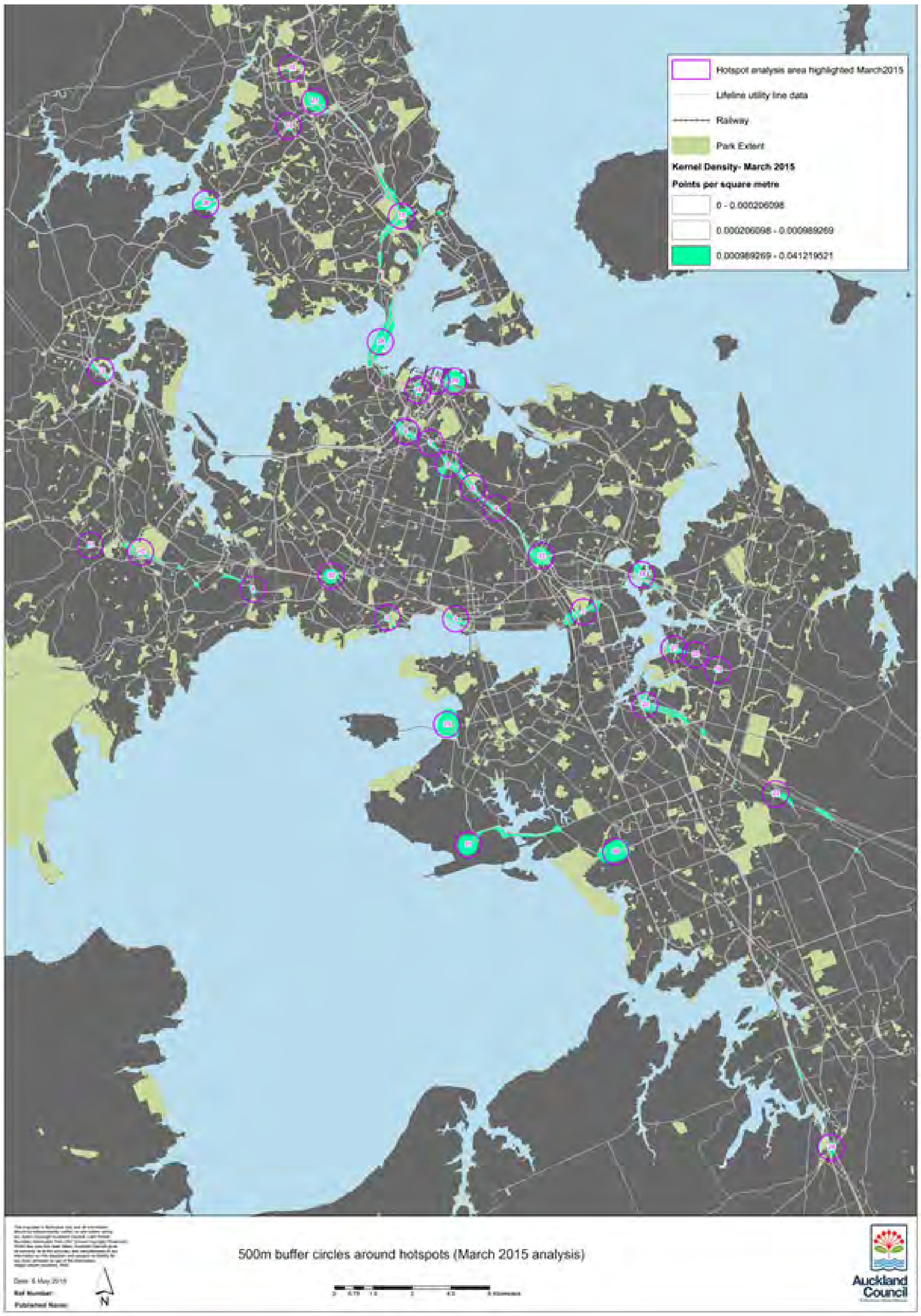


Figure 2-18 Hotspots Analysis (Auckland's Infrastructure Hotspots, 2015)

2.7 Wellington Business Case Development

2.7.1 Project Overview

This project is the most comprehensive of its type carried out in the New Zealand lifelines sector and is regarded as “advanced” practice, providing a step-change improvement to the Wellington region’s resilience. It assessed the impacts of a major earthquake on the region’s infrastructure and communities and the economic benefits of investment in a range of mitigation strategies.

It considered the interdependencies of 16 infrastructure providers. This was a mixture of qualitative and quantitative assessment and was not intended to facilitate a rigorous assessment of interdependencies such as those described in Sections 2.5.3 and 3.3.4 above.

The project firstly analysed the economic costs of not being prepared for this event, and secondly the savings to the Wellington region and nation if the region’s infrastructure was sufficiently resilient to be able to maintain services or recover rapidly. The latter scenario included a suite of resilience investments over a twenty-year period chosen to reflect both the criticality of and interdependencies between the various types of infrastructure.

Many of the resilience investments were already in long term asset management plans with funding identified or planned. The study showed that if these interdependent infrastructure projects were to be accelerated and delivered in a priority order, there would be significant benefits to both Wellington and New Zealand’s economy.

The project found that a coordinated investment of $3.9 billion would save the nation $6 billion in the aftermath of a magnitude 7.5 earthquake on the Wellington Fault.

The study looked beyond the direct costs of infrastructure disruption to customers to include the consequent disruption to businesses operability. The modelling also accounted for the impact of infrastructure disruption on the habitability, liveability and business viability of the region – resulting in population and business relocations out of the region (both temporary and permanent). Impacts on critical markets, such as tourism. were also accounted for. It didn’t however include the “business as usual” benefits to society from having individual projects delivered in a rational and sequenced way over a twenty-year horizon, or the resilience benefits in the face of more frequent but lower impact events such as floods or smaller earthquakes.

The contents pages of the project report are reproduced below. There are also numerous Appendices, including reports relating to the application of risk modelling and economic loss assessment tools associated with the earthquake event.

Figure 2-19 Wellington Lifelines Project Report Contents

The Wellington region and key transport networks are shown in the figure below.

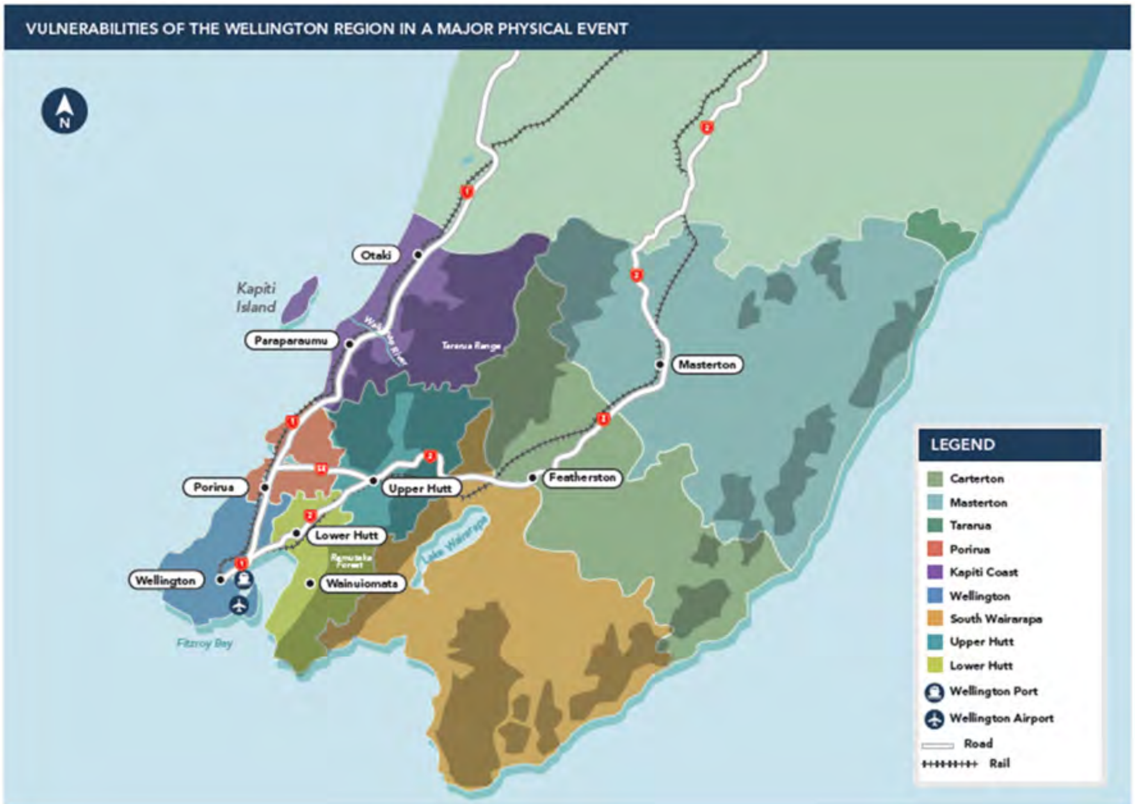


Figure 2-20 Wellington Region, Key Transport Networks

The statement of problems, benefits and investment objectives are listed below. This is part of the Investment Logic Mapping (ILM) process that is a critical starting point for a business case.

4.1.1 – Problems

- A challenging geography, highly concentrated economic activity in the CBD and very low infrastructure redundancy makes the NZ capital uniquely vulnerable to a shock event, resulting in economic and social risks for the region and country.
- Historically low value placed on resilience, unclear expectations and lack of alignment/priority for investment in the NZ capital results in inaction, with increased economic and social risks for the region and country.

4.1.2 – Benefits

- Benefit 1: Significantly reduced risk to New Zealand's economy (60%)
  - o Reduced Predicted NZ Economic Loss
  - o Reduced Predicted Recovery Period
- Benefit 2: Safer People and More Resilient Community (20%)
  - o Reduced Recovery Period
  - o Reduced Population Loss
  - o Reduced Community Isolation
  - o Reduced Disease Risk
- Benefit 3: Optimised Strategic Lifelines Investment (20%)
  - o Finalised Investment Plan
  - o Aligned Central/Local Government
  - o Reduced Recovery Costs

4.1.3 – Investment Objectives

- Investment Objective 1: Significantly reduce the risk to NZ economy from shock events affecting Lifeline Services in the Wellington Region (60%)
- Investment Objective 2: Reduce the safety risk to people living in the Wellington Region from a shock event affecting Lifeline Services (10%)
- Investment Objective 3: Make the Wellington Regional Community more resilient against the effects of a shock event affecting Lifeline Services (10%)
- Investment Objective 4: Optimise the combined investment in Wellington Lifeline Services (20%).

Figure 2-21 Extract from ILM Process

The following image from the report shows the modelling workflow adopted, the key areas being damage, outage and economic modelling.

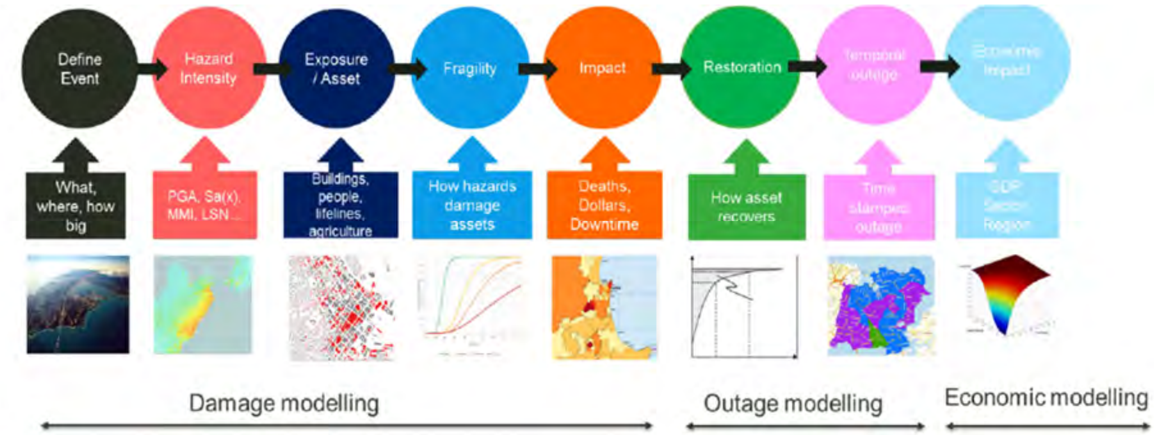


Figure 2-22 Modelling Workflow for Wellington Lifelines Projects

Numerous potential options for improving resilience across infrastructure sectors were identified, short-listed and ultimately a preferred programme developed. The key projects are illustrated in the image below, with an example provided for the key fuel project. Other projects were proposed for roads, rail, sea transport, electricity, potable water, and telecommunications.

Seaview Wharf seismic strengthening	
Project description:	This project involves seismically strengthening the Seaview Wharf and the associated 3km of fuel pipelines that extend from the end of the wharf to Point Howard. It will include conversion of the pipeline to operate in both directions to enable both withdrawal and filling. This project will require the installation of a mooring dolphin to enable berthing in all weather conditions and take account of the likely ship sizes used for transporting fuel in the future[12]. 
Estimated cost:	**Capital cost: $10 million for fuel infrastructure + $25 million for wharf improvements (numbers correct at time of development of this PBC)**
Rationale for potential inclusion:	The Seaview Tanker Dock provides docking facilities to tankers supplying the fuel market into greater Wellington. This project will provide a more resilient fuel supply. Currently the approach wharf is considered high risk and is expected to fail in one or more locations along its length either by pile fracture or loss of support to the timber deck. Fuel is critical to run generators, earth-moving plant and for the transport of residents around the region. There will likely be significant roads outages preventing fuel tankers getting into the region, therefore a robust refuelling and storage facility for fuel is critical.

Figure 2-23 Example of Potential Resilience Improvement Project

Figure 2-24 Preferred Investment Programme

2.7.2 Risk Modelling

Risk assessment software was used to estimate damage and direct losses for assets exposed to natural hazards. The modelling combined spatial information on hazards, assets and asset vulnerability to quantify the impacts and estimate the number of casualties and displaced populations. Losses to physical infrastructure are calculated from the direct replacement costs of the damaged assets.

The modelling was supplemented with a series of expert elicitation workshops with critical infrastructure providers to translate the direct damage to assets to loss of service. Utility operators had to overlay direct damage loss with their understanding of their networks (e.g. redundancies) to determine where service was lost across the region. They then worked through their restoration priorities and timelines (accounting for dependencies with other infrastructures) to generate maps of service loss through time. **This was a resource intensive process but a key step between the risk modelling and economic evaluation processes that needs to be considered in developing the maturity pathway.**

The risk modelling framework is shown below.

Figure 2-25 Risk Modelling Framework

Outages were assessed for the base case and with interventions, with an example shown below for fuel supply. This is a key part of the business case process, understanding the degree and timescale of service outages.

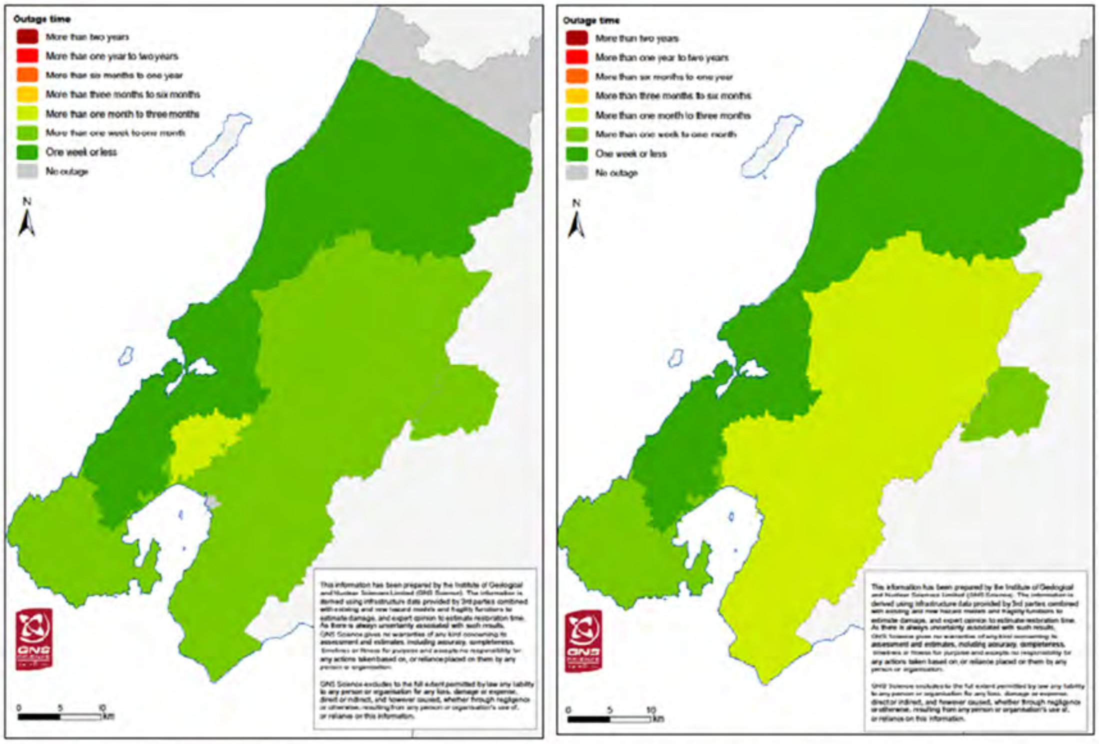


Figure 6.2 Outage map for fuel service to critical customers (left) and general customers (right) from the Seaview facility.

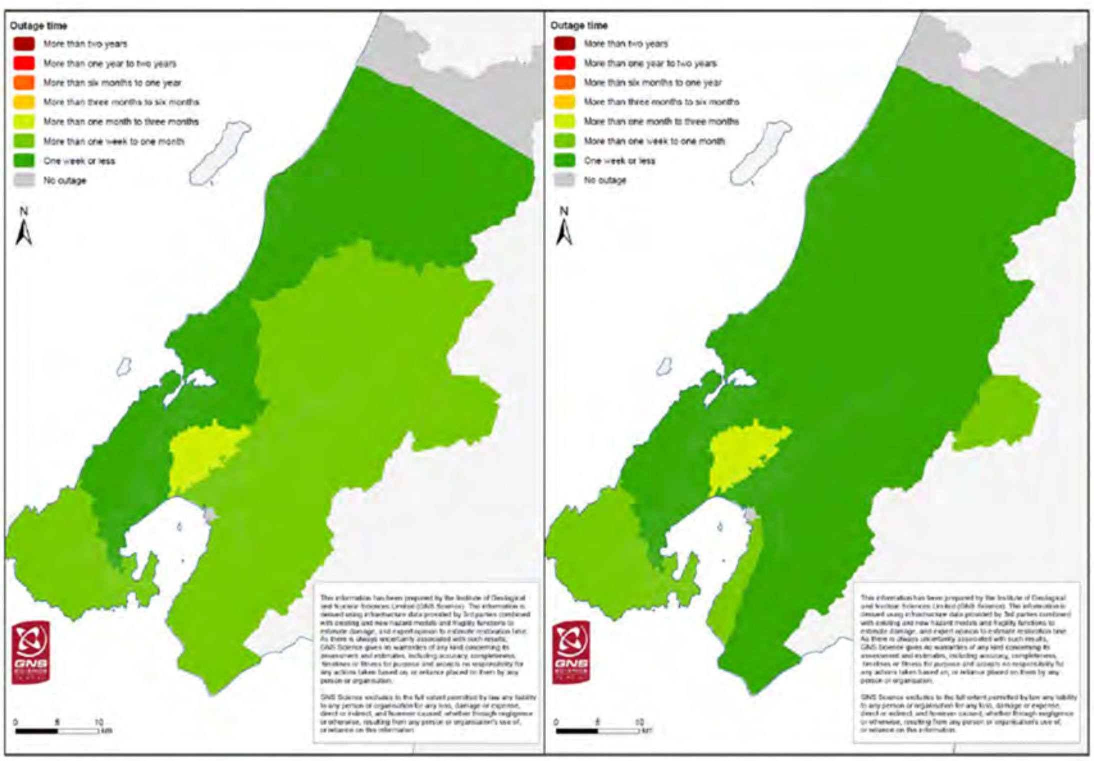


Figure 6.3 outage times for fuel service to critical and general customers with low investment interventions (left) and high investment interventions (right).

Figure 2-26 Examples of Risk Modelling Outage Maps and Durations for Wellington Business Case Project

2.7.3 Economic Evaluation

MERIT is a dynamic economic model that was used to simulate impacts to the economy associated with the assumed earthquake event. The analysis considered indirect economic disruption effects rather than direct losses resulting from losses of life or physical asset damage.

Infrastructure outage maps from the risk modelling expert elicitation process and MERIT were used to provide a combined damage loss assessment and economic impact analysis, giving a more comprehensive approach than either tool would in isolation, as shown in the reproduced figure below.

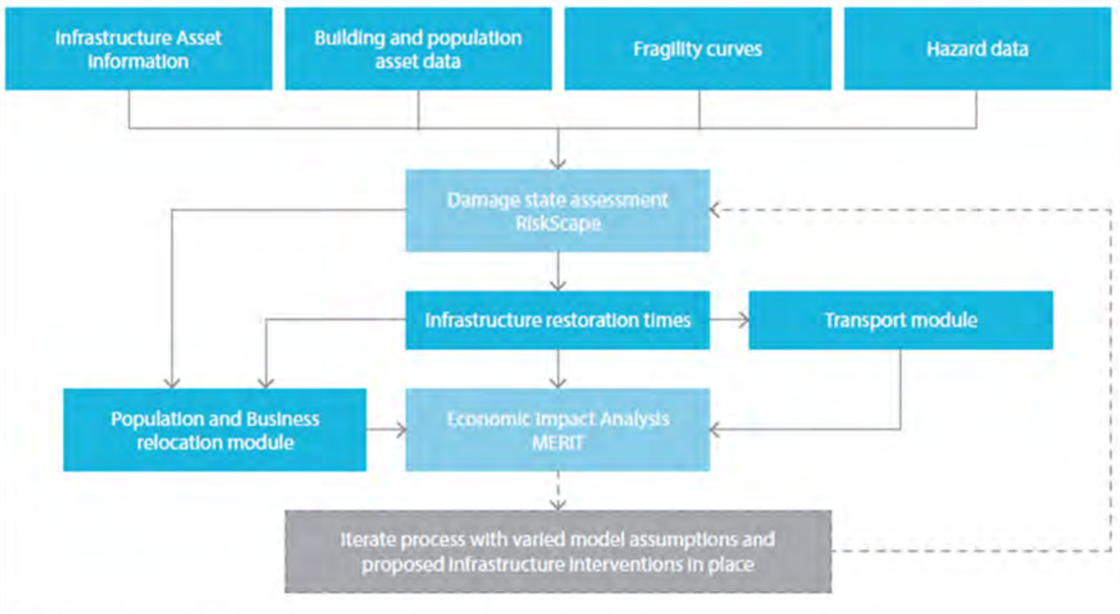


Figure 9: Linkages between the various stages of damage loss assessment and economic impact analysis

Figure 2-27 MERIT Linkages between damage states and economic impact analysis

The MERIT modelling process firstly used workshops with key stakeholders to understand how sensitive the Wellington economy would be to infrastructure and other disaster disruptions, addressing habitability, liveability and business viability.

It was also necessary to develop a set of bespoke models, mostly addressing aspects of transportation and tourism disruption as well as the propensity for people and business relocation. The key drivers of economic system change following a major earthquake event in Wellington were identified and incorporated into the MERIT modelling process (Figure 2-28) and the interactions between sectors modelled (Figure 2-29).

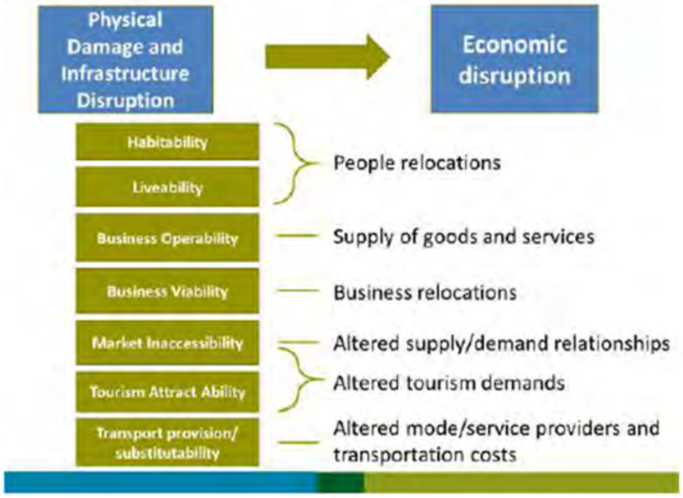


Figure 2-28 MERIT modelling process

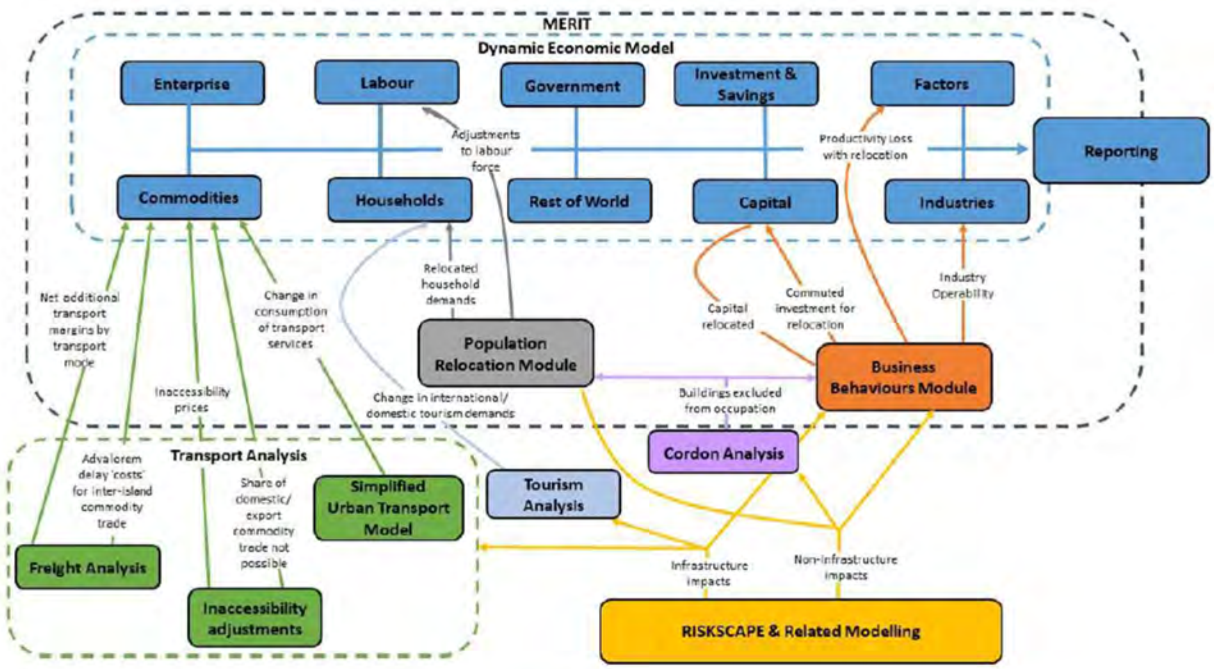


Figure 2-29 MERIT model interactions

2.8 Current Status of Regional Lifelines Projects

Region	Scope / Description of Existing Work	Future Intentions
Northland	Vulnerability assessment based on exposure of mapped critical assets and hazards for tsunami and flooding. Note risk rating not applied.	Intention to progressively update sections by hazard. Will update all sections over next 3 years and add a climate change section.
Auckland	Auckland Engineering Lifelines Project, originally developed 1995-1999, updated in 2014, covered the 'big 4' natural hazards. Completed a detailed 'hotspots' risk analysis in 2007, updated 2015. Note risk rating not applied.	Intention to progressively update sections by hazard. Currently scoping update to 'hotspots' project.
Waikato	Vulnerability assessment first developed in 2014, updated 2021 and development of a GIS viewer to map critical assets and hazards and impact rating (damage and service impact) for volcanic, earthquake, flooding, and coastal / tsunami hazards.	Current project is considered 'Stage 1' with use of Riskscape or other tools to be considered for more detailed analysis, alongside other projects.
Bay of Plenty	Regional Vulnerability Study undertaken in 2011, updated in 2017 with development of GIS portal.	Current focus is Lifelines Infrastructure Climate Change Risk Assessment.
Hawkes Bay	First vulnerability assessment in 2001, updated in 2019 (but no GIS analysis).	Focussing on critical sites (critical customers and lifeline utilities)
Taranaki	Vulnerability assessment completed in 2018, based on the 'big 4' hazards.	Participating in TTVF
Manawatu-Whanganui	Vulnerability assessment completed in 2018, based on the 'big 4' hazards.	Intention to update in next two years.
Wellington	Wellington Business Case – methodology described in Section 2.4.42.7 (use of Riskscape for vulnerability assessment) and Section 2.7 (economic modelling using Merit).	Progressing a variety of other projects. Have had difficulty getting traction with implementation of the business case programme.
Nelson-Tasman	Vulnerability assessment completed in 2018, based on the 'big 4' hazards.	Intention to update in next two years.
Marlborough	Mapped assets in the GIS some years ago but haven't progressed a vulnerability assessment.	Intention to progress in next two years.
West Coast	Vulnerability assessment completed in 2017, included tsunami, earthquake, flooding.	Progressing a variety of other projects.
Canterbury	Multi-hazard Vulnerability assessment being completed in 2021 in conjunction with GIS Lifelines portal development.	Develop practice towards business case model, current NEMA supported project
Otago	Vulnerability assessment completed in 2013/14, based on the 'big 4' hazards, supported by a GIS viewer.	Currently working on an update.
Southland	Mapped assets in the GIS some years ago, but haven't progressed a vulnerability assessment.	Under consideration.

Table 2-6 Current State of Regional Lifelines Projects in New Zealand

2.9 Other Vulnerability Assessment Programmes

Other projects and programmes which have a component of infrastructure vulnerability and risk assessment are summarised in Table 2-7. Along with the above, some individual lifeline utility organisations (including local authorities) have carried out risk and resilience assessments, for example both Waka Kotahi and Transpower have done significant work assessing natural hazard impacts on their networks.

Programme / Report	Description
National Vulnerability Assessment 2020	Draws on information from existing regional lifelines projects, national lifeline utilities and national projects such as the ones below to provide a national view of infrastructure vulnerability and resilience.
Alpine Fault / AF8	Asset damage and interdependency modelling, including community and stakeholder participation and co-creation approaches on the West Coast (Zorn et al 2018, Davies 2019[2], Davies et al 2021). Refer Section 3.3.4 for further information.
Transitioning Taranaki to a Volcanic Future	Research-led project just starting, intention to use RiskScape and MERIT for more detailed risk assessment, economic impacts and business case development.
National Climate Change Risk Assessment	Used workshops with lifeline utilities to form a risk rating for different climate change hazards for different sectors.
LGNZ report on exposure of local government assets to sea level rise.	National modelling of sea level rise impacts on local government infrastructure – this was based on work carried out under the Deep South National Science Challenge programme (see also Section 3.6.2), covering both coastal and pluvial/alluvial flooding.
Hikurangi Subduction Zone Project.	Used workshops with lifeline utilities to form assessment of impacts and recovery times (lifelines data modelling not included).

Table 2-7 Vulnerability Assessment Projects (other than Regional Lifelines Projects)

[2] Davies, A.J. (2019). *Increasing the disaster resilience of remote communities through scenario co-creation*, A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Disaster Risk and Resilience

3.0 Tools and Resources for Lifelines Risk Reduction Planning

3.1 Introduction

Historically, the use of spreadsheets has been widespread in lifelines vulnerability assessments and other work such as priority routes, with GIS applications now becoming much more prevalent. These approaches were described in more detail in Section 2.0.

In addition to GIS tools, the most significant software applications used in New Zealand for infrastructure resilience assessments are RiskScape and MERIT, as described in Section 2.7 for the Wellington business case. These tools are described in more detail below along with other examples of their use. Both are relevant for application in the Canterbury lifelines project.

This section also describes the substantial body of scientific and research work that has been carried out in recent years, or being progressed, through programmes such as the National Science Challenges, QuakeCoRE and MBIE Endeavour Fund programmes. Typically, these involve collaboration between universities and science agencies. The following figure provides an overview of the national landscape of programme areas and research agencies.

Figure 3-1 Disaster Resilience Research Landscape

Of particular interest to Canterbury lifelines work are the outputs of:

- National Science Challenges
- Natural Hazards Research Platform
- AF8
- QuakeCoRE
- MBIE Endeavour
- EQC
- Quake Centre
- Urban Resilience Programme
- Dam Resilience Research Programme (DRRP)

Before these tools and research programmes are described in more detail, a summary is presented below.

3.2 Summary

The following table provides a brief summary of the areas covered in subsequent sections. Links are provided to these sections.

Tools and Resources	Overview	Relevance / Applicability
GIS Applications (Section 3.3)	• GIS tools are increasingly being used across lifelines and CDEM functions • NZGIS4EM and LINZ are working to improve coordination and collaboration in the use of GIS	• GIS is a key element of the Canterbury project • The portal needs to leverage off national work
RiskScape (Section 3.3.4)	• Provides framework for multi-hazard impact modelling and physical loss modelling • Can be used to quantitatively evaluate the benefits of implementing planning and mitigation options • Fragility models – probability of a certain damage state as a function of a hazard metric • Vulnerability models - % of damage or % cost of replacement of an asset as a function of a hazard metric • Consequences are described spatially • RiskScape 2.0 being released late 2021 • Forward programme of research work is contributing to ongoing model development in RiskScape	• Risk modelling tool that integrates datasets together in an efficient way to do analyses • Requires risk data, exposure data, and vulnerability models • Provides an opportunity to demonstrate a “proof of concept” application in disaster modelling and resilience work
MERIT (Section 3.5)	• Suite of ‘Integrated Spatial Decision Support Systems’ used to evaluate the socio-economic impacts of both infrastructure investment and disruption • Wellington addressed economic impacts relating to recovery times and interdependencies, freight impacts as well as people and business relocation	• Advanced modelling tool • MERIT requires detailed outage and duration data • Linked to application for Deep South AF8 funding • Canterbury configured application of MERIT exists • GIS layers to MERIT directly from the Canterbury GIS portal.

National Science Challenges
(Section 3.6)
	• 11 Challenge programmes, including three below that are of interest
	• Resilience to Natures Challenges (RNC):
	  o Multi-hazard Risk Model
	  o Resilience in Practice Model
	  o Various themes and projects, including coastal, weather, earthquake and tsunami
	• Deep South – looking at the role of the Antarctic and Southern Ocean in determining future climate and impacts on infrastructure
	• Building Better Homes, Towns and Cities - aims to improve the quality and supply of
		• RNC – numerous relevant projects with many currently in progress. Includes improvements in hazard models, improvements to MERIT, scenario development, integration of hazards research with Māori programmes. Of particular interest is the area of interdependency modelling (Zorn et al)
		• Deep South – wide range of resources and information that can be considered in developing the Canterbury project’s maturity pathway

Tools and Resources	Overview	Relevance / Applicability
	housing and create smart and attractive urban environments	• Better Towns and Cities - resources may be useful in addressing social impacts of hazard events and potential mitigation strategies
Natural Hazards Research Platform (Section 3.7)	• Superseded by Resilience to Natures Challenges programme	• Research outputs still likely to be useful
AF8 (Section 3.8)	• AF8 is a programme of scientific modelling, response planning and community engagement, designed to build collective resilience to the next Alpine Fault earthquake	• Important seismic hazard for Canterbury • AF8 ground shaking maps from QuakeCoRe included in the Canterbury Lifelines GIS portal • AF8 business case work closely aligned with Canterbury work, so close collaboration needed
QuakeCoRE (Section 3.9)	• NZ Centre for Earthquake Resilience, a Centre of Research Excellence • Significant organisation with interfaces to science, research and consulting communities • Completed projects include: o Spatially distributed infrastructure o Ground motion simulation and validation o Liquefaction impacts on land and infrastructure o Pathways to improved resilience • Resilient NZ Transport System in progress	• Projects are relevant in describing hazards and updated models that are or will be made available in GIS or RiskScape
MBIE Endeavour Fund (Section 3.10)	• Supports programmes that are wider than those of a CDEM or lifelines nature • Examples include tsunami risk, wildfire, climate change and extreme events, space weather, flood inundation risk	• Also describes hazards and updated models that are or will be made available in GIS, RiskScape or other applications
Dam and Stopbank Resilience (Section 3.11)	• Research area – collaboration between Universities, RNC, and lifelines sectors • Dams and stopbanks mapped along with liquefaction potential	• Bring data layer into the GIS portal • Highlight particular vulnerabilities or deficiencies
EQC (Section 3.12)	• Resilience Strategy for Natural Hazard Risk Reduction identifies key programme areas, including loss modelling, improved hazard data, insurance	• Outputs will include updated hazard models
Quake Centre (Section 3.13)	• Government/ University/ Industry partnership – its functions are being transferred into the Building Innovation Partnership • Resource portal offers a range of research outputs	• 3 Waters, Dams, Geotechnical areas useful input to lifelines impact assessment

Tools and Resources	Overview	Relevance / Applicability
Building Innovation Partnership (Section 3.14)	• Industry led research programme based at the University of Canterbury. • Theme 1 Better Investment Decisions has initial focus on improved infrastructure planning, investment tools and decision making for 3-waters	• Water pipe data portal a useful layer for the Canterbury lifelines GIS portal • Developing a digital twin for urban flood modelling
Urban and Community Resilience (Section 3.15)	• Urban Intelligence conducts a range of resilience research, GIS analysis and data science	• Significant future potential – ready development of useful GIS based tools • Brings social dimensions into the impacts analysis using GIS tools, perhaps an additional layer in the Lifelines GIS portal

Table 3-1 Tools and Resources Summary

3.3 GIS Applications

3.3.1 Lifelines Groups

Lifelines groups are making Increasing use of GIS applications, as described earlier, including:

- Mapping critical assets
- Hotspots analysis
- Vulnerability assessments
- Loss modelling in association with RiskScape
- Economic impacts analyses in association with MERIT

The Canterbury portal is a key building block for this project and is being developed with two purposes in mind:

- To enable resilience planning, mapping and presenting hazards against infrastructure layers
- Response during emergency events, including the presentation of situational data

A screenshot from the portal is shown below.

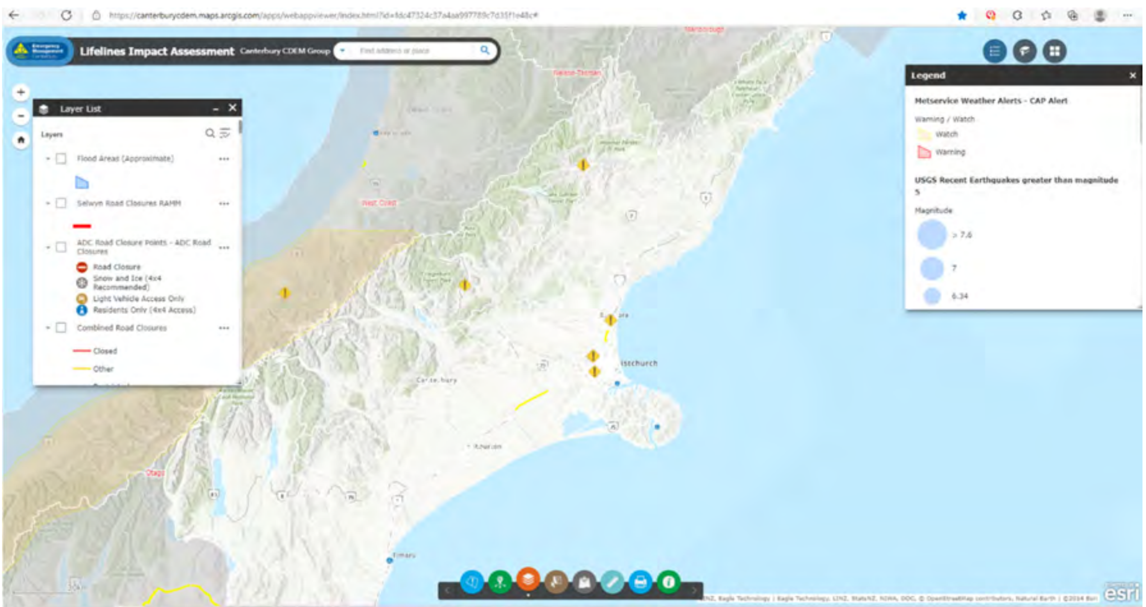


Figure 3-2 Canterbury Lifelines GIS Impact Assessment Portal

3.3.2 NZGIS4EM

NZ GIS for Emergency Management (https://nzgis4em.com/) is a voluntary community of people from both the geospatial and emergency management sectors, formed to improve the ways in which GIS is being used.

NZGIS4EM is involved in a wide range of projects and collaborates with the NZ Lifelines Council. An online workshop was held in August 2021to share practices and tools being developed in relation to the use of lifeline utility data for lifelines resilience (vulnerability) assessment projects and developing Common Operating Pictures in response. Current applications were shared by Canterbury, West Coast, Wellington, with work being carried out by other groups and agencies also highlighted.

3.3.3 NZ GovTech Accelerator Project

One of these initiatives is a project recently initiated and being led by LINZ. It seeks to connect and share often-uncoordinated geospatial data – *“currently, the lack of coordinated geospatial information* *to inform disaster resilience, climate change adaptation, and emergency management cause inefficiencies in decision-making. The consequential duplication of effort, uncertainty and lag in response has meant geospatial information has not been utilised to its fullest to assist in critical response decision-making".*

The intent is to "*create a foundational system layer that underpins and coordinates geospatial data for emergency management. This will bring together current initiatives to enable a live up-to-date common operating picture between agencies. There are already pre-existing initiatives and work done in this space, the GovTech Accelerator provides this project the opportunity to create and test a foundational layer and create cohesion across the system".*

3.3.4 Interdependency Modelling

This is a relatively new area whose benefits are starting to be realised in lifelines resilience work in New Zealand. It offers significant future potential to lifelines groups.

This section provides information sourced from papers prepared by researchers at the Universities of Oxford, Auckland and Canterbury. These papers discuss the modelling of network interdependencies arising from an AF8 earthquake event affecting the South Island, with a particular focus on infrastructure networks on the West Coast. The abstract to the 2018 paper[3] states:

"In this paper, utilising the core Project AF8 Alpine Fault magnitude 8 earthquake scenario, we detail hazard exposure, impacts, and recovery of interdependent critical infrastructure networks, namely: energy (electricity, petroleum), transportation (road, air, ferry, rail), water & waste (water supply, wastewater, solid waste), and telecommunications sectors (wired, wireless).
Asset failures are simulated across each individual network, based on; shaking intensities, exposure to co-seismic hazards (slips, landslides, and major rock falls), and estimated component fragilities, which have been further refined and validated through expert elicitation, via workshops coordinated with regional infrastructure stakeholders. Network disruptions are propagated across an interdependent network framework to quantify and delineate the spatial reach of failures.
By incorporating recovery strategies, temporal changes in service levels are quantified to offer insights into expected interdependent network performance and the possible disconnection of communities from the nationally connected networks, otherwise not apparent when studying each infrastructure in isolation".

A more recent paper[4] published by the New Zealand Society for Earthquake Engineering in 2021 widens the scope of this work, introducing the concept of community participation and further developing the methodology. The paper's abstract states:

"While it is well established that community members should participate in resilience planning, participation with genuine decision-making power remains rare. We detail an end-to-end disaster impact reduction modelling framework for infrastructure networks, embedded within a scenario-based participatory approach. Utilising the AF8+ earthquake scenario, we simulate hazard exposure, asset failure and recovery of interdependent critical infrastructure networks. Quantifying service levels temporally offers insights into possible interdependent network performance and community disconnection from national networks, not apparent when studying each infrastructure in isolation. Sequencing participation enables feedbacks between integrated modelling and participants' impact assessments. Shared ownership of modelling outputs advances stakeholders' understanding of resilience measures, allowing real-time implementation, increasing community resilience. Readily understood by central government, this format may increase support and resourcing, if nationally

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[3] Zorn C, Davies AJ, Robinson TR, Pant R, Wotherspoon L and Thacker S (2018*). Infrastructure failure propagations and recovery strategies from an Alpine Fault earthquake scenario*. 16th European Conference on Earthquake Engineering, Thessaloniki, Greece

[4] Davies, A., Zorn, C., Wilson, T., Wotherspoon, L., Beavan, S., Davies, T., & Hughes, M. (2021). *Infrastructure failure propagations and recovery strategies from an Alpine Fault earthquake scenario: Establishing feedback loops between integrated modelling and participatory processes for impact reduction*. Bulletin of the New Zealand Society for Earthquake Engineering, 54(2), 82–96.

significant. Finally, this method tested integrated modelling and impacts assessments, identifying and enabling improvements for both".

The approach is summarised in the following figure.

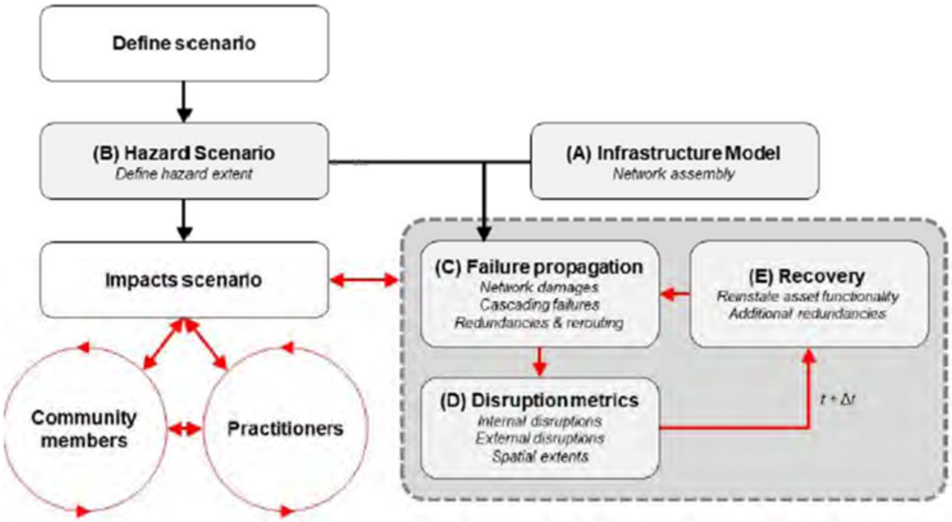

Figure 3-3 Conceptual diagram of the integrated disaster impact reduction modelling framework for infrastructure networks embedded within the scenario-based participatory approach (Source, Davies et al, 2021)

A scenario-based participatory approach was designed[5] and applied with community members and stakeholder groups, contributing to the development of a co-created scenario sequence and associated impacts.

Infrastructure networks were created as geospatial models with nodes and edges representing discrete single point assets (such as water pumping stations or reservoirs) and connections (such as pipelines between these nodes) respectively. The assets modelled are shown in the following figure.

Infrastructure Sector	Network	Asset representation	
		Node	Edge
Energy	Electricity	63 generation sources, 48 transmission and 289 distribution substations	Transmission and sub-transmission power lines
	Petroleum	5 bulk storage facilities, 431 retail petroleum stations	Connected via state highway Network
Telecommunications	Landline	322 exchanges, 2313 cabinets	Fibre and copper connections
	Mobile	1053 mobile transmitter towers	Connectivity to wired network
Water & Waste	Water supply	585 source, treatment, pumping, or storage nodes	Major transmission or distribution pipelines
	Wastewater collection	354 pump station or treatment assets	Major collection pipelines
	Solid waste	239 collection, transfer, or landfill assets	Routed via state highway network
Transportation	State highways (SH)	855 bridges/tunnels	State highway classified roads
	Rail	16 stations	Rail tracks
	Air	13 Airports	Flight routes (41 domestic, 4 international)
	Ferry	13 Ferry terminals	Ferry routes (10)

Figure 3-4 Infrastructure networks modelled as nodes and edges (Source, Davies et al, 2021)

5 Davies AJ (2019). *Increasing the disaster resilience of remote communities through scenario co-creation*. PhD Dissertation, University of Canterbury, Christchurch, NZ

User demands were allocated to each of the individual nodes and edges using statistics adopted from asset owner/operator-provided statistics, publicly available reported statistics, or spatial distribution/collection zones, intersected with the smallest publicly available census area unit (~100 permanent residents each).

Using these network models, initial asset failures or disruptions were assumed based on the network assets' intersection with the modelled hazard scenario. The AF8+ scenario was the "south to north" event, with the hazard effects being ground shaking, seismic-induced landslides, and liquefaction. The scenario included a 10-year sequence of aftershocks and resultant landslides, with the study itself focusing on the first 180 days. A wide body of previous work was brought into the modelling process.

The following figure shows the Modified Mercalli shaking intensities (MMI) applied.

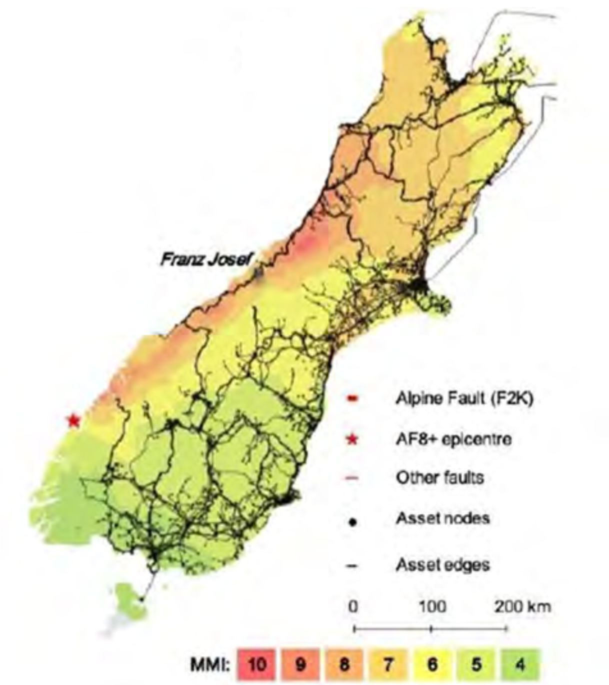

Figure 3-5 AF8+ Scenario – Modified Mercalli Shaking Intensities (Source, Davies et al, 2021)

An iterative process for each modelled time step was applied as the recovery process unfolds:

- Failure propagation both within a network and between networks where dependency connections are lost. Each individual network asset was assigned one of three initial functionality states as a direct result of the shaking and landslide models – complete disruption, interim functionality, no disruption.
- Calculation of disruption consequences, these being direct and indirect. Direct impacts affect the customers of a network that itself is damaged, while indirect impacts are consequential to interdependency failure (such as the loss of electricity to power a water supply network). The spatial outage extent is defined by the intersection of spatial footprints of failed components and dependent user catchments or distribution/reception zones.
- Progressive reinstatement of functionality of the networks to pre-event capability and levels of service.

The time periods and extent of ongoing disruption to levels of service are mapped spatially as shown in Figure 3-6 below. Shading indicates the number of infrastructure networks providing a complete or interim level of disruption to normal service.

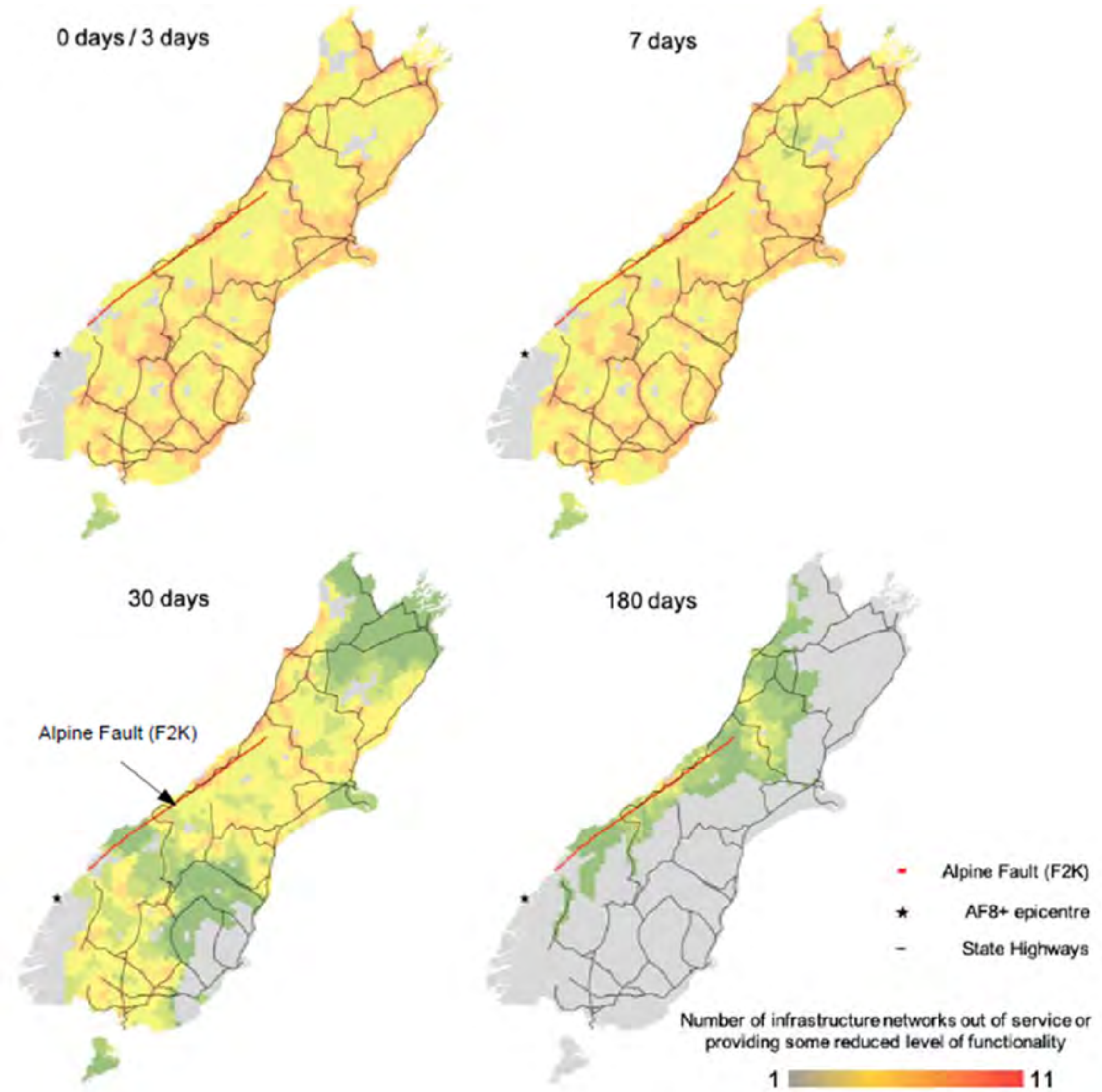

Figure 3-6 Spatial extent of service disruptions following the AF8+ event (Source, Davies et al, 2021)

Further detail relating to impacts on levels of service were derived through workshops with stakeholders for electricity and state highways, shown in the figures below.

The approach described in the 2021 paper enables the integration of knowledge between community members, researchers, and practitioners, also highlighting the benefits of end-to-end disaster modelling and of using a scenario-based participatory approach to integrate modelling with preparedness planning.

Overall, the collaborative linking of scientific, technical, and community knowledge offers great potential to increase the resilience of socio-technical systems in preparing for future disaster events.

Further work is being progressed with interdependency modelling as part of the Resilience to Nature's Challenges programme, discussed in Section 3.6.1.

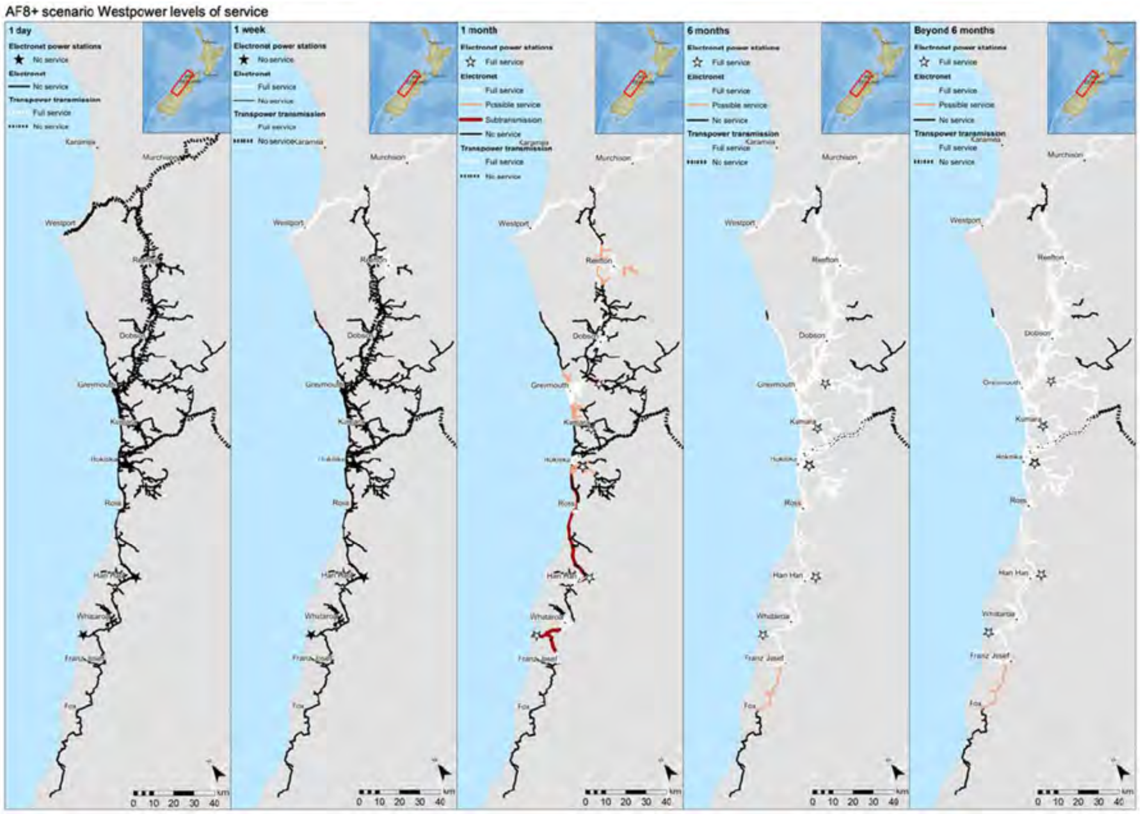

Figure 3-7 Co-created AF8+ impact scenario for Westpower electricity service levels (Source, Davies et al, 2021)

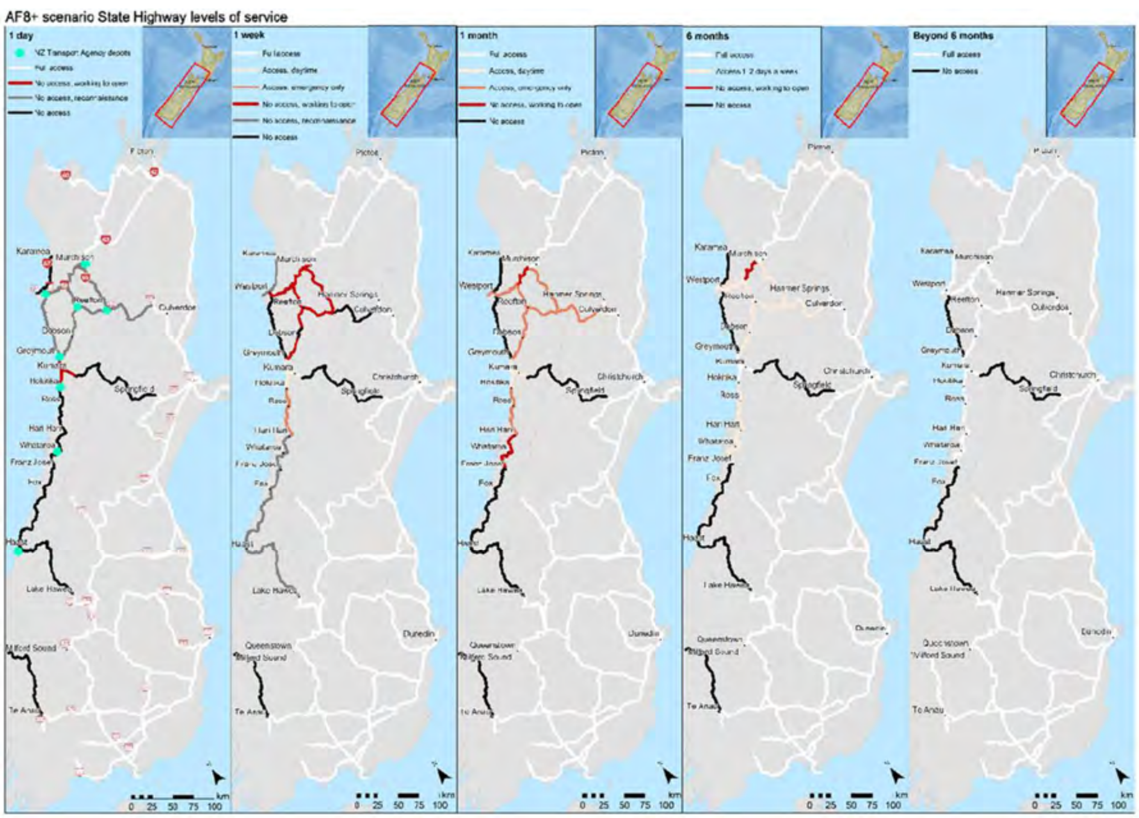

Figure 3-8 Co-created AF8+ impact scenario for state highways service levels (Source, Davies et al, 2021)

3.4 RiskScape

3.4.1 Overview

RiskScape is risk modelling software that has been jointly developed by GNS Science and NIWA since 2004. It is essentially a physical loss modelling tool that relies on both robust risk data and strong collaboration across research institutions.

Following a user-requirements review in 2020[6], GNS has fully rebuilt a new version, RiskScape 2.0, for public release as an open-source product in December 2021. Ongoing improvements to useability are also currently underway or planned, for example, “RiskScape as a service”.

This review highlighted a gap in holistic risk-based assessments, in part due to due to data gaps, access to data and best practice standards. A need was seen for a central risk data repository, which could be provided in RiskScape. The vision for RiskScape was for it to be inter-operable, open-access, transparent, intuitive, flexible, collaborative, reliable, expert-supported, secure, open-sourced, fast and visual.

Currently, this version is largely being used for research purposes and case studies. Auckland and Canterbury universities currently hold licenses, these are tied to PhD students.

3.4.2 Summary of Features

RiskScape provides a generic framework for multi-hazard impact modelling to support disaster risk reduction (DRR) and disaster risk management (DRM) decision making, applicable to the analysis of both natural hazard events and climate change. It assists users to:

- Understand disaster risk
- Identify and understand risk scenarios
- Meet natural hazards legislative requirements

The software models natural hazard losses and can be used to quantitatively evaluate the benefits of implementing planning and mitigation options. The “infrastructure” affected may be in public or private ownership, either point features such as buildings or linear networks such as roads and railway lines.

Figure 3-9 below highlights the key inputs to RiskScape – risk data, exposure data, and vulnerability models. These inputs are analysed by RiskScape in reporting physical damage and financial loss.

Key points associated with this process include:

- RiskScape currently requires reasonably skilled computer risk management programming knowledge to operate the command line interface.
- Hazards data is user defined and fully configurable – the data must be imported as the software does not store default hazards data.
- For example, ECan’s flood data could be imported and used as national flood models are still several years away.
- Exposure is assessed through the consolidation of geospatial layers, these must be formatted with the correct data attributes.
- Vulnerability models are essentially fragility relationships. These describe damage level probabilities that need to be coded into equations in RiskScape.
    - o For example, there could be different damage levels to different classes of road or different bridge standards.
    - o There are also models published by CRIs and Universities that can be applied.
- Consequences are described spatially. Lifeline utilities need to be involved in defining the areas of outage due to the damage event and the expected recovery times.

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6 User Requirements of RiskScape 2.0 Software and Opportunities for Disaster Risk Assessment in Aotearoa-New Zealand, GNS Science Report 2020/10, June 2020

- The software is modular and is now better able to deal with complex cascade events, such as liquefaction following an earthquake.
- The benefits and costs of different mitigation options can be assessed, including both damage costs and mitigation costs.
- Other enhancements include:
    - Web features such as GIS. It has been noted that interoperability with ArcGIS Online can be difficult – this would need to be explored further in relation to the Canterbury Lifelines portal.
    - Customised user interface developed for NEMA for use by CDEM groups.
    - Non-point functionality (i.e. continuous linear networks) can now be used, this improves the level of accuracy where localised impacts may be felt on linear networks.
    - Models are probabilistic, whereas in RiskScape 1.0 they were not. Different return period (ARI's) and event probabilities can be analysed. See Figure 3-10 below.

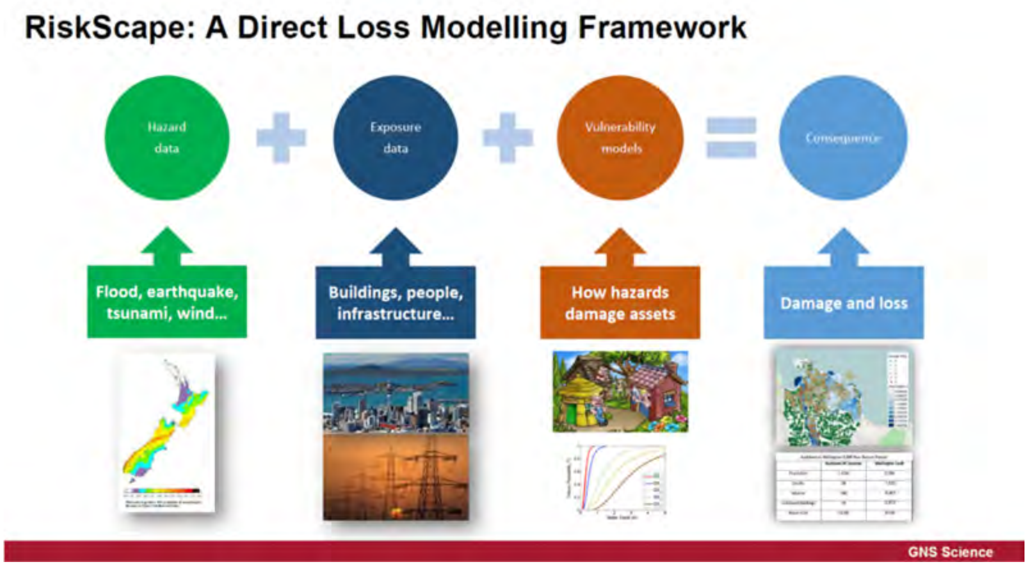


Figure 3-9 RiskScape Loss Modelling Framework

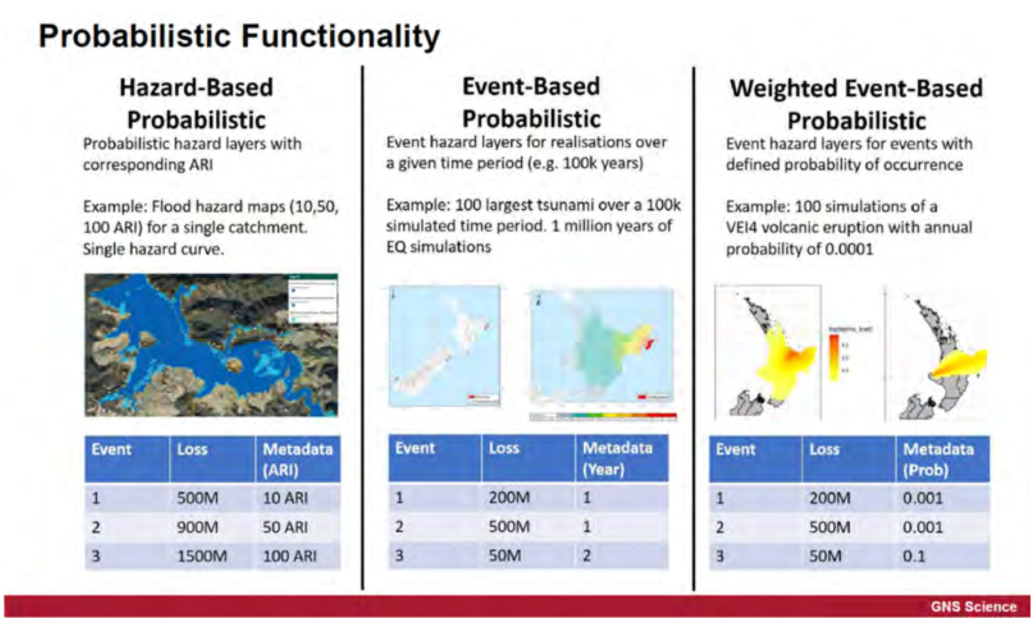


Figure 3-10 Probabilistic Hazard Layers

3.4.3 Future Development

The intention is for RiskScape 2.0 to move beyond "research as a tool", and by 2023 it is hoped to develop a customised platform as shown in the figure below. This diagram shows data and modelling inter-relationships with the research community and asset organisations, and through various interfaces potential workflows that link social and economic impact (e.g. MERIT) and infrastructure analysis. The full capability of the software has therefore yet to be realised.

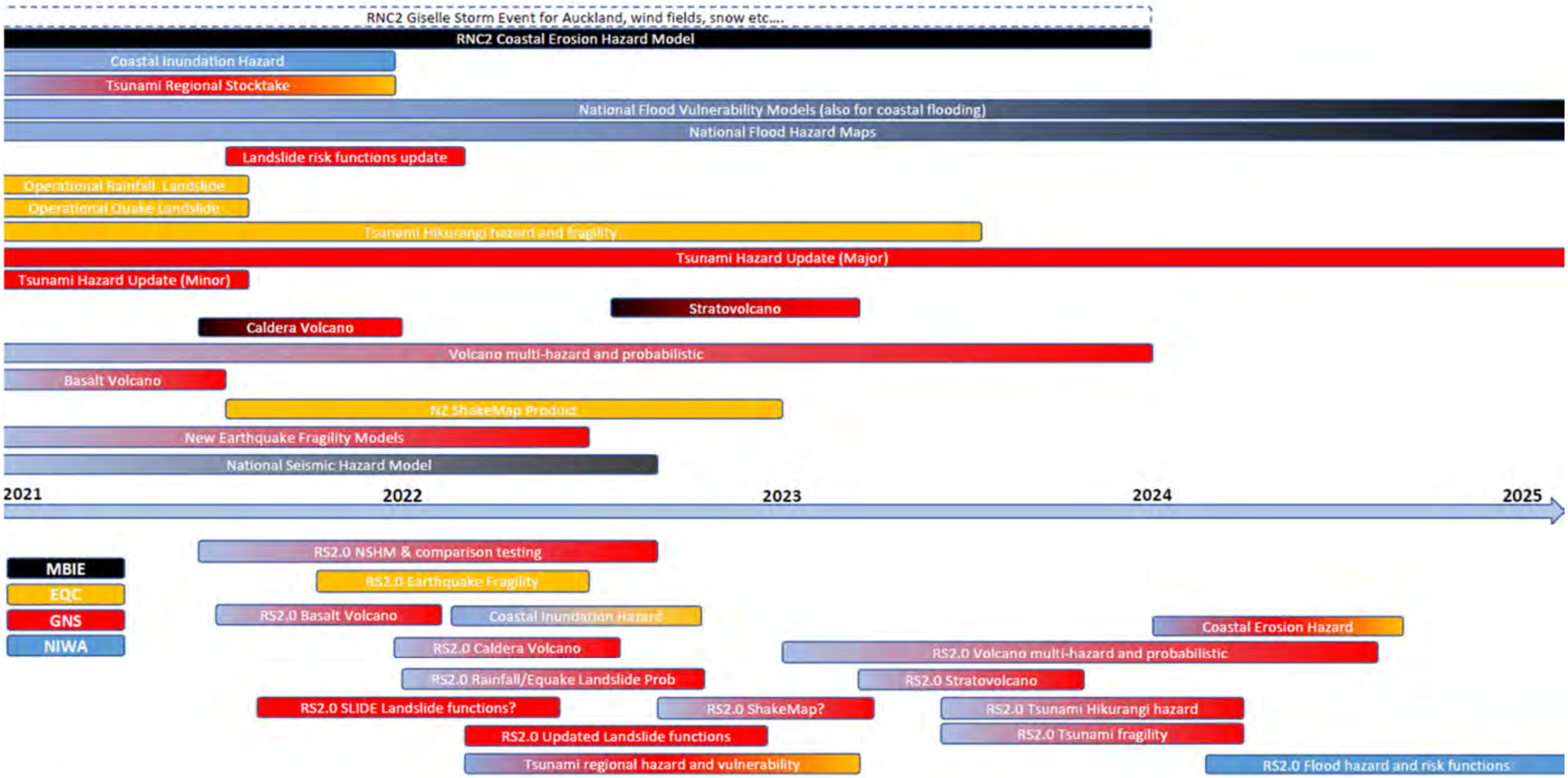
In the meantime, however, RiskScape 2.0 does provide an opportunity for this project, helping to demonstrate a "proof of concept" application in disaster modelling and resilience work.

Figure 3-11 Risk Platform and RiskScape

Ongoing research will contribute to the future development of RiskScape, shown in the following figures. Important for future infrastructure resilience work in Canterbury are the following outputs:

- Updated tsunami risk models
- Seismic hazards and risk model
- Landslide risk model
- Flood risk model
- Coastal inundation risk model

Research that contributes to loss modelling



Implementation projects to make research usable in RiskScape

Figure 3-12 Hazards Research Programme contributing to RiskScape Development

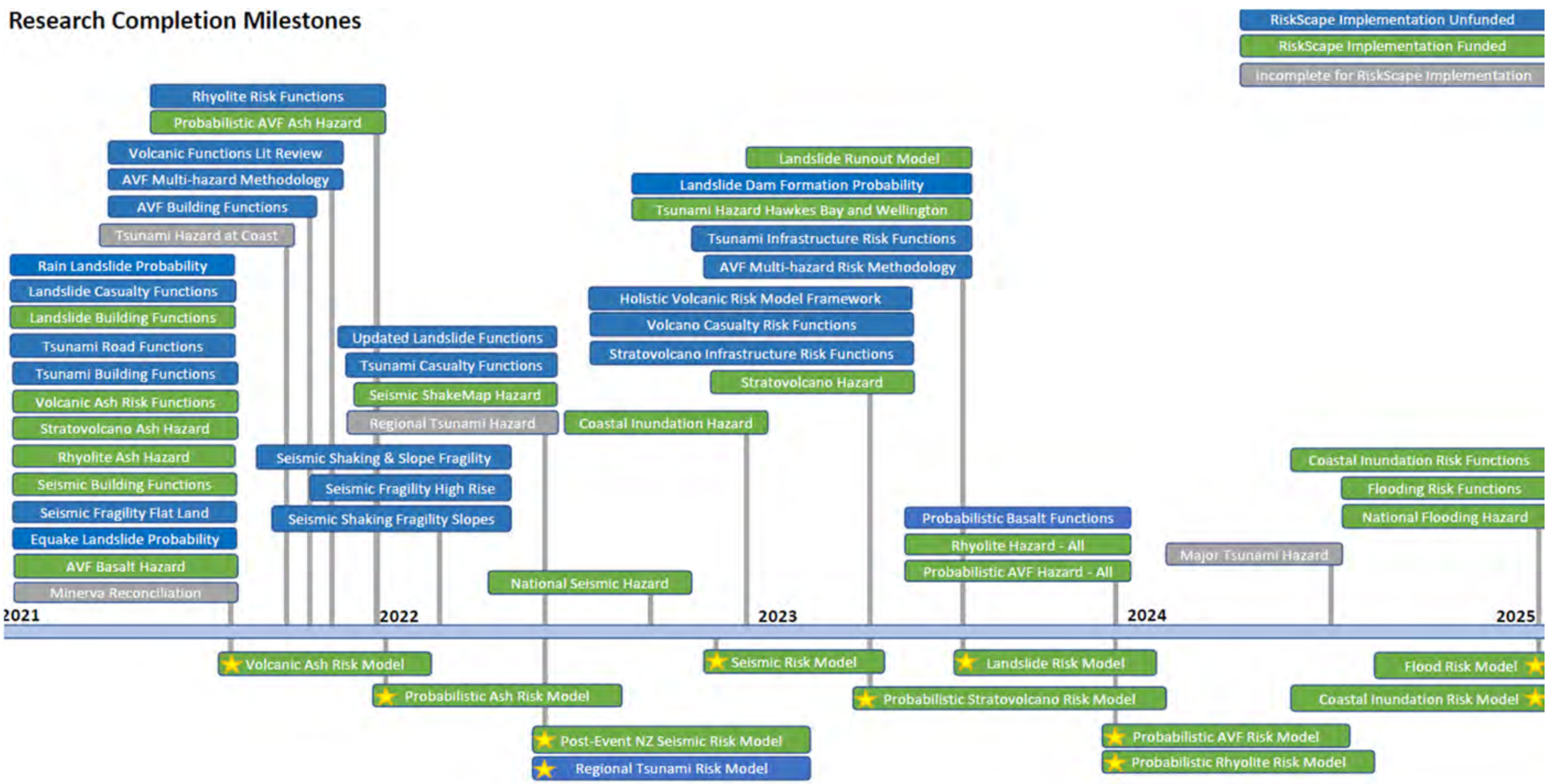


Figure 3-13 Hazards Research Milestones and Models

3.4.4 Queenstown Case Study

This recent work examined planning options for developed urban land immediately below the Reavers Lane Debris Cone, buildings that could be damaged by debris flow. Using geotechnical analysis, the extent and depth of debris flow under three ARI periods was modelled. Damage states and potential financial losses to building owners were based on the depth of flow and the type of building using fragility relationships.

Annualised losses were assessed for four future land-use scenarios – baseline, uncontrolled, manage, and reduce. The latter two options progressively involved more investment in risk reduction, for example this could include property purchase, rezoning compensation or engineering measures. This approach then allows the economic analysis of the cost and benefits of both loss costs and investment costs to be undertaken and an appropriate management option selected.

This type of analysis is equally applicable to damage to infrastructure networks or facilities, provided the replacement cost valuation of the assets is known.

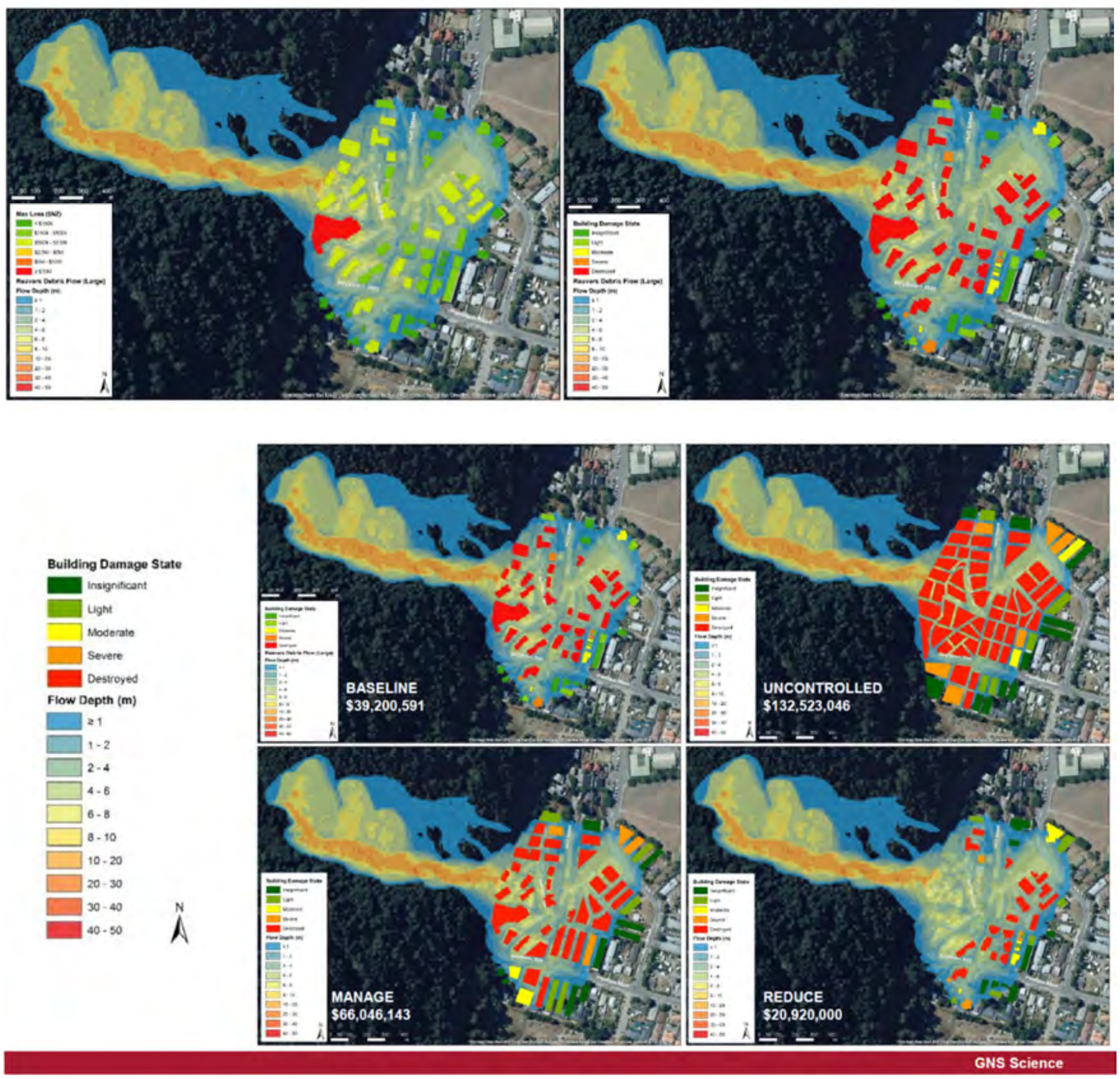


Figure 3-14 Queenstown Case Study – Scenario 1 Baseline Current Building Stock

3.5 MERIT

3.5.1 Overview[7]

The MERIT tool is a suite of ‘Integrated Spatial Decision Support Systems’ that estimate the economic consequences associated with disruption events. It is used to evaluate the socio-economic impacts of infrastructure investment and disruption, and is jointly managed by ME Research, GNS Science and Resilient Organisations.

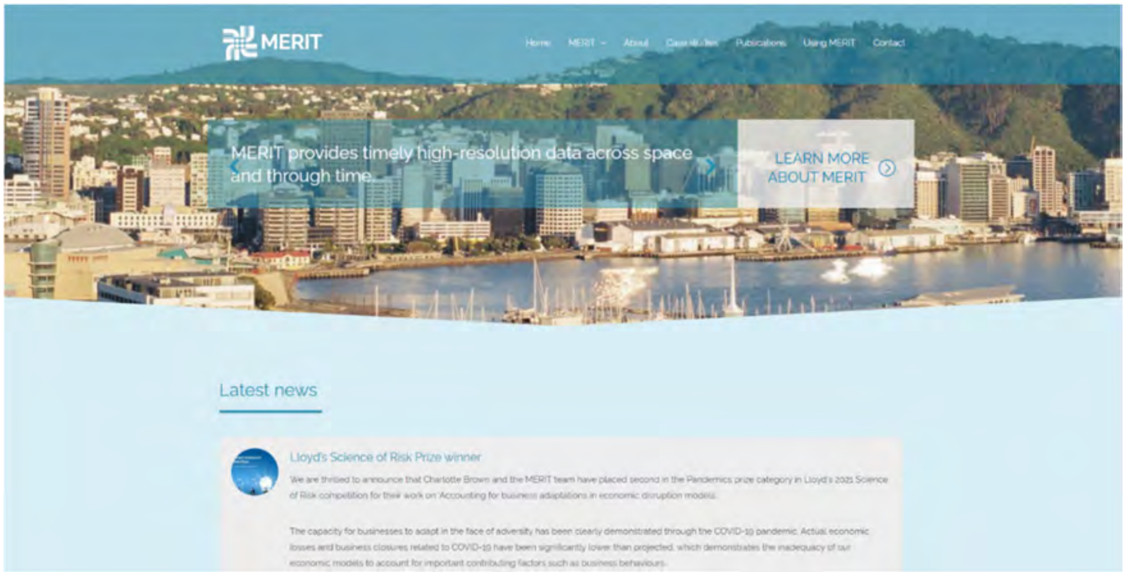


Figure 3-15 MERIT Website home page

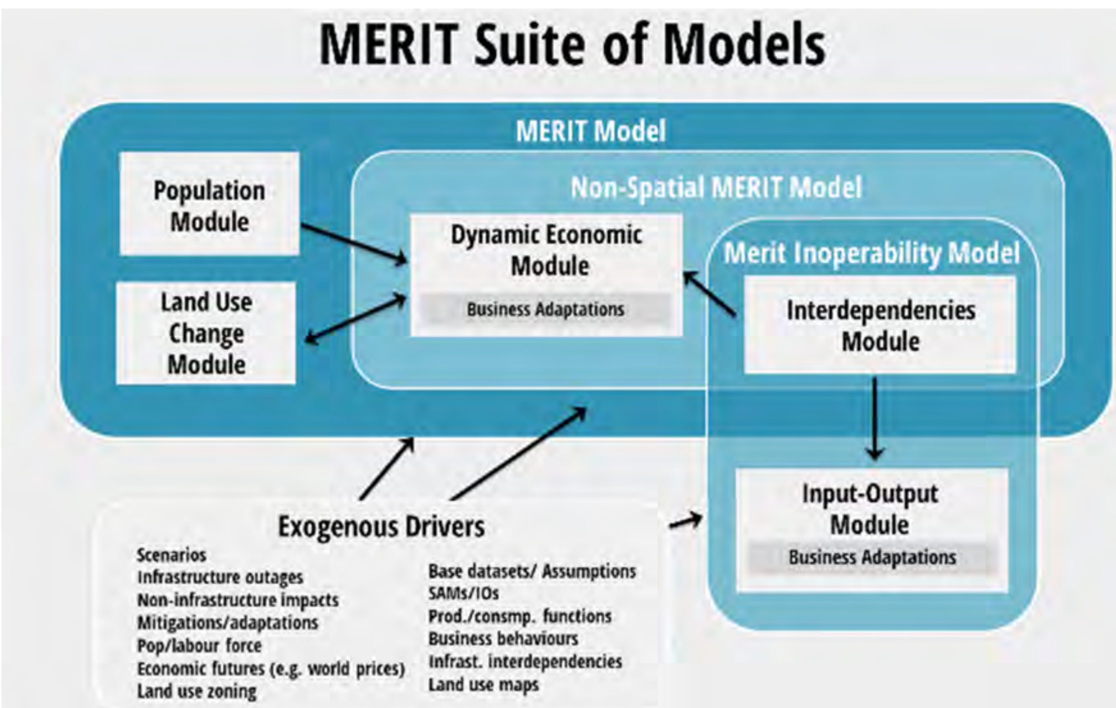


Figure 3-16 MERIT Suite of Models

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[7] Refer https://www.merit.org.nz/merit/

MERIT was developed between 2012-2016 through an MBIE research programme, and is now used by government agencies, infrastructure providers and Councils. Using MERIT involves both a process and the model.

The inter-related modules are:

- The Inoperability MERIT model provides data for short-run outages (between 1-day and 1-week) from localised small-scale disruption events such an electricity, gas, or telecommunication outages. This model assumes that the economic impacts associated with disruption are limited to those felt directly and through flow-on supply chains, i.e. through delays in production and consumption activity. No price change or other market dynamics are assumed to be involved.
- Non-Spatial MERIT. This is the key MERIT tool, designed to assess the economic impacts associated with sizeable disruption events. It reports various economic aggregate impacts (output, income, value added, GDP, balance of trade, exchange rate, commodity, labour and capital prices, and various welfare measures) by industry for both the regional and national economy.
- Spatial MERIT is a research tool solely focusing on the Auckland Region. It has a spatial resolution of 100m x 100m, a daily time step, and ability to run over a 30-year time horizon. It consists of a number of tightly couple modules:
    - Infrastructure outages
    - Demographics
    - Land use
    - Economic (a full version of Non-Spatial MERIT)
    - Transport

3.5.2 Summary of Features

MERIT can be used for wider economic modelling and impact assessment due to disruption, through to narrower localised assessments. Examples of localised assessments include:

- Auckland electricity disruptions
- Port disruptions
- Loss of a state highway segment.

NZTA has a specific MERIT tool which uses an on-line GIS application for state highways which allows users to test disruption scenarios to the road network (single segments through to more large scale disruptions, for user defined time frames).

Service outage data is essential in assessing economic impacts. This includes the location and duration of outage and the time and trajectory of restoration and recovery, in terms of time steps and the direction of change.

From this, MERIT uses supply side models to assess the level of disruption and the proportion of business operations affected through space and time. Population change models are used to address social dislocation, and for larger events business relocation is also included. Demand side adjustments can also be made if necessary, for example changes in tourism demands or policy measures that reduce demand such as fuel conservation measures.

There are around 50-60 industry sectors in the dynamic economic model. Industries are characterised through space based on employment by mesh block. Industries are connected through a systems dynamics model and social accounting matrices which map industries, commodities and factors (such as labour). Business behaviour models, that estimate how industries respond to a range of disruptions, were developed from survey data following the Christchurch earthquakes. The models account for both the impacts of infrastructure and non-infrastructure disruption (building damage, neighbourhood and staff disruption) as well as the capacity for businesses to adapt and continue operation under adversity. The business behaviour model curves are a similar concept to fragility curves and are used as an adjustment factor to industry production with the dynamic economic model.

Economic indicators can be reported at multiple levels, for example, area based, by affected region or at national level.

In terms of the interaction with RiskScape, good GIS data is critical. Translating asset damage maps into loss of service through time (accounting for interdependencies and restoration timeframes) is currently a manual task, relying on expert elicitation with infrastructure providers on a scenario by scenario basis. Streamlining this process is a research opportunity.

3.5.3 Recent Applications

Examples include:

- The Wellington business case work as described in Section 2.7. This addressed economic impacts relating to recovery times and interdependencies, freight impacts as well as people and business relocation. MERIT, together with the RiskScape damage and loss modelling tool and subsequent expert elicitation process, was used to evaluate the wider economic benefits that different infrastructure investment options would have. This project used an MCA multi-infrastructure tool, however the process needed to better account for restoration interdependencies in determining a hierarchy of investment needs.
- Development of an online tool for rapid economic evaluation of road closure scenarios. NZTA have undertaken pilot studies applying MERIT to real recent major network outages. This included a pilot of the SH3 Manawatu Gorge 2011-12 outage.
- NZ Fuel Supply Outages – used non-spatial MERIT to evaluate the economic consequences of fuel outage scenarios, with and without mitigation options to better understand the impact of disruption and potential value of mitigation actions for New Zealand. (Refer MBIE website for report).
- Alpine Fault Earthquake – This case study, applying non-spatial MERIT, examines the economic consequences of a magnitude 8 earthquake on the South Island's Alpine Fault. This is the first study involving multiple infrastructure failures to be undertaken in the ERI programme.
- Water services outage, Auckland – This was a single-infrastructure outage case study undertaken under the ERI programme to test and refine Non-Spatial MERIT. The pilot study was developed in collaboration with Watercare and involved a hypothetical scenario of significant interruption in water service provision in Auckland.
- Transportation disruptions following the Kaikoura earthquake - Non-Spatial MERIT was used immediately following the event to gauge the scale and extent of the likely disruption to transport as well as to evaluate alternative road-opening options.
- Economics hotspot analysis, Waikato - This analysis is aimed at identifying limiting factors in the region's economy, that if disrupted, could have significant socio-economic flow-on effects to both the Waikato and New Zealand economies.

3.5.4 AF8 Case Study

As noted above, MERIT has been applied to a number of different applications. During the initial development of MERIT, MERIT was used to estimate the economic impacts of an Alpine Fault event. The modelling incorporated the impacts of disruption to infrastructure networks (water supply, waste and storm water, electricity, and road and rail networks were all modelled), buildings, and business. Physical infrastructure damage, due to landslides, surface rupture and ground shaking was determined using RiskScape. Expert elicitation processes were then used to develop estimates of infrastructure service loss, based on expected time for repair and restoration. The expected losses were then expressed as time-stamped Geographic Information System (GIS) outage maps for input into MERIT.

Direct physical damage was then translated to 'felt' impacts for households, communities and businesses. MERIT used its business behaviours model, a transport model and other direct impact assessments to determine the experienced disruption at meshblock level.

Given the importance of the Dairy industry to the West Coast region, the seasonal variation and uncertainty over how the sector would respond to the disruption, 3 Dairy industry scenarios were created, to better understand the range of impacts the event might have (scenarios A-C or High to Low impact).

Lastly the dynamic economic model was run to determine the likely economic impact across the different scenarios considered. The economic impact is the difference between the baseline or counterfactual (where there is no earthquake) and the economic impact of a given scenario. The results in Figure 3-17 show that Dairy scenarios A and B are considerably more impactful than Dairy scenario C. The results were also generated by industry, refer Table 3-2. This provides a deeper understanding of where in the economy the impacts are mostly felt, which can help inform disaster planning and mitigation.

While it was not part of this particular application, a natural extension to this modelling would be to compare and contrast different resilience investment measures to understand the relative impact of more timely restoration of different infrastructure services or industries.

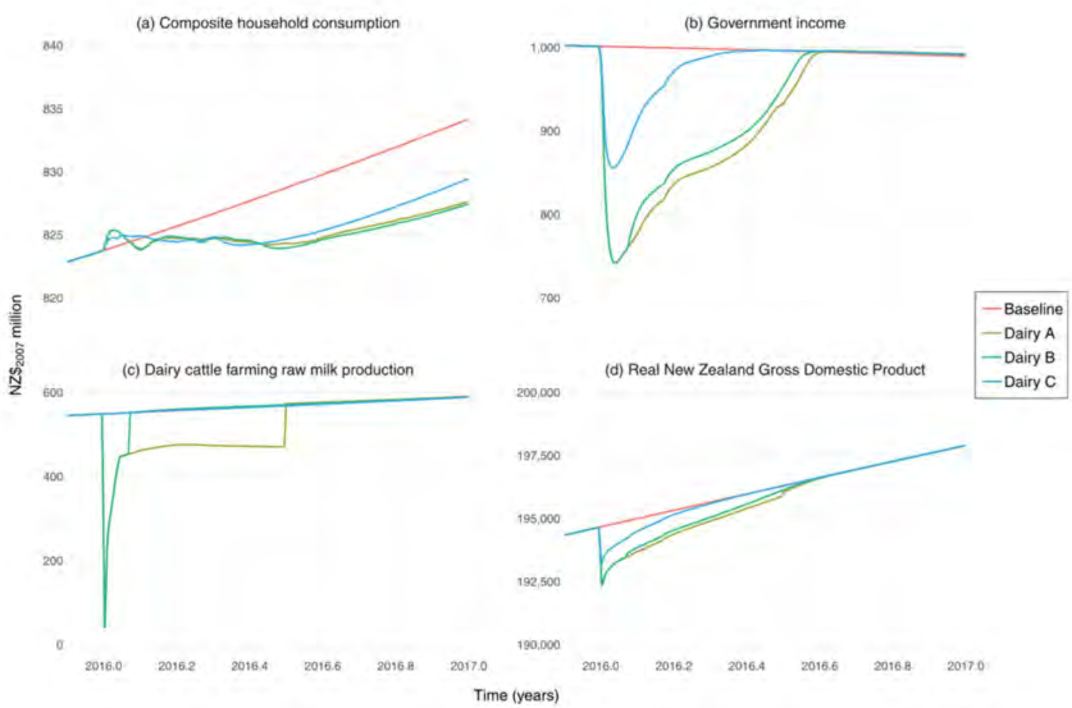


Figure 3-17 Selection of indicators produced by MERIT for Alpine Fault Earthquake in NZ$$_{2007}$ million (source: McDonald et al. 2018).

	Industry	West Coast (%)	Rest of New Zealand (%)	Total (%)
Dairy sub-scenario A – high impact				
1	Dairy cattle farming	13	1	14
2	Other agriculture and forestry	1	0	2
3	Mining and quarrying	3	0	3
4	Dairy product manufacturing	59	−4	55
5	Other food manufacturing	1	−1	0
6	Other manufacturing	0	1	1
7	Utilities and construction	3	2	5
8	Retail and hospitality	1	3	4
9	Transportation services	3	4	6
10	Other services	4	6	9
	Total	87	13	100
Dairy sub-scenario B – medium impact				
1	Dairy cattle farming	4	1	5
2	Other agriculture and forestry	2	0	2
3	Mining and quarrying	3	0	3
4	Dairy product manufacturing	65	−5	60
5	Other food manufacturing	1	−1	0
6	Other manufacturing	0	1	1
7	Utilities and construction	3	2	6
8	Retail and hospitality	1	4	5
9	Transportation services	3	4	7
10	Other services	4	6	11
	Total	87	13	100
Dairy sub-scenario C – low impact				
1	Dairy cattle farming	1	3	3
2	Other agriculture and forestry	5	2	7
3	Mining and quarrying	13	0	13
4	Dairy product manufacturing	12	−4	8
5	Other food manufacturing	3	−1	2
6	Other manufacturing	1	2	3
7	Utilities and construction	12	4	15
8	Retail and hospitality	7	4	10
9	Transportation services	10	3	13
10	Other services	16	9	25
	Total	79	21	100

Table 3-2 Industry share of gross domestic product loss at one year after Alpine Fault earthquake
(source: McDonald et al. 2018)

Garry W. McDonald, Nicola J. Smith, Joon-Hwan Kim, Charlotte Brown, Robert Buxton & Erica Seville (2018): Economic systems modelling of infrastructure interdependencies for an Alpine Fault earthquake in New Zealand, Civil Engineering and Environmental Systems, DOI: 10.1080/10286608.2018.1544627

3.5.5 Future Development

These include:

- There are currently discussions underway with the Infrastructure Commission about MERIT.
- MERIT is linked into a wide range of research programmes, including a current application for funding in the Endeavour South programme focussed on Alpine Fault earthquake reduction and recovery with Caroline Orchiston. This includes agent-based modelling of disruption events.
- Multi-capital wellbeing evaluation capacity is being developed as is the capacity to assess economic impacts at household level to enable equity assessments.
- There is a range of ongoing work that is expected to lead into better integration of RiskScape and MERIT. (Note that Conrad Zorn and Tom Logan are working in this area).

Other considerations include:

- How to integrate long term population / land-use changes with climate change impacts.

- Resilience to Natures Challenges (RNC2) – how modelling results can be used when there is a high level of uncertainty.
- Multi-hazard risk modelling.
- How to turn impacts into a business case for high impact low probability events.

3.5.6 Issues and Opportunities for Canterbury Lifelines

There is already a Canterbury configured application of MERIT – this should be able to be used in the Canterbury lifelines work.

It will be important to scope what we are trying to do, identify gaps, discuss with lifeline utilities – what would be the most useful indicators for them to assist with their decision-making and funding applications for resilience improvement investments?

The project will need information such as damage (RiskScape input), ground shaking (PGAs), etc. It would be efficient to provide GIS layers to MERIT directly from the Canterbury GIS portal. The outcome of ongoing work integrating MERIT and RiskScape could be leveraged.

The MERIT process can, if needed, also provide access to specialist advice in various infrastructure sectors – such as dams, transport, electricity, geotechnical engineering, etc.

It may be necessary to reconfigure some disruption impact models specific for the hazard or scenario being reviewed – this would need to be a recommendation, not a direct part of the project due to scope limitations. Similarly, if population relocation needed to be carried out.

There would be opportunities to link into the Alpine Fault Endeavour programme if the funding application is successful – integration, coordination, etc.

3.6 National Science Challenges

(Refer https://www.mbie.govt.nz/science-and-technology/science-and-innovation/funding-information-and-opportunities/investment-funds/national-science-challenges/)

The National Science Challenges were established in 2014 and aim to tackle the biggest science-based issues and opportunities facing New Zealand. The Challenges bring scientists together to work collaboratively across disciplines, institutions and borders to achieve the objectives.

Each Challenge involves public outreach and exhibits strong engagement between researchers and intended end users of the research activity. All Challenge research gives effect to the Vision Mātauranga policy. This includes developing Māori-specific tools and business strategies to make communal assets more resilient and enhance kaitiakitanga.

Each Challenge has established a governance entity that is responsible for managing the delivery of the research and funding to address the Challenge research goals. This entity is accountable for the fulfilment of contractual and performance requirements as agreed with the Science Board.

There are 11 Challenge programmes funded through to 2024, and an overview of the various programmes is provided in the figure below.

Figure 3-18 National Science Challenges Programmes

Of the programmes, those that are most relevant to lifelines resilience work are:

- Resilience to Natures Challenges (refer Section 3.6.1)
- Deep South (refer Section 3.6.2)
- Building Better Homes, Towns and Cities (refer Section 3.6.3)

3.6.1 Resilience to Natures Challenges

(Refer https://resiliencechallenge.nz/). Its aim is to enhance New Zealand's ability to anticipate, adapt and thrive in the face of ever-changing natural hazards.

Hosted by the Institute of Geological and Nuclear Science (GNS), collaboration partners include:

- NIWA
- Scion
- Auckland University
- Massey University
- Victoria University of Wellington
- University of Canterbury
- Lincoln University
- University of Otago
- University of Waikato
- BRANZ
- Landcare Research
- WSP

Phase 2 of the Resilience Challenge kicked off in July 2019 and is focused around two major themes that align with the Government's National Disaster Resilience Strategy – Multi-hazard Risk and Resilience. The Models associated with these themes harness research from eight Specialist Programme areas as shown below with 37 projects overall.

Communication and collaboration with many of the programmes and projects here will be useful in drawing the latest knowledge into Canterbury's resilience planning work. In many cases the outputs are likely to be beyond the immediate Canterbury project timeframe, but could be categorised as "future watch".

Models and Programme Areas	Summary	Relevance	Timing
Multi-hazard Risk Model (MRM) (Section 3.6.1.1)	Advance the understanding of natural hazard processes. Projects are: • Multi-hazard forecasting and impact modelling • Case study • Dynamic assessment of impacts • Embedding models with robust decision-making • Māori perspectives on risk	These areas are all relevant. Will lead into improvements in hazard models, improvements to MERIT, scenario development, and integration of hazards research with Māori programmes.	See below
Resilience in Practice Model (Section 3.6.1.2)	Social, economic and cultural research to develop tools and methods to embed new resilience knowledge into daily decision making. Projects are: • De-risking Resilience • Building Resilient Futures • Enhancing Resilience and Wellbeing	These areas are also all relevant. Expected to better integrate research into practice, as well as examining social and ecosystem inter-relationships.	See below
Specialist Programme Areas (Section 3.6.1.3)	A wide range of projects across eight areas: Rural — Earthquake Tsunami Urban — Coastal Māori — Volcano Built — Weather	Many of the projects are relevant – see below.	See below

Table 3-3 Programme Summary

3.6.1.1 Multi-hazard Risk Model (MRM)

The overall objective is *to merge time-varying hazard, risk and socio-economic impact modelling tools for multiple hazard types on a consistent basis with a universal treatment of uncertainties.*

Specific research objectives from the *2018 Future Strategy*[8] are to:

A. Integrate multiple diverse hazard types, scales, frequencies and impacts into consistent formats, and models, including uncertainties, coordinating inputs from hazard themes.
B. Examine risk and impact from a dynamic perspective, including multiple and cascading events, and post-event adaptation within our socio-economic system.
C. Extend, link and adapt existing risk tools developed in New Zealand by the Natural Hazards Research Platform and the Resilience Challenge, such as RiskScape and MERIT.
D. Build additional compatible tool suites that enable wider aspects of impact evaluation (infrastructure, economy, environment and society/wellbeing) and risk-reduction planning.

The projects are described further in the Appendices at Multi-hazard Risk Model (MRM), along with project lead details.

3.6.1.2 Resilience in Practice Model

The overall objective is to *co-create best practice in resilience via four New Zealand co-creation themes involving deep end-user partnerships.*

Specific research objectives from the *2018 Future Strategy* are:

A. To identify institutional, behavioural, and financial barriers to applying resilience in different settings, and to improve practice to overcome these.
B. To provide coordination to bridge interactions between MRM research and cultural, ecological and built environments, promoting resilience before and after hazard impacts.
C. To determine the most effective strategies and practices for risk communication across weather, earthquake, volcanic, and coastal hazard areas.
D. To assess the effectiveness of tools, processes and practices in evaluating resilience outcomes at local, regional and national scales to support decision-making.
E. To create a set of recovery outputs (models, visualisation, frameworks), that demonstrate future recovery options.

The projects are described further in the Appendices at Resilience in Practice Model, along with project lead details.

3.6.1.3 Specialist Programme Areas

Projects in each of the eight programme areas are described in the Appendices at Programme Theme Areas, along with project lead details. They are summarised below:

Programme	Projects / Workstreams	Relevance	Timing
Rural	• Disaster Resilient Outcomes for Rural New Zealand • Rural Disaster Risk Decision Making • Understanding our 21st Century Rural Communities and Industries for a Disaster Resilient NZ • Disaster Resilient NZ Co-creation	As Canterbury has a high dependency on the rural sector the outputs of these projects will be relevant to social and economic impacts.	Mid 2024

[8] National Science Challenges (2018), *Resilience to Natures Challenges - Future Strategy*

Programme	Projects / Workstreams	Relevance	Timing
Urban	• Smart Cities • Inclusive Urban Communities • Pathways to Urban Resilience	Pathways is relevant – integration of research into plans and policies etc.	Mid 2024
Mātauranga Māori	• Whakaoranga Te Whenua • Whakaoranga Turangawaewae • Whakaoranga Iwi Whanui	Seek to increase awareness to hazards, decision-making involvement, and resilience – apply the concepts.	Mid 2024
Built	• Horizontal Infrastructure • Vertical Infrastructure • Integrated Scenario	The first is relevant. The third is a Wellington case study and worth monitoring.	Mid 2024
Earthquake Tsunami	• Fault Model Construction • Catalogue Testing and Verification • Probabilistic Tsunami Model • Testing Early Warning Systems • Ground Motion and Co-seismic Landslide Hazard	Most of these projects will be directly relevant.	Mid 2024
Coastal	• New Zealand's Changing Coastline • Coastal Flooding • Coastal Adaptation	These projects will be directly relevant, especially the first two.	Mid 2024
Volcano	• Multi-hazard Forecasting • Volcanic Impact Models – "Volcano Testing Lab" • Volcanic Resilience	Not directly relevant to Canterbury	Mid 2024
Weather	• Hazard Modelling • Extreme Scenarios • Hazard Mitigation	These projects will be directly relevant.	Mid 2024

Table 3-4 Specialist Programme Areas

3.6.1.4 2021 Infrastructure Research Day

Specific projects reported on at the 2021 Infrastructure Research Day are summarised below. Further information is provided in the Appendices, this can be accessed via the links provided.

Project	Summary	Relevance	Timing
Infrastructure Resilience and Marae Adaptations	GIS database of North Island maraes, infrastructure and hazards, including tsunami, flooding, landslides, liquefaction, seismic. Ongoing work in assessing vulnerabilities.	Relevant in assessing the implications of natural hazards to Māori social and cultural well-being. Canterbury will need to engage with the project to determine where and when it can fit in. Available SI geospatial information can be recorded in the portal.	Mid 2024
Coastal and Tsunami Research	Impacts on horizontal infrastructure, including bridges and breakwaters. Adaptation of coastal structures.	Relevant. Work in progress, link into the Canterbury project.	Mid 2024
Transport Resilience Research	Three projects, two in Auckland and the *SI Road Network Resilience Assessment*. AF8 Scenario that considers impacts of bridge outages.	SI project is relevant. AF8 work includes outputs and accessibility maps that are relevant.	Complete
Creating resilient rural value chains in the 'Top of the South'	Nelson Marlborough wine industry transport logistics, Kaikoura EQ lessons learned. Future research ongoing.	Principles are relevant. Look to how this work can be leveraged in relation to supply chain impacts.	Complete
Interdependent Infrastructure Projects	Spans across RNC, QuakeCoRE, AF8, Deep South, NIWA, Universities of Canterbury and Auckland - builds on a deep body of data held by the two universities involved. Overlays infrastructure networks with ongoing work underway.	This work is very relevant and should be investigated further as part of the Canterbury work. It leads on from the work carried out by Zorn et al using AF8 as the event scenario (refer Section 3.3.4). Includes BAU vs post disaster impacts, both the 2019 Rangitata and May 2021 floods have been assessed.	Various deadlines – mid 2024 for the RNC work
Stormwater Research	Atmospheric impacts on rainfall. Disruption impacts and mitigations to improve urban flooding resilience. Looking at lifelines and transport system.	Relevant – considers rainfall events causing flooding of Canterbury rivers and towns	TBC
Integration of Geospatial and Focussed Liquefaction Tools for Regional Assessments	New project to improve liquefaction models including impact severity due to EQ effects.	Relevant – improves the future robustness of liquefaction prediction	Some work complete by Lin et al. – 2022 release

Table 3-5 Specific Research Topics

3.6.2 Deep South

This Challenge is working to understand the role of the Antarctic and Southern Ocean in determining New Zealand's future climate and how the impact this role has on key economic sectors, infrastructure and natural resources.

Hosted by NIWA, other collaboration partners are:

- Victoria University of Wellington
- University of Otago
- University of Canterbury
- University of Auckland
- Institute of Geological and Nuclear Science (GNS)
- Landcare Research
- New Zealand Antarctic Research Institute
- Antarctica New Zealand.

The various sections within the Deep South website provide information and resources, including research reports, webinars, and links. There is a strong focus on adaptation.

For example, a range of reports that cover drinking, storm and wastewater networks, local roads, flood mitigation schemes and coastal defence systems.

There are numerous other resources on other pages within the web-site, with examples provided in the Appendices at Deep South.

Area	Projects / Resources	Relevance	Timing
Local Infrastructure	• Drought and climate adaptation impacts and projections • Climate change: The cascade effect • Sea level rise + big storms: What are we in for? • How exposed are we to river flooding? • How exposed are we to coastal flooding? • Impacts and implications of climate change on wastewater systems: NZ perspective • Climate change and stormwater and wastewater systems • Risks to drinking water from future drought • Stormwater, wastewater and climate change: Impacts on our economy, environment, culture and society • Supporting decision-making through adaptive tools in a changing climate	Wide range of resources and information that can be considered in developing the Canterbury project's maturity pathway.	Available

Table 3-6 Deep South Examples of Resources

Two specific projects relating to river and coastal flooding exposure are described further below. Together, these have produced flood maps and models that allow practitioners and researchers to identify how flood risk may evolve in their area.

3.6.2.1 Exposure to River Flooding

This study[9] by NIWA was a first attempt to enumerate New Zealand's populations and asset exposure in fluvial and pluvial floodplains, seeking to develop a national and consistent flood hazard map. Exposed areas were identified by creating a "composite" flood hazard area map (FLHA) from available modelled and historic flood hazard maps and flood prone soil maps. The map derived for the South Island is shown below.

Figure 3-19 South Island Flood Hazard Area (FLHA) map (Source, NIWA 2019)

"Elements at risk" included population, buildings (number and value), transport infrastructure (roads, railways, airports), electricity infrastructure (transmission lines, structures, sites), three-waters infrastructure (nodes, pipelines), and land cover (built, production, natural or undeveloped).

The report noted that the Canterbury region has the most exposure for population, buildings, roads, electricity network components (transmission lines, structures and sites), potable water pipelines and both built and production land cover. The region's exposed population and built assets are mostly in Christchurch City.

[9] Paulik R, Craig H, Collins D (2019), *New Zealand Fluvial and Pluvial Flood Exposure*, NIWA

Various climate change projections for mean annual flood flow were also included in the analysis, in order to infer potential flood exposed asset sensitivity to flood hazard change in response to future climate conditions.

Given various limitations, a national-scale flood hazard model suite was recommended for New Zealand to estimate and map the frequency and magnitude of present-day fluvial and pluvial flood inundation hazards and their response to future climate conditions.

3.6.2.2 Exposure to Coastal Flooding

In a further study[10] by NIWA, Zealand's exposure to 1% annual exceedance probability (AEP) coastal flood inundation under present-day and future higher sea levels was presented.

Coastal flooding was determined from the 1% AEP extreme sea-level elevation (ESL1) at present-day mean sea-level (MSL), resulting from combination of tide, storm-surge, mean sea-level anomaly and wave setup. Coastal flood inundation was mapped for low-lying coastal land by projecting ESL1 onto both high-resolution airborne LIDAR and a lower resolution satellite derived MERIT digital elevation models (DEM).

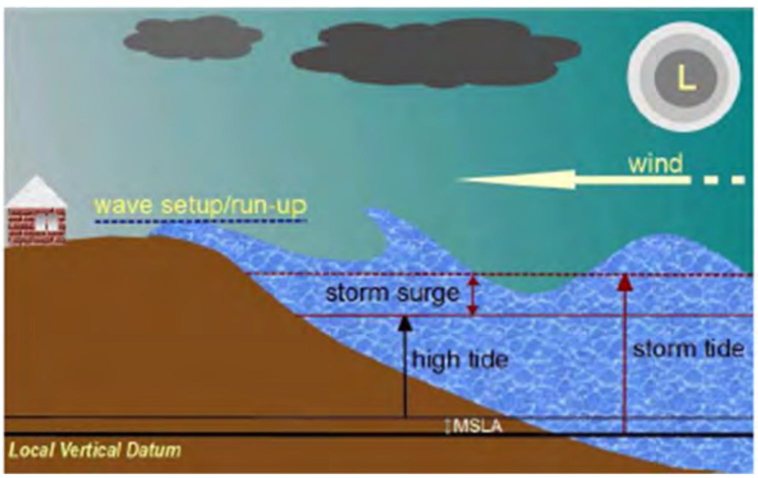


Figure 3-20 Schematic diagram of tidal, weather and climate components contributing to extreme sea-levels and storm-induced coastal flooding (Source, NIWA 2019)

As with river flooding above, elements at risk exposed to coastal flood inundation scenarios included population, buildings, transport infrastructure (roads, railways, airports), electricity infrastructure (transmission lines, structures, sites), three-waters infrastructure (nodes, pipelines), and land cover (built, production, natural or undeveloped).

Future rising sea-levels will increase the frequency of ESL1 at present-day MSL. Elements at risk to these extreme sea-levels in-turn could be more frequently exposed to coastal flood inundation. It was noted that Christchurch's exposure accelerates rapidly to +0.9 m SLR above present-day MSL, before decelerating under higher SLR thereafter.

An example of the graphical output is shown below. It can be seen that Canterbury's roads are more significantly impacted by sea level rise than other regions.

[10] Paulik R, Stephens S, Wadhwa S, Bell R, Popovich B, Robinson B (2019*), Coastal Flooding Exposure Under Future Sea-level Rise for New Zealand*, NIWA

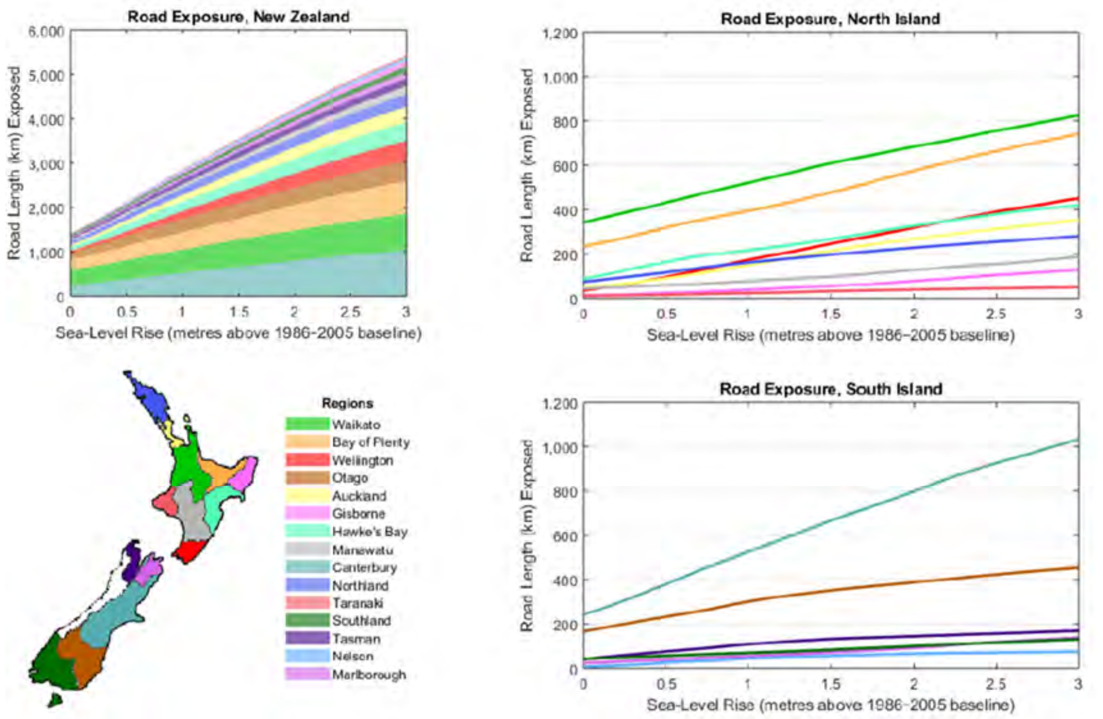


Figure 3-21 National and regional level road exposure for land areas with LIDAR DEM coverage (Source, NIWA 2019)

3.6.3 Building Better Homes, Towns and Cities

(refer http://www.buildingbetter.nz/)

This Challenge aims to improve the quality and supply of housing and create smart and attractive urban environments through:

- an improved housing stock
- meeting future demand for affordable housing
- taking up innovation and productivity improvement opportunities
- improving urban environments and residents' well-being
- better systems for improved land-use decisions.

Hosted by BRANZ there is a wide range of collaboration partners including universities.

The website provides links to many publications and other resources.

Area	Projects / Resources	Relevance	Timing
Urban environments	• Various resources relating to infrastructure services	May be useful in addressing social impacts of hazard events and potential mitigation strategies	Available

Table 3-7 3.6.3 Building Better Homes, Towns and Cities Resources

3.7 Natural Hazards Research Platform

While this programme has now come to a close, there are research outputs available at the web-site depicted below. The Resilience to Natures Challenges programme has superseded this platform of research.

Figure 3-22 Natural Hazards Research Platform Website

Area	Projects / Resources	Relevance	Timing
Natural Hazards	• Reports published over the 10 year programme period.	May be relevant unless updated by more recent or current research – would need to be investigated	Available

Table 3-8 Natural Hazards Research Platform Resources

3.8 AF8

AF8 (Alpine Fault magnitude 8) is a programme of scientific modelling, response planning and community engagement, designed to build collective resilience to the next Alpine Fault earthquake.

AF8 is a collaboration between the six South Island Civil Defence Emergency Management (CDEM) groups and science, including research from six universities and Crown Research Institutes, emergency services, lifelines, iwi, health authorities and many other partner agencies. The programme is managed by Emergency Management Southland.

Research conducted by the University of Canterbury, University of Otago and GNS Science has assessed some of the environmental impacts that can be expected from the next earthquake of magnitude 8 or greater on the Alpine Fault. Until recently, however, there had been no comprehensive study of the impacts a rupture would have on people living in communities across the South Island nor on our infrastructure.

AF8 therefore aims to share the Alpine Fault hazard and impact science and preparedness information widely, through communication and engagement activities, to increase awareness, enable conversation and build societal preparedness to natural hazard events in the South Island.

Published resources include:

- Alpine Fault Magnitude 8 Hazard Scenario, October 2016
- SAFER Framework, August 2018
- AF8 Year 5 Report, July 2021

The South Island Alpine Fault Earthquake Response (SAFER) Framework provides a concept of coordination of response and priority setting across all six South Island Civil Defence Emergency Management (CDEM) Groups and their partner organisations in the first seven days of response.

Subsequent work has included:

- AF8 planning
- AF8 roadshows
- The Ripple Effect, tsunamis affecting SI lakes
- Developing regional risk hazard profiles and improving our understanding of specific lifelines vulnerabilities.
- Alpine Fault exercise

Note that AF8 has made an application for funding for a "business case" approach for the Alpine Fault earthquake, similar to the Wellington work described earlier in Section 2.7.

Area	Projects / Resources	Relevance	Timing
Alpine Fault	• Scientific information, including AF8 ground shaking maps that are available from QuakeCoRe	Maps have been included as a layer in the Canterbury Lifelines GIS portal	Available
	• Business case relating to future Alpine Fault event	If successful, this would be closely aligned with the Canterbury work with collaboration needed. Addresses some of the issues being covered in the Canterbury work.	Awaiting funding

Table 3-9 AF8 Resources Summary

3.9 QuakeCoRE

Otherwise known as the NZ Centre for Earthquake Resilience, a Centre of Research Excellence, QuakeCoRE is currently funded from 2021 to 2028 by the New Zealand Tertiary Education Commission of the NZ Government.

Through partnership with key sectors of Te Ao Māori, Te Hiranga Rū QuakeCoRE research activities seek to develop and harness mātauranga Māori perspectives on earthquake resilience, to achieve the resilience aspirations of tangata whenua.

Partners include University of Auckland, University of Canterbury, Massey University, Victoria University, University of Otago, University of Waikato, Lincoln University, AUT, GNS Science, Market Economics, Resilient Organisations, and BRANZ.

This is a significant organisation with an established structure, Board and programme area leads, as well as interfaces with the science, research and consulting communities.

3.9.1 Current Research Areas

An overview of QuakeCoRE's programme areas where work has been carried out up to 2020 is provided in the diagram below.

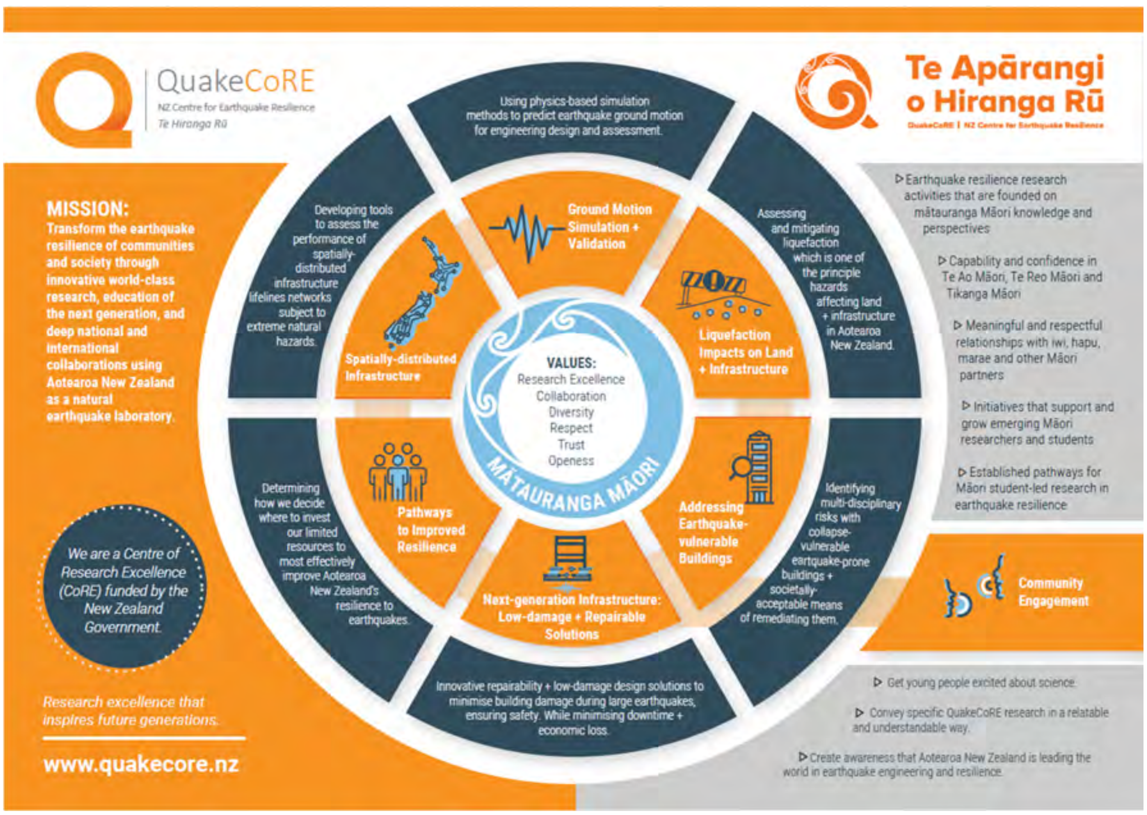


Figure 3-23 QuakeCoRE Overview to 2020

Infographics of these areas are provided in the Appendices at QuakeCoRE.

Of particular interest to the current Canterbury lifelines work are the following areas.

Area	Projects / Resources	Relevance	Timing
Spatially distributed infrastructure	• Developing tools to assess the performance of spatially distributed infrastructure lifelines networks subject to extreme natural hazards. o Led by Liam Wotherspoon at UA (deputy Roger Fairclough)	Relevant to how assets will perform during hazard events	Complete - directly aligned with RNC
Ground motion simulation and validation	• Using physics-based simulation methods to predict earthquake ground motion for engineering design and assessment. o Led by Brendon Bradley at UC	Relevant in terms of providing inputs to models that may be applicable to infrastructure.	Complete
Liquefaction impacts on land and infrastructure	• Assessing and mitigating liquefaction which is one of the principal hazards affecting land and infrastructure. o Led by Misko Cubrinovski at UC	Relevant in assessing liquefaction	Complete
Pathways to improved resilience	• Determining how we decide where to invest our limited resources to improve resilience to earthquakes. o Led by David Johnston at UA	Relevant in developing the business case process	Complete

Table 3-10 QuakeCoRE Project Examples

3.9.2 2021-2028 Research Areas

The structure of the 2021-28 research programme is summarised in the figure below.

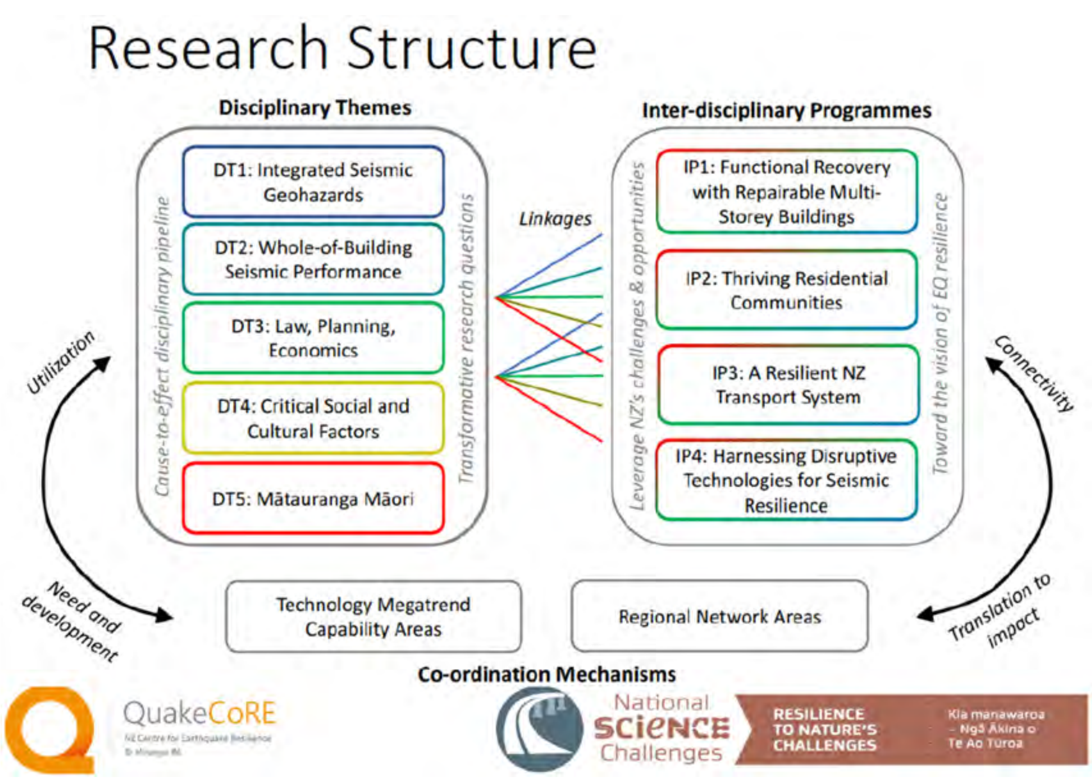


Figure 3-24 QuakeCoRE Overview 2021 to 2028

Many of the disciplinary themes on the left hand side of this diagram are relevant to Canterbury lifelines, and they all feed into the interdisciplinary programmes on the right hand side. These programmes have the potential to improve seismic resilience and potentially change the way infrastructure services are delivered.

Area	Projects	Relevance	Timing
IP2 – Thriving Residential Communities	• Has a focus on resilient housing, including engineering solutions, land-use planning, insurance, communication.	Limited	Mid 2028, staggered outputs
IP3: A Resilient NZ Transport System	• Transport as-a-service system modelling • Post-disaster logistics and resilient logistics networks Resilience investment decision making under uncertainty	Relevant to Canterbury lifelines as it is addressing one of our most critical lifelines – the transport system	Mid 2028, staggered outputs
IP4 – Harnessing Disruptive Technologies for Seismic Resilience	• Considering topics such as renewable distributed energy, smart cities, and autonomous vehicles	Relevant to mitigations - for example, by reducing the reliance on hydro-generated power, transmission and distribution networks through investment in local solar power generation and battery storage	Mid 2028, staggered outputs

Table 3-11 Current QuakeCoRE Projects

3.10 MBIE Endeavour Fund

This Fund supports a range of programmes with a focus on both research excellence and a broad range of impacts. These are much wider than those of a CDEM or lifelines nature. The Fund has been in place since 2015.

Relevant projects funded in the 2021 round include:

- GNS Science – Agent models of tsunami evacuation behaviour to improve planning and preparedness (2 years programme)
- GNS Science – Assessing silent tsunami risk in the Tasman Sea/Te Tai-o-Rēhua (2 year programme)
- GNS Science – Beneath the Waves: Preparedness and resilience to New Zealand's nearshore volcano hazards (5 year programme)
- New Zealand Forest Research Institute Ltd (Scion) – Extreme wildfire: Our new reality - are we ready? (5 year programme)

Relevant projects funded in previous years include:

- GNS Science – Rapid Characterisation of Earthquakes and Tsunami: Fewer deaths and faster recovery (2020, 5 year programme)
- NIWA – Reducing flood inundation hazard and risk across Aotearoa/New Zealand (2020, 5 year programme)
- University of Otago – Solar Tsunamis: Space Weather Prediction and Risk Mitigation for New Zealand's Energy Infrastructure (2020, 5 year programme)
- Meteorological Service of New Zealand Limited – Machine learning for advanced coastal storm surge predictions (2019, 3 year programme)
- Weather Radar New Zealand Limited – A New Approach to Weather Radar Observations for Real-time Natural Hazard Warnings (2019, 3 year programme)
- Victoria University of Wellington – Extreme events and the emergence of climate change (2019, 5 year programme)
- Bodeker Scientific – Near real-time assessment of climate change impacts on extreme weather events (2018, 3 year programme)
- GNS Science – Earthquake-induced landslides and landscape dynamics: planning for, and avoiding landslide hazard and risk (2017, 5 year programme)
- The Research Trust of Victoria University of Wellington – Improved sea-level rise projections for New Zealand to better anticipate and manage impact (2017, 5 year programme)
- The Research Trust of Victoria University of Wellington – ECLIPSE: Eruption or Catastrophe: Learning to Implement Preparedness for future Supervolcano Eruption (2017, 5 year programme)
- GNS Science – Diagnosing peril posed by the Hikurangi subduction zone: New Zealand's largest plate boundary fault (2016, 5 year programme)
- New Zealand Forest Research Institute Ltd (Scion) – Preparing New Zealand for extreme fire (2016, 5 year programme)

Area	Projects / Resources	Relevance	Timing
Hazard Risks	• Various projects	Potentially useful resources	Various
Flooding Hazards	• NIWA – Reducing flood inundation hazard and risk.	Linked to BIP work – see Section 3.14. See also Appendices at Reducing flood inundation hazard and risk.	2025
Climate Change	• VUW – Extreme events and climate change	Highlights effects of climate change on hazard risk	2024

Table 3-12 Endeavour Fund Resources

3.11 Dam and Stopbank Resilience

Dams and stopbank systems pose a potential risk to Canterbury, potentially in either an earthquake or major rainfall event, or both in combination.

Research work is being carried out as summarised in the figure below. This work was previously undertaken by Quake Centre and has now moved to the Universities of Auckland and Canterbury. Note that this does not apply to landslide dams caused by earthquakes that are yet to occur.

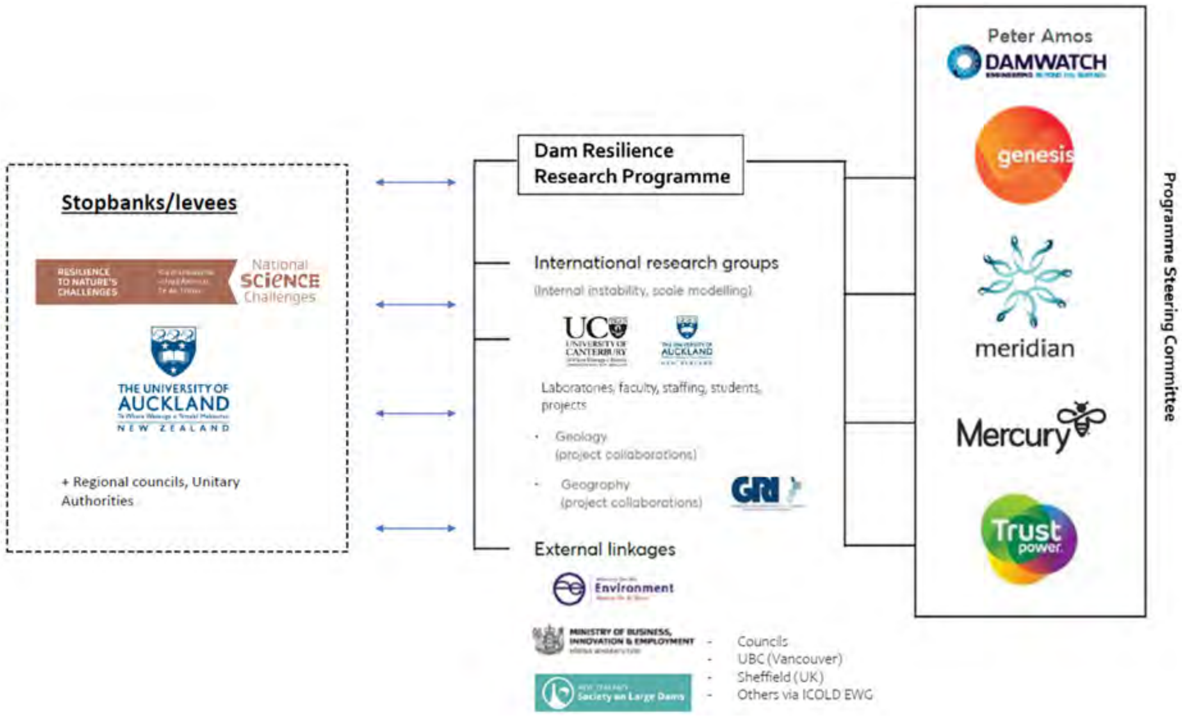


Figure 3-25 Dam and Stopbank Resilience Research Overview

Dams and stopbanks have been mapped along with earthquake faults, liquefaction and ground shaking potential across the country – refer to the Appendices at Dam and Stopbank Resilience. The results of this research are described in a paper by Crawford-Flett et al[11]. This work provides a standardised geospatial overview of New Zealand's 5284 km long stopbank network, enabling spatial reviews and comparisons of flood protection characteristics at national and regional scales.

Area	Projects / Resources	Relevance	Timing
Dams and Stopbanks	• GIS mapping of NZ's stopbank network • Research report(s)	The information that is currently available should be brought into the Canterbury GIS portal, with the results of any particular vulnerabilities or deficiencies highlighted in the project.	Available

Table 3-13 Dams and Stopbanks Resources

[11] Crawford-Flett K, Blake D, Pascoal E, Wilson M, Wotherspoon L (2021); A standardised inventory for New Zealand's stopbank (levee) network and its application for natural hazard exposure assessments

3.12 EQC

EQC has developed a Resilience Strategy for Natural Hazard Risk Reduction for the 2019-2029 period, as shown in the figure below. This includes infrastructure resilience.

Figure 3-26 EQC Resilience Strategy Overview

The Strategy has identified 3-year priorities and a number of areas that are relevant to Canterbury lifelines as listed below. Further detail can be found in the Appendices at EQC Priorities.

3-Year Focus	Initial Priority	Relevance	Timing
Enhance loss modelling / impact estimation products	• Re-platform existing capability and expand the hazard types that can be modelled	Relevant to hazard models being applied.	
Renewed focus on the strategic value of data and information	• Geotechnical data in high risk areas • Improved sharing of hazard information	Relevant to hazards data being used.	
Coordinated and targeted science investment	• Effects of risk-based insurance coverage • Improved volcanic and landslide hazard models	Relevant – landslide models Limited – except where insurance is a mitigation	
Accelerating the synthesis and translation of research and outputs	• Engineering guidance for seismic improvement of buildings	Limited –except for utilities with a dependency on buildings	

Table 3-14 EQC 3-Year Priorities

3.13 Quake Centre

https://www.quakecentre.co.nz/

The Quake Centre has been a partnership between the New Zealand Government, the University of Canterbury, and several leading industry groups. It was an initiative of the University during the 2010-2012 Canterbury earthquake period, and its functions are now being absorbed into the Building Innovation Partnership.

A resource portal contains a range of information relating to categories such as 3 Waters and Dams as shown in the figure below.

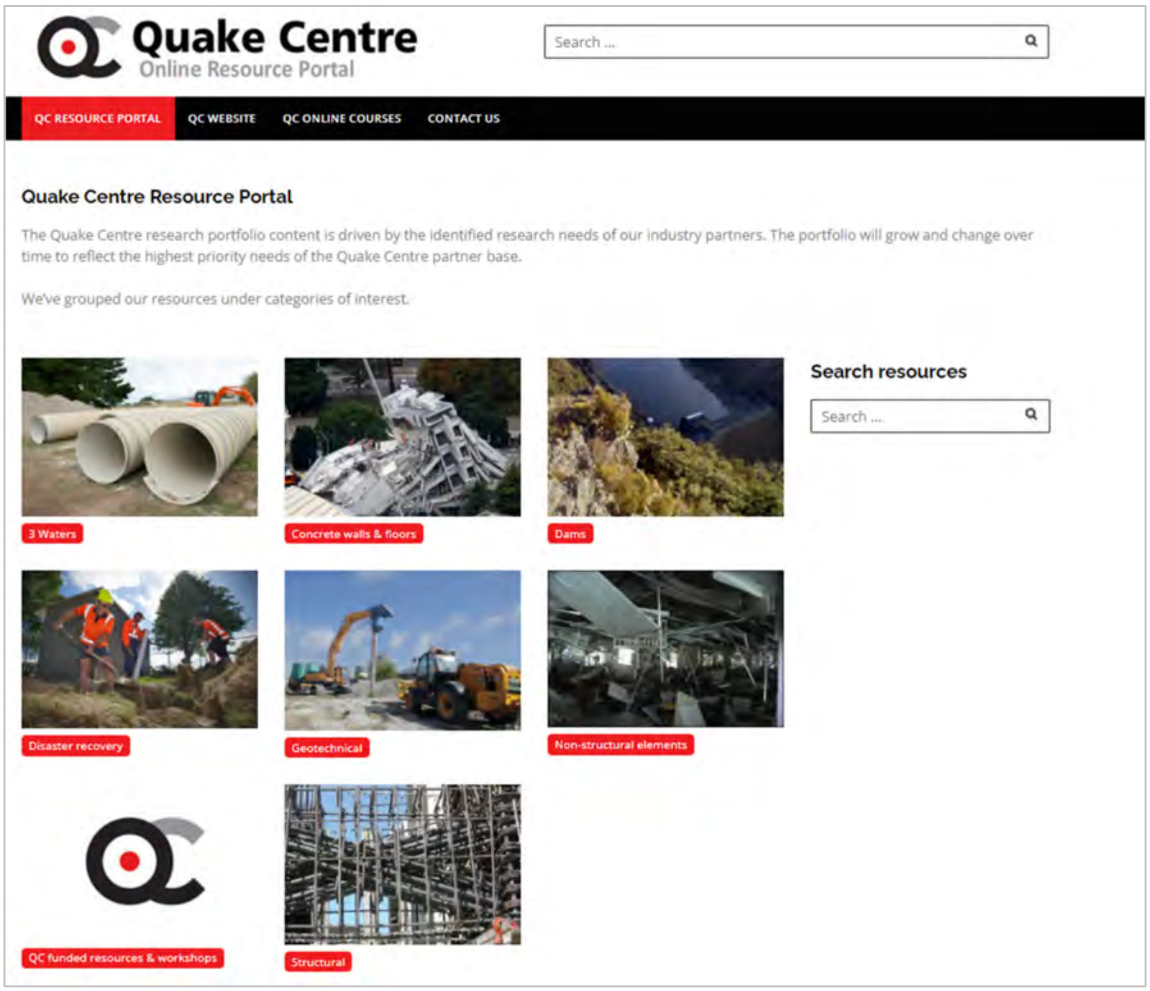


Figure 3-27 Quake Centre Categories of Interest

A framework for assessing the technical resilience of three waters piped assets was published in December 2019. Both Simplified and Advanced methods are available, including spatial assessment capability to estimate damage and network consequence. Further information can be found in the Appendices at Assessing Technical Resilience of Three Waters Networks.

Area	Projects / Resources	Relevance	Timing
3 Waters, Dams, Geotechnical	• Various outputs	Available resources and information should provide useful input to the lifelines impact assessment	Available

Table 3-15 Quake Centre Resources

3.14 Building Innovation Partnership

https://bipnz.org.nz/

This is an industry led research programme based at the University of Canterbury. Theme 1 Better Investment Decisions has an initial focus on improved infrastructure planning and investment tools and decision making for 3-waters, led by Theuns Henning UoA. It runs from 2018 to 2025.

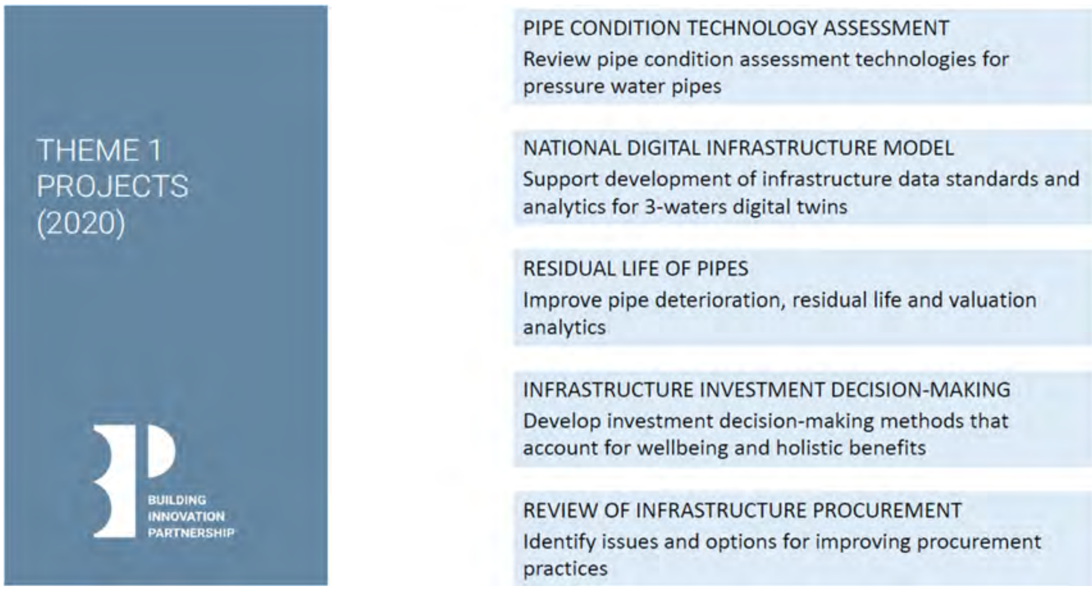


Figure 3-28 Building Innovation Partnership Theme 1 Projects

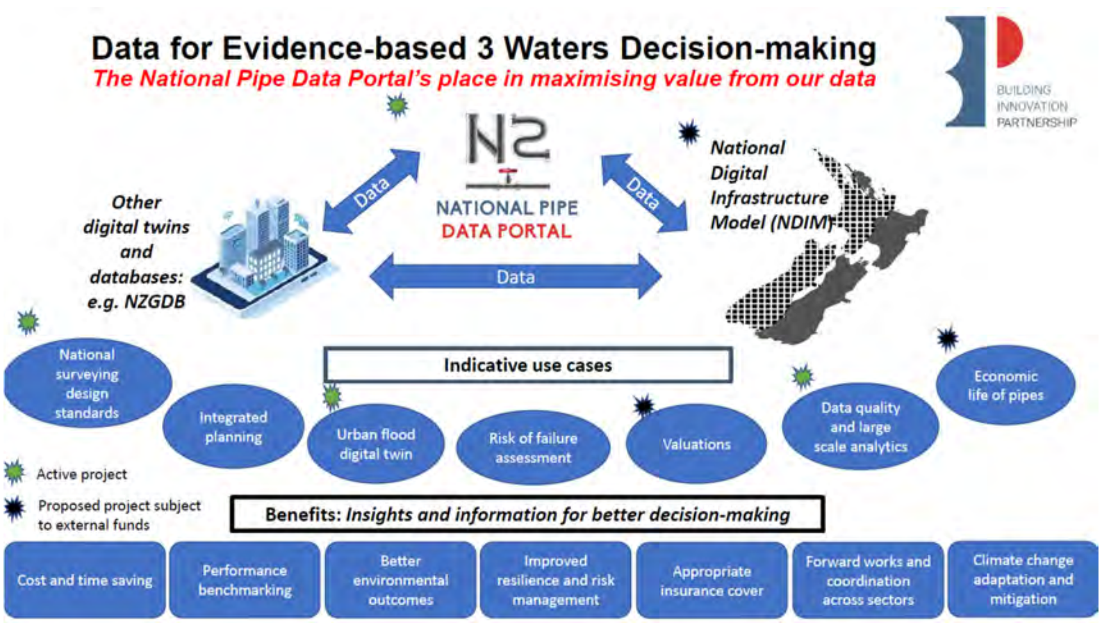


Figure 3-29 National Pipe Data Portal

The *Urban Flood Digital Twin for Flood Resilience in New Zealand* project is a research collaboration between the Building Innovation Partnership and the Geospatial Research Institute (GRI). The purpose of the urban flood digital twin will be to:

- Automate the process of developing pluvial and fluvial models.

- Capture and analyse topographical and infrastructure data to model inundation and flow information in an urban setting.
- Assess the impact of inundation on infrastructure.

A Flood Interoperability Workshop was conducted in January 2021 based on flooding in Kaiapoi as an early part of this work. It utilised the NIWA developed BG-Flood, a numerical model for simulating shallow water hydrodynamics for computation using Graphics Processing Units (GPU) along with RiskScape to assess damage losses for infrastructure and buildings. To deal with a wide range of datasets it used FME (Feature Manipulation Engine) software to enable data input and transformation.

The following figure from the workshop report[12] provides an overview.

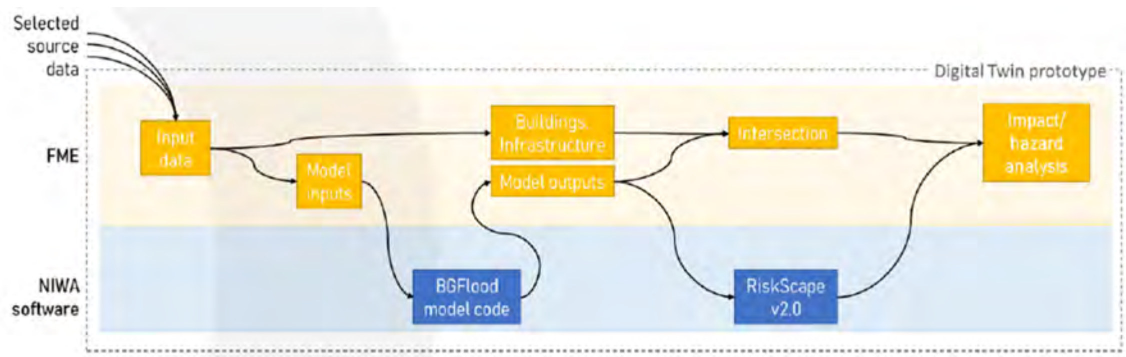


Figure 3-30 Workshop Digital Twin Prototype

Area	Projects / Resources	Relevance	Timing
Water Networks	• Water pipe data portal	A layer that could be considered for the Canterbury lifelines GIS portal	Available
Flooding	• Digital twin for flood resilience work	Has the potential to be used for urban flood modelling in other towns and cities, with development ongoing.	Ongoing

Table 3-16 Building Innovation Partnership Resources

[12] Towards a National Digital Twin for Flood Resilience in New Zealand: Report on the Flood Interoperability Workshop, July 2021

3.15 Urban and Community Resilience

Work being carried out by Tom Logan at the University of Canterbury is assessing urban and community resilience in Christchurch. It considers the effects of cascade failure through interdependent infrastructure on access to key community facilities and services. In turn, this is linked to land use planning and the concept of "multi-criteria spatial optimisation of urban development". Further work is planned in extending this to a wider area, considering electricity and water services under a range of hazard events. Refer https://urbanintelligence.co.nz/.

An example is the tsunami hazard mapped to the impacts on infrastructure, in particular transport, with an interactive dashboard showing household accessibility to essential services. Other relevant work has been carried out for the Wellington lifelines group in relation to Emergency Levels of Service.

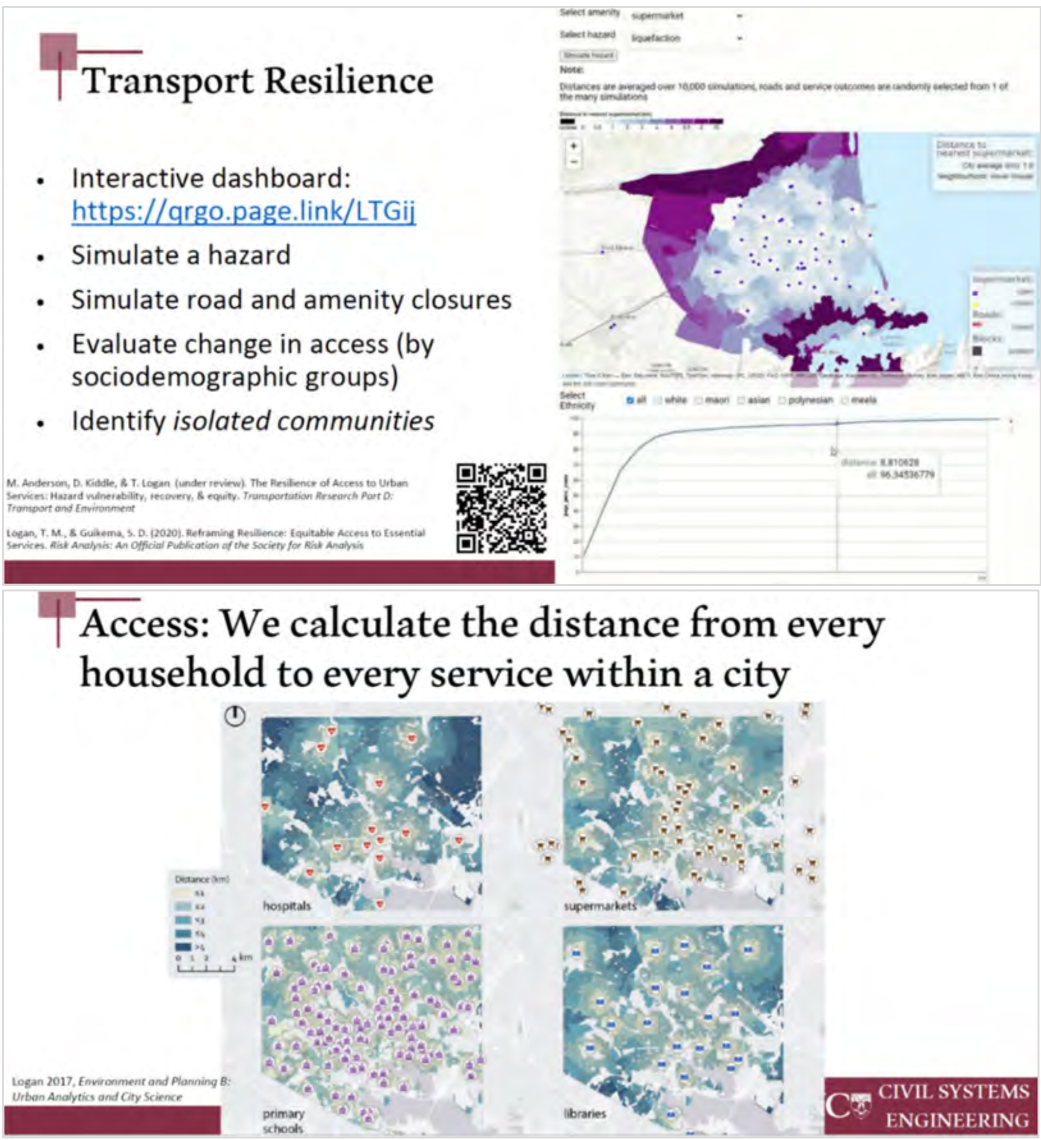


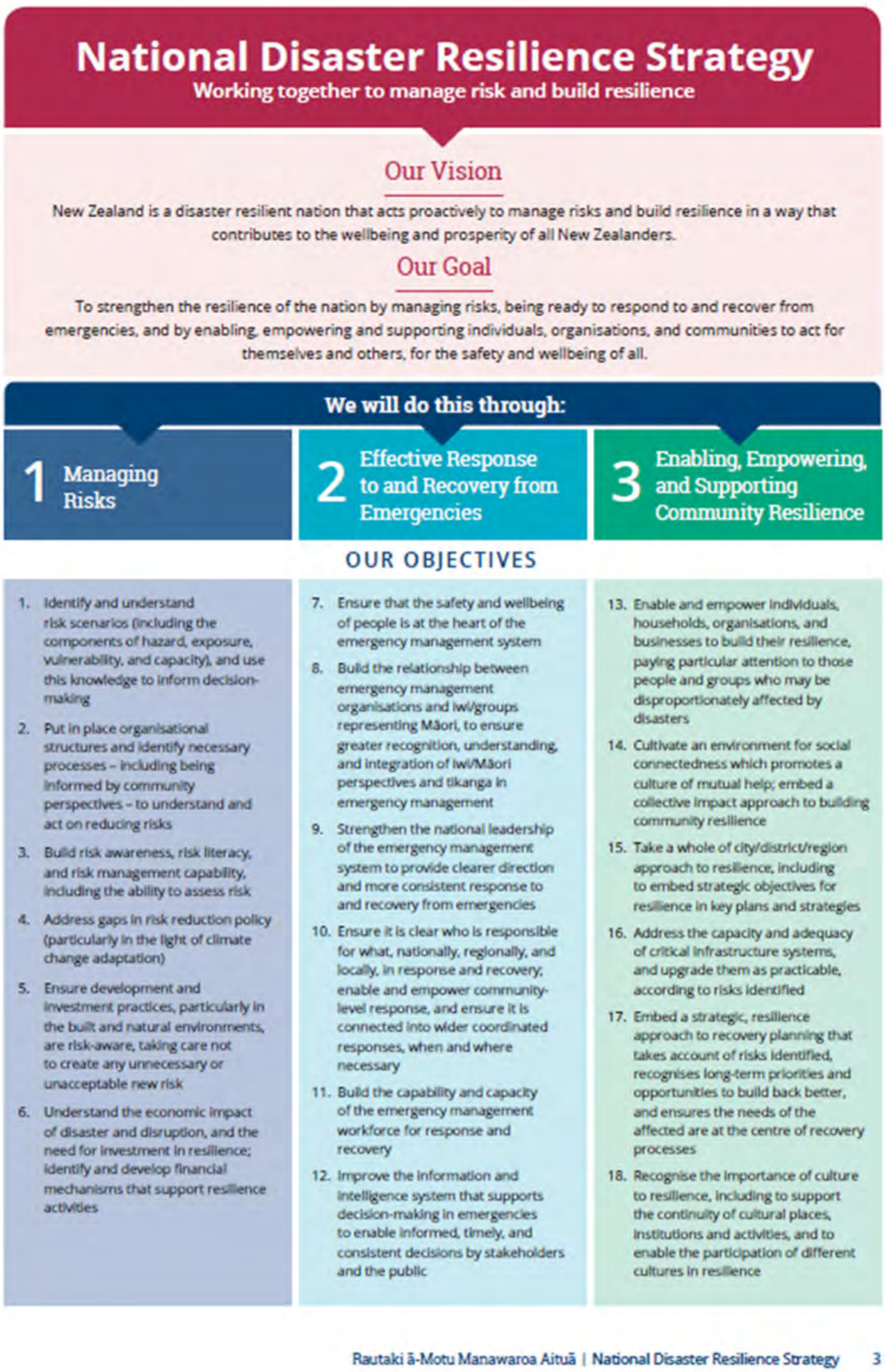
Figure 3-31 Transport Accessibility following a Tsunami Event

Area	Projects / Resources	Relevance	Timing
Urban Resilience	• Brings social dimensions into the impacts analysis using GIS tools	Considered as additional layer in the Lifelines GIS portal	Ongoing

Table 3-17 Urban and Community Resilience Resources

3.16 NEMA National Disaster Resilience Strategy (NDRS)

This document provides overarching objectives for this project.



National Disaster Resilience Strategy

Working together to manage risk and build resilience

Our Vision

New Zealand is a disaster resilient nation that acts proactively to manage risks and build resilience in a way that contributes to the wellbeing and prosperity of all New Zealanders.

Our Goal

To strengthen the resilience of the nation by managing risks, being ready to respond to and recover from emergencies, and by enabling, empowering and supporting individuals, organisations, and communities to act for themselves and others, for the safety and wellbeing of all.

We will do this through:

1 Managing Risks

2 Effective Response to and Recovery from Emergencies

3 Enabling, Empowering, and Supporting Community Resilience

OUR OBJECTIVES

1. Identify and understand risk scenarios (including the components of hazard, exposure, vulnerability, and capacity), and use this knowledge to inform decision-making
2. Put in place organisational structures and identify necessary processes – including being informed by community perspectives – to understand and act on reducing risks
3. Build risk awareness, risk literacy, and risk management capability, including the ability to assess risk
4. Address gaps in risk reduction policy (particularly in the light of climate change adaptation)
5. Ensure development and investment practices, particularly in the built and natural environments, are risk-aware, taking care not to create any unnecessary or unacceptable new risk
6. Understand the economic impact of disaster and disruption, and the need for investment in resilience; identify and develop financial mechanisms that support resilience activities
7. Ensure that the safety and wellbeing of people is at the heart of the emergency management system
8. Build the relationship between emergency management organisations and iwi/groups representing Māori, to ensure greater recognition, understanding, and integration of iwi/Māori perspectives and tikanga in emergency management
9. Strengthen the national leadership of the emergency management system to provide clearer direction and more consistent response to and recovery from emergencies
10. Ensure it is clear who is responsible for what, nationally, regionally, and locally, in response and recovery; enable and empower community-level response, and ensure it is connected into wider coordinated responses, when and where necessary
11. Build the capability and capacity of the emergency management workforce for response and recovery
12. Improve the information and intelligence system that supports decision-making in emergencies to enable informed, timely, and consistent decisions by stakeholders and the public
13. Enable and empower individuals, households, organisations, and businesses to build their resilience, paying particular attention to those people and groups who may be disproportionately affected by disasters
14. Cultivate an environment for social connectedness which promotes a culture of mutual help; embed a collective impact approach to building community resilience
15. Take a whole of city/district/region approach to resilience, including to embed strategic objectives for resilience in key plans and strategies
16. Address the capacity and adequacy of critical infrastructure systems, and upgrade them as practicable, according to risks identified
17. Embed a strategic, resilience approach to recovery planning that takes account of risks identified, recognises long-term priorities and opportunities to build back better, and ensures the needs of the affected are at the centre of recovery processes
18. Recognise the importance of culture to resilience, including to support the continuity of cultural places, institutions and activities, and to enable the participation of different cultures in resilience

Rautaki ā-Motu Manawaroa Aituā | National Disaster Resilience Strategy 3

Figure 3-32 National Disaster Resilience Strategy Overview

4.0 Stakeholders Stocktake

In this section we consider both "critical customers" and stakeholder and iwi groups. All of these groups are likely to be impacted in some way when disruption to lifelines occurs due to significant natural hazard events.

Stakeholder and iwi groups are very important, because the impacts affect more than the "critical customers". In a wider sense the needs and expectations of communities need to be recognised when assessing the economic, social and cultural impacts of hazard events.

In this report, the following terms have therefore been defined:

- **Lifeline utility "critical customers"** – those agencies responsible for the health, safety and welfare of the community and, in an emergency, CDEM response and recovery activities. Typically, this will include emergency services agencies such as health, police, fire, and others, but also those lifeline utilities that depend on another lifeline utility – such as fuel.
- **Stakeholder and iwi groups** – this encompasses a wider representation of community groups and sectors, both people and businesses. It includes representative entities as well as individual sectors.

Identifying the locations of sites that are important to these customers and groups and how they may be disrupted or impacted by hazard events is part of the work to be carried out in this project. While direct impacts such as building damage or loss of a lifeline service such as electricity may occur, only the impacts relating to loss of lifeline services are being considered here.

4.1 Lifeline Utility "Critical Customers"

The asset criticality rating described in Section 2.2 considers the need to supply "critical customers" of lifeline utility services.

The 2020 NZ National Fuel Plan provides a useful definition. It identifies critical customers as those agencies responsible for the health, safety and welfare of the community and, in an emergency, CDEM response and recovery activities. The five sectors shown in Figure 4-1 are defined in the National Fuel Plan as critical customer sectors.

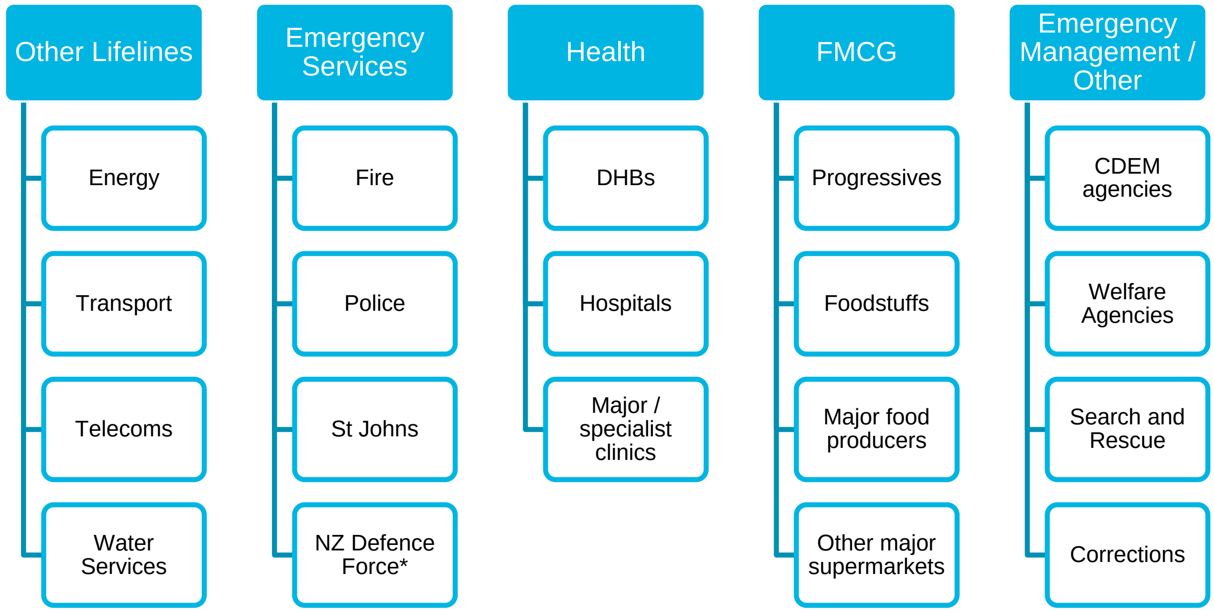
Regional Fuel Plans are required to list specific critical customer organisations that are deemed important and have the right to access priority supply at nominated sites *for the purpose of continuing essential functions*. Therefore, the logical starting point for a list of critical customers for lifelines projects is the Regional Fuel Plan.

The list defined in the current (2016) Regional Fuel Contingency Plan is reproduced below. They tend to fall into two categories:

- *Customers with easily identified marked vehicles, and uniformed staff that require no other type of identification other than their issued identity cards; they are:*
  - *New Zealand Police*
  - *New Zealand Fire Service (now Fire and Emergency New Zealand)*
  - *St John Ambulance*
  - *Rural Fire Authorities*
  - *The Armed Services*
- *Customers who are harder to identify, and who are likely to differ depending on the nature and size of the emergency; these CDEM critical fuel customers will require additional identification and may differ from event to event. The full list of CDEM Critical fuel customers and their essential contractors is in* ***Error! Reference source not found.****, which groups them by sector and Local Authority. The list includes:*
  - *Group Emergency Coordination Centre (ECC) staff and volunteers*

- *Local Emergency Operations Centre (EOC) staff and volunteers*
- *Local Authority road management, water supply, sewerage and stormwater systems, including their staff, essential contractors, consultants and their customer management staff*
- *NZTA staff, its essential contractors and consultants*
- *KiwiRail, including its staff and essential contractors*
- *Electricity line companies, including their staff and essential contractors*
- *Telecommunications companies (Telcos), including their staff and essential contractors*
- *Christchurch International Airport Ltd (CIAL) including aircraft, ground service vehicles, aircraft maintenance fast moving consumer goods facilities, terminal operations (on a reduced scale), emergency generators and essential staff*
- *Civil Aviation Authority air traffic control facilities and staff, including Coopers Knob radar facility, the Southern Air Traffic Control Centre (ATCC) and Christchurch International Airport Control Tower*
- *Urban search and rescue including their staff*
- *Land search and rescue including their staff*
- *Selected staff from welfare agencies such as Work and Income, Child Youth and Family, the Salvation Army etc.*
- *Fuel distribution companies, including LPG distributors, including their staffs and essential contractors*
- *Designated CDEM Emergency Fuel Outlets, including their staffs and essential contractors*
- *Port operators in Lyttelton and Timaru, including their staffs and essential contractors*
- *Public Transport operators and their staffs, including Lyttelton Harbour ferry operations, and essential contractors*
- *Welfare centre volunteers*
- *Other Lifeline Utilities staff and their essential contractors*
- *Healthcare and hospital facilities including their staffs and essential contractors*
- *Fast moving consumer goods facilities, including their staffs and essential contractors*
- *Staff from any of these organisations and from the "easily identified and marked" customers who are required to commute to their place of work / emergency site, to perform their duties*
- *Depending on circumstances:*
    - *Helicopter operators crews and support staff involved in emergency response and lifelines restoration*
    - *Fixed wing aircraft operators, crews and support staff*
    - *Refuse collection and disposal operations, including their staffs and essential contractors*
    - *Other organisations deemed to be critical fuel customers by the Canterbury Group Civil Defence Controller*

These critical customers can be summarised in terms of the following categories. Note that key service providers to those sectors are also considered critical customers (e.g. major contractors, suppliers).



**While the Defence Force is not defined as an ‘emergency service’ it provides a key support role.*

Figure 4-1 Critical Customers / Stakeholders

4.2 Stakeholder and Iwi Groups

The stocktake has identified the following broad groupings where economic, social or cultural impacts may occur. Note that there is some overlap with the “critical customers” above although this section does not specifically cover lifeline utilities themselves.

- Age Care
- Banking
- Businesses
- Central Government Agencies
- Community Groups
- Community Service
- Construction Supplies
- Contractors
- Education
- Emergency Services
- Fast Moving Consumer Goods
- Food Production
- Freight Providers
- Funeral / Crematoria
- Health
- Industry
- Insurance
- Iwi
- Military
- Rural

- Tourism
- Vineyards
- Welfare

A summary of the organisations, agencies and associations within these groups is tabulated below. More detail is contained in a working spreadsheet – this can be utilised if required for the impacts analysis.

Sector	Stakeholder	Function	Location(s)
Age Care	Arvida Group	Retirement villages and residential care homes	Christchurch, Rangiora, Timaru (14 sites)
	Bupa		Christchurch, Rangiora, (11 sites)
	Christchurch Methodist Mission		Christchurch (1 site)
	Heritage Lifecare Group		Ashburton, Timaru, Christchurch (7 sites)
	Nurse Maude	Retirement village and rest home	Christchurch (1 site)
	NZ Aged Care Association	Business association - offices	Christchurch
	Oceania Healthcare		Christchurch (9 sites)
	Presbyterian Support South Canterbury	Retirement villages, rest homes and residential care homes	Timaru, Temuka (6 sites)
	Radius Care		Ashburton, Timaru, Christchurch (6 sites)
	Ryman Healthcare		Christchurch, Rangiora, (16 sites)
	Various other providers	Retirement villages, rest homes and residential care homes	Christchurch, Akaroa, Kaikoura, Amberley, Kaiapoi, Rangiora, Woodend, Rolleston, Darfield, Leeston, Methven, Ashburton, Geraldine, Timaru, Temuka (48 sites)
Banks	Various providers	Banking	Spread throughout the region
Business sector associations	Business NZ	Advocacy	TBC
	Canterbury Employers Chamber of Commerce	Business support & collaboration	Christchurch CBD
	Major Electricity Users Group	Advocacy	TBC

Sector	Stakeholder	Function	Location(s)
Central Govt Agencies	Aviation Security Service	Airport security	ChCh Airport
	Department of Corrections	Prisons	Various
	Department of Conservation	Environment	Various
	Justice Department	Law courts	Justice Precinct
	Kāinga Ora (Housing NZ)	Social housing	Various
	Ministry of Business Innovation & Employment	Various	TBC
	Ministry of Education	Education	Various
	Ministry of Health	Health	Christchurch CBD
	Ministry of Primary Industries	Border clearance, biosecurity, fisheries, forestry	Various
	Ministry of Social Development	Social welfare	Various
	National Emergency Management Agency	Civil defence emergency mg'mt	Justice Precinct
	NZ Customs Service	Border management	Various
	Oranga Tamariki (Ministry for Children)	Children, youth and family services	Various
	WorkSafe NZ	Workplace H&S	TBC
Community Groups	Neighbourhood Support Canterbury	Coordination and community support groups	Christchurch, Rangiora, Selwyn, Ashburton, Timaru
Community Services	City and District Councils	Libraries, Museums, Community Centres, Art Galleries	All local government areas
Construction Supplies	Allied Concrete	Concrete supplier	Kaikoura, Christchurch, Timaru, Rangiora, Ashburton
	Ashburton Prestressed Concrete	Concrete products	Ashburton
	Baier Group	Building Materials Suppliers	Christchurch
	Bunnings Warehouse	Building Materials Suppliers	Christchurch, Ashburton
	Canterbury Concrete	Concrete supplier	Christchurch
	Carters	Building Materials Suppliers	Christchurch, Rangiora
	Christchurch Ready Mix Concrete	Concrete supplier	Various locations
	Firth Concrete	Concrete supplier	Christchurch, Ashburton, Timaru, Twizel
	Firth industries	Concrete products	Christchurch
	Fulton Hogan	Quarry aggregate suppliers	Christchurch
	Goldpine	Building Materials Suppliers	Christchurch, Amberley, Ashburton, Timaru

Sector	Stakeholder	Function	Location(s)
	Great Southern	Building Materials Suppliers	Timaru, Waimate
	Hanham Concrete	Concrete supplier	Ashburton
	Humes Christchurch	Concrete products and pipes	Rolleston (manufacturing), various outlets
	Hynds Pipe Systems	Concrete products and pipes	Christchurch
	Isaac Construction	Quarry aggregate suppliers	Christchurch
	ITM	Building Materials Suppliers	Christchurch, Rangiora, Amberley, Kaiapoi, Darfield, Leeston, Ashburton, Timaru, Geraldine
	KBS Quarry	Infrastructure/civil Contractors	Christchurch
	Marley NZ	Plastic products and pipes	Christchurch
	McAlpines	Building Materials Suppliers	Rangiora
	Mico Pipelines	Plastic products and pipes	Christchurch
	Mitre 10	Building Materials Suppliers	Christchurch, Rangiora, Kaikoura, Hanmer Springs, Ashburton, Timaru
	Placemakers	Building Materials Suppliers	Christchurch, Ashburton, Timaru, Twizel
	RMC Concrete	Concrete supplier	Christchurch
	Road Metals Co	Quarry aggregate suppliers	Christchurch
	Selwyn Quarries	Quarry aggregate suppliers	Rolleston
	Stahlton Engineered Concrete	Concrete products	Christchurch
	Taggart Earthmoving Ltd	Quarry aggregate suppliers	Rangiora
	Winstone Aggregates	Quarry aggregate suppliers	Christchurch
Contractors	ARC Projects Ltd	Infrastructure/civil Contractors	Christchurch
	Burnise Contractors Ltd		Christchurch
	CityCare Group		Christchurch, Timaru
	Civil Contractors New Zealand	Business association	Christchurch
	Doug Hood Mining Ltd	Infrastructure/civil Contractors	Christchurch
	Downer EDI Works		Various locations
	Fulton Hogan Civil		Various locations
	GSL		Christchurch
	Geovert Ltd		Christchurch
	Hawkins Construction		Christchurch
	Isaac Construction		Christchurch

Sector	Stakeholder	Function	Location(s)
	Isaac Construction		Christchurch
	JCL Asphalt		Christchurch
	Johnston Civil Ltd		Leeston
	KJS Contracting		Kaikoura
	LB Civil		Christchurch, Ashburton
	March Construction		Christchurch
	Maugers Contracting Ltd		Christchurch
	RJ Civil Construction Ltd		Christchurch
	Rooney Earthmoving		Ashburton
	Sicon		Rolleston
	Taggart Earthmoving Ltd		Christchurch
	Waddell Holdings		Christchurch
	Works Infrastructure		Timaru
	White Stone Contracting		Fairlie
Education	ARA	Tertiary Education	Christchurch CBD, Woolston, Ashburton, Timaru
		Student Accommodation	Christchurch CBD
	Lincoln University	Tertiary Education	Lincoln
		Halls of residence	Lincoln
	University of Canterbury	Tertiary Education	Christchurch
		Halls of residence	Christchurch
	Ministry of Education	Early Learning Centres	Various locations
		Primary Schools	Various locations
		Secondary Schools	Various locations
Emergency Services	City and District Council	Emergency Ops Centres	Kaikoura, Amberley, Rangiora, Christchurch, Rolleston, Ashburton, Timaru, Waimate, Fairlie
		Welfare Centres, CD Sector Posts	Various locations
	Environment Canterbury	EOC - River management and control	Christchurch, Timaru
		Canterbury CDEM offices	Justice Precinct, ChCh
	Coast Guard	Lifeboat station	Lyttelton, Kaiapoi, Timaru
	Sumner Lifeboat	Lifeboat station	Sumner
	FENZ	Fire Management and Response	Justice Precinct, ChCh
		Fire Stations	Various locations
	Police	Management and Response	Justice Precinct, ChCh
		Police stations	Various locations

Sector	Stakeholder	Function	Location(s)
	GCH Aviation - air ambulance service	Heliport and maintenance facility	TBC
Fast Moving Consumer Goods (FMCG)	Foodstuffs South Island	Distribution centres	TBC
		Supermarkets	Various locations
	Progressive Enterprises	Distribution centres	TBC
		Supermarkets	Various locations
Food Production	Alliance Smithfield Ltd	Meat processing works	Timaru
	ANZCO Foods	Meat processing works	Ashburton, Rakaia
	Ashburton Meat Processors	Meat processing works	Ashburton
	Beef + Lamb New Zealand	Business association	TBC
	DairyNZ	Business association	TBC
	Fonterra	Corporate office	Christchurch
		Dairy processing plant	Christchurch, Darfield, Clandeboye, Waimate
	Harris Meats	Meat processing works	Domett
	Independent Fisheries Ltd	Fish cold store and processing plant	TBC
	McCains Foods	Food Manufacturer	Timaru
	New Zealand Fishing Industry Guild	Business association	Auckland
	Sanford Ltd	Fish cold store and processing plant	Timaru
	Silver Fern Farms Ltd (PPCS Ltd)	Meat processing works	Christchurch, Ashburton, Timaru, Pareora
	SPM Malvern	Meat processing works	Burnham
	Synlait	Dairy processing plant	Rakaia
		DairyWorks and Corporate office	Christchurch
	Talley's group	Vegetable processing and Cold store	Fairton
		Fish cold store and processing plant	Timaru
	Tegel Foods	Meat processing works	Christchurch
	United Fisheries	Fish cold store and processing plant	Christchurch
Freight Providers	Air New Zealand Cargo	Air cargo	Christchurch Airport
	Bascik Transport	General freight	Christchurch
	Canterbury Freight	General freight	Christchurch
	Daily Freight	General freight	Christchurch
	DHL Global Forwarding	International freight	Christchurch Airport

Sector	Stakeholder	Function	Location(s)
	Fliway	General freight	Christchurch Airport
	Frews Transport	General freight	Christchurch, Darfield, Oxford
	H&J Bruce Transport Ltd	General freight	Timaru
	Hanmer Haulage	General freight	Hanmer Springs
	Linfox Logistics	General freight	Christchurch
	Mainfreight	General freight	Christchurch, Ashburton, Timaru
	Other Freight & Courier Companies	Various providers	Christchurch
	Sollys Freight	General freight	Christchurch
	South Island Transport Logistics	General freight	Christchurch
	Summerland Express Freight	General freight	Christchurch
	Transport Rangiora	General freight	Rangiora
	Tranz Rail Services	General freight	Christchurch
Funeral / Crematoria	Academy Funeral Services	Mortuary	TBC
	Canterbury District Health Board	Mortuary	TBC
	Christchurch Crematorium Funeral Services	Crematorium	TBC
	John Rhind Funeral Services	Funeral service	TBC
	South Canterbury Crematorium	Crematorium	TBC
Health	Canterbury District Health Board	Christchurch office	Christchurch
		Major Hospital - ED & ICU	Christchurch Hospital
		Medium Hospital - ED	Christchurch Women's Hospital
		Minor Hospital - No ED	Akaroa Health
		Minor Hospital - No ED	Ashburton Hospital
		Minor Hospital - No ED	Burwood Hospital
		Medical lab	Canterbury Health Labs
		Minor Hospital - No ED	Chatham Islands Health Centre
		Minor Hospital - No ED	Christchurch Outpatients
		Minor Hospital - No ED	Darfield Hospital
		Minor Hospital - No ED	Ellesmere Hospital
		Minor Hospital - No ED	Hillmorton Hospital
		Minor Hospital - No ED	Kaikōura Health
		Minor Hospital - No ED	Lincoln Maternity Hospital
		Minor Hospital - No ED	Oxford Hospital

Sector	Stakeholder	Function	Location(s)
		Minor Hospital - No ED	Rangiora Health Hub
		Minor Hospital - No ED	Princess Margaret Hospital
		Minor Hospital - No ED	Ashburton
		Minor Hospital - No ED	Waikari Hospital
	Canterbury Primary Response Group	Primary Health EOC	Christchurch
	Pegasus Primary Health Services	Offices	Christchurch
	South Canterbury District Health Board	Medium Hospital - ED	Timaru
		Offices	Timaru
	St Georges	Private Hospital	Christchurch
Industry	Wood Processors & Manufacturers Association	Sector association group	TBC
	Forestry & Timber Processing	Various companies	Various locations
	Oji Fibre Solutions	Pulp fibre and paper packaging	TBC
Insurance	Insurance Companies	Various companies	Various locations
Iwi	Ngai Tahu	Corporate office	Christchurch
		Marae	Various locations
Military	NZDF	Army Base	Burnham
	NZDF	Training Facility	Tekapo
	NZDF	Offices	Christchurch
	RNZAF	Air Movements	Christchurch
Rural	Federated Farmers	Business association	TBC
	Landcare Research	Agricultural research and testing	Lincoln
	Rural Contractors	RAG member	Various locations
	Rural Support Trust	RAG member	Various locations
	NZ Institute for Plant & Food Research Ltd	Agricultural research and testing	Lincoln
	Carrfields Grain & Seed/Canterbury Seed	Seed merchants	Ashburton
	Leeston Seeds Limited	Seed cleaning & treatment	Leeston
	Livestock agents	Various companies	Various locations
	Luisetti Seeds	Seed merchants	Rangiora
	Methven Seed Cleaning 2010 Ltd	Seed cleaning & treatment	Methven
	NZ Grain and Seed Trade Association	Business association	TBC
	Norwest Seed Ltd	Seed merchants	Rakaia
	PGG Wrightson	Stock Saleyard	Hawarden, Culverden, Cheviot, Christchurch,

Sector	Stakeholder	Function	Location(s)
			Sheffield, Temuka, Tekapo
	Ravensdown Fertiliser	Agrichemical supplier	Amberley, Christchurch, Rakaia, Methven, Ashburton, Mayfield, Kakahu, Kerrytown, Waimate
	South Pacific Seeds NZ Ltd	Seed merchants	Methven
Tourism	Various companies	Various activities, e.g. skiing	Various locations
Vineyards	Various companies	Grape growing and wine-making	Waipara, Waikari, Christchurch, Akaroa, Amberley, Kaiapoi, Lyttelton (42 locations)
	NZ Wine	Business association	
Welfare	Red Cross	Office locations, storage	Christchurch, Ashburton, Timaru
	Salvation Army	Depots, kitchens, mobile plant	Christchurch, Rangiora, Amberly, Ashburton, Timaru

Table 4-1 Stakeholder Groups

Appendix 1: Glossary

Term	Definition
Asset	The physical hardware (e.g., pipes, wires), software and systems to own, operate and manage Lifelines Utilities (energy, transport, telecommunications, water). In the broadest sense this includes utility business owners, operators and contractors.
Business Continuity Planning	An organisational activity to build its ability to maintain its internal systems and operations, in order to promote service continuity to customers.
Consequence	The impact of a supply outage on direct customers, usually extending to include the downstream impacts of the outage on society as a whole.
Critical Assets (Sites / Facilities / Routes)	Assets that have a high consequence of failure with potentially significant consequences to societal wellbeing. *Note:* Both Infrastructure and community sites/facilities will generally feature in regional lifelines group critical sites / facilities lists.[13] A broad criticality rating of *Nationally Significant, Regionally Significant and Locally Significant* has been used.
Critical Customer	An organisation that provides services deemed critical to the functioning of communities and that rely on lifelines services to function. For this report, these include emergency services, health, banking, Fast Moving Consumer Goods and Corrections services, as well as the lifeline utilities themselves.
Emergency	A situation that • is the result of any happening, whether natural or otherwise, including natural hazard, technological failure, failure of or disruption to an emergency service or a lifeline utility; and • causes or may cause loss of life, injury, illness or distress, or endangers the safety of the public or property; and • cannot be dealt with by emergency services, or otherwise requires a significant and co-ordinated response under the Civil Defence Emergency Management Act 2002. *Paraphrased from the Civil Defence Emergency Management Act 2002*
Event	An occurrence that results in, or may contribute substantially to, a utility supply outage (i.e. an inability to continue service delivery). Notes: This informal term is often used by lifeline utilities to refer to the onset of a hazard or an emergency. Events can be 'external', i.e. something that happens to the utility, or 'internal', i.e. a breakdown within the utility.
Exposure	The extent to which an asset is potentially exposed to a hazard.
Four R's	Categories that form a framework for emergency planning and post-event actions. New Zealand's civil defence emergency management framework breaks down into four such categories: Reduction, Readiness, Response and Recovery. • Reduction means identifying and analysing risks to life and property from hazards, taking steps to eliminate risks if practicable, and, if not, reducing the magnitude of their impact and/or the likelihood of occurrence • Readiness means developing systems and capabilities before an event happens to deal with risks remaining after reduction possibilities have been put in place, including self-help and response programmes for the general

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

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

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

Appendix 2: Supporting Information

Resilience to Natures Challenges

Multi-hazard Risk Model (MRM)

The projects are summarised in the following extract:
https://resiliencechallenge.nz/scienceprogrammes/multihazard-risk-model/

1 Multi-hazard forecasting and impact modelling

We will extend the mathematical and computational basis of hazard and impact modelling to the case of multiple and cascading hazards, and linked impacts to infrastructure. The latter will be in collaboration with the Built Environment programme.

Project lead: Prof Mark Bebbington (Massey)

2 Case study

Flooding can be caused by a variety of overlapping or cascading events (rainstorms, sediment build-up, landslides, volcanic ashfall etc). Here, through a mix of computational, graphical, and statistical approaches, we will examine the effects of correlation on hazards, and the effect of river control structures on flood inundation hazard.

Project lead: Prof Tim Davies (University of Canterbury)

3 Dynamic assessments of impacts

We will both widen and sharpen the ability of the MERIT tool to rapidly assess economic consequences, in order to more holistically capture impacts of natural hazard events. This will involve extension to dynamic value chains, and to multiple and social capitals.

Project lead: Dr Garry McDonald (Market Economics)

4 Embedding models within robust decision-making

We will systematically explore the consequences of alternative sets of assumptions in our risk and economic modelling, with the aim of generating representative scenarios that characterise key vulnerabilities and trade-offs of alternative resilience-building strategies. Changing the prioritisation or scheduling of resilience building initiatives (both pre-event mitigations, e.g. as laid down in Council 30-year asset management planning processes, NZTA's Land Transport Programme and so on, and post-event adaptions) can dramatically change the impacts felt in response, recovery and rebuild.

Project lead: Dr Charlotte Brown (Resilient Organisations)

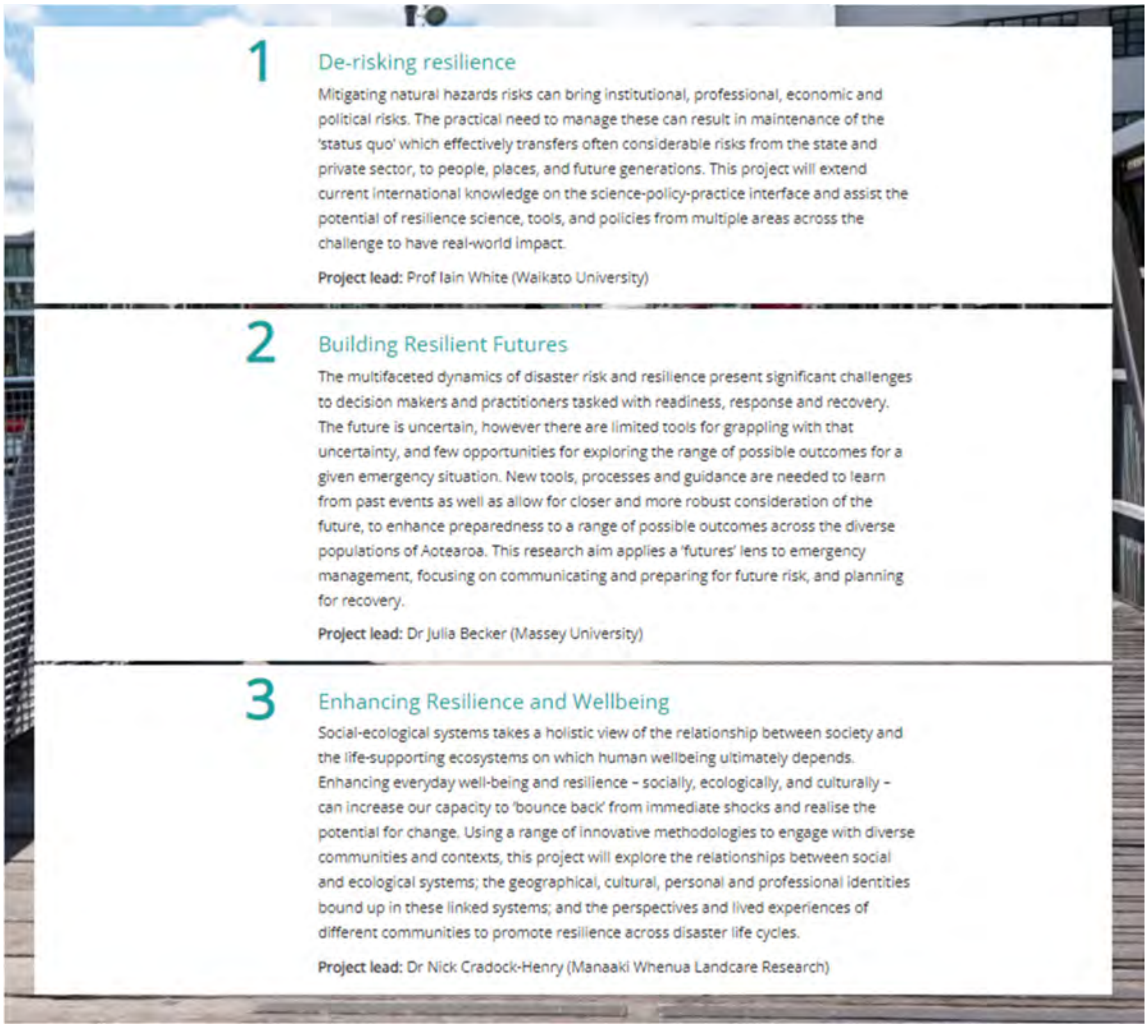
5 Māori perspectives on risk

Working with the Mātauranga Māori programme, we propose a joint national identification of Māori values, perspectives and Mātauranga Māori for risk across the four key hazard themes (e.g., coastal; volcanic; earthquake/tsunami; weather/climate). Findings will be documented within appropriate frameworks as key attributes/factors of risk and resilience. We will then build on that to design kaupapa Māori/ Mātauranga Māori approaches, frameworks and attributes for modelling risk and multi-hazard planning, and test and validate integration and modelling within one catchment area/rohe.

Project lead: Garth Harmsworth (Manaaki Whenua Landcare Research)

Resilience in Practice Model

The projects are summarised in the following extract.
https://resiliencechallenge.nz/scienceprogrammes/resilience-in-practice/



1 De-risking resilience

Mitigating natural hazards risks can bring institutional, professional, economic and political risks. The practical need to manage these can result in maintenance of the 'status quo' which effectively transfers often considerable risks from the state and private sector, to people, places, and future generations. This project will extend current international knowledge on the science-policy-practice interface and assist the potential of resilience science, tools, and policies from multiple areas across the challenge to have real-world impact.

Project lead: Prof Iain White (Waikato University)

2 Building Resilient Futures

The multifaceted dynamics of disaster risk and resilience present significant challenges to decision makers and practitioners tasked with readiness, response and recovery. The future is uncertain, however there are limited tools for grappling with that uncertainty, and few opportunities for exploring the range of possible outcomes for a given emergency situation. New tools, processes and guidance are needed to learn from past events as well as allow for closer and more robust consideration of the future, to enhance preparedness to a range of possible outcomes across the diverse populations of Aotearoa. This research aim applies a 'futures' lens to emergency management, focusing on communicating and preparing for future risk, and planning for recovery.

Project lead: Dr Julia Becker (Massey University)

3 Enhancing Resilience and Wellbeing

Social-ecological systems takes a holistic view of the relationship between society and the life-supporting ecosystems on which human wellbeing ultimately depends. Enhancing everyday well-being and resilience – socially, ecologically, and culturally – can increase our capacity to 'bounce back' from immediate shocks and realise the potential for change. Using a range of innovative methodologies to engage with diverse communities and contexts, this project will explore the relationships between social and ecological systems; the geographical, cultural, personal and professional identities bound up in these linked systems; and the perspectives and lived experiences of different communities to promote resilience across disaster life cycles.

Project lead: Dr Nick Cradock-Henry (Manaaki Whenua Landcare Research)

This work includes:

- Producing new resilience practices that are well targeted, and well used by decision-makers
- Co-designing initiatives tailored to a range of contexts and scales, such as:
    - New network resilience evaluation tools applied to single and multiple inter-connected electricity distribution and communications networks in the Canterbury-West Coast region
    - New resilience modules for NZTA planning for transport disruption and repairs/replacements during major outages anywhere in New Zealand.
    - New emergency management plans and practices developed and tested by all South Island local authorities under an Alpine Fault (AF8) earthquake scenario.
- Integrating with the research carried out under the Natural Hazards Research Platform (refer Section 3.7)

Specialist Programme Areas

MRM Coastal Theme
https://resiliencechallenge.nz/scienceprogrammes/coastal-theme/

1 New Zealand's Changing Coastline:

Project leaders: Assoc Prof Mark Dickson and Dr Murray Ford (The University of Auckland)

We aim to to develop a national framework for assessing New Zealand's changing coastline that will deliver an understanding of slow onset coastal change and data to underpin modelling of ongoing impacts. A national-scale approach is proposed, comprising two sub-projects:

- Smart coastal change detection
- Understanding New Zealand's coastal change and supporting projections of future shoreline change

2 Coastal Flooding:

Project leaders: Prof Karin Bryan (University of Waikato) and Dr Scott Stephens (NIWA)

Our overarching aim is to improve understanding of current and future coastal flooding hazard and risk, and its implications for decision making, in the complex environments that characterise New Zealand's coast through three sub-projects:

- Estuarine flooding predictors
- Influence of human–climate interactions on coastal flood hazard and risk
- Compound risk from multiple coastal hazards

3 Coastal Adaptation:

Project leaders: Dr Judy Lawrence (Victoria University of Wellington) and Dr Rob Bell (NIWA)

The overarching aim of this project is to provide consistent, proactive and implementable knowledge to address the coastal adaptation challenge. New tools will be developed for national guidance, risk and vulnerability assessments, land-use planning and codes of practice for decision making in different coastal environments around New Zealand. They will be 'fit for purpose', aligned to the changing risk regimes for implementation at different levels of governance, and have resilience outcomes (e.g. community cohesion, health and safety, and infrastructure needs) that achieve more effective and sustainable decision making. This project consists of four sub-projects:

- Improved understanding of coastal risk and vulnerability exposure
- A vulnerability assessment framework that 'fits' the changing coastal risk
- Enabling proactive implementation of coastal adaptation
- Versatile adaptation of coastal infrastructure

MRM Weather Theme
https://resiliencechallenge.nz/scienceprogrammes/weather-theme/

1 Hazard modelling

We will create hazard models of extreme weather events over time and space scales not previously available in New Zealand.

2 Extreme scenarios

We will use three extreme scenarios (ex-tropical cyclone, wildfire, extreme winter storm) to quantify the multi-component affects (wind, flood, snow, landslide, rural fire, etc) on infrastructure, buildings and communities.

3 Hazard mitigation

We will develop more effective weather hazard mitigation, including communication strategies, via in-depth case-study research on risk perception and warning behaviours.

MRM Volcanism Theme
https://resiliencechallenge.nz/scienceprogrammes/volcanism/

1 Multihazard forecasting

Develop new models to forecast the long-term multihazards of New Zealand's cone volcanoes.

2 Volcanic impact models – the "eVolcano Testing Lab"

- Developing new-generation volcanic impact analysis by empirical testing of physical and chemical impacts of a range of volcanic processes.
- Developing a new suite of modelling tools designed to improve the assessment of volcanic hazards.

3 Volcanic Resilience

- Integration with emergency management planning scenarios
- Contributing to mātauranga Māori and building kaitiakitanga

MRM Earthquake and Tsunami Theme
https://resiliencechallenge.nz/scienceprogrammes/earthquake-and-tsunami/

1 Fault Model Construction

Project goal: Build an earthquake source model using known active faults from throughout New Zealand and nearby offshore areas. We will test and refine earthquake sources using existing geological, seismological and GPS information, and use the source model to compute millions of synthetic earthquakes unique to New Zealand's faults and tectonics.

Project leads: Dr Bill Fry (GNS Science) and Prof Andy Nicol (University of Canterbury)

2 Catalogue Testing and Verification

Project goal: Evaluate the ability of synthetic earthquakes to replicate the statistics of natural earthquakes. Test the sensitivity of the results to changes in model inputs and different modelling approaches, and develop estimates of the likelihood of future large magnitude earthquakes over the next century.

Project leads: Mark Stirling (Otago University) and Matt Gerstenberger (GNS Science)

3 Probabilistic Tsunami Model

Project goal: Develop models for the likelihood of tsunami hazard using synthetic earthquakes in offshore New Zealand and the Tonga-Kermadec region.

Project leads: William Power (GNS Science) and Emily Lane (NIWA)

4 Testing Early Warning Systems

Project goal: Test the limitations and utility of earthquake and tsunami early warning systems in New Zealand.

Project leads: Sarah-Jayne McCurrach (Ministry of Civil Defence and Emergency Management) and Caroline Holden (GNS Science)

5 Ground Motion and Co-seismic Landslide Hazard

Project goal: Improve estimates of topographic amplification and seismically-triggered landslide hazards using synthetic earthquakes.

Project lead: Anna Kaiser and Chris Massey (GNS Science)

Mātauranga Māori Theme
https://resiliencechallenge.nz/scienceprogrammes/matauranga-maori/

1 Whakaoranga Te Whenua:

How can we increase iwi, hapū and whānau awareness to natural hazards including volcanic eruptions, tsunami, earthquakes, landslides, wildfires, coastal erosion and extreme weather events?

2 Whakaoranga Tūrangawaewae:

How can we increase Māori decision-making with respect to built infrastructure, technologies, lifelines, warnings, all-hazard risk modelling, designs, codes, communication, and environmental management plans?

3 Whakaoranga Iwi Whānui:

How can we build the resilience of iwi, hapū, whānau with respect to urban/rural issues, social issues, health, economics, communities, and businesses?

Built Environment Theme
https://resiliencechallenge.nz/scienceprogrammes/built/

1 Horizontal Infrastructure

This workstream will build on the outcomes of the RNC Phase 1 Infrastructure theme, by developing:

- Models for infrastructure component performance across a range of natural hazards.
- Expanded geographic coverage and capabilities of infrastructure network models.
- High resolution regional and urban interdependency models.
- Decision making and rating tools for infrastructure.

Project lead: Assoc Prof Liam Wotherspoon (Auckland University)

2 Vertical Infrastructure

This workstream will seek to identify effective means of reducing the damage and disruption caused by future earthquakes. The research will focus on two main research areas:

- Quantifying and mitigating the risk (in terms of monetary losses) associated with different design solutions and building technologies.
- Supporting the development of design and assessment standards for NZ buildings to enable enhanced performance objectives to be achieved in practice.

Project lead: Prof Tim Sullivan

3 Integrated Scenario

Wellington City and a major earthquake rupture will be used in this workstream as a case study in order to apply and advance modelling and analysis methods in an end-to-end fashion to provide a true appreciation of the vulnerability and impacts of Wellington in significant detail. This study will form the baseline for informing decision making, and feed into other Challenge research themes. The principal focus areas will be:

- Physical damage to vertical infrastructure
- Physical damage to horizontal infrastructure
- City-wide integration of effects

Project lead: Prof Ken Elwood (University of Auckland)

Rural Theme
https://resiliencechallenge.nz/scienceprogrammes/rural/

1 Disaster Resilient Outcomes for Rural New Zealand

Rural communities and value chains are vulnerable to a range of slow and rapid onset hazards, including climatic and geophysical hazards, and social, economic, cultural and political drivers which create a complex yet dynamic setting to build disaster resilience.

This project will co-produce and broker innovative solutions for enhancing the resilience of rural New Zealand. It will tailor tools, strategies and resources specifically for rural communities, businesses, and support systems.

Project lead: Dr Caroline Orchiston (University of Otago)

2 Rural Disaster Risk Decision-Making

A foundation of disaster risk management is understanding the hazards, the exposure and vulnerability of people and assets to those hazards. By quantifying the risks and anticipating the potential impacts of hazards, governments, industries, communities, and individuals can make informed decisions on resilience.

This work stream will produce an integrated national framework for valuing, promoting, incentivising and assessing resilience across rural value chains, from households to regions and small to global-scale agribusinesses.

Project lead: Prof Thomas Wilson (University of Canterbury)

3 Understanding our 21st century rural communities & industries for a disaster resilient NZ

This project aims to better understand the disaster risk and resilience of specific rural communities and industries, including rural Māori communities, Māori agribusiness and tourism interests in Nelson/Tasman, and other under-researched communities including temporary migrant communities in rural Aotearoa, and rural lifestyle block owners.

Project leads: Prof Tom Wilson (University of Canterbury), Dr Nick Cradock-Henry (Manaaki Whenua)

4 Disaster Resilient Rural New Zealand Co-creation

The Rural programme is dedicated to finding innovative solutions for enhancing the resilience of rural New Zealand, to better protect these integral and potentially vulnerable communities and enable them to thrive in the face of natural hazard risks. Central to this approach will be using and extending the co-creation approaches successfully tried and tested during Phase 1.

Project leads: Rural – Dr Sarah Beaven (University of Canterbury); Taranaki – Prof Tom Wilson (University of Canterbury); AF8 – Dr Caroline Orchiston (Otago University);

Urban Theme
https://resiliencechallenge.nz/scienceprogrammes/urban/

1 Smart Cities

Emerging technology and data processing tools, such as self-configurable Sensor Networks, Internet of Things technologies, Next Generation Mobile and Broadcasting platforms, Machine Learning, and Artificial Intelligence are transforming the cities that we live in, and the way we live in them. The Smart Resilience Cities workstream explores how the Smart City model could be used for pre-disaster recovery planning and post-disaster recovery operations.

Project lead: Prof David Johnston (Massey University)

2 Inclusive Urban Communities

How to most effectively enable our diverse communities to become advocates for resilience.

Project lead: Dr JC Gaillard (University of Auckland) and Loïc Le Dé (Auckland University of Technology)

3 Pathways to Urban Resilience

Whether our existing hazard, risk and other resilience research is being adequately integrated into plans and policies, and through these insights, developing best practice approaches for linking our research to urban governance.

Project lead: Prof Jan Lindsay (University of Auckland)

Infrastructure Resilience and Marae Adaptations

This work is being carried out through the University of Auckland and the Resilience to Nature's Challenges programme.

It's aims are to explore and better understand:

- Current status of marae and infrastructure
  - Lifelines and infrastructure
  - Areas of vulnerability
- Marae community engagement
  - Traditional management approaches
  - Challenges and opportunities
- Potential adaptations

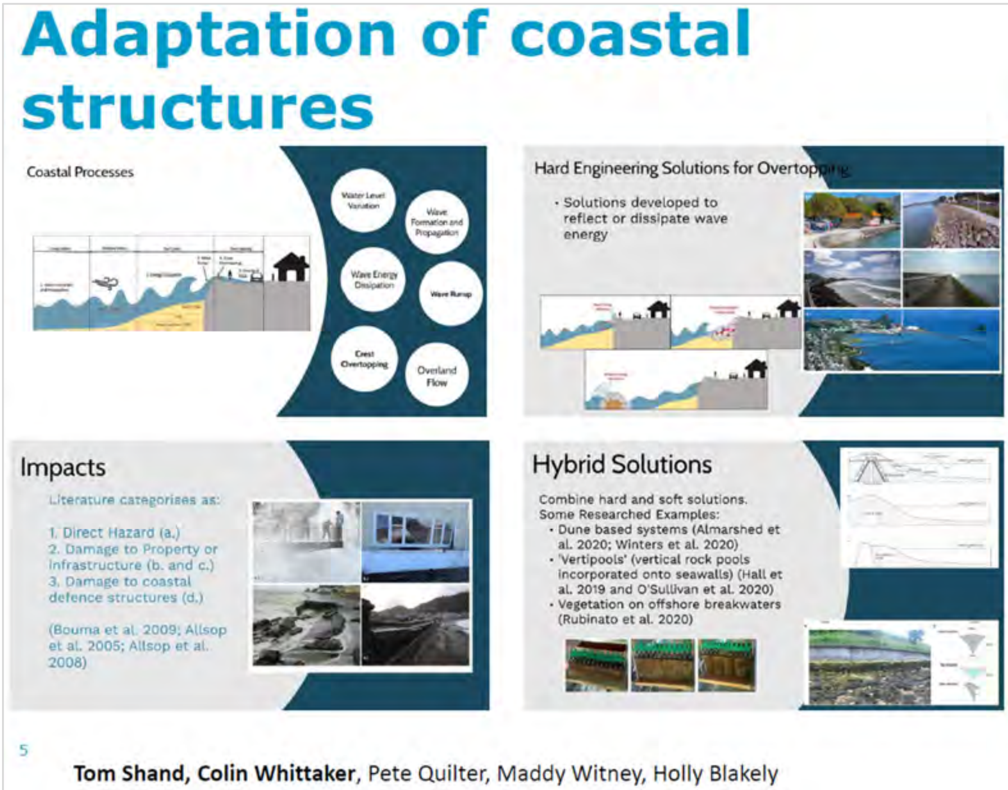
A North Island GIS database of maraes and associated infrastructure has been established and the hazards they are exposed to have been identified – for example, tsunami zones, flooding, landslides, liquefaction, seismic.

Engagement has involved a qualitative, holistic approach, also addressing the social and cultural infrastructure and communication networks.

Work now to be undertaken includes:

- Identify existing IHMPs and hazard related plans
- Linking in with other work focused on marae and Māori in RNC
- Mapping out marae and infrastructure vulnerability
- Expand reach into other parts of the country

Coastal and Tsunami Research (University of Auckland)



This research includes impacts of tsunamis on bridges and breakwaters.

Transport Resilience Research (University of Auckland)

Projects

THE UNIVERSITY OF AUCKLAND NEW ZEALAND | ENGINEERING

Criticality of Auckland's Road Network
BE(Hons) students: Kester Rebello and Karan Jaggi
Supervisor: Costello

urban

South Island Road Network Resilience Assessment
PhD Student: Mohammad Aghababaei
Supervisors: Costello and Ranjitkar

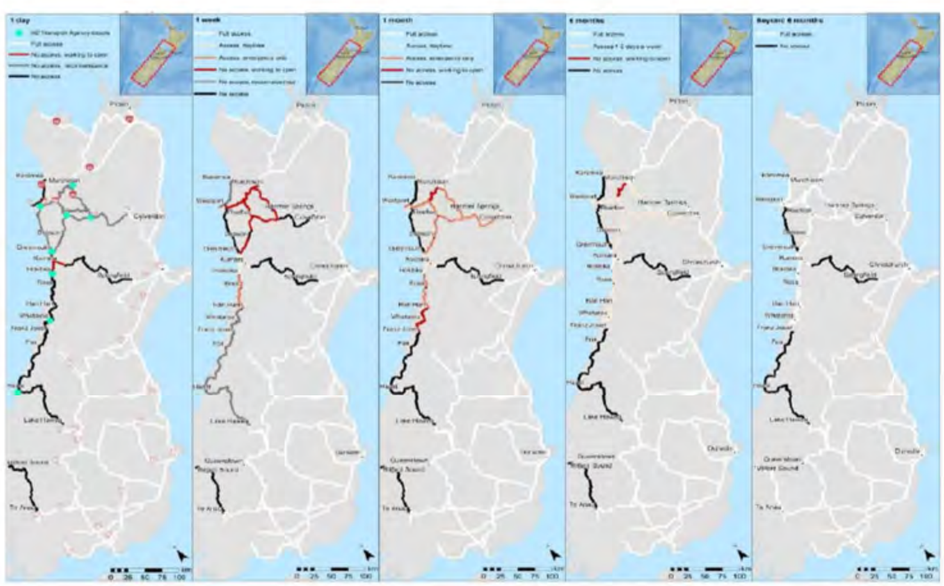
infrastructure

Auckland Mass Evacuation Travel Time Model
PhD Student: Mujaddad Afzal
Supervisors: Ranjitkar and Costello

infrastructure

AF8 Scenario

THE UNIVERSITY OF AUCKLAND NEW ZEALAND | ENGINEERING

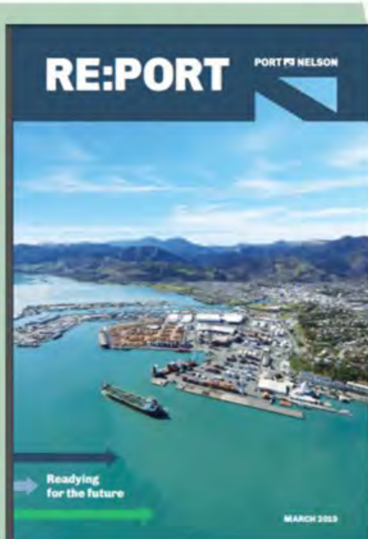


Source: Davies (2019) and Davies et al. (2021).

As part this, the impacts of bridge outages have been considered.

Creating resilient rural value chains in the 'Top of the South' (Lincoln University and Manaaki Whenua Landcare Research)

Port of Nelson: enhancing resilience



- Working to develop innovative wine logistics solutions in close consultation with wine industry
- Re-thinking transport logistics
  - Reduced truck journeys by more than half between Nelson & Marlborough
  - cut time trucks on road by 10,000 hours
  - Saved 348,436 litres of fuel; 1,602 tonnes of CO_2 equivalent in first year

National Science Challenges | RESILIENCE TO NATURE'S CHALLENGES

Future research


RNZ

Resilience in tourism. Lessons learned from Kaikoura

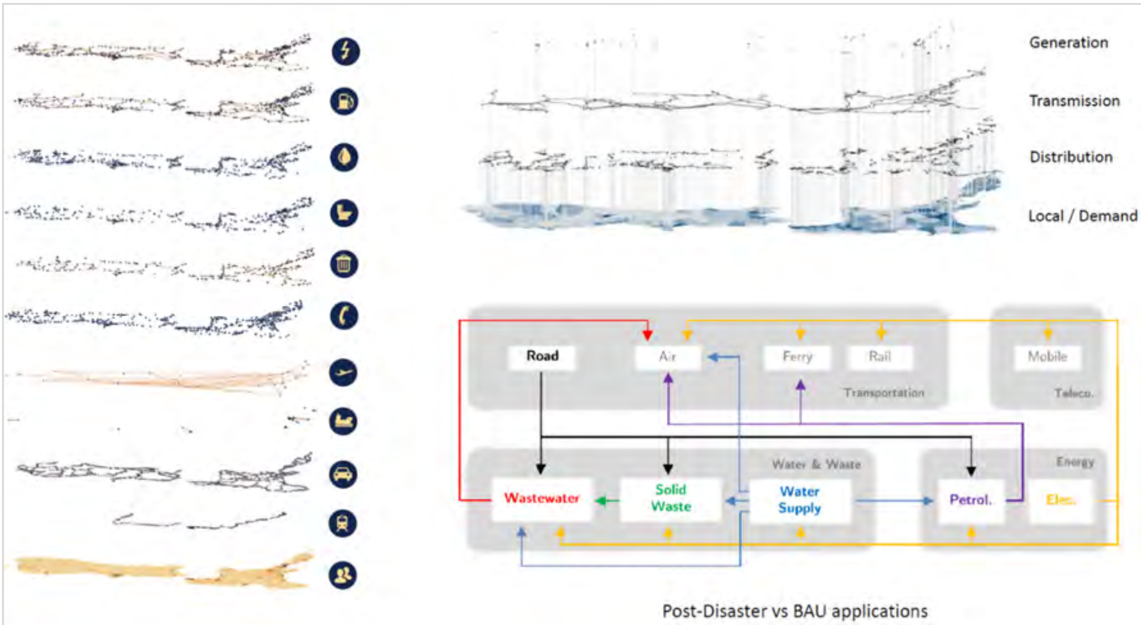
- Build on existing networks and knowledge
- Share results – within and beyond community
- Explore barriers to transformation community and businesses:
  - Scale of operations; Structures of decision making
  - Value chains between producers → hospitality

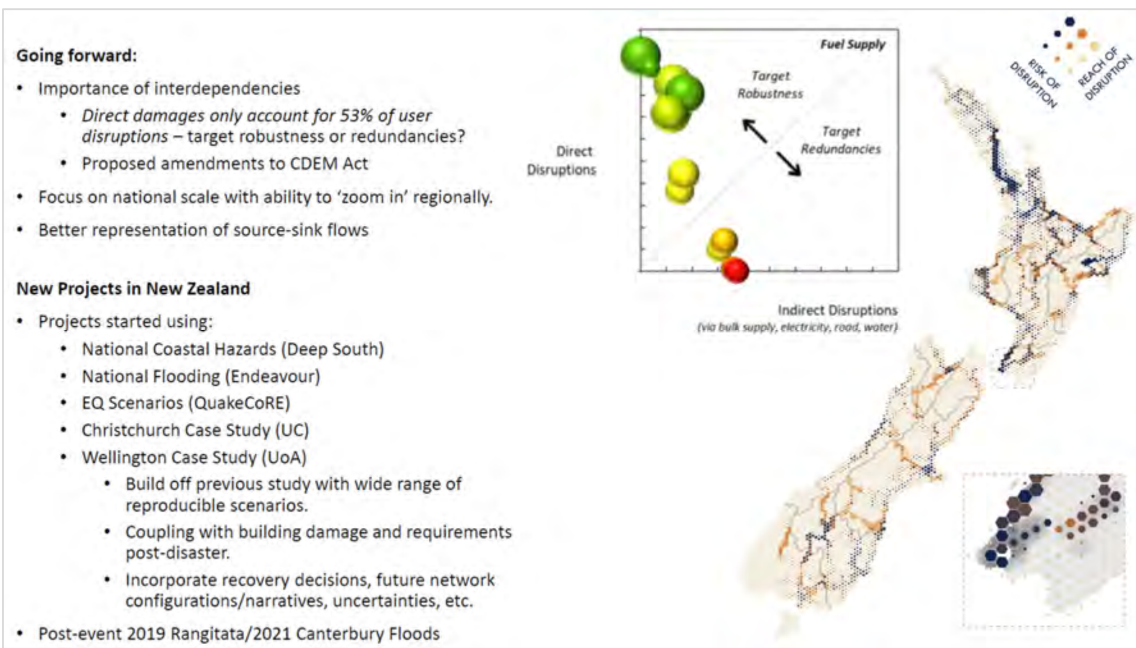
- Cradock-Henry, N., Fountain, J. & Buelow, F. (2018) 'Transformations for resilient rural futures: The case of Kaikōura, Aotearoa-New Zealand', *Sustainability,* **10**, 1952. https://doi.org/10.3390/su10061952

National Science Challenges | RESILIENCE TO NATURE'S CHALLENGES

Interdependent Infrastructure Projects

(Spans across RNC, QuakeCoRE, AF8, Deep South, NIWA, Universities of Canterbury and Auckland, Conrad Zorn et al).



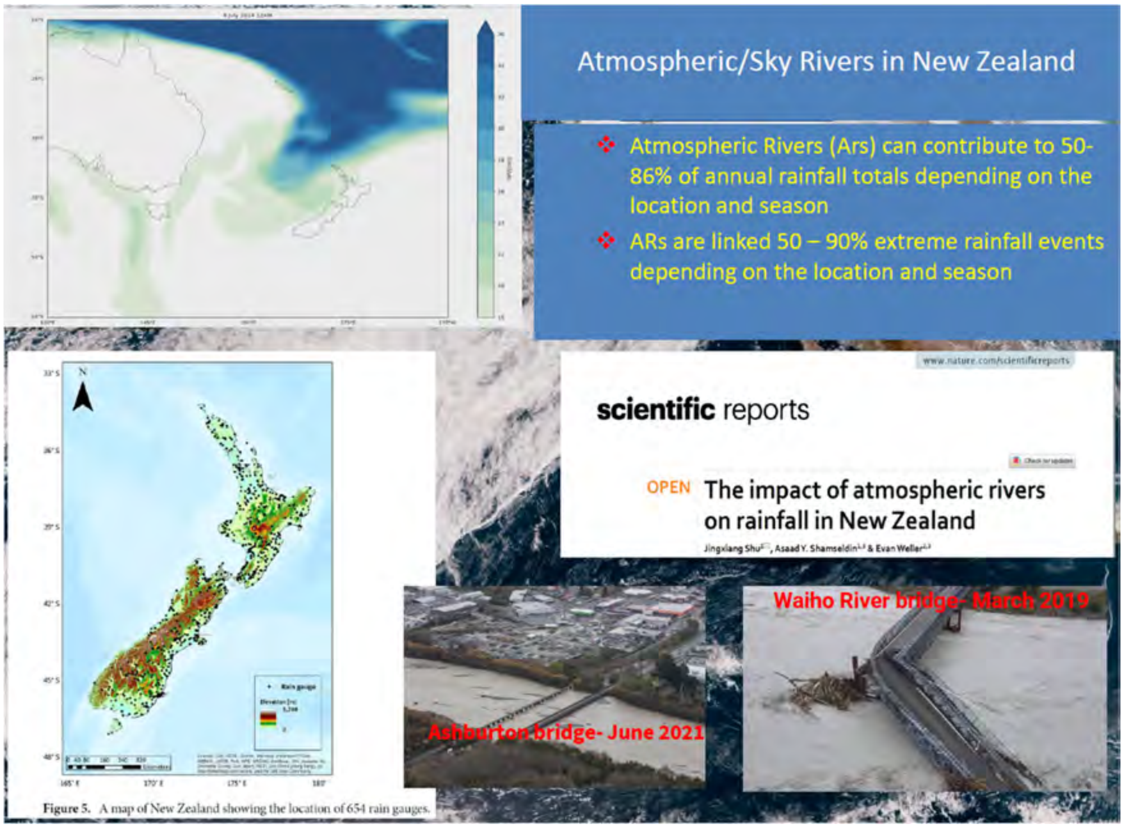


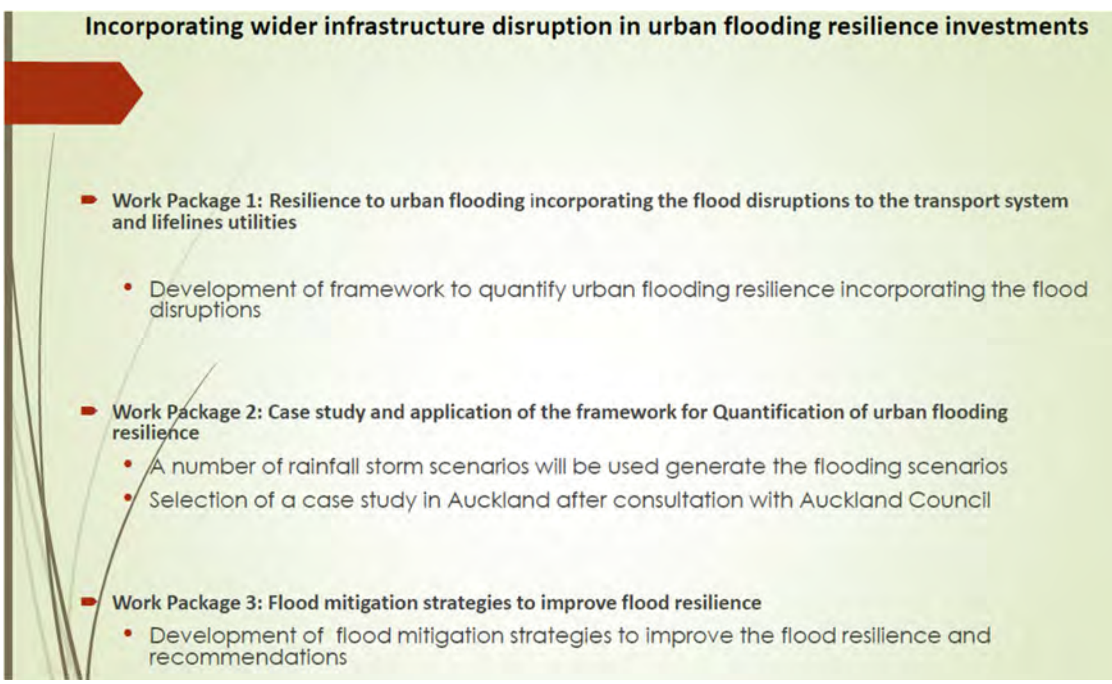
This work builds on a deep body of data held by the two universities involved.

It considers "business as usual" scenario with a "what if "scenario. Note that both the 2019 Rangitata and May 2021 floods have been assessed.

Stormwater Research

Work being carried out at the University of Auckland is addressing atmospheric impacts on rainfall and disruption impacts in terms of mitigations to improve urban flooding resilience.



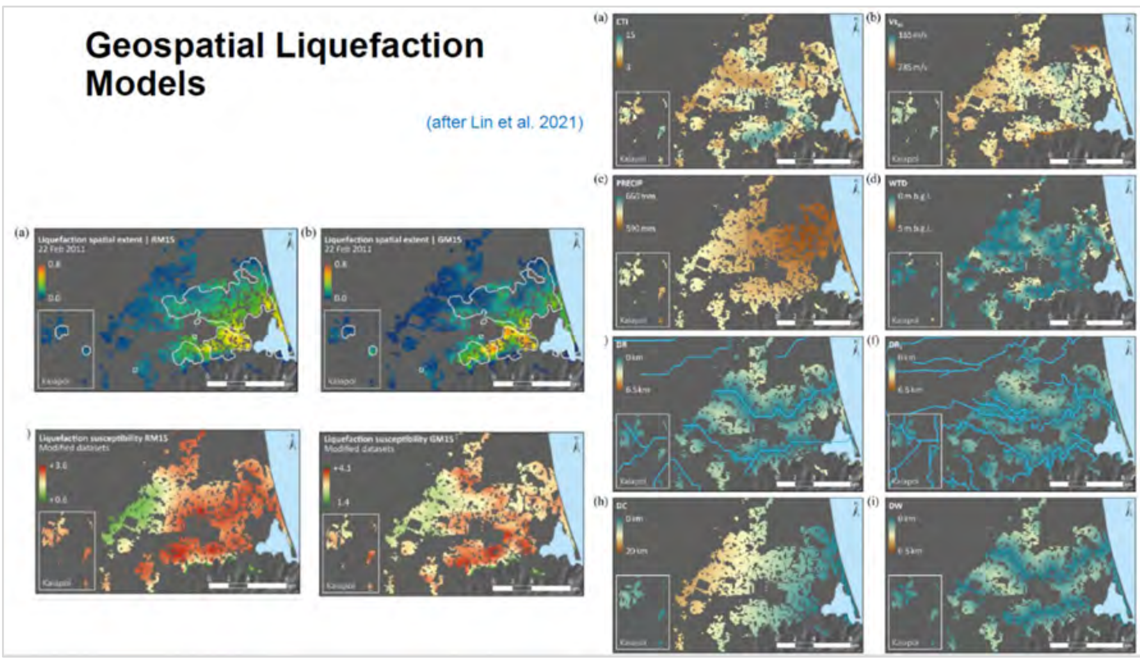


Relevance – rainfall events causing flooding of Canterbury rivers and towns

Integration of Geospatial and Focussed Liquefaction Tools for Regional Assessments

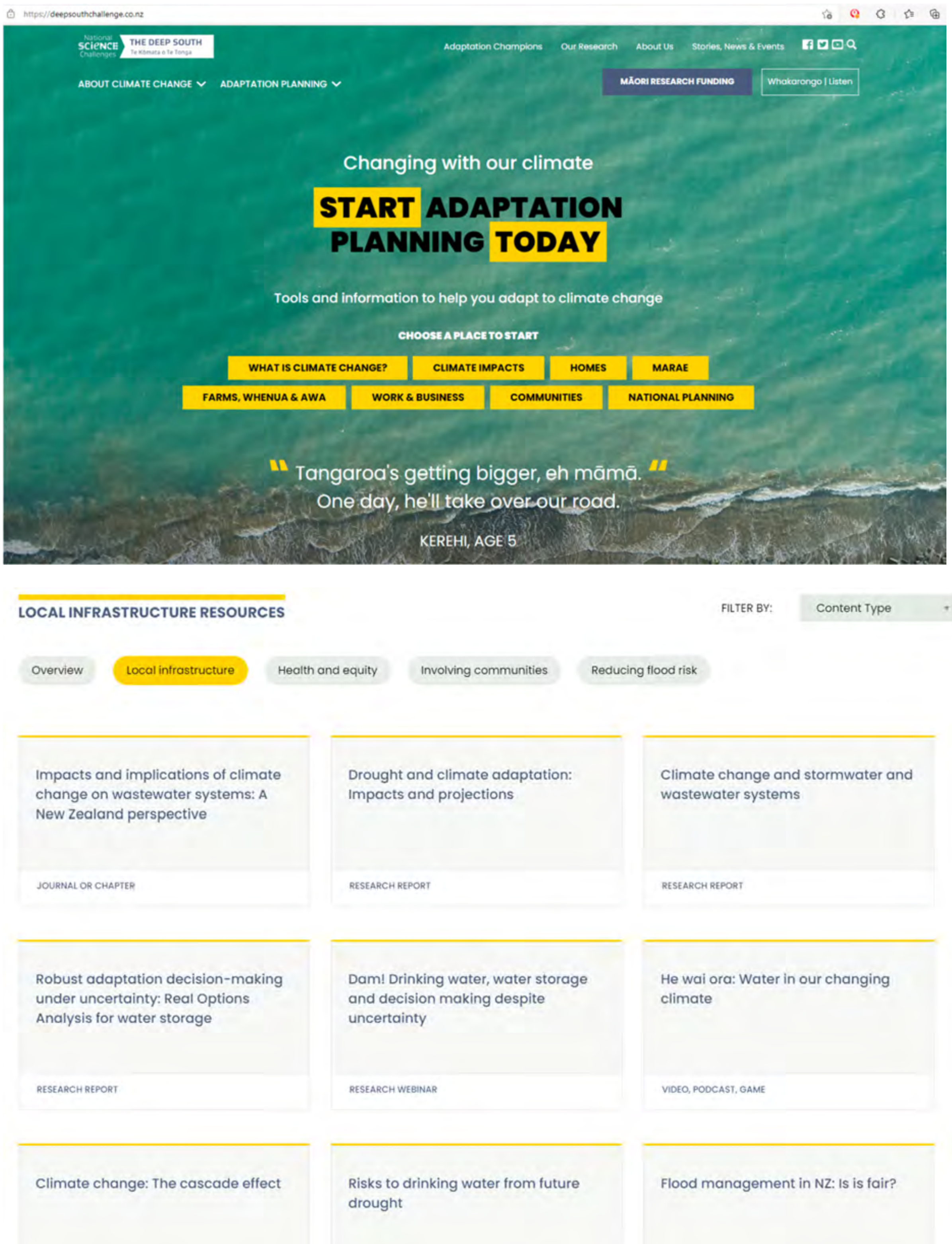
This is a new research project with the following objectives:

- This project will attempt to integrate geospatial data and available liquefaction tools to develop robust models not only for assessing liquefaction extent in a region but also the severity of liquefaction induced damage
- Moreover, common ground motion intensity measures (e.g. PGA, PGV, SI, etc.) will be examined to identify the most applicable intensity measure to use.
- While the models will be largely based on the data and lessons from CES, other problematic soil deposits in NZ, such as:
    - the pumice rich deposits in central North Island
    - the gravelly soils in Blenheim (Marlborough Region)
- Recommendations on the use of the model to wider NZ setting will also be formulated.



Deep South

(refer https://deepsouthchallenge.co.nz/)



RESEARCH REPORT

RESEARCH REPORT

RESEARCH WEBINAR

How should the risks of sea level rise be shared?

RESEARCH REPORT

Sea level rise + big storms: What exactly are we in for?

RESEARCH WEBINAR

How exposed are we to river flooding?

RESEARCH REPORT

How exposed are we to coastal flooding?

RESEARCH REPORT

Stormwater, wastewater and climate change: Impacts on our economy, environment, culture and society

RESEARCH REPORT

Supporting decision making with adaptive tools

RESEARCH REPORT

The added value of real options analysis for climate change adaptation

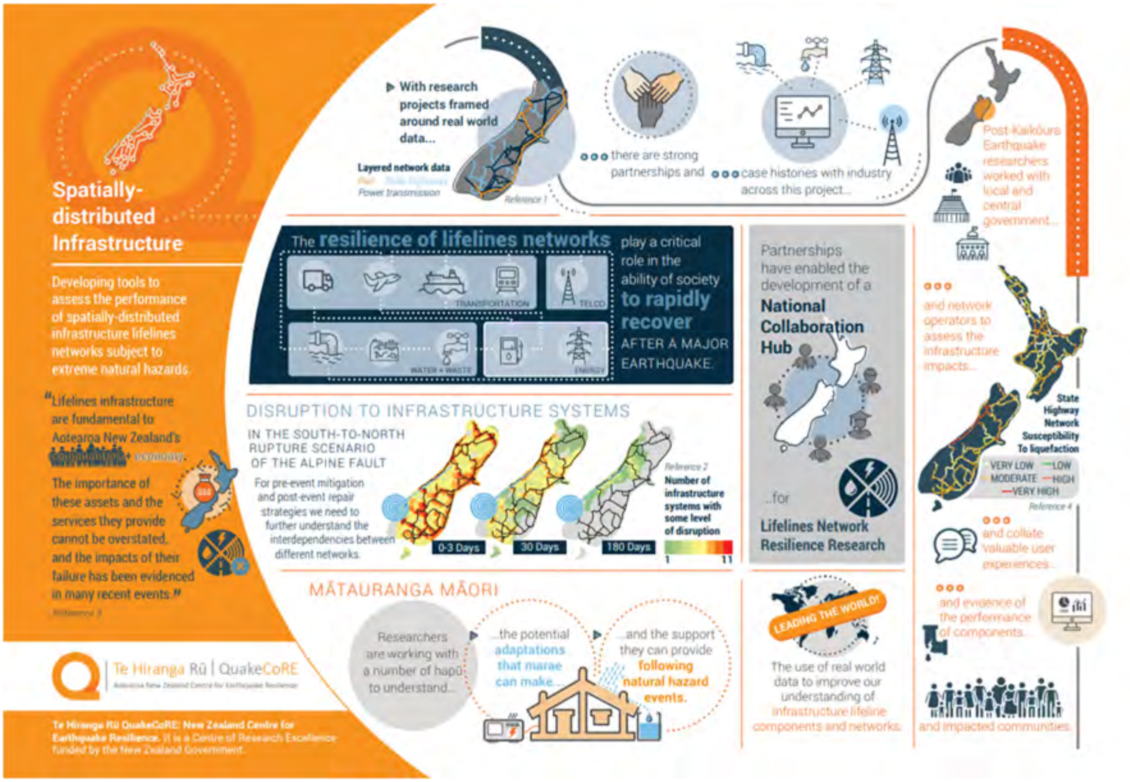
JOURNAL OR CHAPTER

Enhancing drinking water in remote Māori communities

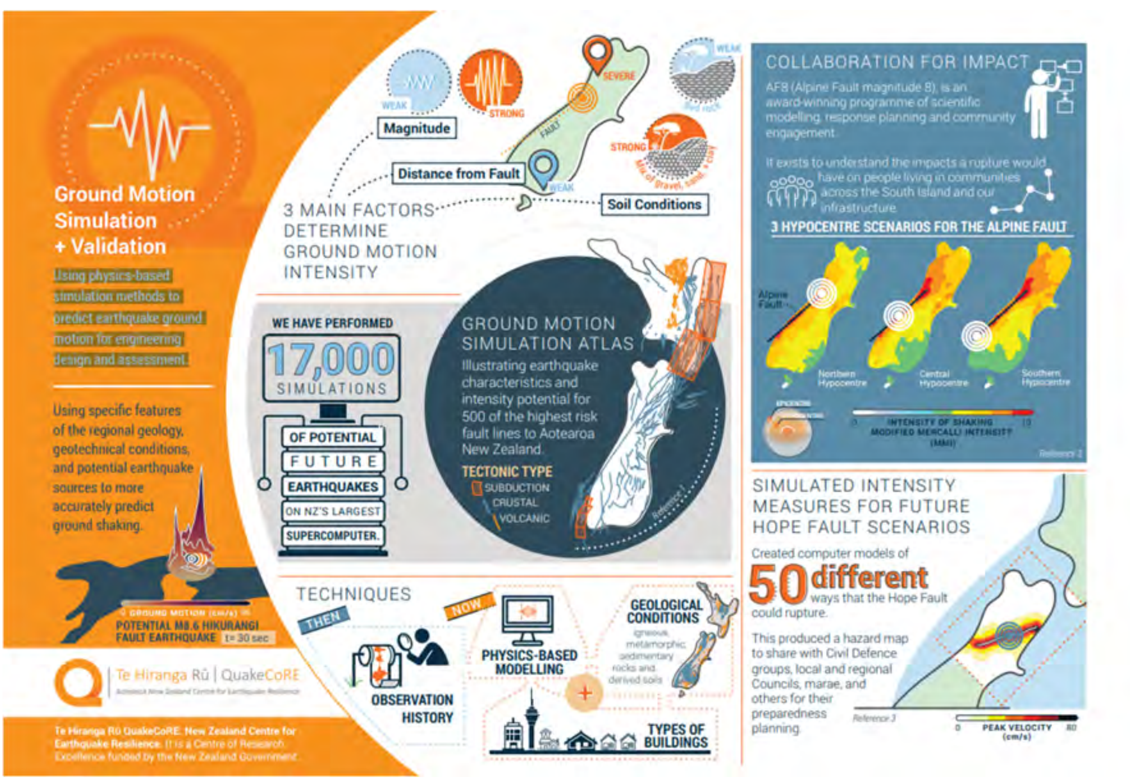
JOURNAL OR CHAPTER

QuakeCoRE

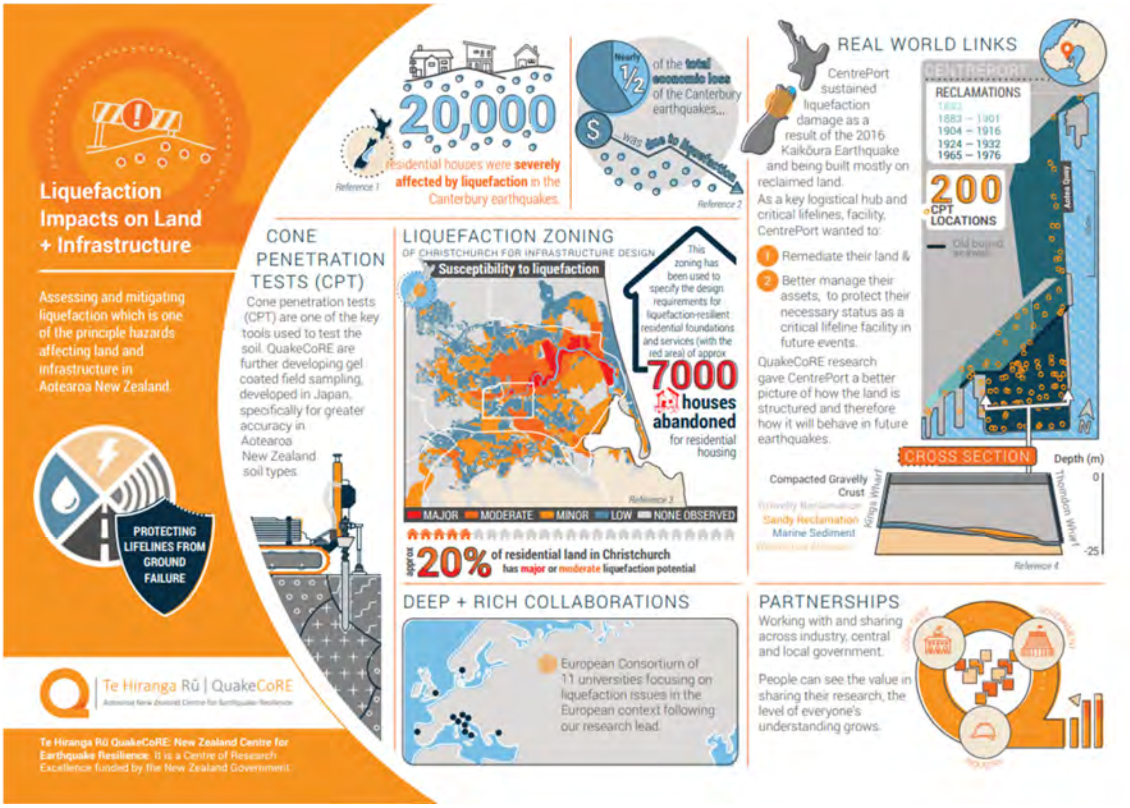
Spatially distributed infrastructure



Ground motion simulation and validation



Liquefaction impacts on land and infrastructure



Pathways to improved resilience

IP3: A Resilient NZ Transport System

Being co-led by Liam Wotherspoon of UoA, Charlotte Brown of ResOrgs, Tim Sullivan at UC.

A resilient transport and logistics system is critical to the ongoing and future viability of businesses and communities across the country, supporting the efficient movement of goods and people. This programme will integrate component- and system-level modelling of networks and their users, consider interaction between different transport and logistics modes, and the social and economic impacts of disruption, to inform policy and investment decisions on the transport and logistics systems of the future.

There are three key activity areas:

- Transport as-a-service system modelling:
    - Assessment of the performance of transport hub components and systems.
    - Computational modelling-based fragility models for transport system components.
    - Complete framework for national transport system seismic and co seismic geohazard exposure models.
    - Development of the first iteration of an integrated national transport network model
- Post-disaster logistics and resilient logistics networks:
    - Retrospective analysis of logistics impacts across past earthquakes.
    - Scoping study on the influence of changing consumer demands on logistics requirements.
    - Development of the first iteration national logistics models.
    - Synchro modality-based frameworks for post event logistics systems.
- Resilience investment decision making under uncertainty:
    - Review and evaluate current transportation system decision making processes.
    - Transport hubs resilience strategies and investment case study.
    - Explore transportation decision making and uncertainty.
    - Develop decision making processes that extend beyond business-as-usual benefits and fully evaluate the risk of new technologies and potential resilience dividends.

An example within the logistics area addresses *Intermodal freight transport in the wake of an earthquake: key enablers and existing barriers in New Zealand*. (Cécile L'Hermitte, University of Waikato and Liam Wotherspoon, University of Auckland)

Research focus

THE UNIVERSITY OF WAIKATO

- Earthquakes disrupt pre-existing transport networks and freight operations
  - To ensure supply chain continuity, freight operations are swiftly adjusted across modes
  - However, the factors influencing rapid modal shifts in the wake of an earthquake were not well understood

➡ The research aimed to identify the **key enablers** and **existing barriers** to the rapid reconfiguration of freight movements when an earthquake strikes

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Findings

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- Overall, this study highlighted:
  - The importance of building redundancies at all levels
    - Infrastructure (e.g. roads, seaports)
    - Modes
    - Equipment (shipping containers)
    - Safety stock (≠ reliance on just-in-time deliveries)
  - The need for a more integrated freight system in NZ
    - Use of shipping containers for domestic movements of goods
    - Standardised data format and for interoperable information systems

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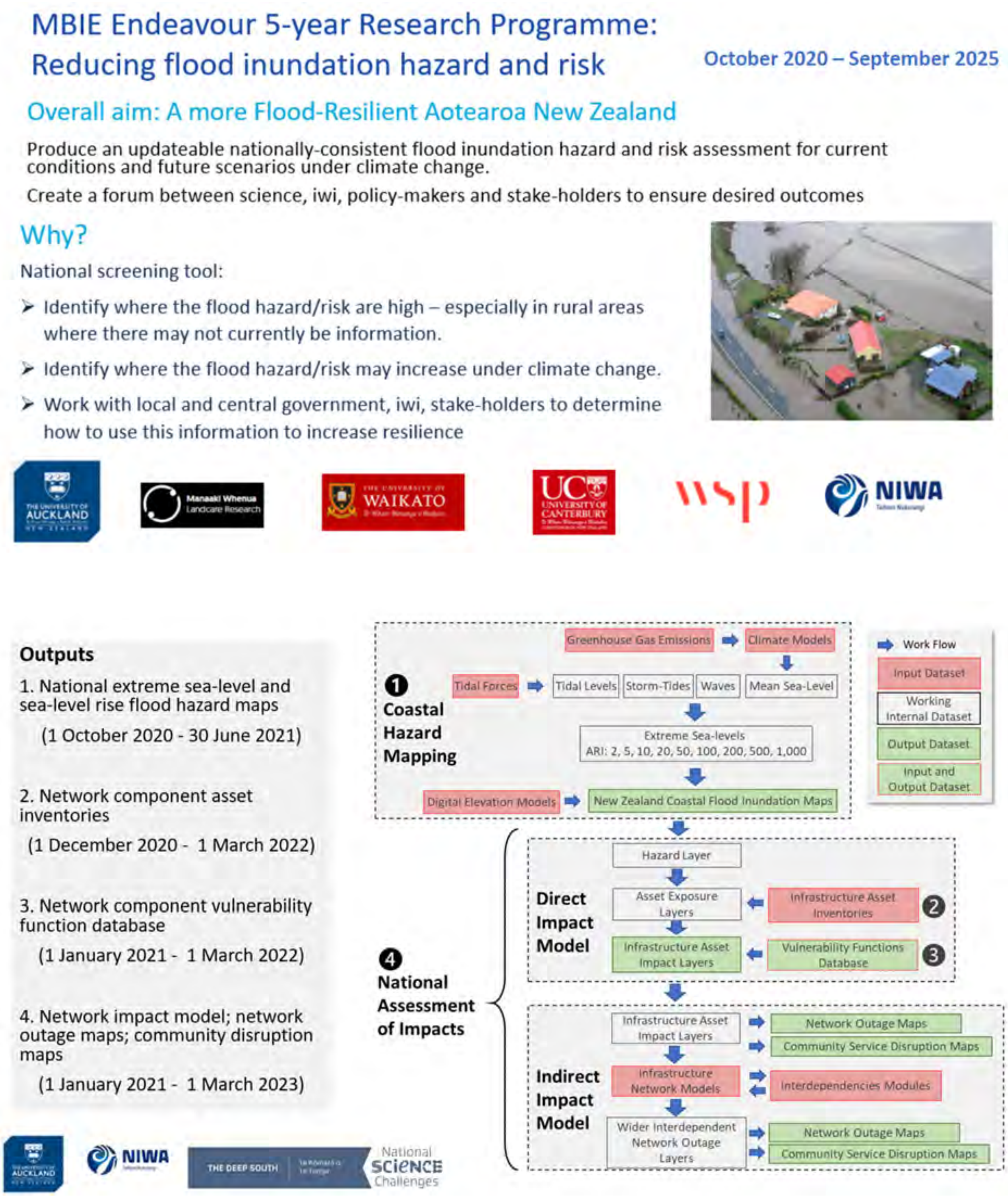
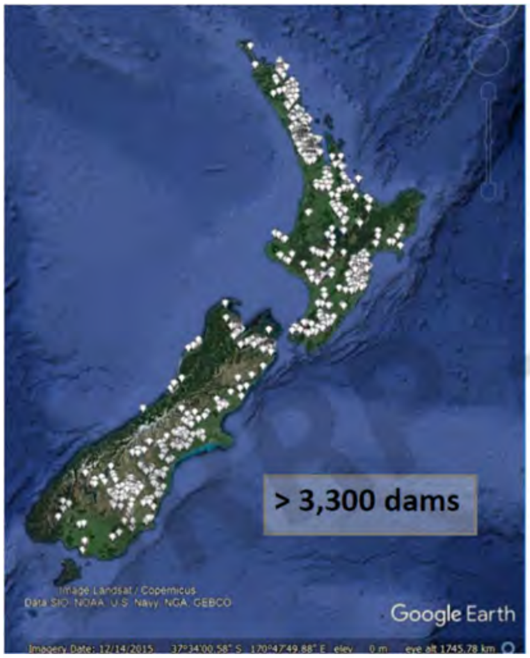
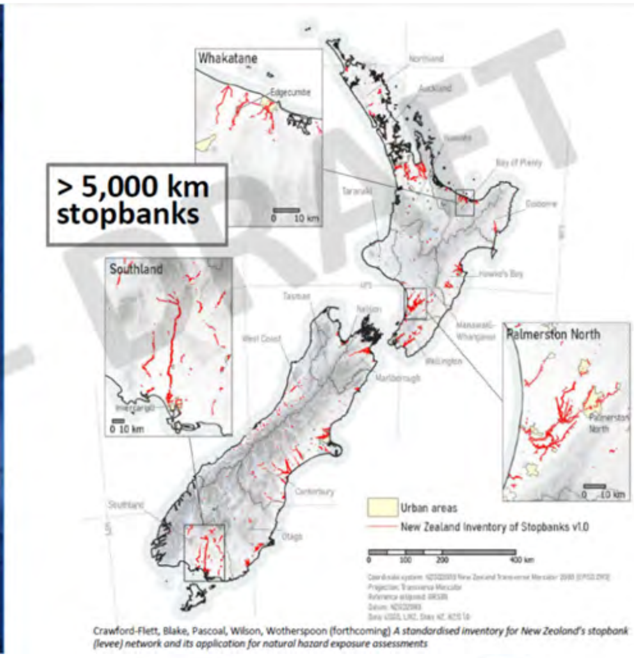
Endeavour Fund

Reducing flood inundation hazard and risk across Aotearoa (2020)

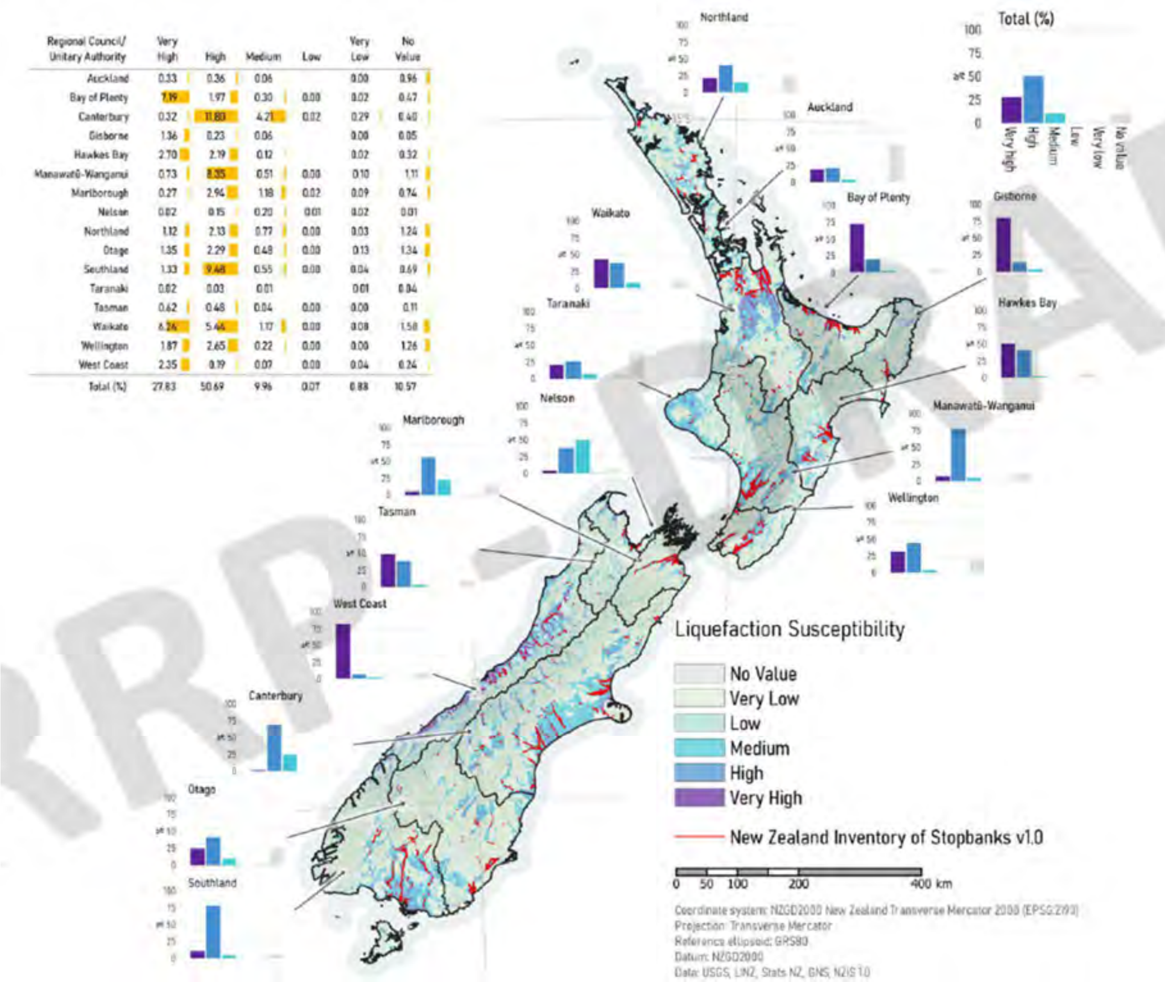


Dam and Stopbank Resilience



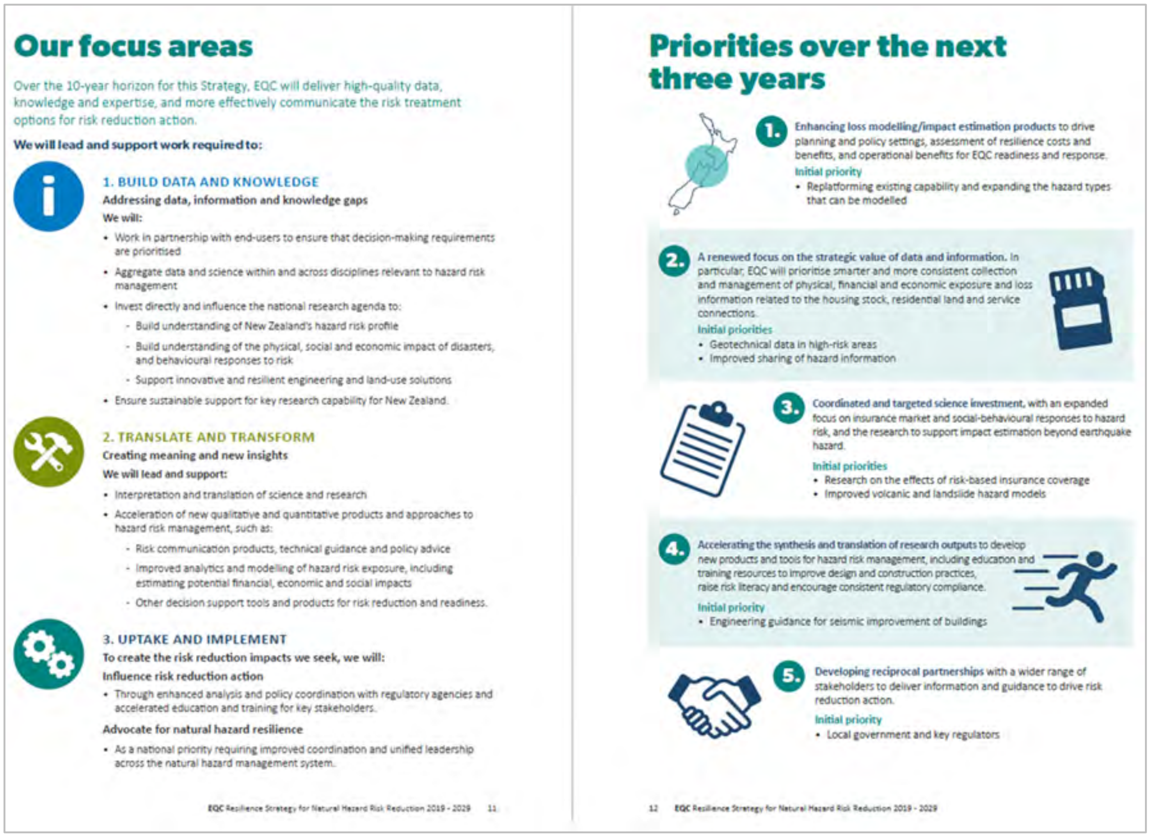


Crawford-Flett, Blake, Pascoal, Wilson, Wotherspoon (forthcoming) *A standardised inventory for New Zealand's stopbank (levee) network and its application for natural hazard exposure assessments*



Regional Council/ Unitary Authority	Very High	High	Medium	Low	Very Low	No Value
Auckland	0.33	0.36	0.06		0.00	0.96
Bay of Plenty	7.19	1.97	0.30	0.00	0.02	0.47
Canterbury	0.32	11.80	4.21	0.02	0.29	0.40
Gisborne	1.36	0.23	0.06		0.00	0.05
Hawkes Bay	2.70	2.19	0.12		0.02	0.32
Manawatū-Wanganui	0.73	8.35	0.51	0.00	0.10	1.11
Marlborough	0.27	2.94	1.18	0.02	0.09	0.74
Nelson	0.02	0.15	0.20	0.01	0.02	0.01
Northland	1.12	2.13	0.77	0.00	0.03	1.24
Otago	1.35	2.29	0.48	0.00	0.13	1.34
Southland	1.33	9.48	0.55	0.00	0.04	0.69
Taranaki	0.02	0.03	0.01		0.01	0.04
Tasman	0.62	0.48	0.04	0.00	0.00	0.11
Waikato	6.24	5.44	1.17	0.00	0.08	1.58
Wellington	1.87	2.65	0.22	0.00	0.00	1.26
West Coast	2.35	0.19	0.07	0.00	0.04	0.24
Total (%)	27.83	50.69	9.96	0.07	0.88	10.57

EQC Priorities



Our focus areas

Over the 10-year horizon for this Strategy, EQC will deliver high-quality data, knowledge and expertise, and more effectively communicate the risk treatment options for risk reduction action.

We will lead and support work required to:

1. BUILD DATA AND KNOWLEDGE

Addressing data, information and knowledge gaps

We will:

- Work in partnership with end-users to ensure that decision-making requirements are prioritised
- Aggregate data and science within and across disciplines relevant to hazard risk management
- Invest directly and influence the national research agenda to:
  - Build understanding of New Zealand's hazard risk profile
  - Build understanding of the physical, social and economic impact of disasters, and behavioural responses to risk
  - Support innovative and resilient engineering and land-use solutions
- Ensure sustainable support for key research capability for New Zealand.

2. TRANSLATE AND TRANSFORM

Creating meaning and new insights

We will lead and support:

- Interpretation and translation of science and research
- Acceleration of new qualitative and quantitative products and approaches to hazard risk management, such as:
  - Risk communication products, technical guidance and policy advice
  - Improved analytics and modelling of hazard risk exposure, including estimating potential financial, economic and social impacts
  - Other decision support tools and products for risk reduction and readiness.

3. UPTAKE AND IMPLEMENT

To create the risk reduction impacts we seek, we will:

Influence risk reduction action

- Through enhanced analysis and policy coordination with regulatory agencies and accelerated education and training for key stakeholders.

Advocate for natural hazard resilience

- As a national priority requiring improved coordination and unified leadership across the natural hazard management system.

EQC Resilience Strategy for Natural Hazard Risk Reduction 2019 - 2029 11

Priorities over the next three years

1. **Enhancing loss modelling/impact estimation products** to drive planning and policy settings, assessment of resilience costs and benefits, and operational benefits for EQC readiness and response.

Initial priority

- Replatforming existing capability and expanding the hazard types that can be modelled

2. **A renewed focus on the strategic value of data and information.** In particular, EQC will prioritise smarter and more consistent collection and management of physical, financial and economic exposure and loss information related to the housing stock, residential land and service connections.

Initial priorities

- Geotechnical data in high-risk areas
- Improved sharing of hazard information

3. **Coordinated and targeted science investment,** with an expanded focus on insurance market and social-behavioural responses to hazard risk, and the research to support impact estimation beyond earthquake hazard.

Initial priorities

- Research on the effects of risk-based insurance coverage
- Improved volcanic and landslide hazard models

4. **Accelerating the synthesis and translation of research outputs** to develop new products and tools for hazard risk management, including education and training resources to improve design and construction practices, raise risk literacy and encourage consistent regulatory compliance.

Initial priority

- Engineering guidance for seismic improvement of buildings

5. **Developing reciprocal partnerships** with a wider range of stakeholders to deliver information and guidance to drive risk reduction action.

Initial priority

- Local government and key regulators

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Quake Centre

Guideline for Assessing Technical Resilience of Three Waters Networks

This framework for assessing the technical resilience of three waters piped assets was published in December 2019.

Two methods are offered:

- Simplified – a qualitative assessment based on engineering judgement
- Advanced – a quantitative assessment based on analytical modelling with spatial assessment capability to estimate damage and network consequence.

Some information is provided below, extracted from this report.

Table 1: Relative damage factors for earthquake scenarios for pipe normalised to PVC.

Pressure Pipe Type	Simplified relative damage factors for earthquake scenarios for pressure pipe normalised to PVC					
	Wave Propagation	Ground Deformation				
	No Liquefaction	Low	Minor	Moderate	Major	Severe
Ground Settlement	-	<0.02m	0.02m – 0.10m	0.10m – 0.25m	0.25m – 0.50m	>0.5m
Lateral Displacement	-	<0.02m	0.02m – 0.05m	0.05m – 0.20m	0.20m – 0.40m	>0.4m
Thickness of Liquefied Layer	-	-	2m - 4m	4m - 8m	5m - 10m	5m - 10m
Pressure Network						
Polyethylene (LDPE, MDPE & HDPE, <50mm dia)	0.10	1	1.5	3	4	5
Polyethylene (MDPE & HDPE, >50mm dia)	0.01	0.5	1	1	1.5	2
Polyvinyl Chloride (PVC)	0.05	1	1	1.5	2	3
Ductile Iron	0.05	1	2	4	5	7
Steel	0.10	1	1	2	3	5
Wrought Iron	0.15	2	3	5	7	9
Cast Iron	0.20	1	2	4	5	7
Asbestos Cement	0.30	3	4	6	7	10
Galvanised Steel (<50mm dia)	0.35	5	7	11	15	20
Gravity Network (Suggested initial values - in need of further research)						
Polyethylene	0.01	1	2	3	4	6
Polyvinyl Chloride (PVC)	0.05	4	7	10	15	20
Asbestos Cement	1	25	35	60	80	110
Reinforced Concrete Rubber Ring Jointed	3	50	60	90	110	150
Earthenware	10	250	300	450	550	800

Note:

- For gravity networks not all defects affect post disaster functionality and/or require remedial. Damage factors to be reduced based on proportion of damage expected to require repair/ replacement.
- Provided as an example, to be refined considering the characteristics of the network materials, construction quality and age.

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Table 2: Example of simplified pipe criticality rating for different pipe network type and diameter.

Network Type	Pipe Diameter	Simplified Asset Criticality Rating
Pressurised	<50mm	1
	50-100mm	2
	100-150mm	3
	150-200mm	7
	200-300mm	20
	>300mm	50
Gravity	≤100mm	1
	100-150mm	2
	150-300mm	3
	300-600mm	7
	600-900mm	15
	900-1200mm	25
	>1200mm	50

Table 3: Example of definition of Equivalent Standard Customer for different stakeholders within a community.

High Demand Customer	Number of Equivalent Standard Customers
Hospital	1000 - +5000
Medical Centre	150
Rest Home/Aged Care Facility	100 - 500
School/Preschool	20 - 200
Emergency Services/Civil Defence	500
Marae	10 - 50
Local/ Regional Government	20 - 100
Airport	100 - 1000
Port	100 - 1000
Industry * >1000 employees	300
Industry * >300 employees	30
Industry * >100 employees	10
Industry * >10 employees	5
Commercial Business >300 employees	30
Commercial Business >100 employees	10
Commercial Business >10 employees	3
Food Distribution Organisation (e.g. supermarket)	50
Townhouse/Apartment Complex	No. units within complex
Vulnerable Community Members (aged, chronically sick, disabled, etc.)	5
Standard Residential Property	1

* Industry that is reliant on three waters operation to manufacture/process.