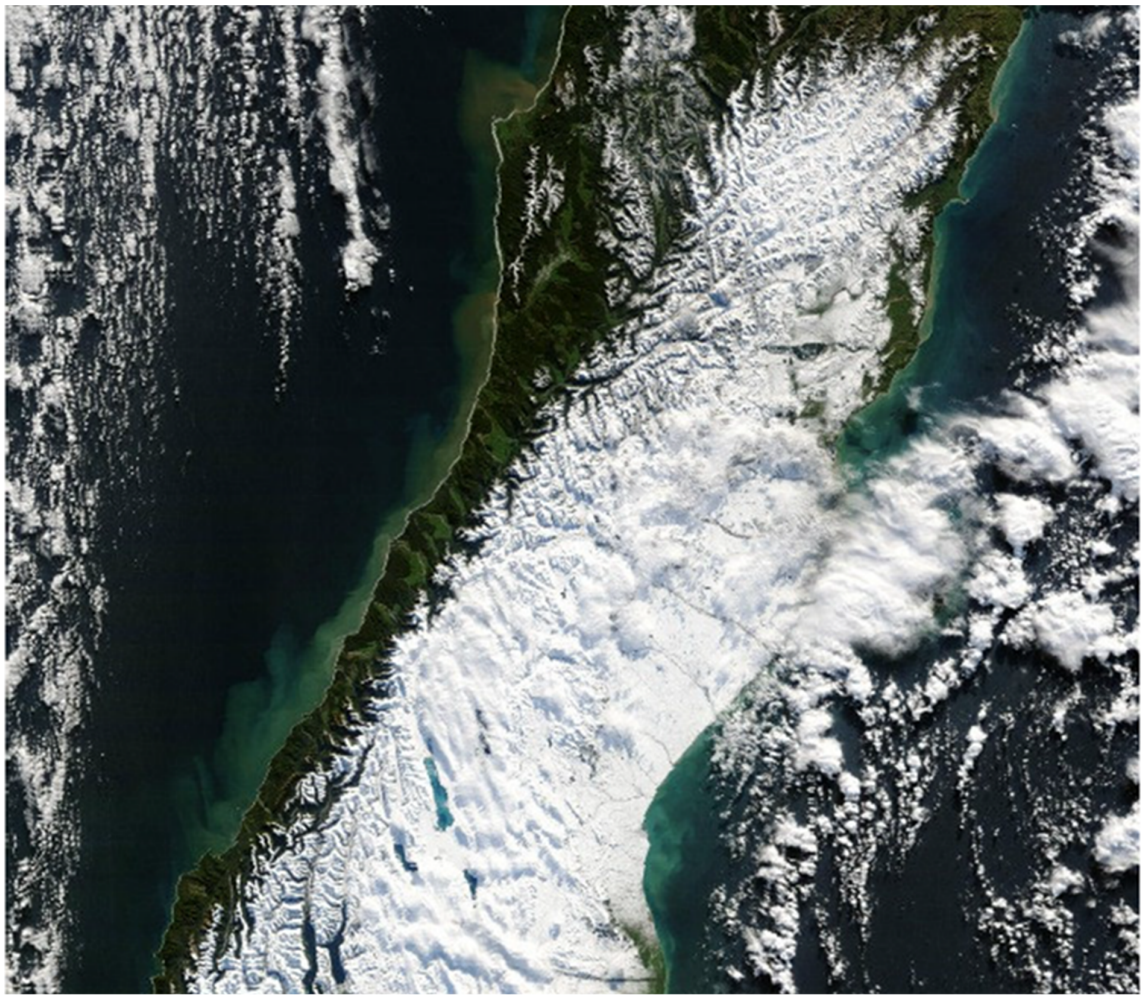
Risks and Resilience

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

Maturity Pathway 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), Executive Summary.

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 Regional Lifelines programme business case" approach[1].

Using the Canterbury region and Lifelines Group as a pilot, 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, using impact assessment tools such as RiskScape and 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 Describe Integrated Approach, Tasks 5 and 6 of the NEMA Resilience Fund application, being:

- **Task 5:** Describe the features and approaches of a "maturity-based" pathway from "core" vulnerability assessment work through "intermediate" to "advanced" practice incorporating tools such as MERIT and RiskScape. Describe how the above resources would be connected with the ECan Lifelines GIS portal and how they could be used by practitioners at different maturity levels and what to expect out of them.
- **MILESTONE 2 - Task 6**: Produce report describing the "Integrated Approach" and recommendations for application at different maturity levels.

[1] Refer to https://www.wremo.nz/assets/Uploads/191111-Wellington-Lifelines-PBC-MAIN-20191009.pdf

2.0 Maturity Approach

2.1 "Maturity" Themes

In this section, the themes of a "maturity-based" pathway from "core" vulnerability assessment work through "intermediate" to "advanced" practice incorporating research-based resources and existing tools such as MERIT and RiskScape are described.

This approach is intended to be similar conceptually to the asset management maturity approach described in the International Infrastructure Management Manual (IIMM). Three intermediate levels are proposed – "low", "medium" and "high", and it is expected that this initial view of the maturity pathway will evolve and improve over time and with experience, both as this project proceeds and in the future.

2.1.1 Overview

The following diagram provides an illustrative view of the concept. "Core" practice is shown in the bottom left, with "intermediate" practice progressively pulling in more detail from the research space and making more use of available tools. "Advanced" practice, such as the Wellington Programme Business Case, is at the top right of the diagram. Here, resilience mitigation interventions are coordinated across sectors, evaluated and prioritised in a Programme Business Case.

In practice, application can become increasingly sophisticated over time, given more granularity around inputs and improvements in research and tool capability. To some extent increased sophistication and complexity incurs more cost, however, increasingly tools are being developed to streamline and automate assessment processes to reduce costs. Complete automation is some time away. The intent at the lower levels is to obtain "quick, cost-effective wins".

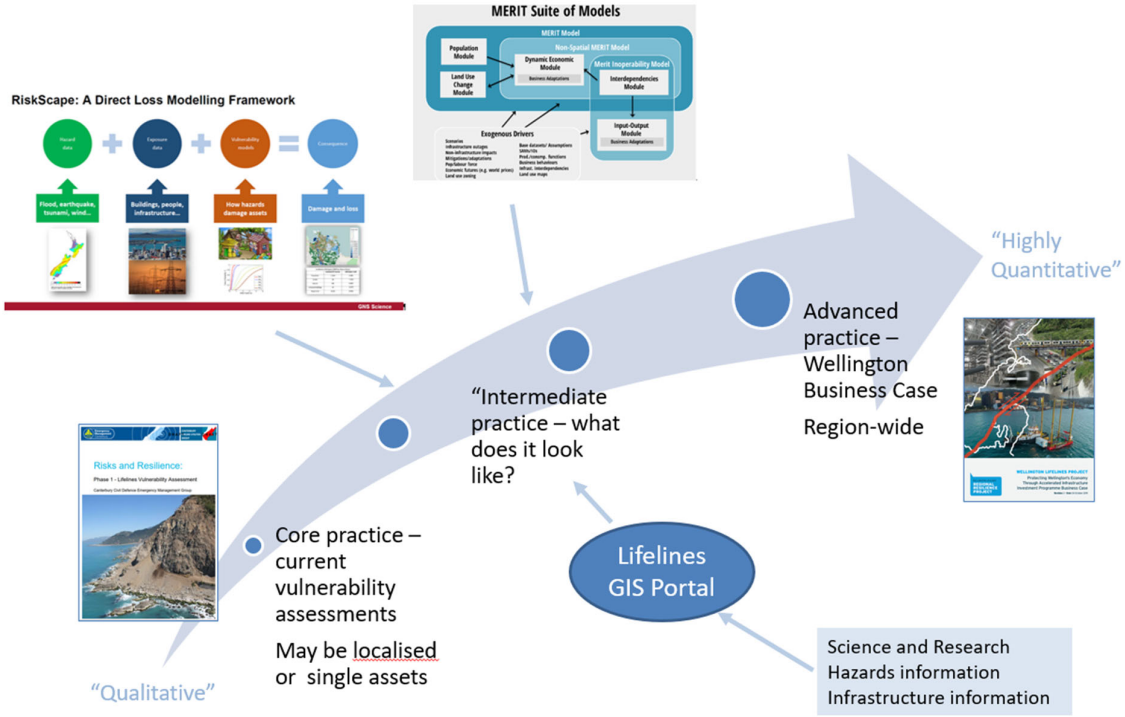


Figure 2-1 Maturity Pathway

2.1.2 Features of Core Practice

Typical features:

- Vulnerability assessments – may be spreadsheet or GIS based
- Multiple natural hazards approach using national, regional or local datasets at a generally broad level
- Critical "Community sites" identified and mapped – such as hospitals, Police, Fire, FMCG, Corrections, etc
- Critical infrastructure assets identified and mapped – at up to 4 levels, local to national, but not necessarily reflecting importance to the lifeline utility and its customers
- Exposure of lifelines infrastructure and community sites to natural hazards identified and mapped with damage severity categorised at up to 5 levels[2]
- Extent of service impact, also up to 5 levels[3], and duration of service impact described, but not specific levels of service
- Timeframes for restoration of service described, but not to what levels or stages
- Assessment typically qualitative with input by LLU staff
- Interdependencies matrix to 3 levels[4] plus identification of hotspots and pinchpoints, but not cascading failure
- Typically identify types of mitigations to reduce the risk, the impacts, or degree of severity – but not the costs involved nor priorities / justification / evaluation
- Use of GIS – increasingly being used for mapping, overlay of hazards and infrastructure, etc
- Limited application of modelling tools and processes, and typically carried out for a single infrastructure type but not across multiple types

The current typical process is captured in the following diagram. This approach is traditional, and a largely qualitative assessment.

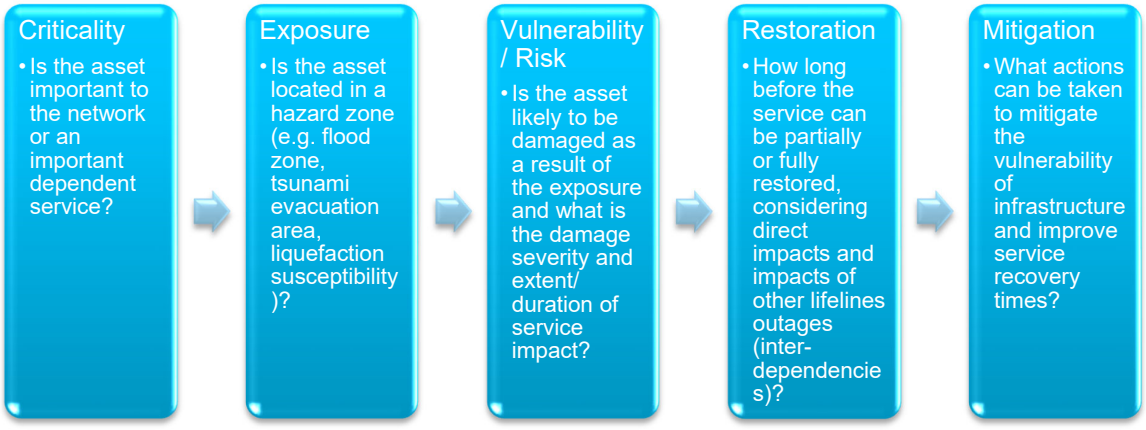


Figure 2-2 Core Practice Typical Approach

In addition, a range of other lifelines projects typically comprise "core practice", such as Priority Routes and Sites.

[2] 1 = unlikely to cause damage through to 5 = complete failure with reconstruction likely to take months/years
[3] 1 = minimal impact (<500 customers) through to national impact (>100,000 customers)
[4] 1 = minimal requirement, 2 = important but can partially function, 3 = required for service to function

2.1.3 Features of Intermediate to Advanced Practice

Typical features are as for Core, plus:

- More detailed hazard information, which may be highly granular – for example, liquefaction probability based on ground conditions on a 10m x 10m grid
- Capacity to model multiple hazards and cascading failures.
- Detailed physical attribute data-sets relating to infrastructure exposed to the hazard(s) – may include asset characteristics such as material type, condition, age, etc. that affect the asset's vulnerability to the hazard and associated levels of damage
- Detailed, granular damage levels and service outages data relating to each hazard event – including spatial extent, duration, recovery timeframes
- Service disruptions and restoration timeframes account for interdependencies and post-event restoration priorities and resource constraints
- Disruption impacts relating to the hazards and damaged infrastructure above are quantified – such as business interruption, relocation, displacement of populations
- Social impacts are considered – including distributional equity of impacts and impacts on particular cultural, Māori and other ethnicities or social groups.
- Economic analysis of impacts carried out and the impact on GDP determined
- Risk loss modelling based on well-developed data-sets above – using sophisticated tools such as RiskScape to model damage to infrastructure drawn also from asset replacement costs data
- Application of business case principles – "strategic case" or "programme case" including sequencing of investment
- Development of investment / mitigation scenarios – with cross sectoral coordination
- Investment plans / programmes reviewed and updated to reflect overall resilience priorities
- Benefits of interventions assessed in terms of reduced GDP impact and/or social, cultural, environmental impacts
- Consideration of uncertainty – in particular how changing hazard landscapes and community physical, social and economic structures impact today's investment prioritisation.

2.1.4 Maturity Pathway Themes

In developing the maturity pathway, a number of tools and resources were identified in the scanning stocktake. They, and their potential application in improving on core practice, are grouped under the following themes, also reflecting the features above. Note that there is a degree of inter-relatedness between them, and each can exist at different levels of maturity.

- Improving understanding of hazards and climate change and their potential impacts, including cascading or co-occurrent hazards (e.g. flooding following a major earthquake).
- Enhancing and expanding the application of GIS and the level of detail relating to hazards, infrastructure networks, and sites of social, community, or economic significance, within the GIS.
- Improving the assessment of physical damage to infrastructure in relation to hazard scenarios.
- Quantifying / modelling the effects of interdependencies between lifeline infrastructure networks, including the effects of cascading infrastructure failure (e.g. damage to a bridge also breaks the fibreoptic cable on the bridge).
- More granularity and clarity around how damage to infrastructure networks due to natural hazards and climate change impacts on levels of service and the extent and scale of disruption.
- The infrastructure recovery pathway – given the above information, how might the various networks be restored, what are the interdependencies in recovery, and how this links to levels of service at different periods following the event.

- This then leads into social and cultural impacts assessment related to level of service disruption at different points in time, from the occurrence of the event through to eventual recovery.
- Assessment of the economic impacts of service disruption to communities – from an initial snapshot through the recovery process to a new equilibrium.
- Leading on from the various assessments above, the application of loss modelling to relate the level of physical damage to infrastructure to financial losses and the costs of recovery.
- Integrated economic evaluation – the integration of social and economic impacts assessment and infrastructure loss modelling
- Mitigation, solutions and business case development, using the results above in developing alternative scenarios for infrastructure mitigations, carrying out risk assessments, evaluating and justifying the investments required, determining preferred options for funding purposes.

These are summarised in the figure below with the primary "delivery" mechanism highlighted by colour. Further description is provided in subsequent sections.

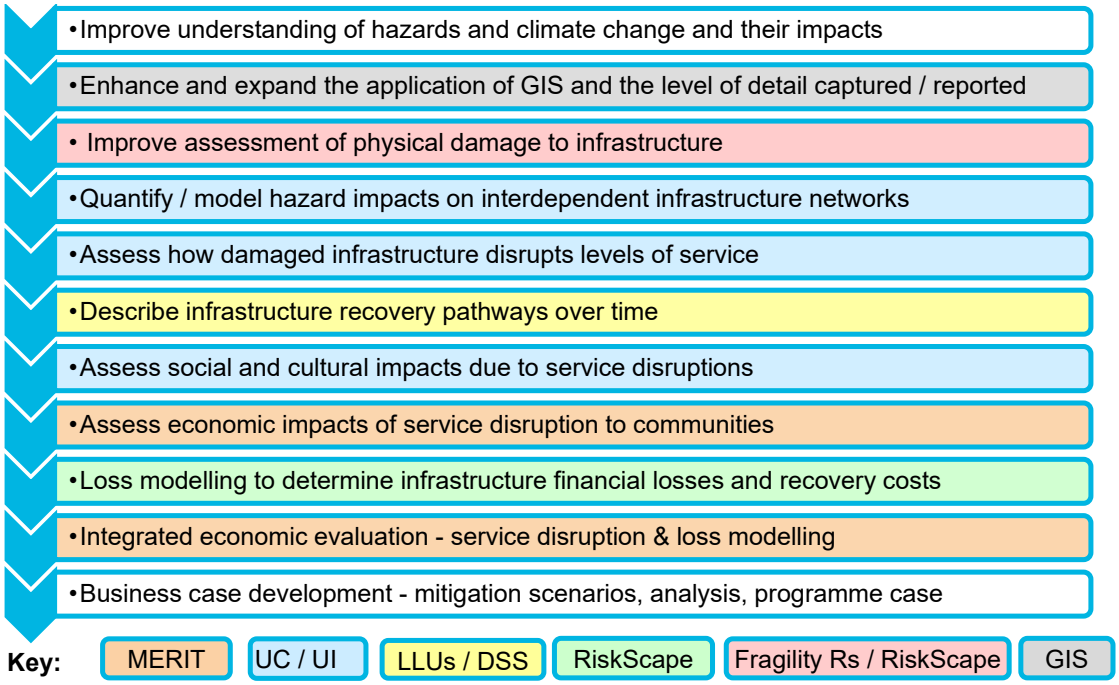


Figure 2-3 Features of the Maturity Pathway

Note that *"Assess how damaged infrastructure disrupts levels of service"* and *"Describe infrastructure recovery pathways over time"* are intertwined as both damage and the recovery path will feed into levels of service.

2.1.5 Data Needs

Each of the above themes has particular data needs, both for hazards and infrastructure networks, typically these become more comprehensive with increasing maturity level. At lower levels, there is likely to be a greater level of uncertainty with more assumptions being made than at higher maturity levels.

A parallel maturity pathway for data therefore also needs to be developed – this will be completed as part of the next phase relating to data schema and reported on in the Milestone 3 report.

2.1.6 Lifeline Utility Resilience Initiatives

It is recognised that many lifeline utilities have advanced their own resilience work, often in collaboration with the research sector and associated University programmes. Examples include:

- Collaboration between Christchurch City Council and the University of Canterbury / Urban Intelligence team
- Waka Kotahi NZTA's resilience planning work in relation to the state highway network
- Transpower's work in better understanding and planning for the impact of hazards (e.g. floods) on electricity transmission infrastructure

This work needs to be recognised in the pathway and built upon. What this project seeks to do is create a platform to facilitate collaboration across sectors, so as to coordinate resilience opportunities and investments for the benefit of the wider community.

2.1.7 Overview of Research Programmes

The following table summarises existing and completed research programmes described in Section 3 of the Scanning Stocktake report. Some additional content has been included here, for example, more details around completed Resilience to Nature's Challenges projects. Many of the programmes below are ongoing with the results to be absorbed at a later date.

Table 2-1 Science and Research Programmes

Research Programme	Summary	Comment
Resilience to Nature's Challenges – 2014-2019 programme	Included a wide range of themes, including Governance, Culture, Economics, Hazards, Infrastructure, and a range of Co-creation laboratories. Subject areas of particular interest relate to hazards and impacts on infrastructure.	Numerous papers are on the RNC web-site, most available for download. Many are not relevant to this project, or the information has been absorbed into other more recent or ongoing projects, but some do provide additional material.
Resilience to Nature's Challenges – Multi-hazard Risk Model (RNC-MRM) (refer Section 3.6.1 of the Phase 1 report)	Includes: • Multiple and cascading hazards, linking impacts to infrastructure • Volcanic event and cascading flooding hazard case study • MERIT enhancements • Embedding models within decision-making (e.g. mitigation investments) • Māori perspectives on risk	Informs hazards knowledge. Interfaces with MERIT and RiskScape. Note – UC, ResOrgs and Market Economics are involved in several of these initiatives. Completion 2024 – *"collaborate and watch".*
Resilience to Nature's Challenges – Resilience in Practice Model (RNC-RIPM) (refer Section 3.6.1 of the Phase 1 report)	Includes: • De-risking resilience – international knowledge • Building resilient futures – preparing for future risk • Enhancing resilience and wellbeing – social-ecological	Social, economic and cultural research that informs the impacts on people and communities. Likely to require a "how to operationalise" mechanism. Completion 2024 – *"watching brief".*
Resilience to Nature's Challenges – Specialist Programme Areas (RNC-SPA)	Includes: • Rural – improving social resilience	Several workstreams relevant, including Rural, Urban, Māori, Built as well as hazards. "Built" has potential to inform damage loss models.

Research Programme	Summary	Comment
(refer Section 3.6.1 of the Phase 1 report)	• Urban – improving urban resilience • Māori – improving awareness, decision-making, resilience • Built – horizontal, vertical, integrated – how infrastructure performs across hazards • Earthquake tsunami • Coastal – changing coastline, coastal flooding, coastal adaptation • Volcano • Weather and wildfire – modelling, scenarios, mitigation	Improves hazard knowledge, hazard modelling. Improving community resilience. Volcanism generally not of relevance to Canterbury. Completion 2024 – *"collaborate where relevant, watch, absorb later".*
Resilience to Nature's Challenges – "2021 Infrastructure Research Day" (refer Section 3.6.1 of the Phase 1 report) (Note – there may be overlaps / duplication between the projects reported here and other programme areas)	Includes: • SI Road Network Resilience Assessment (AF8) • Supply chain transport logistics • Atmospheric rainfall and Canterbury rivers • GIS integration of liquefaction and EQ	Various research areas where knowledge is available now – both hazards and infrastructure impacts – *bring these into maturity pathway where appropriate.*
	Includes: • Marae adaptations • Coastal and tsunami research • Interdependent infrastructure projects	Informs hazards and social impacts. Completion 2024 – *"collaborate where relevant, watch, absorb when appropriate".*
Resilience to Nature's Challenges – Deep South (RNC-DS): Local Infrastructure (refer Section 3.6.2 of the Phase 1 report)	Wide range of resources and information relating to climate change, coastal and river flooding, social impacts, etc.	Informs hazards and social impacts. Resources are available now – *bring these into the maturity pathway where appropriate.*
Resilience to Nature's Challenges – Building Better Homes, Towns and Cities (RNC-BBHTC): Urban environments (refer Section 3.6.3 of the Phase 1 report)	Various resources relating to infrastructure services.	May be useful in addressing social impacts of hazard events and potential mitigation strategies. At this stage, this has not been taken further in terms of the pathway – *would need to be investigated.*
Natural Hazards Research Platform (refer Section 3.7 of the Phase 1 report)	Reports published over the 10 year programme period	May be relevant to hazards unless updated by more recent or current research – *would need to be investigated*
AF8 Programme	Scientific information, including AF8 ground shaking maps that are available from QuakeCoRe,	Informs hazards – shaking maps on GIS portal.

Research Programme	Summary	Comment
(refer Section 3.8 of the Phase 1 report)	and future development of a business case.	*Ongoing work and collaboration an important part of maturity pathway.*
QuakeCoRE (refer Section 3.9 of the Phase 1 report)	Completed work includes: • Spatially distributed infrastructure • Ground motion simulation and validation • Liquefaction impacts on land and infrastructure • Pathways to improved resilience	Resources are available. Informs hazards, infrastructure impacts, investment in resilience. *Bring these into the maturity pathway where appropriate.*
	Ongoing work includes: • IP2 – Thriving residential communities • IP3: A resilient NZ transport system • IP4 – Harnessing disruptive technologies for seismic resilience	Informs impacts, decision-making and uncertainty IP3 (UA, UC, ResOrgs) and IP4 are relevant, includes supply chain and logistics. Completion of overall programme by 2028 - *"collaborate where relevant, watch, absorb later".*
MBIE Endeavour Fund programmes (refer Section 3.10 of the Phase 1 report)	Various programmes, includes: • Hazard Risks • Reducing flood inundation hazard and risk • Extreme events & climate change	Informs hazards and climate change effects. Some work completed and available – *bring into maturity pathway where appropriate*. Otherwise, completion 2024/25 - *"collaborate where relevant, watch, absorb later".*
Dam and Stopbank Resilience (refer Section 3.11 of the Phase 1 report)	Includes: • GIS mapping of NZ's stopbank network	Informs infrastructure knowledge – *bring into GIS*
EQC (refer Section 3.12 of the Phase 1 report)	EQC Strategy 3-year priorities include improved hazards modelling, geotechnical and landslide risk	Informs hazards knowledge – *bring into maturity pathway where appropriate*.
Quake Centre / Building Innovation Partnership (BIP/QC) (refer Section 3.13, 3.14 of the Phase 1 report)	Includes: • 3 Waters, Dams, Geotechnical resources l • Water pipe data portal • Digital twin for flood resilience work	Informs infrastructure layers – pipe portal, completed – *bring into GIS*. Informs hazards modelling, ongoing - *bring into maturity pathway where appropriate*.
Urban and Community Resilience in association with University of Canterbury (refer Section 3.15 of the Phase 1 report)	Includes: • Social equity and levels of service in impacts analysis • Improving community risk and vulnerability assessments including cascading impacts	Ongoing programmes and research areas that inform social impacts analysis. This also includes work for WREMO in the analysis and visualisation of emergency levels of service.

Research Programme	Summary	Comment
	• Understanding community access resilience • Spatial multi-criteria optimisation	*"Collaborate, develop further and incorporate in maturity pathway".*

Section 2.2 provides a perspective on how the above resources align with maturity pathway themes, also bringing forward possible improvements from Section 2 of the Scanning Stocktake – in particular, initiatives that are not "business as usual" practice at the Lifelines Group level and from which learnings can be drawn.

In some cases, there are apparent gaps, and comments on these are made in Section 2.2.12 below.

2.2 "Maturity-Based Pathway"

The following sections and tables address each of the areas shown in Figure 2-3 Features of the Maturity Pathway. They draw from the research programmes described above and provide more context in terms of application, with the maturity level classed as Advanced, High, Medium or Low.

At the end of this section a matrix summarises this information, placing each by theme and level of maturity.

2.2.1 Hazards, Climate Change and Impacts

The following table provides guidance on information in the research sector summarised above and considered relevant to both climate change impacts and Canterbury's hazardscape. Where work is complete, the results can be absorbed, while for research still underway future action may be needed.

Additional items of existing information have also been included, e.g. LINZ hazard layers.

Table 2-2 Application of Tools and Resources – Hazards and Climate Change Research

Tools / Resources	Summary	Application Intent & Maturity Level
HCC1: RNC-MRM: Multiple and cascading hazards, linking impacts to infrastructure	Led by Massey in collaboration with Built Environment programme. Extends hazard and impact modelling to multiple and cascading hazards. This is a case study in BoP, very specific and complex volcanic, weather, flood model with the aim of seeing how to model cascading impacts, link to a forecasting model and feed into decision making. Probably a long way off operationalising.	Completion expected 2024 – could investigate further at that time. Would need science sector involvement to operationalise. ADVANCED
HCC2: RNC-SPA Earthquake and Tsunami: Various projects	Led by GNS and UC. Aim is to generate synthetic or virtual earthquakes using physics-based computer models, which will enable new avenues of research to assess and forecast a range of hazards including ground shaking, liquefaction, landslides and tsunami.	Completion expected 2024. This work is expected to update the hazards models in the GIS portal, leading to improved impacts assessments. MEDIUM
HCC3: RNC-SPA Coastal: Various projects	Led by UA and UW. Projects address the changing coastline, coastal flooding, coastal adaptation. Will create a national coastal-change database, improve understanding of flooding hazard and risk in coastal areas and estuaries, and develop guidance and tools	Completion expected 2024. Will inform coastal vulnerabilities about future coastal change, including erosion and flooding. Will also contribute to Social Cultural & Environmental Impacts theme below. MEDIUM
HCC4: RNC-SPA Weather: and Wildfire Various projects	Led by GNS and NIWA. Addresses high impact weather, including heavy rain, heavy snow and strong winds plus associated risks such as wildfire, flooding and landslides. New hazard models, extreme scenarios, and hazard mitigations.	Completion expected 2024. Will provide more detailed models for the GIS portal and improved impacts assessments. Will

Tools / Resources	Summary	Application Intent & Maturity Level
		also contribute to Social Cultural & Environmental Impacts, Economic Impacts, and Mitigation themes below. MEDIUM
HCC5: RNC: Atmospheric rainfall and Canterbury rivers	Led by UA. Addressing atmospheric impacts on rainfall and disruption impacts leading into mitigations to improve urban flooding resilience. Has assessed the 2019 Rangitata and May 2021 floods.	Completion expected 2024. Utilise current work, also relevant to Impact Assessment and Mitigations themes below. Include in assessment process and seek to use in the GIS portal. MEDIUM
HCC6: Natural Hazards Research Platform	Numerous reports published over the 10 year programme period – this has now finished, and material may be superseded by more recent work. Areas covered include Geological hazards, Weather, flood & coastal hazards, Resilient buildings & infrastructure, Risk, Societal resilience. Specific report entitled *Research-informed Advancements in Guidelines and standards of Engineering Practice for Natural Hazards* refers to research of liquefaction induced lateral spreading, lessons from bridge performance under seismic loading, and tsunami impacts on coastal infrastructure	Draw material from existing research into pathway themes as applicable to the hazard being considered, this being a specific task, hazard by hazard. Note that some material has already been absorbed into *Risks & Resilience Phase 1*. LOW
HCC7: AF8 Programme	A programme of scientific modelling, response planning and community engagement, designed to build collective resilience to the next Alpine Fault earthquake. AF8 ground shaking maps available from QuakeCoRe.	Shaking maps have been included in the GIS portal. As an ongoing programme, the intent is to coordinate implementation of the pathway with AF8 developments. LOW
HCC8: MBIE Endeavour Fund: Various project resources – a sample is represented here	Projects include: • Climate change impacts on extreme weather events (available) • Preparing New Zealand for extreme fire (available) • Earthquake-induced landslides and landscape dynamics (2022) • Improved sea-level rise projections (2022)	These projects contribute to various hazard themes and should be considered in parallel with RNC and other hazards programmes above. Bring the results into the GIS portal and

Tools / Resources	Summary	Application Intent & Maturity Level
	• Tsunami risk (2023) • Extreme wildfire risk (2023) • Extreme events and the emergence of climate change (2024) • Solar tsunamis (2025) • Reducing flood inundation hazard and risk (2025) • Transitioning Taranaki to a Volcanic Future (2024)	pathway once available. Review implications for vulnerability assessments and business case updates at that time. MEDIUM
HCC9: EQC: Resilience Strategy (2019-2029)	Short term priorities include: • Re-platform existing capability and expand the hazard types that can be modelled. • Geotechnical data in high risk areas and improved sharing of hazard information – residential service connections • Improved volcanic and landslide hazard models.	Completion expected 2024. Need to keep informed about developments that could improve understanding of hazards and how the information could be used. MEDIUM
HCC10: RNC 2014-19 Completed projects	Published papers include (examples only): • A risk-based approach to land use: planning for natural hazards (2017) • Challenges and Opportunities for Economic Evaluation of Disaster Risk Decisions (2017) • Economic and social reconnaissance: Kaikōura earthquake 2016 (2017) • Impact of the Kaikōura earthquake on the electrical power system infrastructure (2017) • Impacts of the 14th November 2016 Kaikōura earthquake on three waters systems in Wellington, Marlborough and Kaikōura, New Zealand: Preliminary observations (2017) • Implementing the “sustainable Development Goals”: Towards Addressing Three Key Governance Challenges—Collective Action, Trade-Offs, and Accountability (2017) • Mātauranga Māori—the ūkaipō of knowledge in New Zealand (2017) • Resilience and fragility of the telecommunication network to seismic events: evidence after the Kaikōura (New Zealand) earthquake (2017) • Transport infrastructure performance and management in the South Island of New Zealand, during the first 100 days following the 2016 mw 7.8 “Kaikōura” earthquake (2017) • Māori oral histories and the impact of tsunamis (2018) • Defining Extreme Wildfire Events: Difficulties, Challenges, and Impacts (2018)	Available. Liaise with the research sector in absorbing relevant work into the pathway where it adds value now or pending completion of current research (e.g. as per above). VARY

Tools / Resources	Summary	Application Intent & Maturity Level
	• National guidance for adapting to coastal hazards and sea-level rise: Anticipating change, when and how to change pathway (2018) • Project AF8: developing a coordinated, multiagency response plan for a future great Alpine Fault earthquake (2018) • The Inverse Response Law: Theory and Relevance to the Aftermath of Disasters (2018) • Increasing communities' resilience to disasters: An impact-based approach (2018) • Communicating model uncertainty for natural hazards: A qualitative systematic thematic review (2018) • A Hybrid Process to Address Uncertainty and Changing Climate Risk in Coastal Areas Using Dynamic Adaptive Pathways Planning, Multi-Criteria Decision Analysis & Real Options Analysis: A New Zealand Application (2018) • Fit-for-purpose Resilience in Aotearoa New Zealand: Challenges and Recommendations (2019)	
HCC12: LINZ Hazard Layers	• Historical information relating to different hazards mapped by LINZ[5]	Available – refer website
HCC13: RiskScape layers	• Historical information relating to different hazards and scenarios carried out in various analyses by GNS, potentially recorded in RiskScape as layers	Available – refer GNS

2.2.2 GIS Data

The following table lists areas where GIS datasets are available or being developed, and that could be brought into the GIS portal.

Table 2-3 Application of Tools and Resources – GIS and Data

Tools / Resources	Summary	Application Intent & Maturity Level
GIS1: RNC: GIS integration of liquefaction and EQ induced damage	Integration of 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.	Expected to be available 2022. Review recommendations on the use of the model and how it could be applied in the GIS portal. LOW
GIS2: RNC: Marae adaptations	Led by UA. North Island GIS database of maraes and associated infrastructure and hazard exposure	Completion expected 2024. Useful for assessing the implications of natural hazards to Māori social and cultural well-being. Expand approach to include South Island maraes. MEDIUM

[5] Can be found at https://catalogue.data.govt.nz/group?q=emergency&sort=title+asc

Tools / Resources	Summary	Application Intent & Maturity Level
GIS3: GIS mapping of NZ's dams and stopbank network	Led by UC and UA. Dams and stopbanks have been mapped along with earthquake faults, liquefaction and ground shaking potential across the country	Available. Bring into the GIS portal, with the results of any particular vulnerabilities or deficiencies highlighted. Refer research report. LOW
GIS4: BIP/QC: National water pipe data portal	As of July 2021, 19 Councils were federated into the portal, including three in Canterbury (KDC, CCC, TDC). This is an ongoing activity.	Available (partly). Develop linkage between the pipe data portal and GIS lifelines portal. LOW
GIS5: QuakeCentre: Compilation and analysis of a New Zealand Inventory of Dams (2016).	Provides a cross-sectional characterisation of dams in New Zealand, based on compilation and analysis of a New Zealand Inventory of Dams (NZID).	Available. Complements GIS3 above. Need to determine whether GIS data layer is available, and the currency of this work. LOW

2.2.3 Infrastructure Damage Assessment

The next table summarises research relevant to infrastructure damage arising from natural hazard events. Note that there are gaps, with no information relating to fuel, telecommunications, and rail. Some hazards are addressed, but not all.

Table 2-4 Application of Tools and Resources – Infrastructure Damage Assessment

Tools / Resources	Summary	Application Intent & Maturity Level
IDA1: BIP: Digital twin for flood resilience work	Has developed a pilot for Kaiapoi, using NIWA BG-Flood, a numerical model for simulating shallow water hydrodynamics for computation, and RiskScape to assess damage losses for infrastructure and buildings. Also uses FME (Feature Manipulation Engine) software to enable data input and transformation.	Ongoing project. Pilot is available, and Canterbury Lifelines have been involved to date. This needs to continue and opportunities to utilise the methodology applied in other parts of the region. Also contributes to Financial loss modelling theme below. MEDIUM
IDA2: QuakeCentre: Guideline for Assessing Technical Resilience of Three Waters Networks	Provides a framework for assessing technical resilience of three waters piped assets – pressurised and gravity. Requires specific detailed engineering input.	Available. Utilise in carrying out damage assessments for water, wastewater and stormwater pipe systems. Consider whether this could be semi-automated in the GIS portal. LOW
IDA3: RNC: Coastal and tsunami research	Impacts on horizontal infrastructure, including bridges and breakwaters. Adaptation of coastal structures.	Completion expected 2024. Use results and findings for damage impact assessments, development of mitigation options. Closely related to HCC2 above. MEDIUM

Tools / Resources	Summary	Application Intent & Maturity Level
IDA4: QuakeCoRE: Various hazards impacts projects	Ground motion simulation and validation, Liquefaction impacts on land and infrastructure, Spatially distributed infrastructure	Completed projects. There are detailed models and tools developed by UC and UA that can be applied to specific hazard assessments. MEDIUM
IDA5: Assessment of the historic seismic performance of the New Zealand highway bridge stock[6]	Research report that examines historic seismic bridge performance of the New Zealand highway bridge stock from 1968 through to 2016.	Available. Liaise with research sector and NZTA in obtaining / deriving fragility curves for different types of bridges. LOW
IDA6: Assessment of subduction zone-generated tsunami hazards in New Zealand Ports[7] (RNC)	Research report that evaluates tsunami effects in terms of water levels and current speeds caused by both local and distant source subduction zone earthquakes.	Available. Apply results of this work in assessments of potential port damage at Lyttelton and Timaru. LOW
IDA7: Quantifying the seismic risk for electric power distribution systems[8]	Research report that proposes a seismic risk assessment framework for electric power distribution systems	Available. Liaise with research sector and electricity lines businesses in utilising this work along with fragility relationships. MEDIUM

2.2.4 Interdependencies Modelling

The table below describes a range of approaches, from simplistic to high. This is a key area for the maturity pathway.

Table 2-5 Application of Tools and Resources – Interdependencies Modelling

Tools / Resources	Summary	Application Intent & Maturity Level
IM1: Canterbury Lifelines Group Interdependencies and cascade impacts pilot approach (2010). (Refer Section 2.5.2 in the Phase 1 report).	A simple spreadsheet application that allows a user to rate co-dependencies and then cascade scoring through multiple levels if desired. Both Dependency and Importance can be scored and aggregated.	Useful for workshop settings to allow either high level (e.g. network) or localised (e.g. site specific) interdependencies to be understood and scored. Could be developed further as a software application within other tools. CORE

[6] Shong Wai Lew, Liam Wotherspoon, Lucas Hogan, Moustafa Al-Ani, Pavan Chigullapally & Vinod Sadashiva (2020): Assessment of the historic seismic performance of the New Zealand highway bridge stock, Structure and Infrastructure Engineering, DOI: 10.1080/15732479.2020.1762675

[7] Popovich, Wotherspoon, Borrero; 2021

[8] Yang Liu, Liam Wotherspoon, Nirmal-Kumar C. Nair & Daniel Blake (2021), Quantifying the seismic risk for electric power distribution systems, Structure and Infrastructure Engineering, 17:2, 217-232, DOI: 10.1080/15732479.2020.1734030

Tools / Resources	Summary	Application Intent & Maturity Level
IM2: NZTA Interdependencies approach (2020) (Described by Hughes, refer Section 2.5.3 in the Phase 1 report, see Figure 2-5 below).	This extends the UoA work by Zorn et al above to focus on the downstream dependencies of both lifeline utilities and key sites such as hospitals on specific state highways (or other roads). It modifies the "criticality rating" of elements of the network, however whether it can be incorporated in the Zorn et al model above is unclear.	Useful for assessing state highway criticality. Optional modules below need to be explored further – this needs to be discussed with UC. MEDIUM
IM3: Interdependency Modelling. (Refer Section 3.3.4, Zorn, Davies, et al, UoA, in the Phase 1 report, see Figure 2-4 below)	Interdependency approach as applied on the West Coast using the AF8 event, including the participatory approach.	Need to understand how this would work, what steps would be needed to model both the AF8 and other hazards across Canterbury, and what would be gained from its use. The forecast spatial extent of service disruption in periods following the event is useful for CDEM planning but we need to be clear about definitions of "reduced level of functionality" when "service is restored". Would be useful to view by sector on the GIS rather than number of networks. HIGH
IM4: Interdependent infrastructure projects	Spans across RNC, QuakeCoRE, AF8, Deep South, NIWA, Universities of Canterbury and Auckland. Overlays infrastructure networks with ongoing work.	Leads on from the work carried out by Zorn et al using AF8 as the event scenario. 2019 Rangitata and May 2021 Canterbury floods have been assessed. MEDIUM
IM5: Enhancing risk assessment by understanding cascading failures through interdependent urban infrastructure.	A new QuakeCORE funded research project whose goal is to improve understanding of how urban communities could be impacted by natural hazards, focus is on electricity and water in Christchurch. Aligns with IP3 with an urban focus.	This work is being managed by Tom Logan of UC. As the project has just been approved, it is not yet available for application, however, it should be aligned as part of the maturity pathway. HIGH

2.2.5 Service Disruption due to Infrastructure Damage

The following table covers the impacts on levels of service arising from damage to infrastructure networks.

Table 2-6 Application of Tools and Resources – Service Disruption due to Infrastructure Damage

Tools / Resources	Summary	Application Intent & Maturity Level
SD1: RNC: South Island road network resilience (AF8) – Transportation	UA research project. Developed a methodology to simulate post-disaster (AF8) transportation impacts on a large regional road	Available. Transportation model that can be applied to any major event, requires knowledge of how the network

impact assessment and post-disaster trip resilience	network. Includes outputs and accessibility maps. Covers one day, one week, six months, and > 6 months periods. Various published papers refer, including Measures to evaluate post-disaster trip resilience on road networks[9]. This develops an approach to assess resilience in the period after a disaster, "Equivalent Daily number of Impacted Trips" measure.	is damaged and restored (e.g. bridge outage, slips, etc.). Core information that should be built on and utilised. Bring in GIS maps, update assessments. Offers an approach to assess changes in accessibility as part of the recovery pathway. Look to tie into MERIT. MEDIUM
SD2: RNC: Supply chain transport logistics	Led by Lincoln University and Manaaki Whenua Landcare Research. While focus is on the wine industry the principles are relevant to other sectors.	Available / emerging research area. Look at how this work can be leveraged in relation to supply chain impacts. MEDIUM
SD3: QuakeCoRE IP3: A Resilient NZ Transport System	Led by UA, UC, ResOrgs. Covers: • Transport as-a-service system modelling • Post-disaster logistics and resilient logistics networks • Resilience investment decision making under uncertainty	Completion in 2028. Show on maturity pathway, and liaise with this project as it progresses. Takes AF8 and supply chain logistics resources above to next level. Also has relevance for investment decision-making. HIGH
SD4: QuakeCentre: Levels of Service Performance Measures for the Seismic Resilience of Three Waters Network Delivery	A framework to define the current or potential operating stage of any part, or parts, of a 3 waters network in the event of, or planning for, a significant earthquake.	Available. Consider this (along with more recent work by WREMO) on emergency levels of service. Refer project report. LOW

2.2.6 Infrastructure Recovery Pathway

There is less information relating to this important area. Modelling work is likely to require assumptions to be made about timelines for recovery of services together with input provided by lifeline utilities.

Table 2-7 Application of Tools and Resources – Infrastructure Recovery Pathway

Tools / Resources	Summary	Application Intent
IRP1: GNS Decision Support System	Software application that uses damage state data and service restoration timeframes by asset type to develop service recovery timeframes	Available. Look to utilise this tool as part of the pilot, perhaps for one sector (electricity) to illustrate proof of concept. ADVANCED
IRP2: SCIRT Learning Legacy	Learnings from the infrastructure rebuild following the 2011 Christchurch earthquakes as documented in a website[10]. This is a platform for sharing tools, insights and information from the recovery	Available. Review the resources and determine how best to use the learnings in the pathway. ADVANCED

[9] Aghababaei M., Costello S., Ranjitkar P.; 2021, Journal of Transport Geography
[10] https://scirtlearninglegacy.org.nz/

Tools / Resources	Summary	Application Intent
	to help leaders and communities faced with disaster recovery in the future.	

2.2.7 Social, Cultural, Environmental Impacts Assessment

More attention is currently being given to this area from a lifelines perspective than in the past. This is important in increasing maturity levels.

Table 2-8 Application of Tools and Resources – Social, Cultural, Environmental Impacts

Tools / Resources	Summary	Application Intent & Maturity Level
SCI 1: RNC-MRM: Māori perspectives on risk	Led by Manaaki Whenua Landcare Research. Will develop attributes of risk and resilience for four hazards and design approaches for modelling and planning.	Completion in 2024. Determine how this work could interface with other elements (e.g. social impacts – direct effects of hazards and lifeline disruptions). MEDIUM
SCI 2: RNC-RIPM: Enhancing resilience and wellbeing	Led by Manaaki Whenua Landcare Research. Explores the relationship between social and life-supporting ecosystems and identities within these linked systems.	Completion in 2024. Need to determine how the outcomes of the work could interface with this theme. HIGH
SCI 3: RNC-SPA Rural: Rural disaster risk decision-making AND Understanding our 21st century rural communities & industries for a disaster resilient NZ	Projects hosted by UC. Will produce an integrated framework for promoting, incentivising and assessing resilience across rural value chains. The second project focuses on specific rural communities and industries, including Māori.	Completion in 2024. Need to determine how the outcomes of the work could interface with this theme. HIGH
SCI 4: RNC-SPA Mātauranga Māori: Whanake te Kura I Tawhiti Nui programme of research	Several projects hosted by Massey. Will develop research methods and models applied to investigating multiple natural hazards, and their complex impacts on Māori society.	Completion in 2024. These approaches can be applied to a regional scale assessment once available. Linked to SCI1 above MEDIUM
SCI 5: RNC-DS Local Infrastructure: Various projects	Hosted by NIWA. Wide range of resources and information relating to climate change, sea level rise, coastal and river flooding, stormwater and wastewater systems, drought and drinking water. Covers social, cultural and economic impacts and provides decision-making tools.	Resources available now. Bring in the knowledge to the assessment process. Will also contribute to Mitigation theme below. LOW
SCI16: UC/UI: Urban Intelligence impacts assessment and visualisation	A wide ranging group of GIS based applications and dashboards developed by UC and Urban Intelligence. Key areas include: • Risk and vulnerability assessments and GIS based dashboards	This work would usefully form a base for developing impacts assessments within the Canterbury lifelines GIS portal. This would involve expanding coverage to include a rural view and a more complete list of “community sites”, drawing from interdependencies

Tools / Resources	Summary	Application Intent & Maturity Level
	• Resilience underpinned by access • Integrating risk, sustainability, and strategic planning – spatial multi-criteria optimisation of urban development See further information below relating to work for WREMO.	modelling and service disruption impacts, and making a connection to MERIT for socio-economic analysis. MEDIUM

2.2.8 Economic Impacts of Service Disruption

MERIT is the key tool for economic evaluation as summarised below. It is also being developed for modelling multiple and social capitals as noted in Section 0 below.

Table 2-9 Application of Tools and Resources – Economic Impacts of Service Disruption

Tools / Resources	Summary	Application Intent & Maturity Level
EISD1: MERIT	The MERIT tool is a suite of 'Integrated Spatial Decision Support Systems' that estimate the economic consequences associated with disruption events. NZTA has a specific MERIT tool which uses an on-line GIS application for state highways that allows users to test disruption scenarios to the road network.	Learn from the results of existing MERIT applications. Develop a linkage between the Interdependencies modelling and service impacts themes and MERIT. Use MERIT as the primary tool for economic evaluation. MEDIUM

2.2.9 Infrastructure Financial Loss Modelling

RiskScape is also a key tool for modelling infrastructure or other property or direct losses in the New Zealand context, as summarised below.

Table 2-10 Application of Tools and Resources – Infrastructure Financial Loss Modelling

Tools / Resources	Summary	Application Intent & Maturity Level
IFLM1: RiskScape 2.0	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. RiskScape 2.0 has been released for research purposes, and is free to use for researchers. Need to understand whether this incudes access to fragility curves and other relationships that are needed to use it.	Utilise RiskScape 2.0 – "RiskScape as a Service". Use RiskScape 2.0 for financial loss modelling in relation to damage to infrastructure networks. Seek to create linkages with the other tools in the Maturity Pathway (including MERIT, interdependency models, service disruption impact models, etc. to create a seamless end-to-end process, enabling strategic or mode detailed analysis, localised or network wide. HIGH

2.2.10 Integrated Economic Evaluation

This section expands on the wider application of MERIT to the overall integration of impacts, a critical aspect for the maturity pathway.

Table 2-11 Application of Tools and Resources – Integrated Economic Evaluation

Tools / Resources	Summary	Application Intent & Maturity Level
EE1: RNC-MRM: Dynamic assessment of impacts	Led by Market Economics this will allow MERIT to more rapidly assess economic consequences and extend to multiple and social capitals.	Completion in 2024. This will allow more efficient and more effective economic evaluation and wider impacts analyses, adding significant value to the Maturity Pathway. ADVANCED

2.2.11 Mitigation, Solutions and Business Case Development

Finally, the following table summarises research resources that could be utilised in developing and evaluating business cases.

Table 2-12 Application of Tools and Resources – Mitigation, Solutions and Business Case Development

Tools / Resources	Summary	Application Intent & Maturity Level
BC1: RNC-MRM: Embedding models within robust decision-making	Led by ResOrgs. Explores consequences of alternative assumptions and scenarios. Leads into prioritisation and trade-off analysis amongst resilience investment strategies.	Completion in 2024. Expect this to be a useful precursor, or an alternative approach, to formal business case analyses. Needs to be explored early as work progresses. HIGH
BC2: RNC-RIPM: De-risking resilience	Led by Waikato Uni. Extends international knowledge on the science-policy-practice interface in addressing risks (e.g. political, economic) associated with mitigating natural hazards.	Completion in 2024. Expected to be useful in assessing programme business case risks. HIGH
BC3: RNC-RPIM: Building resilient futures	Led by Massey Uni. Addresses uncertainty, providing tools, processes and guidance to help prepare for a wide range of possible outcomes and enhance preparedness.	Completion in 2024. There are aspects here relating to communicating and preparing for future risk and planning for recovery that could form part of a business case or programme. ADVANCED
BC4: RNC-SPA Urban: Pathways to Urban Resilience	Project hosted by UA. Examines best practice for integrating existing hazard, risk and other resilience research into plans and policies, linking to urban governance.	Completion in 2024. High level, this is about implementation and integration. Guidance will be useful in mapping to maturity of resilience planning overall. MEDIUM
BC5: RNC-SPA Built: Horizontal infrastructure	Led by UA. Builds on the outcomes of RNC Phase 1 Infrastructure theme. Develops models for infrastructure performance, interdependency models, and decision making and rating tools for infrastructure.	Completion in 2024. Apply models and tools in developing and assessing intervention options and solutions. This work is also relevant to HCC and IM themes above. MEDIUM

Tools / Resources	Summary	Application Intent & Maturity Level
BC6: QuakeCoRE: Pathways to improved resilience	Determining how to decide where to invest limited resources to improve resilience to earthquakes. Focus on Wellington earthquake.	Available. Addresses social and cultural dimensions through collaborative community based programmes. Can draw from learnings – need to obtain project reports. MEDIUM
BC7: QuakeCoRE IP4: Harnessing disruptive technologies for seismic resilience	Identifying how transformational advancements in infrastructure resilience can be achieved through strategic adoption of disruptive technologies, via government and market-led initiatives (e.g. distributed solar power).	Completion in 2028. Show on maturity pathway, and liaise with this project as potential mitigations and investment scenarios are being formulated. ADVANCED
BC8: Treasury Criticality / Consequences Model (2020) (refer Section 2.2.1, Fig 2-3 in the Phase 1 report, see Figure 2-7 below).	This is also aligned with best practice risk management and asset management, is multi-dimensional (social, economic, etc.), and more specific in terms of the consequence definitions. Note that consequence is generally closely aligned with criticality – the greater the consequences, the more critical the asset is in terms of its continuing functionality.	Apply to business case evaluation. Use in place of the current 4-level national criticality approach, with its singular focus on customer scale. Provides a consistent risk and consequence focussed view that can be applied across different utilities and the assets being considered. LOW

2.2.12 Gaps

In describing the various resources above, several gaps have emerged that should be addressed, either through this project or as recommendations for further work. They are summarised in the table below.

Maturity Theme	Description of Gap	Approach to Resolving Gap
GIS Data	Data attributes from lifeline utilities, providing details of network assets, is currently incomplete in the GIS portal.	Work with lifeline utilities to close the data gaps, use the proposed data schema as the structure.
Infrastructure Damage Assessment	Incomplete coverage of all lifelines sectors in the research space – for example Port assets, Railways, Fuel. There is a general lack of robust fragility relationships, although a number are embedded in RiskScape 1 software.	Liaise with the research sector and affected infrastructure sectors to determine what is available and could be utilised. Fragility relationships will be a start, with assumptions needing to be made. Likely to be part of the improvement plan for the maturity pathway.
Service Disruption due to Infrastructure Damage	Infrastructure sector coverage is incomplete. Guidance or frameworks do not appear to be available for service disruption impacts for several sectors, including Electricity, Telecommunications, Fuel. Road	Liaise with the research sector and affected infrastructure sectors, could be part of ongoing work in NZ or overseas. Look also to the research work relating to hazards and climate change. May need to be part of the

Maturity Theme	Description of Gap	Approach to Resolving Gap
	networks and Three Water infrastructure have more coverage.	improvement plan for the maturity pathway.
Infrastructure Recovery Pathways	These are generally not well addressed in the current scope of research programmes. Some material has been developed through the AF8 work, e.g. state highways and electricity transmission although this is West Coast focussed.	Liaise with the research sector and affected infrastructure sectors. Likely to require assumptions to be made. Expected to be part of the improvement plan for the maturity pathway.

2.2.13 Key Elements of Proposed Approach for Canterbury Pilot

Overall, the following interim conclusions have been drawn from the work to date:

1. The existing GIS portal developed by Environment Canterbury forms a critical building block, with further work needed in terms of data layers (both infrastructure and hazards) and linking it to other applications as noted below.
2. Further work is also likely to be needed in defining fragility profiles for the various asset types under multiple hazard events. This is to be explored further with GNS in relation to RiskScape models, but it is likely that assumptions will also need to be made to demonstrate "proof of concept".
3. The interdependencies work conducted by Waka Kotahi NZTA and Zorn, Davies et al with cascading infrastructure network impacts offers significant potential and should form a basis for further development.
4. The work by various Universities in association with Urban Intelligence in relation to levels of service and social impacts following an emergency event utilising GIS also offers significant potential. This work can be extended to address the wider needs of the Canterbury project.
5. Both MERIT and RiskScape are important tools and should feature in the Canterbury project.
6. A key point in relation to the various tools and models is their ability to provide output that can usefully be absorbed in the economic modelling process, in particular MERIT, in order to develop business case information.

The eventual outcome desired is the ability of lifelines to assess the implications of particular hazards and/or climate change impacts at a regional or sub-regional level utilising agreed model relationships (such as fragility, service loss, interdependencies, service recovery timeframes, etc.), using GIS to overlay hazard parameters with infrastructure networks and community sites, for example:

- Assessing damage and service disruption impacts arising from 100, 500 and 1000 year flood events, or different earthquake scenarios
- Applying interventions such as more robust infrastructure or new links or nodes to improve resilience to the particular hazard(s)
- Running the analysis to determine the relative financial, economic and social benefits of interventions compared to the status quo

In summary, this means developing a "product" that is feasible and can be widely applied, and that provides the "minimum viable" case for investment decision-making.

Further comments in relation to some of the above points follows.

2.2.13.1 Interdependencies Analysis

The following figure summarises the approach developed by Zorn et al for an AF8 earthquake affecting the West Coast of the South Island – the challenge will be expanding it to a wider area, multiple hazard scenarios, and the formulation of fragility relationships for the various asset classes.

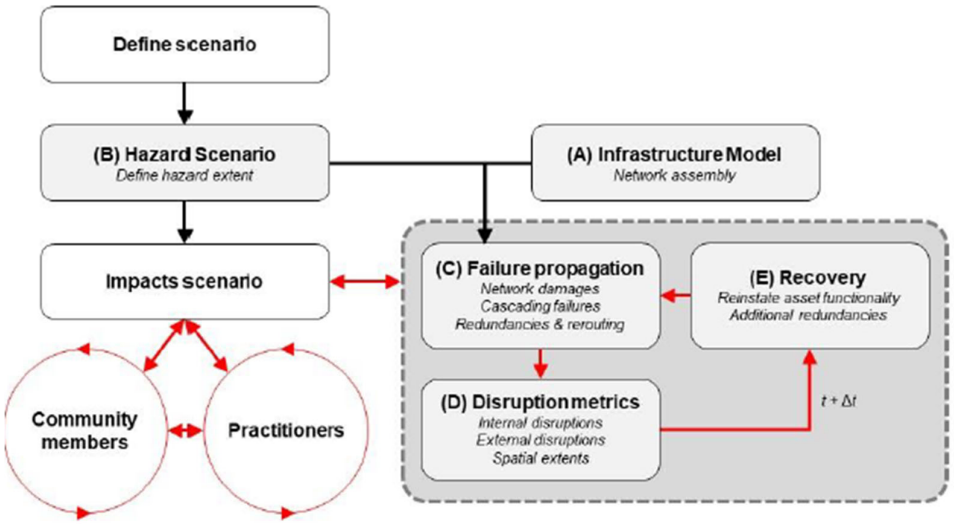


Figure 2-4 Conceptual diagram of the integrated disaster impact reduction modelling framework for infrastructure networks embedded within the scenario-based participatory approach (Source, Davies et al, 2021)

The following figure summarises the NZTA framework which could form an extension of the above. Importantly, it is understood that the optional modules shown here have yet to be fully developed. This framework has a state highway roads focus.

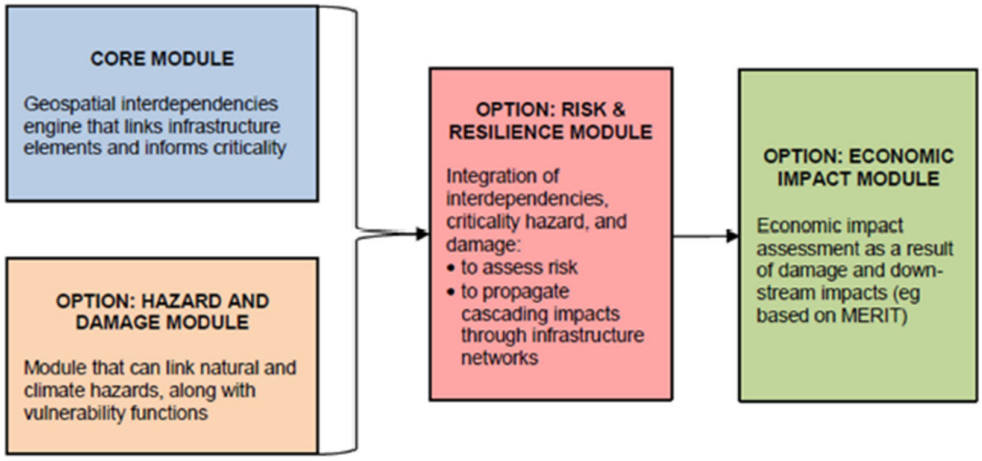


Figure 2-5 NZTA Proposed Interdependency Framework (Source, NZTA Research Report 671)

2.2.13.2 Service Disruption Impacts

Promising work is being undertaken in linking infrastructure damage with interdependencies, levels of service and social impacts following an event. There is an opportunity to integrate the work being carried out by the Universities and Urban Intelligence as part of the maturity pathway in linking diverse data inputs.

This includes work in both Christchurch and Wellington, addressing infrastructure levels of service and social impacts following an emergency event[11]:

- There is a focus on distance from individual properties to particular “lifelines or community sites”. The user can enter an address to obtain the information and the level of service available at different time periods after the event.

[11] https://projects.urbanintelligence.co.nz/wremo/

- Key inputs needed for this model include the availability or not of each site to provide a service and the "emergency level of service" (ELoS) available at given time periods after the event. While this will likely be a continuum as sites come back up, there will be a transition, and some sites may only offer a partial level of service. This information needs to be established in close collaboration with the infrastructure owner / service provider.
- Time periods are based on the recovery process and can be modified to suit local conditions.

Level of service impacts / outages are crucial to how communities will be able to cope following an event. This GIS-based tool widens the perspective beyond physical damage to include social impacts illustrating:

- Minimum LoS visualisation
- Planning LoS needed and the time for services to come up
- Condition of roads linked to accessibility

The sites currently include Supermarkets, Water Points, Health Services, Emergency Management Hubs, and Fuel Service Stations. Examples are shown below.

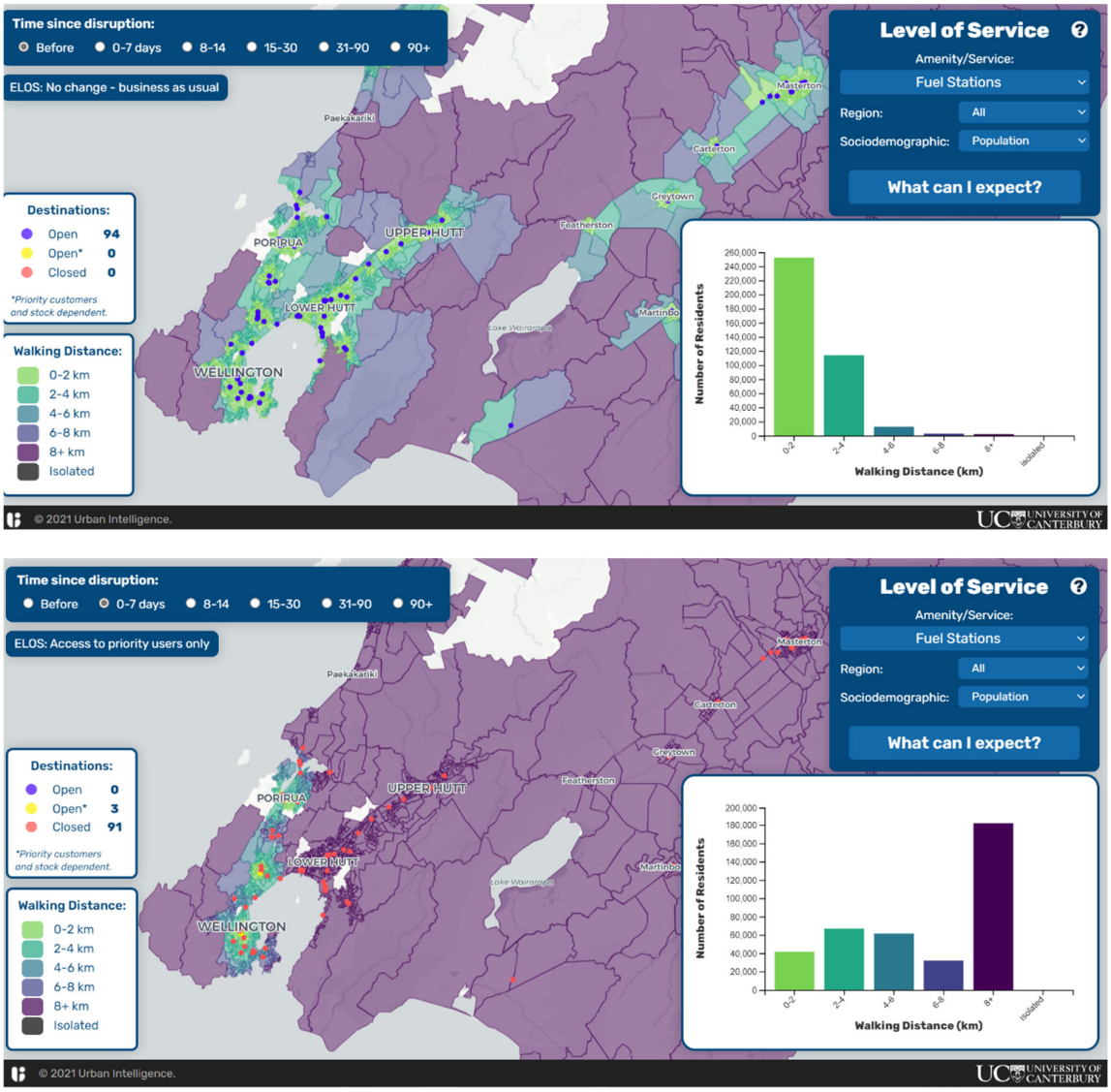


Figure 2-6 ELoS Visualisation Examples for Wellington (WREMO)

For the proposed Canterbury work it would be useful to expand the list of sites to include

- Fire, Ambulance, Police, Hospitals, and other emergency services
- Social, economic, and cultural sites

Other potential modifications or additions to the Wellington process could include:

- Linkages to the levels of service in the Interdependency work above. This would not be so much about distance or accessibility, but the degree to which the service is available – i.e. what is the ELoS at different points in time for critical infrastructure – electricity, telecommunications, water supply, wastewater, etc.
- Estimating threshold levels where businesses are adversely affected and suffer economic loss.
- Estimating threshold levels where households and cultural sites are adversely affected with significant social impacts (e.g. relocation, loss of employment, etc.).
- Linking these impacts to some form of economic and social impacts modelling.

2.2.13.3 Risk Consequences

In the risk management process, it is important to apply a robust and consistent approach to describing and rating the consequences of an event. The Treasury consequences model below offers such a system and should be utilised where appropriate.

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

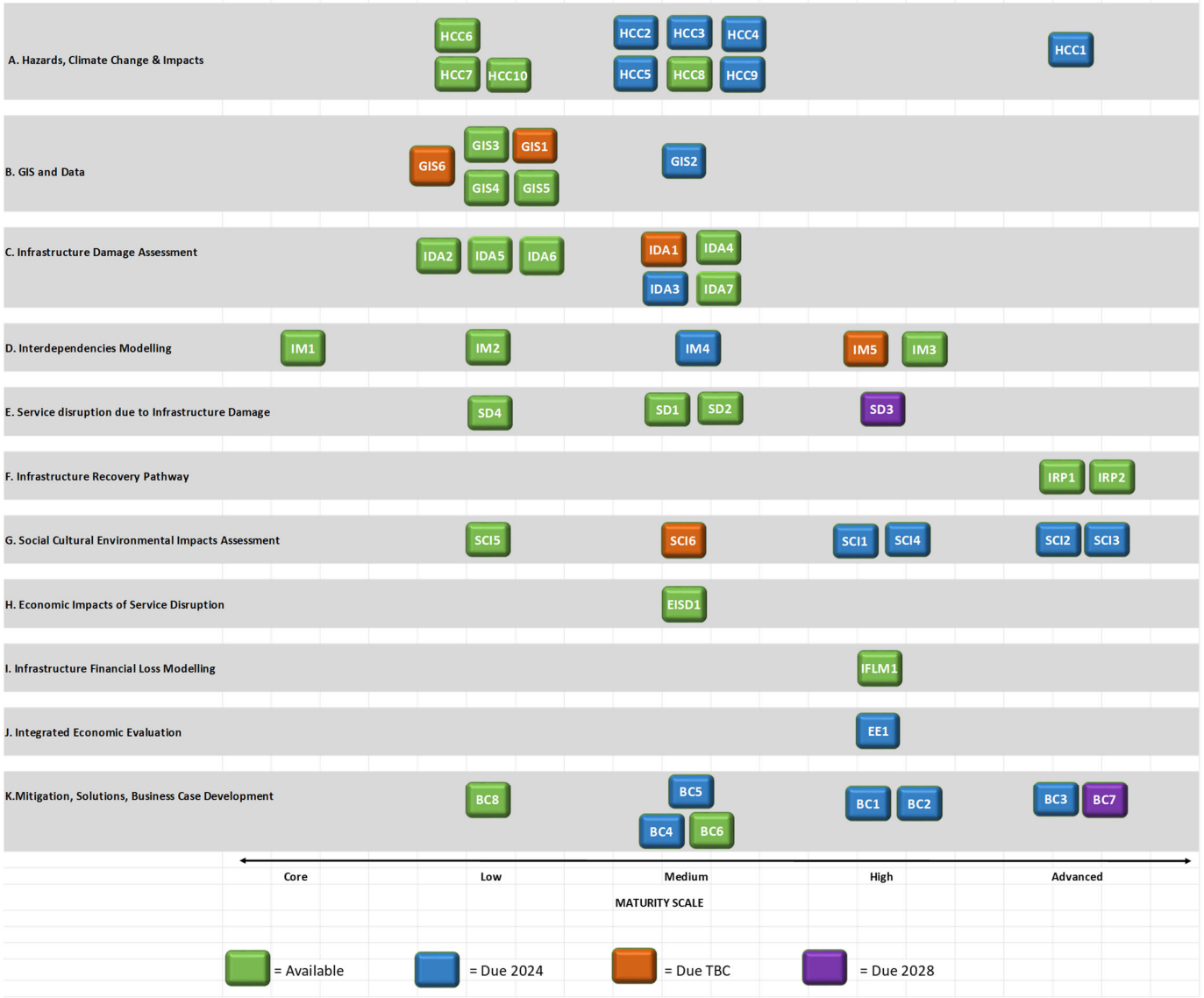
Figure 2-7 Draft Treasury Criticality / Consequences Model (Treasury, 2020)

2.2.14 Maturity Pathway Themes Matrix

The following figure shows how the research areas and initiatives identified above could fit into the maturity pathway for this project. …

THEMES / FEATURES - APPLICATION OF TOOLS AND RESEARCH OUTPUTS

Any of the elements below may progress through different stages of maturity



A. HAZARDS, CLIMATE CHANGE AND IMPACTS

- HCC1: RNC-MRM: Multiple and cascading hazards, linking impacts to infrastructure
- HCC2: RNC-SPA Earthquake and Tsunami: various projects
- HCC3: RNC-SPA Coastal: various projects
- HCC4: RNC-SPA Weather: Various projects
- HCC5: RNC: Atmospheric rainfall and Canterbury rivers
- HCC6: Natural Hazards Research Platform
- HCC7: AF8 Programme
- HCC8: MBIE Endeavour Fund: Various project resources
- HCC9: EQC: Enhance loss modelling / impact estimation products
- HCC10: RNC 2014-19 Completed projects

B. GIS AND DATA

- GIS1: GIS integration of liquefaction and EQ induced damage
- GIS2: RNC: Marae adaptations
- GIS3: GIS mapping of NZ's stopbank network
- GIS4: BIP/QC: Water pipe data portal
- GIS5: QuakeCentre: Compilation and analysis of a New Zealand Inventory of Dams.
- GIS6: GAP - Lifeline utility data gaps

C. INFRASTRUCTURE DAMAGE ASSESSMENT

- IDA1: BIP: Digital twin for flood resilience work
- IDA2: QuakeCentre: Guideline for Assessing Technical Resilience of Three Waters Networks
- IDA3: RNC: Coastal and tsunami research
- IDA4: QuakeCoRE: Various hazards impacts projects
- IDA5: Assessment of the historic seismic performance of the New Zealand highway bridge stock
- IDA6: Assessment of subduction zone-generated tsunami hazards in New Zealand Ports
- IDA7: Quantifying the seismic risk for electric power distribution systems

D. INTERDEPENDENCIES MODELLING

- IM1: Canterbury Lifelines Group Interdependencies & cascade impacts pilot (2010)
- IM2: NZTA Interdependencies approach (2020)
- IM3: Interdependency Modelling
- IM4: Interdependent Infrastructure Projects
- IM5: Enhancing risk assessment by understanding cascading failures through interdependent urban infrastructure

E. SERVICE DISRUPTION DUE TO INFRASTRUCTURE DAMAGE

- SD1: South Island Road Network Resilience (AF8)
- SD2: Supply chain transport logistics
- SD3: QuakeCoRE:IP3: A Resilient NZ Transport System
- SD4: QuakeCentre: Levels of Service Performance Measures for the Seismic Resilience of Three Waters Network Delivery

F. INFRASTRUCTURE RECOVERY PATHWAY

- IRP1: IRP1: GNS Decision Support System
- IRP2: IRP2: SCIRT Learning Legacy

G. SOCIAL CULTURAL ENVIRONMENTAL IMPACTS ASSESSMENT

- SCI1: SCI1: RNC-MRM: Māori perspectives on risk
- SCI2: SCI2: RNC-RIPM: Enhancing resilience and wellbeing
- SCI3: SCI3: RNC-SPA Rural: Rural disaster risk decision-making AND Understanding our 21st century rural communities & industries for a disaster resilient NZ
- SCI4: SCI4: RNC-SPA Mātauranga Māori: Whanake te Kura i Tawhiti Nui programme of research
- SCI5: SCI5: RNC-DS Local Infrastructure: Various projects
- SCI6: SCI6: UC/UI: Urban Intelligence impacts assessment and visualisation

H. ECONOMIC IMPACTS OF SERVICE DISRUPTION

- EISD1: EISD1: MERIT

I. INFRASTRUCTURE FINANCIAL LOSS MODELLING

- IFLM1: IFLM1: RiskScape 2.0

J. INTEGRATED ECONOMIC EVALUATION

- EE1: EE1: RNC-MRM: Dynamic assessment of impacts

K. MITIGATION, SOLUTIONS AND PROGRAMME BUSINESS CASE DEVELOPMENT

- BC1: BC1: RNC-MRM: Embedding models within robust decision-making
- BC2: BC2: RNC-RIPM: De-risking resilience
- BC3: BC3: RNC-RPIM: Building resilient futures
- BC4: BC4: RNC-SPA Urban: Pathways to Urban Resilience
- BC5: BC5: RNC-SPA Built: Horizontal infrastructure
- BC6: BC6: QuakeCoRE: Pathways to improved resilience
- BC7: BC7: QuakeCoRE: IP4 – Harnessing disruptive technologies for seismic resilience
- BC8: BC8: Treasury Criticality / Consequences Model

2.3 Theme by Theme Maturity

The table below is another way of describing the maturity pathway, showing the evolution of maturity on a theme by theme basis. Generally, the evolution from low to advanced also reflects a number of common features, both in terms of practice and role:

- From low cost to implement to high cost to implement – depending on the level of detail and sophistication of modelling effort
- From a low degree of sophistication and robustness in modelling to highly complex, for example, more granular data with fewer broad assumptions being made as the level of maturity increases
- From simply using available knowledge and research outputs, through influencing or collaboration roles, to participation or driving research outcomes and programmes

Note that theme B below reflects specific intentions for the Canterbury CDEM Lifelines GIS portal, enhancing geospatial data use and linking progressively to tools such as MERIT and RiskScape.

Table 2-13 Maturity Themes

Theme	Low	Medium	High	Advanced
A. Hazards, Climate Change & Impacts	Core plus: • Uses available hazards and climate change research information at a network or sub-network level in the vulnerability assessment process	Low plus: • Uses data at a more localised level to assess the physical impacts on important assets (see also C below) • Engages with the research community to address particular issues or improve the assessment outcome • Considers multiple hazards and climate change effects	Medium plus: • Data used in lifelines planning becoming increasingly granular and applied to specific assets across networks – links and nodes • Multiple hazards and impacts of climate change on hazards well described • Considers cascading hazards or co-occurrence of hazards and impacts of climate change on hazards	High plus: • Highly granular approach to describing hazards and climate change effects – both physical and geographic
B. Canterbury GIS Portal and data needs	Core plus: • Static feeds to current hazards information • Live or static feeds to lifelines networks, relevant data portals, and other locations such as	Low plus: • Live feeds to current hazards information • Link established between GIS portal and RiskScape – data can be readily	Medium plus: • Link established between GIS portal and MERIT – data can be readily transferred to MERIT for economic analysis	High plus: • The GIS portal is able to be used by Lifeline Utilities for their own resilience analyses

Theme	Low	Medium	High	Advanced
	contractor depots, quarries, etc. • Live or static feeds to emergency and essential services, including Police, FENZ, supermarkets, medical centres, service stations, schools, etc. • Used for regional or sub-regional lifelines resilience planning and response purposes	transferred to RiskScape for loss modelling • Stakeholder locations and significant employment sites / zones captured (e.g. dairy factories, industrial zones, etc.). • Locations of social and cultural sites (e.g. Marae) recorded using available research information. • Spatial representation of infrastructure damage state (see C below)	• Spatial representation of level of service loss (see D and E below)	
C. Infrastructure Damage Assessment	Core plus: • Involves infrastructure owners in defining general damage states • Uses research guidance and methodologies for predicting infrastructure impacts • Typically, a broadly based high level approach to damage state assessments, often with many assumptions being made including fragility profiles • Typically hazard scenario by hazard scenario, not automated	Low plus: • Uses more comprehensive research information including fragility profiles and other modelling inputs • May use RiskScape to model damage states based on expert lifeline utility knowledge, embedded fragility relationships, and up to date research outputs • Partly manual, partly automated approach	Medium plus: • High level of involvement of infrastructure owners in assessing possible damage states, at a detailed asset by asset level and by asset material type • Increasing modelling automation using embedded fragility relationships on a hazard by hazard basis at different levels of hazard intensity.	High plus: • Fully or semi-fully automated approach – can model different scenarios, including coincident or cascading hazard scenarios • Probabilistic assessments using likelihood of damage
D. Interdependencies Modelling	Core plus: • Utilises existing typically simple easy to use approaches that have	Low plus: • Interdependencies are modelled based on the impacts on one	Medium plus: • Increasing number and complexity of steps	High plus: • Automated approach, can model multiple scenarios / hazards utilising multiple

Theme	Low	Medium	High	Advanced
	been developed and tested by lifeline utilities • Some consideration of interdependencies, but qualitative	infrastructure network affecting other networks – at a high level • Uses existing research in multiple hazards interdependency analyses – becoming more quantified	required in the analysis process • Considers cascading failures from specific assets to other networks' assets, more granular, higher level of detail – semi automated • Involves community / stakeholders in describing the effects of interdependencies on them	sources of information and inputs with results leveraged into economic, social and cultural impacts analyses below (refer G, H, J).
E. Service Disruption due to Infrastructure Damage (*relates to the immediate to short-term effects of the event on services)*	Core plus: • Utilises existing approaches that have been developed by lifeline utilities or through research programmes	Low plus: • Extent of loss of service by network (e.g. water, electricity, fuel, etc.) described spatially based on infrastructure damage states • Focus is on what services the community has access to and the broad social and cultural implications of service disruption • Also considers supply chain impacts, in particular fuel, supermarkets, etc.	Medium plus: • Increasing granularity around service disruption, both in terms of extent (e.g zoning, mesh block level) and degree • Increasing sophistication applied in incorporating the impact of interdependencies modelling (refer D above) • Describes spatial accessibility to available services –transport options LoS – walking, cycling, car, bus, etc. • Community / stakeholder contribution to describing the impacts • Addresses post-disaster logistics and resilient logistics networks	High plus: • Granularity further refined to include specific business sectors aligned with economic indicators (e.g. PPI) and the service disruption impacts on those sectors

Theme	Low	Medium	High	Advanced
F. Infrastructure Recovery Pathway *(Relates to the duration and rate of return of the service to "normality")*	Core plus: • Emergency levels of service (ELoS) defined by individual lifeline utilities • Service restoration timeframes and priorities broadly described • Assumptions made and tested with lifeline utilities	Low plus: • ELoS described at different points in time in the recovery process by lifeline sector and for essential services (food, medical, etc). • Service restoration times to multiple hazards defined in general spatial terms by lifeline utilities	Medium plus: • Increasing granularity around spatial distribution of service recovery timeframes (e.g. mesh blocks as above) • Intra-network connectivity defined in GIS / data schema (nodes, links, etc.) and used to model service recovery	High plus: • Granularity of service recovery timeframes also aligns with business sector impacts above (refer E above) • Decision Support Systems recognising interdependencies used to model restoration timelines across multiple lifeline networks and addressing uncertainties
G. Social Cultural Environmental Impacts Assessment	Core plus: • Limited assessments – may be at a high level, such as "impact on health services is XX over YY timeframe"	Low plus: • Uses service disruption information (refer C above) to assess social and cultural impacts in more detail, typically linked to specific sites (e.g hospitals, schools, Marae, etc.) • Spatial distribution and location of affected sites described in GIS	Medium plus: • Spatial distribution of impacts modelled at a mesh block level to illustrate the nature and severity of impacts across communities over the recovery pathway timeframes above • Stakeholder / community involvement in describing and assessing impacts over time • Consideration and inclusion of community based resilience incentives	High plus: • Modelling of impacts carried out in MERIT or other advanced tools at a highly granular level • Includes the effects of disruption changes across business sectors (as well as lifeline utilities) and their reduced ability to operate and provide goods and services to communities
H. Economic Impacts of Service Disruption	Core plus: • Analyses conducted by individual lifeline utilities in isolation using their own evaluation methods	Low plus: • Uses service disruption metrics from above to model broad economic impacts, possibly in	Medium plus: • Economic impacts modelled in MERIT, using outputs imported from the impacts modelling and spatial distribution above	High plus: • High level of granularity in MERIT based economic modelling, including business sector impacts and consideration of

Theme	Low	Medium	High	Advanced
	• Economic impacts broadly described but not quantified • Typically hazard by hazard approach	MERIT or other tools, on multiple lifeline systems • May be based on several hazard scenarios • Qualitative interdependency analysis or uses models which include significant assumptions with a high level of uncertainty	across multiple lifelines sectors and hazard types • Fewer assumptions reflect lower levels of uncertainty and better output reliability • Stakeholder / community involvement in assessing economic impacts	transport accessibility issues • High level of reliability of outputs for investment justification
I. Infrastructure Financial Loss Modelling	Core plus: • Analyses conducted by individual lifeline utilities using their own evaluation methods • Typically hazard by hazard approach	Low plus: • Infrastructure asset valuation information used in association with modelled damage state information to broadly assess losses across multiple lifeline utilities • May be based on several hazard scenarios	Medium plus: • Uses RiskScape or other assessment tools to assess direct financial loss costs at a more granular level, based on the more detailed damage state information (refer C above)	High plus: • Automated approach – can model losses from different event and damage scenarios, including probabilistic analysis and coincident or cascading hazard scenarios (from C above) • High level of reliability of outputs for investment justification
J. Integrated Economic Evaluation *(This brings together the outputs from G, H and I above)*	Core plus: • Broad, high level manual integration of results from the above analyses • Likely to be many gaps and assumptions	Low plus: • Brings together results of social, cultural, economic impacts analysis and loss analysis above into a high level view • Manual approach, although aspects may be modelled in MERIT or other tools and supported by GIS	Medium plus: • Semi-automated approach using GIS, RiskScape, MERIT and other analysis tools • More granular, more robust evaluation outputs reflecting the spatially based outputs above	High plus: • Automated approach – can integrate the analyses above across multiple hazard scenarios and infrastructure networks • High level of reliability of outputs for investment justification
K. Mitigation, Solutions and Programme	Core plus:	Low plus: • Makes the case for coordinated intervention	Medium plus: • More robust decision-making process –	High plus: • Cross-sector Programme Business Case that is

Theme	Low	Medium	High	Advanced
Business Case Development	• Applies good practice risk management tools and processes • Pulls together the results of work by individual lifeline utilities or sectors • Identifies mitigation measures supported by qualitative evaluation of benefits	across infrastructure sectors, a strategic approach or case for change • May be by way of pilot or proof of concept approach – utilises tools and tests possible outcomes • Develops Programme Business Case[12] at individual infrastructure sector or agency level	considers different assumptions and scenarios • Addresses broad range of programme implementation risks • Develops coordinated Programme Business Case at a regional level – cross sectoral • Addresses interdependencies and considers multiple hazard scenarios	optimised across all sectors with investment scheduled over a 10-20 year period • Deals systematically with uncertainty in decision-making • May consider disruptive or new technologies

[12] A programme business case identifies an optimal mix of alternatives and options through multi-criteria assessment of the widest practicable set of potential alternatives and options which could alleviate the identified or perceived problems, or address the potential opportunities. Source https://www.nzta.govt.nz/roads-and-rail/highways-information-portal/processes/project-development/programme-business-case/

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 public and specific

[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
	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.*