WELLINGTON LIFELINES PROJECT

Protecting Wellington's Economy Through Accelerated Infrastructure Investment Programme Business Case

Revision 3 - **Date** 04 October 2019

WELLINGTON LIFELINES
REGIONAL RESILIENCE PROJECT

Fault scarp of the Wellington Fault at Long Gully
(Source: Lloyd Homer, GNS Science)

Foreword

The probability of a major earthquake hitting our capital city of Wellington is widely accepted. In recent years local councils have worked on increasing household resilience and have tightened building codes to protect lives in such an occurrence, but this focus on readiness has not been reflected in other areas of emergency preparedness. Saving lives is paramount, but the survivors of a major disaster also need to be able to function in a working economy after the event. In the case of Wellington, the need for economic resilience is critical, not only for the half a million people who live in the region, but also for the nation.

The bald figure of 13.5% of New Zealand's GDP does not tell the entire story of why Wellington's economy is important. Not only is it the seat of Government and the transport hub between the North and South Islands, but its large knowledge sector also has New Zealand's fastest growth in digital businesses. This concentration of services financial and technology sectors makes it vulnerable to loss of firms who rely on intellectual capital and have the agility to move quickly to another place – not necessarily in New Zealand – should their current location be unsustainable.

To ensure rapid economic recovery following a major earthquake, it is imperative that core infrastructure is as resilient as possible. In 2016 the Wellington Lifelines Group took up this challenge and began its Regional Resilience Project.

The project analysed the economic costs of not being prepared for "the big one" and then analysed the savings to the nation if we were prepared, with infrastructure sufficiently resilient to be able to maintain services or recover rapidly. The latter scenario included the appropriate sequencing of work over a twenty-year period to reflect interdependencies between the various types of infrastructure.

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

There are other paybacks as well - the quantitative analysis modelled only a narrow slice of the benefits. For example, it did not include the "business as usual" benefits for society from having the individual projects delivered in a rational and sequenced way over a twenty year horizon, or the resilience benefits in the face of more frequent but lower impact events such as floods or smaller earthquakes. The modelling related only to an extremely large earthquake, but the work programme would provide protection in many other circumstances.

Nor did the study capture two other benefits that have been the subject of increasing public scrutiny in the years following the Christchurch earthquake sequence – firstly, social wellbeing benefits and, secondly, the value to society of underpinning financial confidence in a region.

Regarding social benefits, we are not aware that the cost of reduced societal wellbeing has been exactly quantified in Christchurch. However, it is clear that faster recovery would help mitigate the high levels of stress and anxiety that are experienced in a major event and that are a cost not only to individuals but to the whole community.

On the second point, instilling confidence in a city or region is critical in terms of attracting investment and maintaining adequate insurance cover. This plan would underpin that confidence in Wellington. Current conversations on a proposed transport plan for Wellington ("Let's Get Welly Moving") and a high-level regional investment plan would be better informed by, and would benefit from, the prudent approach taken in this plan, which is about building in resilience.

No person or organisation can totally guarantee against infrastructure failure in a large event, but this plan provides a sequenced and inter-related map of what is required to substantially enhance resilience, thus reduce the risk to the economy.

With this part of the work now complete, the question is: who is responsible for ensuring delivery and who will champion this plan to completion?

Wellington's infrastructure is owned by a mix of central government, local government and private sector shareholders and the project so far has been a shared process between management and technical staff of those utilities. However, the challenge now rests with decision-makers in boardrooms, council rooms and the Beehive to achieve a high degree of collaboration.

Delivering the outcomes we have identified will require a re-think of investment plans because we will be asking elected representatives, company governors and senior managers to agree to sequence their work to take account of interdependencies, rather than each organisation running its own separate programme. Central government will have a key leadership role and will need to work with the Lifeline providers to drive that interdependent approach.

Investment in resilience is always front-of-mind immediately after an event but the urgency fades with time. This study is a compelling case for action. It is not a quick fix, but if we do not start and complete it we are gambling against the probability of an event.

The prize for getting this right will be a highly resilient Wellington: future-proofing an important part of New Zealand.

Dame Fran Wilde

Chair, Wellington Lifelines Group (WeLG)

Executive Summary

Significant benefits identified by improving Wellington and New Zealand's infrastructure resilience to earthquake events

This study details how investing in infrastructure resilience will reduce the national economic impact of a large Wellington earthquake by more than $6 billion. In addition to the avoided economic losses, there will be significant social benefits achieved through Wellington's communities surviving and thriving after a major seismic event.

The study is the first of this size and complexity ever undertaken in New Zealand. It considers the interdependencies of 16 infrastructure providers in order to identify a step-change improvement to the Wellington region's resilience to a large earthquake.

Many of the resilience projects are already on long term asset plans and have funding earmarked. This study identifies that if the interdependent infrastructure projects are accelerated and delivered in a priority order, there will be significant benefits to Wellington and New Zealand's economy when a major earthquake occurs.

Wellington is vital to New Zealand's economy but is currently very vulnerable to large seismic events

Wellington is a vibrant and growing capital city and a key contributor to the New Zealand economy. It is the seat of Government, has high concentrations of professional and value-added services, is a centre for arts and innovation, a key tourist destination and also fulfils a role as a vital transport link between the North and South Islands. Wellington contributes 13.5% of New Zealand's gross domestic product (GDP), has a significant place in the national identity and is home to more than 400,000 people.

Wellington's vulnerability to a major earthquake is well-known and it is not a question of if, but when "the big one" will occur. The imminent questions are: how big will the economic and social impact be when the earthquake happens and what can be proactively done about this? To give confidence to Wellington residents and the people of New Zealand, as well as international investors, insurers and visitors, we must have a credible plan in place to minimise the potentially devastating impact of a disaster in Wellington.

The recent Kaikoura and Canterbury earthquakes demonstrated the need to build resilient infrastructure in our cities. Evidence from our domestic experience and recent international disasters has shown that communal infrastructure is critical to habitability and, when it fails, cities can quickly become unliveable. When key infrastructure is out or operating at degraded levels of service, people leave, productivity drops and communities - and the economy - suffer as a result. Lifeline infrastructure organisations are key service providers to our cities and regions. They have a major role to play in minimising the impacts of hazard events.

Lifeline organisations have historically planned their resilience investments independently and over long periods of time. The drawback of this approach is that planning can become disaggregated and projects delayed due to a lack of urgency and/or internal competition from other priority projects. Even more compelling is that a city's overall resilience is inherently interdependent across lifelines. For example, there is limited benefit in building a resilient water network, if the electricity network is not equally resilient so that pumping stations can function after an earthquake. Lack of co-ordination in planning resilience projects will result in suboptimal investment outcomes.

Integrated infrastructure approach to understand and model Wellington's economic resilience

This study draws on the expert knowledge held by Wellington Lifeline Infrastructure providers. Each Lifeline organisation helped identify infrastructure projects that would increase resilience and support faster economic recovery in the Wellington region in the aftermath of a 7.5 magnitude earthquake. A preferred programme of infrastructure projects was identified and modelled in RiskScape (by GNS Science) and MERIT (by Market Economics) to understand potential economic benefits flowing from pre-earthquake investment. RiskScape and MERIT are the most advanced outage and economic modelling tools available and it is the first time that these have been applied on this scale to provide insights into the national economic impacts of any large natural disaster.

Demonstration of benefits of improving Wellington Region's resilience

The first key finding from the modelling was that if a magnitude 7.5 earthquake occurs on the Wellington Fault with no investment (the do-nothing scenario), the expected loss to New Zealand's GDP over a 5-year period will exceed $16 billion (this is in 2016 dollars and excludes recovery costs or building damage - it is just the economic impact).

The second key finding from the modelling was that if the preferred investment programme is implemented before the earthquake occurs, the expected economic loss reduces to $10 billion over a 5-year period, and a $6 billion impact to New Zealand's economy is avoided. This reduction in economic loss is due to the reduction in outage durations on key lifeline infrastructure with the preferred programme implemented. The people of Wellington will be less impacted and economic activity in New Zealand will return to normal sooner.

Preferred programme of infrastructure investment to deliver maximum resilience benefits

The preferred programme of investment comprises 25 resilience projects at an estimated total capital cost of $3.9 billion. This cost is not all extra or new expenditure,

as many of the projects identified already feature in the long-term capital plans of Wellington's infrastructure providers. Additionally, many of the projects are justified on the primary (non-resilience) benefits they provide to the people of Wellington. By undertaking smart prioritisation and acceleration of these infrastructure improvements, the '"business as usual" benefits are also further amplified.

The programme includes projects across the fuel, transport, electricity, telecommunications, water and gas sectors. Projects have been scheduled across a 20-year time horizon and have been arranged so that interdependencies between projects and other lifeline services are considered. Fuel, road, and electricity projects were found to provide the greatest resilience benefit to other projects.

The investment programme has been broken into three equal phases with projects in Phase One (years one to seven) typically being of higher feasibility and more fully solutioned. Investment in Phase One will lay the foundations, while scoping and planning of Phase Two and Three initiatives should commence immediately.

Funding capital costs for Phase One is 28% committed, 20% contingent with a small amount of revenue from user payments. Approximately 51% remains unfunded at this stage. In order to ensure that there is adequate funding at the right time, central government will need to be involved. This does not mean that central government needs to fund the 51% - the lifeline entities themselves will need to work out new funding mechanisms over forthcoming years and will require consumer/community understanding and support. There will be difficult conversations about long versus short term thinking - conversations that will benefit from central government leadership, given the national economic value of the approach.

This study schedules projects so that resilience benefits can be optimised. For the first time an economic value is placed on what these projects collectively provide in terms of resilience when a major earthquake (or another natural hazard event) occurs.

The study analyses the benefits of improving resilience to a high-impact but infrequent major earthquake. The proposed infrastructure improvements will also make the Wellington region more resilient to higher frequency seismic events (for example earthquakes similar to the Cook Strait and Kaikoura events). Taking these smaller and more frequent types of shock events into account will mean the real economic benefits will exceed $6 billion of avoided impacts for the single magnitude 7.5 earthquake modelled in this study.

Wellington and New Zealand must make improving resilience a priority

It has been over 160 years since a truly large earthquake hit the Wellington region – the magnitude 8.2 Wairarapa earthquake. Every day that passes without "the big one" means we are one day closer to when it will occur. Statistics suggest that there is around a 30% chance of a damaging earthquake every decade, so we need to keep pressing forward to realise the benefits that are clear from this study before the inevitable happens.

The people of Wellington and New Zealand are relying on key decision-makers to ensure their wellbeing and economic future are secure. Our objective is to galvanise into action everyone concerned - infrastructure providers, local government and central government. The target is to confirm the Wellington region's integrated infrastructure resilience plan by early 2020 and commit to making it happen.

Now that we have identified the pathway to resilience success, any other outcome will be a failure.

Please note:

This Programme Business Case (PBC) has been undertaken in 2 stages. Stage 1 of the PBC '**Demonstration of Benefits**' was completed in April 2018. Stage 2 '**Financing and Timing**' was completed in September 2019. The remaining Commercial and Management cases will be developed individually by the Lifeline organisations.

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*[**Explanatory Statement:** In producing this report Aurecon has relied on inputs supplied by GNS Science under contract to GWRC and information from other parties. The report is provided strictly on the basis that the information that has been provided is accurate, complete and adequate. While all due care has been taken by Aurecon in compiling this draft report Aurecon can neither warrant nor take responsibility for the accuracy of the GNS work or such other parties. Aurecon takes no responsibility and disclaims all liability whatsoever for any loss or damage that the client or any other party may suffer resulting from any conclusions based on information provided to Aurecon, except to the extent that Aurecon expressly indicates in the report that it has verified the information to its satisfaction.]*

PART A – THE STRATEGIC CASE

1. Integrated Infrastructure Resilience to Protect Wellington's Economy

1.1 – Integrated Infrastructure Resilience

The Wellington Lifelines Regional Resilience Project is an initiative of the Wellington Lifelines Group (WeLG) which recognised the need for a step-change and an integrated approach to increase the resilience of lifeline services. Local Councils and others have put great effort into imbuing the population with resilience. However, in the case of a large earthquake, Wellington's infrastructure also needs to be resilient, not only for people, but to ensure that business can continue after the event and to substantially minimise GDP loss for New Zealand.

This project was initiated because all infrastructure providers want to collaborate to address infrastructure deficiencies and, more explicitly, show the significant value of understanding interdependencies between different lifeline services. Working together ensures any investment is focussed on the best results for the building of resilience for the region, not just for each individual utility.

The work addresses the likely economic impact of a M7.5 earthquake to help inform options to reduce the economic effects through targeted infrastructure investments. Given Wellington's strategic importance as a transport hub with a large advanced economy and its role as the capital city, such investments will also benefit the wider national economy.

The work is being carried out with Central Government as a part funder, together with local government and the infrastructure providers. It is closely aligned with regional resilience initiatives[1] and built environment resilience initiatives.

Figure 1: Convoy of army trucks carrying essential supplies for Kaikoura Hospital following the 2016 Kaikoura Earthquake. Transport links to Wellington Region will be highly compromised after a shock event like a major earthquake, which could require similar convoys. (Source: RadioNZ)

[1] *The PBC is expected to be a substantial contribution to developing a resilience strategy, alongside other initiatives, such as the work of the Wellington Regional Resilience Coordination Group (WRRCoG), which focuses on the six-month period following a major event.*

1.2 – Context of this Document

The purpose of this Programme Business Case (PBC) is to help enable smart and integrated investment decisions for public value across a raft of lifeline organisations and the wider sectors. The New Zealand Treasury's Better Business Case (BBC) process has been used to guide the development of this PBC.

The five-stage BBC model was followed which covers the: strategic, economic, financial, commercial and management cases.

The development of this PBC is being undertaken in two stages:
Stage 1 – Demonstration of Benefits
Stage 2 – Financing and Timing

Stage 1 focuses on the strategic and economic cases for improving Wellington's infrastructure resilience. The outcomes of this stage were then used to profile the benefits of having an integrated infrastructure plan across all lifeline organisations in the region.

Subsequent to Stage 1 being completed, lifeline organisations were consulted on the outcomes and alignment sought between individual organisations long term plans and the integrated infrastructure plan.

The aligned finance and timing of the resilience programme (i.e. the financial case) has been delivered as Stage 2, with the remaining, commercial and management cases of the BBC process left up to individual lifeline organisations to complete.

1.3 – Elements of Resilience and Focus of this PBC

Resilience can be broken down into three main elements:
Infrastructure Resilience = Robustness + Redundancy + Response

Robustness relates to the inherent capacity of an asset or system to be able to withstand a shock event. Redundancy is the existence of alternative options to back up an infrastructure service (such as an alternate road to a destination or diversity in power supply connections). Response relates to the pre-planning and resources available in order to respond immediately after a shock event. While it may be desirable to minimise the reliance on response, after a shock event there is a practical reality that response will always be required.

This PBC targets the robustness and redundancy elements of infrastructure resilience. This is because these elements have the largest impact on the economy, the key purpose of this PBC as demonstrated by the Project's title - ***Protecting Wellington's Economy Through Accelerated Infrastructure Investment.***

1.4 – Development of the PBC

The Strategic Case and the Options and Alternatives Assessment Report documents have been prepared by a team of infrastructure specialists, scientists and economists. This PBC has undergone interim peer reviews throughout its development by members of the project team and project steering group.

2. Strategic Context for Investing in Wellington's Resilience

2.1 – Wellington's Seismic Risk

The potential for a major shock event, especially a large earthquake affecting Wellington, is well known. A wealth of studies, reports and experience show that the Wellington Region (focussing on the western side from Wellington City in the south-west to Kapiti Coast and Upper Hutt in the north and north-east) is highly vulnerable to a major physical shock event.

While the physical impacts of an earthquake are appreciated, the likely economic consequences have not been fully grasped. This Resilience Project has simulated the impact of a M7.5 earthquake to provide information and to enable systematic analysis on how the vital lifelines perform following the event. This information has been used to assess specific potential coordinated investments across the lifeline organisations.

2.2 – Wellington's Geographic and Infrastructure Context

Some of Wellington's infrastructure is highly vulnerable to physical shock events such as earthquakes. This is due to the historic build quality, the location of the region's lifeline services being heavily constrained to limited geographic corridors suitable for these services, and the infrastructure crossing fault lines in multiple locations.

The pattern of urban development of the western part of the Wellington Region is shaped by its seismic history. The Wellington Fault line that forms the western side of the Hutt Valley and the escarpment to the south is but one of a series of fault lines that have raised the hills and formed the valleys. The whole area is being lifted as the Australasian Plate is being under-thrust by the subducting Pacific Plate (Hikurangi Subduction Zone). Infrastructure and regional development has taken place over and around these seismically-created geographic features.

The western side of the Wellington Region at the south-west corner of the North Island has a physical geography that makes it especially vulnerable to major events. This is because a large

"When" not "If" - Large Earthquake in Wellington Region

Major earthquakes in 1848, 1855, 1942, and 2016 caused significant damage in the Wellington Region since European settlement in about 1840. In addition, geological research has identified many more large earthquakes resulting from rupture of the regional active faults over the past several thousand years. Therefore, it is certain that the region will be exposed to the threat of strong earthquakes in the future.

The current National Seismic Hazard Model of 2010 (NSHM2010)[2] has synthesised the research data to derive the average recurrence interval of various levels of shaking on the Modified Mercalli Intensity (MMI) scale (refer to Appendix A for more details on the MM Intensity scale). For a firm soil site in Wellington there is an average ~30-year recurrence interval for MMI 7, ~120 years for MMI 8 and ~ 400 years for MMI 9.[3]

For reference, the February 2011 Canterbury Earthquake typically had MMI values of 9 in the Christchurch Central Business District. The 2013 Seddon and 2016 Kaikoura earthquakes resulted in MMI values in Wellington of about 6 and 7.

Future earthquakes that will cause damage in Wellington could be centred on nearby active faults (Wairarapa, Wellington, Ohariu), the Hikurangi subduction fault extending beneath Wairarapa and Wellington, or rupture of more distant faults in northern South Island (including the Alpine Fault), Cook Strait, or further north and northeast in Manawatu, Wairarapa and southern Hawkes Bay.

[2] *Information from the NZ National Seismic Hazard Model supplied by Russ Van Dissen, GNS Science*

[3] *Abridged and adapted from: https://www.geonet.org.nz/earthquake/mmi*

VULNERABILITIES OF THE WELLINGTON REGION IN A MAJOR PHYSICAL EVENT

Figure 2: Overview of the Wellington Region (dark shading indicating the location of major ranges between Wellington and the rest of the North Island)

earthquake will cause isolation of the communities between mountain ranges and the sea. The Tararua and Remutaka ranges effectively surround Wellington and limit the access points and routes for lifeline services into the region from the remainder of the North Island. Further south on the western coast, there are extremely narrow transport and infrastructure corridors between steep slopes and the sea from Paekakariki to Paremata.

The eastern corridors to the metropolitan region via the Remutaka Range and Hutt Valley are also very constrained owing to the steep topography.

The steep terrain continues into the western region – the Belmont Hills – separating the Hutt Valley from the western coastal area and further constraining infrastructure corridors. Wellington itself is surrounded by hills and the harbour with only three corridors for transport access and utilities. *(Figure 2)*

Disruptions to the above corridors, particularly if they happened at the same time, would have significant impacts on the transport routes and other lifeline services in the Wellington Region. Such disruption would prevent people travelling and cause severe difficulties in transporting food, water and essential emergency supplies into the region. The long-term recovery efforts would be significantly constrained by the limited corridors and the damage they would sustain.

Several other factors make Wellington's infrastructure vulnerable to shock events. Since Wellington was founded 175 years ago, the infrastructure has been progressively developed to support population and economic growth. However, much of the early infrastructure is still in use today.

The earlier infrastructure was constructed without awareness of the sort of shock events it might be subjected to, and so used construction methods/materials now known to have low resilience to such events. For example, widely used unreinforced (or lightly reinforced) masonry and concrete construction is now known to be susceptible to earthquake damage and, similarly, cast iron water pipes that are commonly used in the region are brittle and cannot accommodate ground movement from earthquakes.

Another factor is the way infrastructure networks are configured with few, if any, alternate (or redundant) paths

Figure 3: Damage to CentrePort from the 2016 Kaikoura earthquake (Source: Maarten Holl, Fairfax NZ)

Figure 4: SH1 access along the South Island coast severed by large landslides following the 2016 Kaikoura Earthquake. Similar landslides of this magnitude are expected to occur in Wellington should a major earthquake occur in the region. (Source: Walter Rushbrook / Aurecon)

to enable services to continue to be provided if they are damaged by a shock event. For example, there is a lack of practical alternative transport routes or water/electricity connectivity once primary routes are severed.

With reference to the Canterbury and Kaikoura Earthquakes previously described (refer excerpt: *Large Earthquake in Wellington Region – "When" not "If"*), even relatively low to moderate levels of shaking from these earthquakes caused considerable disruption to the Wellington Region including affecting the normal functioning of infrastructure networks. Most notably, there was damage to the port which is a key link in providing a 'State Highway 1 across Cook Strait' and an export connection to the rest of the world. The port is a major contributor to the regional economy and should a major earthquake occur, would be a vital lifeline access point.

The economic impact of the Kaikoura earthquake using the MERIT model (as is being used for the present business case) was estimated at $360m lost GDP over 18 months. Of this, $92m was in Canterbury, with the balance in the rest of New Zealand – Wellington having a major share in the first two weeks.

The recovery time from a major earthquake in Wellington will also be significant (see below for more details). While basic infrastructure services may be restored, returning to pre-quake levels of service will take many years. A modern New Zealand analogue for this is the slow Christchurch infrastructure recovery after the 2011 magnitude 6.3 earthquake. More than seven years on, the infrastructure recovery work is still ongoing and impacting how the city functions. Arguably, recovery in Wellington from an earthquake shock event will be even longer, owing to the current level of lifeline resilience, more difficult geography and lack of redundancy, in comparison to Christchurch.

In this context, it is critical that Wellington's resilience planning is of the highest order to sustain the people and economy of the capital city of New Zealand.

2.3 – The Economic Context – The Importance of Wellington to New Zealand

The Wellington Region has characteristics that make it exceptional in terms of its attractiveness as an advanced economic location. Whilst the impact of being the capital is apparent, there is a unique mix of location, appealing natural and built environment and history, that creates a culture attractive to more advanced industries and the mobile knowledge workers they employ.

As a result:

- The capital has the highest proportion of Masters and post-graduates in the country, and 88 per cent of high school students pass NCEA level 2, compared with 83 per cent in the rest of the country.
- Wellington has the highest median income in the country, and the local economy has grown 21 per cent since 2011.
- It hosts the fastest rate of new tech businesses, and highest concentration of web and digital businesses in New Zealand, which provide 16,000 jobs and 4000 businesses, contributing $2.1 billion in GDP.

The special significance of the Wellington economy is shown by its position within the Globalisation and World Cities (GaWC) hierarchy - *The world according to GaWC*[4] is a city-centred world of economic flows. Cities are assessed in terms of their advanced producer services.

Wellington is ranked as a Gamma city which means that it links a small but high-performing economic region into the world economy. Auckland, as a Beta+ city links a moderate economic region into the world economy.

As a Gamma city, Wellington has a "high degree of accountancy, advertising, banking/finance, and law services so as not to be dependent on world cities". By contrast, Christchurch as a Sufficiency level city, only has a "sufficient degree of these (more sophisticated) services".

With a tendency for higher-order services to gravitate towards the upper-tier cities, the major risk for New Zealand is that a large event will badly affect the Wellington CBD (which generates 77% of total GDP for Wellington City, 48% for the Wellington Region and 8% of national GDP[5]).

In the event of a big shock, businesses in the higher level – professional services, finance, telecommunications and internet sectors – with key relationships in Australia and other countries, are more likely to relocate abroad than elsewhere in New Zealand. Such businesses would take with them 8% of the national GDP, resulting in skilled people leaving Wellington.

Emigration is most probable because it is inconceivable that all the inter-connected set of elements that make Wellington a Gamma city would transfer together within New

Figure 5: Wellington's hills and slopes (Source: Epicbeer/Flickr)

[4] *http://www.lboro.ac.uk/gawc/gawcworlds.html*

[5] *Wellington City at a Glance: ecoprofile.infometrics.co.nz/Wellington%2bCity/Infographics/Overview*


Figure 6: State Highways 1 and 2, and the railway line linking Wellington City to the Hutt Valley & Wairarapa along the Wellington Fault line, circa 1985 (Source: Lloyd Homer, GNS Science)

Zealand. Wellington has unique characteristics; ideal location, making it easily accessible from the North and South islands, a strong culture of arts, creativity and innovation that includes its high-performance, globally recognised Digital Technologies sector, and the seat of Government. It has a very appealing setting with easy access to the natural environment. All this makes it attractive for high-level businesses and the 'creative classes'. It is probable, in the event of a major earthquake, that significant components of the economy would move to the upper tier cities in the region with similar profiles – notably Melbourne and Sydney – with consequent losses to the New Zealand economy. Even once Government returned to Wellington it could be expected that there would be permanent losses.

The Wellington Resiliency Strategy[6] quotes a BERL study finding that a significant earthquake in Wellington could result in New Zealand losing about 1-2% of its current GDP per year. The Net Present Value of such a loss over time would be about $30-$40 billion[7].

Previous studies had put the cost of a "major Wellington earthquake" at US$24 billion in 1995[8] – roughly equivalent to NZ$50 billion today.

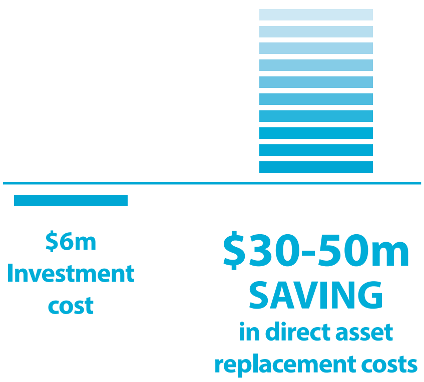
Whilst there has been considerable focus on the Wellington city centre and its office buildings, the impact on private homes – and therefore the people of the region - should not be forgotten. Wellington's workers will need somewhere to live.

Wellington has many major assets that are themselves of significant value – they include universities, schools, hospitals, arts and cultural venues, eateries, international sports venues, Wellington Airport and the sea port. Together they support the special elements of Wellington's higher order economy. Losing them would be a major loss for New Zealand.

The level of the economic impact of a major shock event on New Zealand and the region depends on its precise nature and scale. But very clearly it can be expected that large numbers of people will leave the region should Wellington's infrastructure cease to function for a period of time and there will be an economic impact of many billions of dollars. Exploring ways to minimise the social and economic impact is why this PBC is being undertaken.

"A Wellington quake could leave up to half of the city's houses unliveable and the average repair cost per home a third higher than in Christchurch. The repair cost for the city would likely total over $6.9 billion for residential properties alone"[9]

Case Study: Benefits of Investing in Resilience – Orion's 2010 and 2011 Earthquake Experience



There were huge societal benefits from Orion's ability to restore power to 90% of the city within 24 hours following the September 2010 earthquake and within approximately 10 days following the more severe, February 2011 earthquake.

Orion invested $6m in its seismic strengthening programme from 1996, which served both the company and Christchurch well following the 2010 and 2011 earthquakes. Orion saved $30m-$50m in direct asset replacement costs following these events, far exceeding the $6m investment.

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[6] *Wellington Resilience Strategy March 2017 100 Resilient Cities*

[7] *Wellington – essential to NZ's Top Tier: Its resilience is a national issue BERL, December 2015, p.3*

[8] *Gregory, op cit, quoting Professor Hal Cochrane from the Department of Economics at Colorado State University*

[9] *Victoria University Senior Lecturer Geoff Thomas speaking at the NZ Society for Earthquake Engineering's technical conference as reported on Stuff http://www.stuff.co.nz/national/nz-earthquake/92081766/wellington-homes-repair-costs-predicted-to-be-a-third-higher-than-in-christchurch-in-a-big-quake*

[10] *Resilience Lessons: Orion's 2010 and 2011 Earthquake Experience Independent Report, Kestrel Group, September 2011*

3. Alignment to Existing Strategies

3.1 – Strategic Mandate

This PBC is the most realistic study undertaken in New Zealand to date, in terms of the level of detail and complexity of the analysis. It provides an in-depth assessment of the interdependencies between lifelines, and details the benefits of a combined suite of interventions that would not be realised if these were assessed separately.

One of the key drivers for improving infrastructure resilience is provided by the Civil Defence Emergency Management Act 2002, which states that lifeline services (utilities) must "function at the fullest possible extent during and after an emergency". This is why lifeline services have taken the initiative to work together to lessen the impact of an earthquake hazard event.

Given the large number of organisations covering multiple infrastructure types, there is no individual document that could be described as New Zealand's definitive lifeline resilience strategy. However, a variety of plans, policies and strategies exist that collectively provide the strategic context for preparing this business case. Some of the plans are in the Civil Defence Emergency Management sector, while others are found in more general infrastructure plans, often for a particular infrastructure type. These plans for particular infrastructure are important as they show how resilience fits within the organisations' overall priorities.

Additionally, New Zealand is a signatory in the United Nations Sendai Framework for Disaster Risk Reduction. The purpose of the framework is to substantially reduce disaster risk and losses in lives, health effects, livelihoods and economic impacts. This PBC is highly aligned with the priorities of the Sendai Framework:

- Understanding disaster risk
- Strengthening disaster risk governance to manage disaster risk
- Investing in disaster risk reduction for resilience
- Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction.

The legislative and organisational frameworks provide a strong mandate for lifeline services to plan for emergencies and improve resilience.

3.2 – Summary of Existing Strategies

A summary of previous WeLG studies and their findings can be found in Appendix B.

Table 1 overleaf provides a summary of strategies which support the investment in the Wellington Region's Resilience. Appendix C contains more exhaustive details of each piece of supporting information.

Figure 7: Wellington Water reservoirs near Karori, Wellington City. Water supply after a shock event such as an earthquake is a key resilience issue facing the region (Source: Graham Hancox, GNS Science)

Table 1: Strategies identified which support investment in resilience

Organisation	Strategy Identified	Description	Relevance to Resilience / the Business Case
Ministry of Civil Defence	Civil Defence and Emergency Management Act 2002	Defines the roles and responsibilities of government departments, local government agencies, emergency services and lifeline utilities in planning and preparing for emergencies, plus response and recovery in the event of an emergency. The legislation requires lifeline utilities to ensure their business is able to function to the fullest possible extent, even though this may be at a reduced level, during and after an emergency. Additionally, organisations are required to participate in the development of national and regional plans.	The CDEM Act provides a clear mandate to be prepared and ensure resilience measures are in place to respond to a shock event. This WeLG PBC is a key initiative to comply with the legislation and enable resilience to be improved for the people and economy of the Wellington Region.
Ministry of Civil Defence	Guide to the National Civil Defence Emergency Management Plan 2015	Provides a cohesive strategy for operational arrangements for an emergency of national significance. The Guide comments that Lifeline utilities are primarily responsible for the reduction of outage risks, for example by the location and installation of assets consistent with local hazard conditions.	This business case is a major contribution towards the plan's goals of enhancing New Zealand's capability to recover from emergencies and reducing the risks from hazards to New Zealand.
Department of Internal Affairs	Local Government Act 2002	Outlines the responsibilities of local government and has requirements to provide for the resilience of infrastructure assets by identifying and managing risks relating to natural hazards.	Local councils and their related organisations are closely involved in this resilience business case. Their funding contribution to this PBC and participation in preparing this business case demonstrates their compliance and commitment to the legislation.
Ministry for the Environment	Resource Management Act 1991	Sets out matters of national importance that decision-makers must recognise and provide for in various circumstances. An explicit mandate was introduced in the 2017 Amendment including "*the management of significant risks from all natural hazards*" as a matter of national importance.	Alongside other legislation, the recent amendment further strengthens Central Government leadership and direction to improve resilience to natural hazards such as earthquakes.
National Infrastructure Unit, Treasury	National Infrastructure Plan 2015	Helps set the national direction for infrastructure management and development. The plan specifically identifies the importance of having resilient infrastructure. It notes that resilience can be achieved through a combination of investing to make things stronger and operational changes. The plan encourages research to shed light on resilience to natural hazards and apply the lessons learned from Christchurch.	The preparation of this resilience business case is highly aligned with the intent of the plan. This PBC utilises the RiskScape and MERIT modelling tools which have been developed from government funded research and development programmes. As part of the options assessment used in this business case both physical and operational resilience options will be considered to identify the preferred programme/s of infrastructure work.

Organisation	Strategy Identified	Description	Relevance to Resilience / the Business Case
Ministry of Civil Defence	Emergency Relocation of Executive Government and Parliament Plan 2014	Provides a continuity plan to ensure government functions can continue after a shock event (including relocating key government functions and Parliament to Auckland should the need arise). The Plan is based on nine assumptions concerning the level of assumed functionality of key infrastructure and lifeline utilities, such as transport links and roading networks, power, drinking water, wastewater and telecommunications.	Improving the resilience of the capital city to minimise the thresholds for key government functions and Parliament to relocate – a move which will be highly disruptive.
Local Councils	Wellington Resilience Strategy 2017	Sets out how to prepare for, respond to and recover from disruptions. Highlights some key actions including: investing in water and sewage resilience and awareness; and integrating resilience into transport projects. It also makes specific mention and support of this Resilience business case work.	This business case specifically addresses the water, wastewater and transport projects. The interdependencies with other lifelines providers and critical customers are explored to help provide a coordinated and prioritised plan.
Ministry of Transport	Government Policy Statement 2018/19 – 2027/28	Gives priority to investments that improve resilience on transport routes where disruptions pose the highest economic and social costs, through recognition of interdependencies between lifeline networks. Supports the development of regional resilience plans to provide solutions for the critical transport routes in urban areas, including Wellington.	The economic benefits across multiple lifeline services of investing in improving resilience on key transport routes have been modelled as part of the work. This in turn informs and helps prioritise solutions for critical transport routes.
Lifeline Organisations	Resilience Strategies	Sets out each lifeline organisation's obligations under the CDEM Act relating to resilience. These are given effect to in the form of projects and plans. Documentation outlining their commitment to resilience is often set out in asset management plans and policies available from each organisation.	This business case is highly aligned with the strategies and obligations of lifeline providers. As a sign of their strong commitment to resilience, lifelines providers have helped fund this PBC work and providied asset information required for the modelling. The coordinated and prioritised programme/s of work from this PBC work will feed into their short- to long-term plans for implementation.

4. Investment Objectives

This section of the Strategic Case documents the specific investment objectives of the business case, drawing on the identified problems and the expected benefits. The logic map set out in this section informed the final resilience programme described in section 6.

4.1 – Problems, benefits and investment objectives

Facilitated workshops were held with lifeline organisations and government representatives in 2017, to identify the specific problems and benefits to be addressed and subsequently, the investment objectives. See Appendix D for the Investment Logic Map (ILM). The participants collectively identified and agreed the problems, benefits, investment objectives, and their respective weightings as summarised in the following sections. Refer also to Figure 8 on the following page.

4.1.1 – Problems

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

4.1.2 – Benefits

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

4.1.3 – Investment Objectives

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

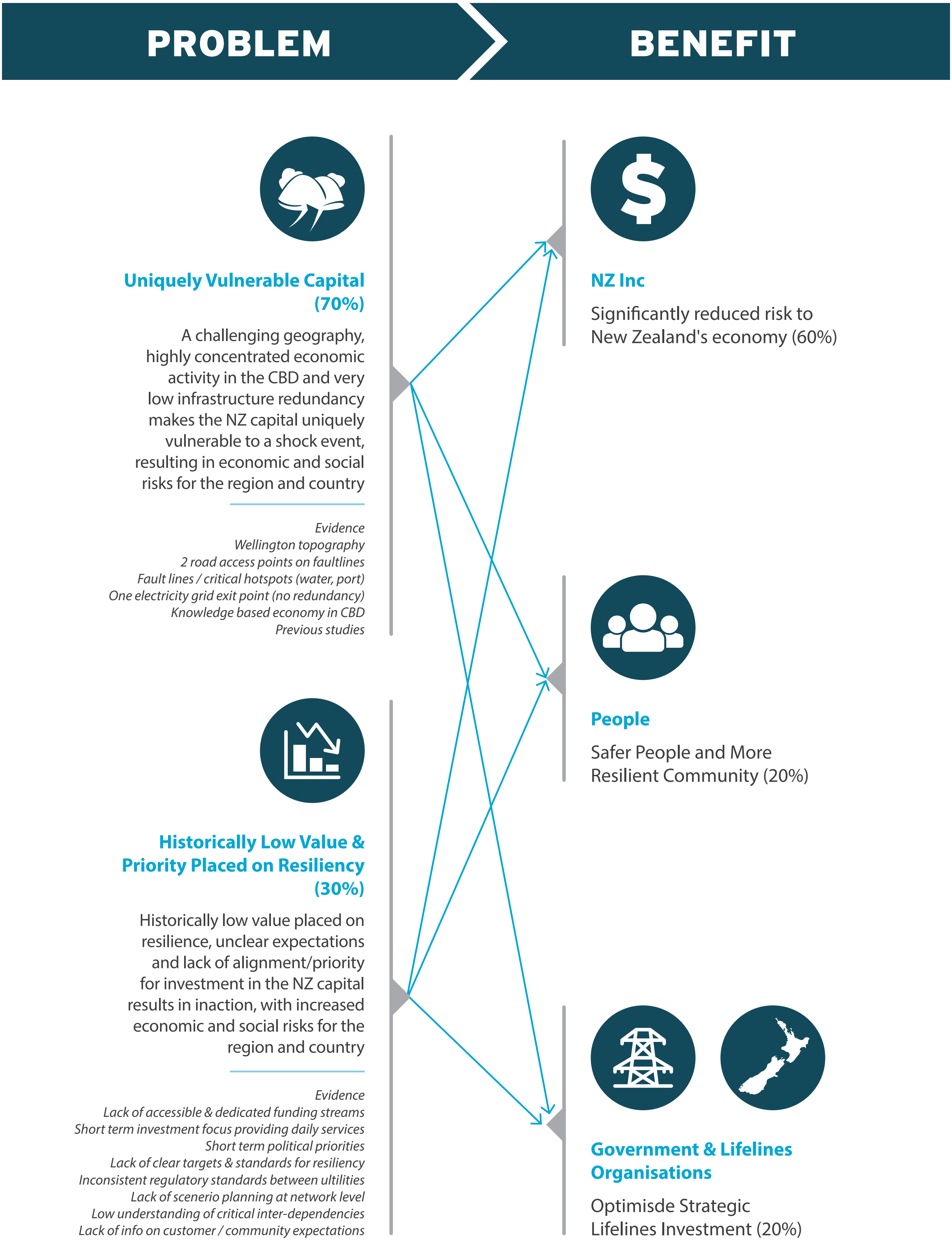


Figure 8: Summary of Investment Logic Mapping Outputs

5. Risks, Constraints and Dependencies

5.1 – Risks

Table 2 highlights the main risks identified, relating to this business case. BBC guidance is that "a risk is the chance of something happening that will have an impact on the achievement of the investment objectives". In that context, the following have been identified, in accordance with the 80/20 principle in the BBC documentation:

Table 2: Risks Assessment Summary

Main Risks	Consequence (H/M/L)	Likelihood (H/M/L)	Comments and Risk Management Strategies
Failure to invest prior to the next catastrophic shock event occurring, resulting in multiple deaths and injuries.	High	Medium	A major shock event occurring prior to investment will result in catastrophic life and economic losses in the Wellington Region. The actions recommended in the business case need to be pursued expeditiously.
The programme is not accepted as a valid case for investment.	Low	Low	All strategies assessed support infrastructure investment for resilience purposes. The business case is developed following leading practice, is peer reviewed and appropriately injected into critical decision-making processes.
Resource consents for important programme components, for example works on or near the Wellington Harbour foreshore and seabed, are opposed or rejected.	High	Medium	Resource consents for individual works will be the responsibility of the particular lifeline organisations. WeLG could be an active supporter, where needed, drawing evidence from this business case.
The economic benefits are not seen as sufficient justification for any additional public sector investment.	Medium	Medium	Ensure correct representation of the resilience benefits as only a proportion of the total. Provide clarity on the range of events where increased resilience is provided. Have credible supporting peer review.
Fuel is a critical lifeline which all other lifeline services depend on to restore their network but may not receive the required investment owing to the structure of the industry and lack of engagement.	High	Medium	Enhance the contacts with the fuel companies alongside relevant authorities. Make sure that the business case proposals are sound.

Main Risks	Consequence (H/M/L)	Likelihood (H/M/L)	Comments and Risk Management Strategies
Land use changes as a result of Transmission Gully or a major facility relocating such as CentrePort may reduce the potential benefits realisation for other projects.	Medium	Low	The Transport Agency will undertake a detailed business case for each transport intervention which will consider demand and land use as well as resilience.
Substantive alteration to project scope through the planning and design process altering the assumptions used to identify the preferred programme.	Low	Medium	This PBC demonstrates the criticality of these projects in providing resilience to the Wellington Region. Significant changes to scope for projects within the preferred programme should ensure that the same or higher resilience LoS is achieved. WeLG could be an active supporter and work with infrastructure providers to ensure that the potential resilience benefits are not lost through the project's lifecycle.

The risk assessment summary shows that the consequences of the current state of Wellington's lifelines infrastructure and rejection of future funding will have significant impacts on both the Wellington's regional economy and the wider New Zealand economy.

Transmission Gully (Source: Transmission Gully SAR, NZTA)

5.2 – Constraints and Dependencies

According to BBC guidelines, "constraints are limiting parameters within which the investment must be delivered. These can include relevant Government policy decisions, initiatives or rules. Affordability constraints can include funding envelopes or limits on the amount of either operating or capital expenditure that can be incurred".

The following tables indicate the high-level constraints and dependencies of the existing lifelines networks in the Wellington Region.

Table 3: Constraints

Constraints	Notes
Lead time	Long decision-making, planning and construction times before infrastructure resilience projects are able to generate potential benefits.
Funding mechanisms	The ability of some lifeline organisations and the public sector to invest in infrastructure is restricted.
Commercial constraints	Many providers of lifeline services operate in competitive markets, including telecommunications, port services and fuel providers. Their existing infrastructure vulnerabilities and potential resilience improvements are commercially sensitive, which can result in an unwillingness to disclose details and approximate investment costs for some initiatives.
Benefit realisation interdependency	Benefits are presented at the macro level and consider the GDP impact of the programme of projects as a whole. Cost benefit analysis will be applied to individual projects as they are advanced and funding decisions are made.

Dependencies are described in the BBC literature as "any actions or developments required of others and outside the scope of the project or programme should be identified and describe if the success of the investment proposal is dependent upon them".

Table 4: Dependencies

Constraints	Notes and Management Strategies
Regulation	Electricity distributors are regulated by the Commerce Commission, which controls how much of the additional investment cost can be passed through to consumers. Hence Wellington Electricity's ability to invest in new or previously unplanned infrastructure projects is at the discretion of the Commerce Commission.
Community preparedness	To fully realise the benefits of the investment, individual household preparedness is imperative. This Business Case addresses the long-term recovery period following an event, however it depends on communities remaining in Wellington and therefore on their preparedness for the recovery period immediately following an event. WREMO's work in this respect needs to be continued and strengthened.
Business preparedness	This business case does not address the resilience of buildings – including commercial buildings such as those damaged by the Kaikoura earthquake. Without resilient buildings, some advantages of investment in lifelines may be fruitless. It will be important that the parallel processes to promote stronger buildings are supported.

5.3 – Opportunities

Improving resilience for one particular shock event will potentially have positive implications for other shock scenarios. Additionally, if resilience for a maximum credible shock scenario was provided for, it will also result in improved resilience for less severe shock events.

Lastly, while the exact impacts of a shock event are difficult to predict, if major elements of infrastructure are resilient, then it provides improved options/ pathways to recovery than would have otherwise existed.

Most infrastructure projects to help improve resilience have co-benefits (for example improved transport networks for day-to-day users).

PART B – EXPLORING THE PREFERRED WAY FORWARD

6. Options Identification and Assessment

This section records the long list of options which were developed through workshops with lifeline organisations and subject matter experts. Further, it describes the process by which these options were generated and assessed against the investment objectives using a multi criteria analysis tool. How the options were then packaged into alternative programmes and tested is covered in detail in the next section.

6.1 – Critical Success Factors

The critical success factors for this investment proposal have been derived using the NZ Treasury Guidance.

Table 5: Critical success factors

Factor	Description
Strategic fit and business needs	Meets the requirements of the identified central, local government and private sector plans including: - Reduces the risk from hazards - Reduces the predicted loss to the NZ economy - Enhances the region's ability to recover from emergencies - Ensures that lifelines can function at the fullest extent possible after an emergency (even though this may be at a reduced level).
Potential value for money	Economic benefits and more importantly, the avoided costs of the infrastructure resilience investment, are higher than the costs to undertake the works.
Supplier capacity and capability	Commercial considerations will be addressed at the individual project level as projects are advanced, including the sourcing of competitive tenders from competent contractors.
Potential affordability	Affordability has a specific focus on the likelihood of funding and/or the available funding mechanism. Affordability will be addressed at the individual project level as projects are advanced and funding decisions made. It should be noted that Potential Affordability has not been given a strong consideration in this PBC. This work focuses on identifying the preferred programme to improve infrastructure resilience. A key outcome of this PBC will be to provide alignment on a preferred programme across all the lifeline providers, which can then be used to underpin discussions on how the works can be funded. This is discussed in more detail in the Financial Case.
Potential achievability	The infrastructure resilience improvements can be implemented quickly enough to ensure the benefits stated in this report are achieved as soon as possible. However, earthquakes are unpredictable events that could strike at any time. The sooner resilience improvements are carried out the higher the potential benefit realisation.

These critical success factors are used to inform the options assessment.

6.2 – Option Generation

A wide range of options to address the problem statements were generated by stakeholders at a facilitated Options Workshop on 1 June 2017. Participants at this workshop included representatives from lifeline organisations and subject matter experts, who were encouraged to put forward ideas that ranged from regulatory changes and previously identified resilience improvements, through to 'blue-sky thinking' ideas. To ensure a robust set of options was developed, consideration of the following types of resilience measures was prompted:

- Governance (underlying changes that could allow others to be implemented)
- Recovery
- Redundancy
- Robustness

The list of options was further added to from projects identified in lifeline organisations' Asset Management Plans (and equivalents), long term options identified previously in the Department of the Prime Minister and Cabinet's register which was compiled shortly after the 14 November 2016 Kaikoura Earthquake, and those which emerged from subsequent meetings with stakeholders. The resulting comprehensive long list contained 137 ideas. For a full list of the ideas generated and for which infrastructure type they provided resilience, see Appendix F.

A critical assessment was undertaken of the long list to remove duplicates, generic options and options included in the base case. The comprehensive set of ideas was subsequently considered by the project team and were allocated into three categories:

1. Those not to be assessed further and to be removed from scope
2. Those not to be assessed further for the main programmes but to be retained and included in the business case narrative as having a supporting or complementary role
3. Those options remaining.

6.3 – Options removed from scope

Options were removed from consideration altogether if they were a duplicate, too generic or not feasible. Fourteen options were also removed because they respond to the rescue and short-term response periods rather than the recovery and return to business as usual (BAU) that is the focus of the business case. Many of these options are being picked up in a separate project undertaken by Wellington Region Resilience Coordination Group or form part of the Wellington Civil Defence Emergency Management Group's ongoing work.

For a full list of these options and the rationale behind their removal from further consideration, see Appendix G.

6.4 – Options not Assessed but Retained

Nine options were classified as 'governance' measures, providing a limited direct effect in themselves but which enable the realisation of other options. As such, these items were not critically assessed against the investment objectives but were retained and referenced later in this report as regulatory-type changes that may be required to support the preferred programme.

Peka Peka to Otaki and Transmission Gully (TG) road construction projects were noted as currently being pursued at the time of writing this Programme Business Case, and excluded from assessment against the Investment Objectives. TG was included in the RiskScape modelling of the base case while Peka Peka to Otaki is outside the area of principal interest.

For a full list of the options retained, but not assessed further for the core programme(s), see Appendix G.

6.5 – Options Remaining

A full list of the remaining options judged to have potential and grouped by infrastructure type is provided in Table 6 below.

Table 6: List of potential options

Infrastructure Resilience Ideas	
FUEL	
Improve seismic resilience of existing diesel stores at Ngaio Gorge	Seaview Wharf seismic strengthening including fuel pipeline infrastructure
Move Seaview Fuel Terminal to higher ground	Replace Burnham Wharf and existing fuel infrastructure
TRANSPORT (ROAD)	
Upgrade Akatarawa Road and Moonshine Road	Ngauranga to Petone shared pathway and rail realignment
SH58 – seismic upgrade from Transmission Gully to Haywards	Takapu link – alternate link between Petone to Grenada and Transmission Gully
Cross Belmont Regional Park link	Wadestown to Johnsonville route seismic strengthening
Remutaka Hill Road resilience measures	Ngauranga Gorge accelerated resilience
Petone to Grenada new road link	Taita Gorge access strengthening
Wellington Urban motorway: Shell Gully – embankment and structure strengthening	Hutt Valley East-West new road connection from SH2 to Seaview/fuel terminal (Cross Valley Link)
Grays Road flooding improvements	Hutt River bridges seismic upgrades
Better engineered road links to the Port	Improved resilience of airport connection via Newtown
Middleton Road retaining walls upgrade (also a gas supply project)	
TRANSPORT (SEAPORT)	
Minor seismic upgrade of Thorndon Container Terminal	Major seismic upgrade of Thorndon Container Terminal
New roll on roll off ferry (RORO) terminal at unspecified location	Upgrade of existing RORO terminal
RORO facility at Seaview Wharf	Strengthening of RORO facilities in the Port
Aotea Wharf redevelopment	Procure floating RORO pontoon
Burnham Wharf, Miramar - upgrade existing facility	Alternate ship mooring point
TRANSPORT (RAIL)	
North Island Main Trunk (NIMT) geotechnical seismic upgrades	Remutaka rail link – Featherston and Upper Hutt portal resilience
Hutt Valley line geotechnical seismic upgrades	Alternate National Control Centre in Auckland

Infrastructure Resilience Ideas	
ELECTRICITY	
Seismic upgrade of cables and creation of 33kV rings	Central Park Substation improved resilience
Replace high risk 33kV cables in liquefaction zones only	Increase 160MW interconnectedness between substations
Duplicate spares for repair	Plan emergency overhead cable routes
Replacement of all fluid filled cables	Central Park – Frederick Street cable replacement
POTABLE WATER	
General water supply toughening of pipes in critical locations	Porirua emergency pumping plant
Porirua low level zone reservoir	Reservoir for Airport and Miramar Peninsula
Cross harbour pipeline	Prince of Wales and Bell Road II Reservoir upgrade
Porirua branch replacement	Carmichael to Johnsonville and Karori pipeline
Waterloo Pump Station extension	New pipeline from Waterloo to Haywards
Critical customer network strengthening and isolation	Emergency water infrastructure in communities
Construct Whakatiki Dam and bulk water supply infrastructure	Waterloo Water Treatment Plant liquefaction mitigation project
Silverstream Bridge pipeline replacement	
WASTE WATER	
Procure and stockpile portaloos and chemical toilets	Off-grid ablution facilities installed at schools
COMMUNICATIONS	
Harden communications network – protect critical routes	Diversified handover agreements between networks
Develop supersite network with all telcos	Dedicated back-up power at cell towers
Strengthen telecommunication buildings to an IL4 seismic resilience rating	Provide redundancy of submarine fibre cables into Wellington
GAS	
Readying point solution conversion to LPG	
AIRPORT	
Runway seismic improvements	


(Source: Lloyd Homer, GNS Science)

6.6 – Short-listing Assessment

Following the Options Development Workshop, the options remaining were put through a multi-criteria assessment (MCA) during a two-day workshop by the project team comprising representatives of WeLG, Aurecon, EY, Tonkin + Taylor, Resilient Organisations, GNS Science and Market Economics.

This assessment considered how each option performed against the benefit statements and investment objectives described in the Strategic Case. It provided a comprehensive assessment of the direct effects an option would have on improving the Wellington Region's ability to return to business as usual and enable a faster recovery for the Wellington Region.

An adapted version of a NZ Transport Agency Resilience Decision Making Tool[11] was used. The tool's assessment framework, initially developed for the purposes of assessing transport resilience, was modified to take into account the additional critical infrastructure types (water, fuel, electricity, wastewater, communications) as well as the agreed investment objectives and corresponding weightings.

The role of this tool was to transparently and objectively narrow the long list of options using data provided by lifelines and applying expert judgement. The assessment criteria were developed to align with the investment objectives and KPIs agreed in the ILM. Feedback on the framework architecture had been sought from workshop participants and the criteria updated accordingly. A summary of the assessment criteria framework and associated weightings used in the tool is provided in Table 7.

Certain lifeline organisations provided supporting information on specific projects where these projects were more developed to help support the project team's scoring decisions. In lieu of this information for the remainder of the options, Aurecon subject matter experts or members of the assessment team provided specialist advice to facilitate understanding in the individual assessments.

For each of the criteria in the analysis tool, a score between -3 and +3 was agreed by the project team in accordance with standard MCA practice. A -3 represented a significant negative contribution to that success factor and +3 indicating a significant positive contribution to that success factor. Exceptions to this existed, such as for the assessment of 'ease of implementation', a scale from 0-4 was used, where a negative value was not considered possible. To ensure a consistent approach was applied to each option a common set of definitions was used in this assessment and within each infrastructure type.

Finally, each option that was assessed received a total MCA score between 0 and 1 based on the individual criteria scores multiplied by the associated criteria weightings. The higher the score the higher the option's efficacy and performance against the investment objectives. Transport, fuel and electricity options generally performed well because they are enablers for many other options to also be realised, an important criterion.

The complete assessment of each option that was scored is provided in Appendix I.

[11] *Research Report 614 Establishing the value of resilience, C Money, N Bittle and R Makan (Ernst and Young); R Reinen-Hamill and M Cornish (Tonkin + Taylor), 2017*

Table 7: Assessment criteria used in the assessment tool and the associated links with investment objectives

Investment Objective	Link to KPIs	Criteria	Rationale	Weighting
Significantly reduce the risk to NZ economy from shock events affecting lifeline services in the Wellington Region (60%)	Reduced predicted recovery period	Enabling benefits	Options that have enabling benefits for other infrastructure resilience options, or 'positive interdependency benefits', can support faster recovery times.	30%
		Impact on operational level of service	Recovery time objective is a direct representation of this criteria.	35%
	Reduced predicted NZ economic loss		MERIT modelling will determine the economic impact of an event to the New Zealand economy. However, the speed at which lifelines services can be brought back to service can be used as a proxy for economic loss.	
		Indirect economic costs/benefit	Indirect economic costs/benefits feed into the expected national economic loss.	5%
Reduce the safety risk to people living in the Wellington Region from a shock event affecting lifeline services (10%)	Reduced predicted safety risk from infrastructure failure	Safety risk	RiskScape modelling will determine the safety risk from infrastructure failure. In lieu of this modelling, for the purposes of shortlisting, the extent to which an option decreases the risk of infrastructure failure (causing safety issues) was qualitatively scored.	5%
	Reduced predicted risk of major disease outbreak	Public health benefits	An assessment of the direct and indirect contributions to public health outcomes as well as the impact on life and injury risk.	5%
Make the Wellington Regional Community more resilient against the effects of a shock event affecting lifeline services (10%)	Reduced predicted population loss	Impact on operational level of service	The speed at which lifeline services can be brought back to service can be used as a proxy for population loss. Residents will not stay in a city when lifeline services are not functioning.	5%
	Reduced predicted community isolation period		The speed at which lifeline services can be brought back to service can be thought of as a proxy for community isolation.	
		Indirect environmental, social and cultural impacts	Indirect environmental, social and cultural costs/benefits are a proxy for the expected loss of community capital (population loss and isolation).	5%
Optimise the combined investments in Wellington lifeline services (20%)	Finalised combined investment plan	Ease of implementation	The expected ease of implementation of an option is used as a proxy for the expected ability to develop an investment plan.	10%
	Reduced predicted recovery costs	Impact on operational level of service	The speed at which lifeline services can be brought back to service can be used as a proxy for population loss. Residents will not stay in a city when lifeline services are not functioning.	Scored earlier as 'recovery time' objective

7. Programme Development

This section explains how a recommended programme was developed to address the problems identified in the Strategic Case, with the expectation that it would generate the benefits sought. It describes the 'options' included. The full development and analysis process is covered in Appendix H.

Initially, three draft programmes were developed, beginning with an assessment of the 'critical vulnerabilities' to Wellington, namely fuel and transport access, and the options that best performed in responding to these vulnerabilities, at different levels of investment.

Options for the next most critical lifeline, electricity, were reviewed and assigned to programmes according to their expected scale of investment, followed by the remaining infrastructure types in descending order of vulnerability.

The resultant three programmes represented de facto low, medium and high investment. As the options were selected for each programme, interdependencies were also considered which led to certain options being required across all of the programmes. These three programmes were refined and reduced to one programme with the assistance of lifeline, council and central government representatives, and using specialist analytical tools, RiskScape and MERIT, described below.

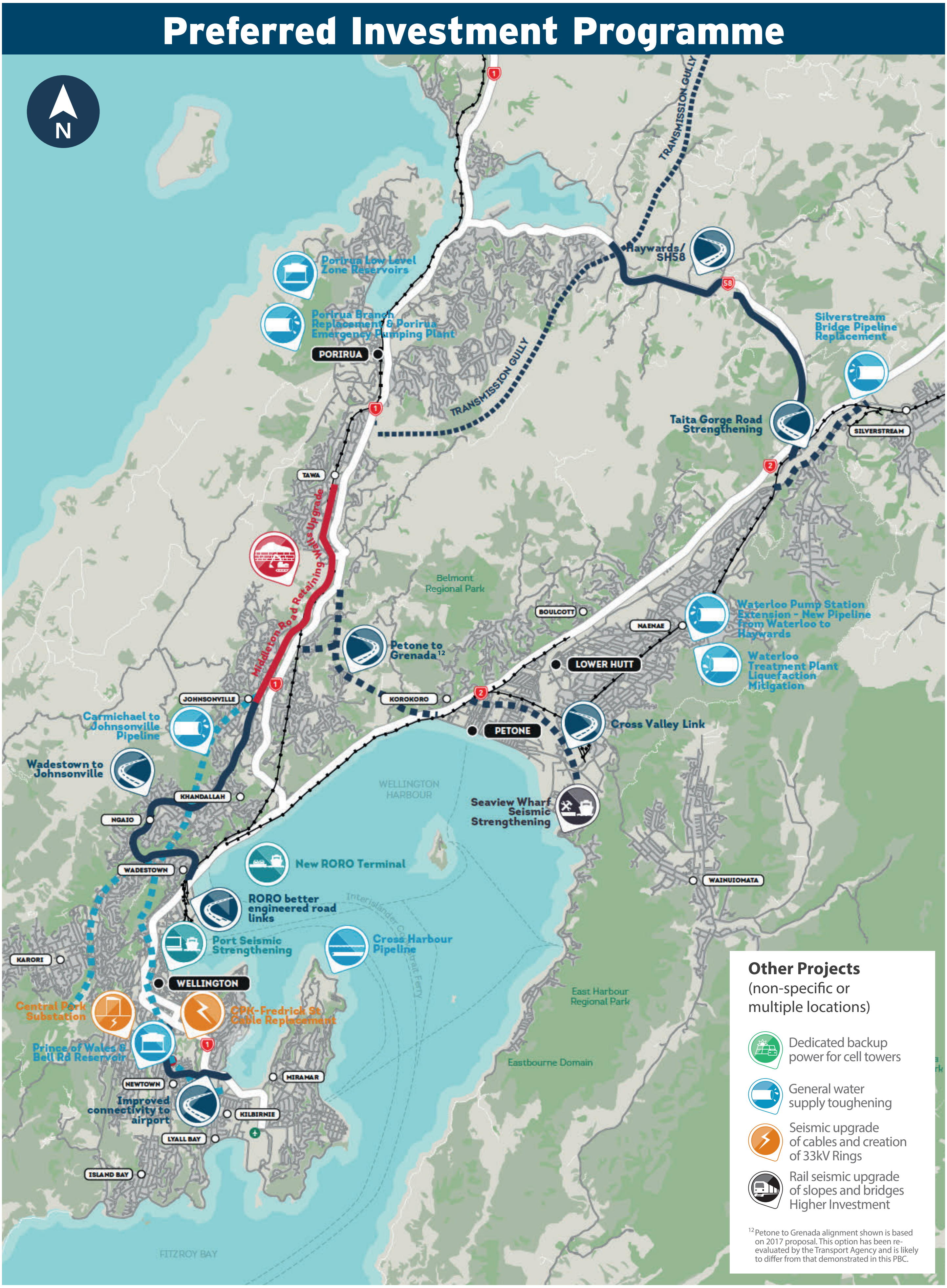
7.1 – Base Case

The base case was established as the base-line against which the efficacy of the improvement programmes could be tested. The base case comprises the existing utility and transport networks, along with the projects already under construction or committed for construction in the near future, including the Transmission Gully motorway, which already provides a partial transport connection for bringing in fuel and supplies to the region from the north. GNS Science modelled the base case in RiskScape to measure outage periods for each infrastructure type.

7.2 – Projects included in the recommended programme

This section shows the full recommended programme and sets out the individual projects included. They have been grouped by the specific lifeline infrastructure type to which the resilience is provided. Six of the projects are committed by lifeline organisations for future construction, and therefore were automatically selected for the programme, other projects are those that are considered 'must-dos' for the Wellington Region given they are enablers of other lifelines recoveries or emerged from the analysis.

7.2.1 – Full programme



7.2.2 – Fuel project

Seaview Wharf seismic strengthening

Project description:	This project involves seismically strengthening the Seaview Wharf and the associated 3km of fuel pipelines that extend from the end of the wharf to Point Howard. It will include conversion of the pipeline to operate in both directions to enable both withdrawal and filling. This project will require the installation of a mooring dolphin to enable berthing in all weather conditions and take account of the likely ship sizes used for transporting fuel in the future[13]. 
Estimated cost:	**Capital cost: $10 million for fuel infrastructure + $25 million for wharf improvements (numbers correct at time of development of this PBC)**
Rationale for potential inclusion:	The Seaview Tanker Dock provides docking facilities to tankers supplying the fuel market into greater Wellington. This project will provide a more resilient fuel supply. Currently the approach wharf is considered high risk and is expected to fail in one or more locations along its length either by pile fracture or loss of support to the timber deck. Fuel is critical to run generators, earth-moving plant and for the transport of residents around the region. There will likely be significant roads outages preventing fuel tankers getting into the region, therefore a robust refuelling and storage facility for fuel is critical.

7.2.3 – Road transport projects

Wadestown to Johnsonville – seismic strengthening

Project description:	This project involves strengthening the retaining walls and engineering of some major uphill slopes on Churchill Drive, Blackbridge Road and Wadestown Road, which service Bowen Hospital.
Estimated cost:	**Capital cost: $20 million**
Rationale for potential inclusion:	This route is likely to be one of the first access routes open for ambulances to get through to Bowen Hospital. This route also provides access through to WE's critical Wilton Substation for inspection and repair following an event, and provides a potentially important secondary route towards Wellington's CBD.

[13] *Wellington Region CDEM Group Fuel Plan 2015, CDEM, 2016*

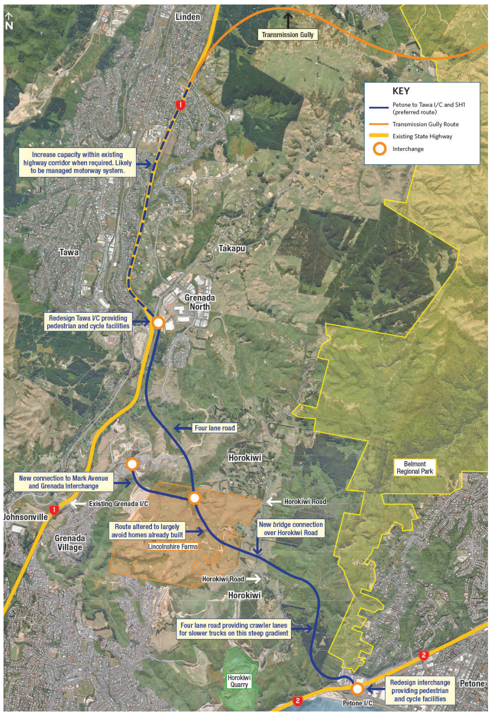
Cross Valley Link – SH2 to Seaview

Project description:	The Cross Valley Link proposal (also known as East West Connection) currently has provision of a new grade separated two-lane road with cycle lanes between Hutt Road in the west and White Lines Road in the east, approximately following the alignment of the Hutt Valley Rail Line. The project would be constructed to withstand probable liquefaction and bridges or raised piers would be constructed to ensure the route is useable following an earthquake event.
Estimated cost:	**Capital cost: $65 million**
Rationale for potential inclusion:	From a resilience perspective - given the criticality of fuel to the recovery of the Wellington Region following a major event - this link would provide a stronger connection between the fuel terminals at Seaview with the transport network and the rest of the region.

Special Note Regarding the Cross Valley Link – as mentioned above, this project is a key element to ensure fuel supply. The project has been included as a proxy for improving fuel links to ensure the resilience necessity is captured. As part of future detailed work, there could be alternative preferable solutions to achieve the necessary fuel supply objectives.

Petone to Grenada

Project description:	This project includes a new road link from Hutt Valley to SH1. It will include slope stabilisation measures and basic resilience enhancements to increase the chance of a link between the two corridors following a 7.5 Wellington Fault earthquake event. A more resilient version with a very low probability of closure would be possible at a significantly higher cost. This project was re-evaluated by the Transport Agency in 2018. The re-evaluation recommended the project be redesigned with a focus on resilience, safety and improving transport choice across the state highway network. The next step is to seek funding for the development of a business case, which will include working with the community and local government partners.



Estimated cost:	**Capital cost: $250 million to $2,200 million (2018 re-evaluation summary report), however for this report we are using the figure of $1,062 million.**
Rationale for potential inclusion:	This project provides significant benefits to communities in terms of access into and out of the Hutt Valley. It also improves the lifeline restoration times of other lifelines which require road access to refuel and repair.

Better engineered road links to existing RORO Terminal and port area

Project description:	This project involves mitigation measures to potential liquefaction on Aotea Quay following a seismic event, seismic upgrading of the Skew Rail Bridge and an emergency ramp from SH1 to the RORO area that can withstand a Wellington Fault event.
Estimated cost:	**Capital cost: $71 million**
Rationale for potential inclusion:	The project would enhance the likelihood of access both to the core port and to a RORO facility.

Resilience of airport connectivity to city network via Newtown

Project description:	This project involves emergency response planning for the roads alongside the Hospital and the Constable Street and Crawford Street areas. It would involve potential interventions around the Mt Victoria Tunnel portals to protect from landslides either side and reduce the tunnel outage time.
Estimated cost:	**Capital cost: $10 million**
Rationale for potential inclusion:	This project provides access from Wellington Airport through to the CBD should the Evans Bay route be blocked due to landslides. This provides access through to the airport for personnel, for both the response and recovery periods. *Note: The airport runway is assumed to be open after 3 days for emergency/military flights, with the full runway disrupted for 3 months, returning to full service within 6 months.*

Middleton Road retaining walls upgrade

Project description:	This project involves the strengthening of retaining walls for gas main protection or alternatively the re-laying of the gas main on the uphill side of the slope. Minor improvements to batter slopes may also be included to reduce the amount of material likely to slide during an event, and therefore reduce the recovery time.
Estimated cost:	**Capital cost: $50 million**
Rationale for potential inclusion:	By strengthening the existing retaining walls there will be fewer and smaller landslides along Middleton Road from an earthquake event, therefore improving the recovery time for the gas main which is currently located beneath Middleton Road. This project also provides an alternate route through Johnsonville should there be damage closing SH1.

SH58/Haywards Resilience Improvements from Transmission Gully to Hutt Valley

Project description:	This project involves the stabilisation of slopes above SH58 at Haywards Hill from SH2 to summit (just east of Mt Cecil Rd). It is in addition to the 2.5km of safety improvements currently committed on SH58 between TG and SH2.
Estimated cost:	**Capital cost: $24 million**
Rationale for potential inclusion:	This project will provide alternate access through to Porirua from the Hutt Valley. This will allow residents of the Hutt Valley to travel through to Wellington City via Porirua (and vice versa) in the likely event that access along the SH2 coastal road is cut off. This project will also provide access for fuel trucks to transport fuel from Petone through the region. The safety improvements element of this project has been committed.

Taita Gorge Access – strengthening road network

Project description:	This project includes slope stabilisation and upgrading of the walls supporting the Eastern Hutt Road just north of Stokes Valley Road roundabout.
Estimated cost:	**Capital cost: $2.5 million**
Rationale for potential inclusion:	This project will help prevent collapse of the Eastern Hutt Road into the Hutt River, maintaining access up the eastern side of Taita Gorge following an event. This project also helps maintain access to Hutt Hospital.

7.2.4 – Sea transport projects

Port Seismic Strengthening – major works	
Project description:	Lateral spread prevention measures across the standing area along Aotea Quays 1 to 3, and strengthening of the associated wharf facilities, to provide protection against seaward slumping and interference with the berthing pockets (being 500m centred on the TCW1 container cranes). Removal of buried underground structures and treatment of the main hard-standing area (Thorndon Reclamation) is also proposed to reduce the extent of non-uniform settlement/ liquefaction induced surface undulation of the hard stand area. This will likely involve the use of stone columns in areas of unconsolidated material to reduce potential settlement. 
Estimated cost:	**Capital cost: $312 million (numbers correct at time of development of this PBC)**
Rationale for potential inclusion:	These works will help ensure the shipping link is retained and that ships can use the Aotea quays following an earthquake event. The realignment (to a secure and accessible zone) and upgrade of the 11kV crane electricity supply will enable full crane operation within 3-4 weeks of an event. These works are also expected to enable the Thorndon hard standing area to remain functional for relevant port operational vehicles and reduce the outage times for the container wharf and cranes.

New RORO Terminal	
Project description:	Construction of a new ferry terminal and associated roll on/roll off docking facilities. Options for new terminal(s) are currently being considered, and may be at the current locations or other sites. For the purposes of this study it is assumed that a suitable location will be confirmed. It should be noted that the current Kaiwharawhara terminal has the Wellington fault passing through it. Depending on the terminal option(s) selected, resource consents for in-harbour works may be required, as it is outside of CentrePort's existing consent. It is intended that accessibility to SH1 and other parts of the transport system will be improved as part of these works.
Estimated cost:	**Capital cost: $250 million (in consultation with the Futureports workstream, numbers correct at time of development of this PBC)**
Rationale for potential inclusion:	This project is critical to retaining the connection between the North and South Island which is an essential link in New Zealand's freight distribution network. Port operations may require transfer of all ferries to a common docking facility over the next three years with the resulting demand for new docking capability. Options are being looked at with resilience considerations, given the proximity to the Wellington fault line.

7.2.5 – Rail Transport projects

Rail Seismic Upgrade of slopes and bridges – NIMT Line and Hutt Valley Line	
Project description:	Seismic upgrading of structures and slopes along the NIMT, Hutt Valley Line, Upper Hutt Line and Wairarapa Line
Estimated cost:	**Capital cost: $100 million (notional)**
Rationale for potential inclusion:	This project would allow freight and commuter trains to be back running earlier and with greater reliability.

7.2.6 – Electricity projects

Central Park Substation – improved resilience	
Project description:	This project will improve the resilience of the assets contained within Central Park Substation by spreading them over a larger geographic footprint. Specifically, this project involves construction of a second Central Wellington grid exit point (GXP) substation, at an unspecified location nearby to the Central Park Substation and the associated 33kV cable connections into the WE network. One cable from each zone substation would be extended to the new switchboard. Assumed to be designed to code and no damage expected to Central Park or the 33kV cables.
Estimated cost:	**Capital cost: $40 million**
Rationale for potential inclusion:	This project will improve the resilience of the electricity network, in particular the supply of electricity to Wellington CBD including Parliament and the stock exchange, which are crucial for the return to BAU. This project would move one transformer and half the 33kV switchboard to the new location, mitigating the risk of Central Park site failure. Improved resilience in the provision of electricity to Wellington Hospital will have direct health benefits. This project will support recovery of other lifelines including pump stations and the telecommunications network, and will also mitigate against other risks such as fire or sabotage. This project has been identified in WE*'s Asset Management Plan 2017.

Seismic upgrade of cables and creation of 33kV rings	
Project description:	The seismic upgrade of 33kV buried cables will be undertaken, replacing oil and gas filled cables with modern solid insulated cables, 33kV rings will be constructed with areas in significant liquefaction zones being prioritised. These cables will perform much better in a fault event and rings will provide diversity of supply, further improving the resilience of the electricity network.
Estimated cost:	**Capital cost: $160 million**
Rationale for potential inclusion:	This project has been previously identified in WE*'s Asset Management Plan and is a key enabler of a number of other infrastructure types to operate. It will benefit the entire region and have direct public health benefits through improved resilience of supply to hospitals and medical facilities. This project has been included in the programme to potentially accelerate its implementation rather than waiting for cables to reach the end of their life before requiring replacement.

Central Park to Frederick Street cables replacement	
Project description:	Replacement of the cables between Central Park Substation and Frederick Street Zone Substation with cross-linked polyethylene.
Estimated cost:	**Capital cost: $5 million**
Rationale for potential inclusion:	This project is scheduled for implementation under WE*'s ongoing cable replacement programme and therefore has been included to accelerate funding.

7.2.7 – Potable Water projects

Cross Harbour Pipeline

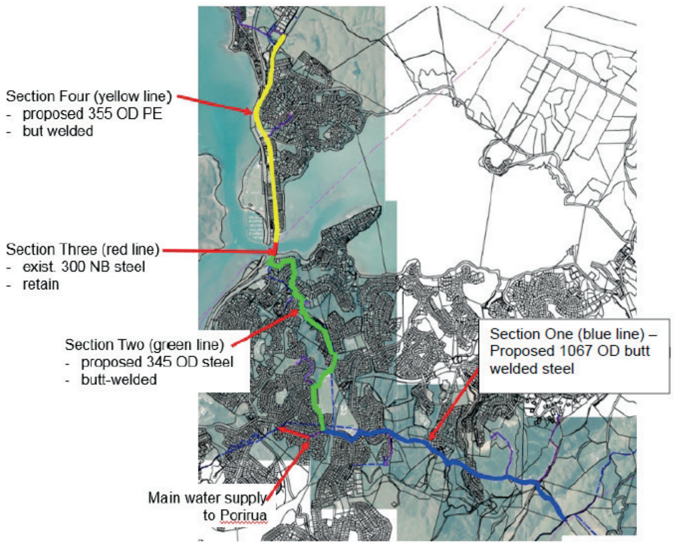
Project description:	This project involves the installation of a 12.7km underwater pipeline from Seaview to Evans Bay and with a connection to the Carmichael Reservoir. The pipeline will be trenched into the seafloor as well as on land. It will likely be constructed of electrofused 500mm (ID) HDPE.
Estimated cost:	**Capital cost: $139 million**
Rationale for potential inclusion:	Provision of an alternate major bulk water main provides resilience to the network, should the existing watermain be ruptured by a Wellington Fault event. Without this alternative pipeline Wellington City will be without water for an extended period of time.

General water supply toughening acceleration

Project description:	Upgrading a critical network of pipes to ductile pipes, approximately 152km total length and predominantly watermains and mains-to-reservoirs. Priority 1 Upgrades: Total length 50km ($120million) Priority 2 Upgrades: Total length 100km ($420million)
Estimated cost:	**Capital cost: $654 million**
Rationale for potential inclusion:	Upgrading of the core network to ensure critical customers can quickly access network water services.

Porirua Branch Replacement & Emergency Pumping Plant

Project description:	This project involves construction of a 1150mm Concrete Lined Steel (CLS) fully-welded watermain from Moonshine Valley Tee to Cleat Street, and a 345mm welded steel pipe through from Cleat Street to SH1, including a 300mm bridge crossing with isolation valves. Construction also includes a 345mm butt-welded steel pipeline along Mana. Provision of a containerised emergency water treatment facility which can treat 10-15ML of water a day. Water will be drawn from a tributary near the Tee in the Moonshine Valley and pumped into the Porirua Branch Main once treated.



Estimated cost:	**Capital cost: $33 million**
Rationale for potential inclusion:	An emergency water treatment station is required to extract and treat water from an identified river source. The branch replacement is required as the existing pipeline will suffer severe damage due to age, materials and joint type.

Porirua Low Level Zone Reservoirs

Project description:	Providing an additional 9ML reservoir, near the existing Porirua Low Level 1 and 2 Reservoirs and providing an additional 3ML of storage at Takapuwahia. Reservoirs will be fed by the upgraded Porirua Branch main and constructed to an ultimate limit state of a 1-in-2500 year event and a serviceability limit state to withstand a 1-in-1000-year event.
Estimated cost:	**Capital cost: $25 million**
Rationale for potential inclusion:	Elsdon reservoir supports a long-term supply to Kenepuru reservoir and the wider Porirua zones not initially served until reticulation is restored.

Waterloo Pump Station extension and new pipeline from Waterloo to Haywards

Project description:	Installation of a new pump system adjacent to Waterloo Water Treatment Plant, and provision of a 1067mm (OD) CLS fully welded watermain from Waterloo Pump Station to the Haywards Valve, including a new flexible Wellington Faultline crossing.
Estimated cost:	**Capital cost: $126 million**
Rationale for potential inclusion:	There is no connection between the Te Marua river supplied system and the Waterloo aquifer-supplied system. This connection allows Wellington Water to focus energy on restarting a single plant that can effectively meet all initial regional water demands.

Waterloo Water Treatment Plant liquefaction project

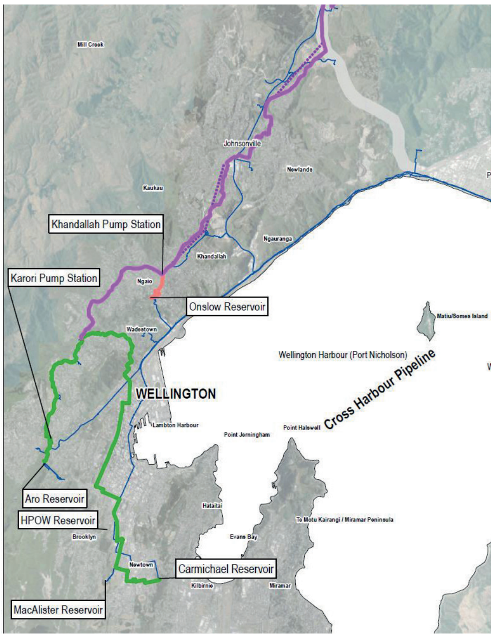
Project description:	This project involves measures to mitigate liquefaction risk and improve the ground at the southern end of the site or providing additional structural support.
Estimated cost:	**Capital cost: $2 million**
Rationale for potential inclusion:	This initiative would enable the Waterloo Water Treatment Plant to remain operational and bulk water to be supplied to the network following a major quake.

Prince of Wales and Bell Road Reservoir Upgrade

Project description:	This project involves replacing the existing Bell Road Reservoir with a new 10ML reservoir and construction of a new 35ML reservoir at the Prince of Wales (Omaroro) site. These will be constructed to withstand an ultimate limit state of a 1-in-2500 year event and a serviceability limit state to withstand a 1-in-1000-year event.
Estimated cost:	**Capital cost: $78 million**
Rationale for potential inclusion:	The existing Bell Road Reservoir is over 100 years old and does not meet current seismic standards. If it was to fail it could potentially take out the Central Park Substation in its path causing a cascade of lifeline asset failures and loss of life. A larger reservoir at Omaroro is required to support flows from the cross-harbour pipeline.

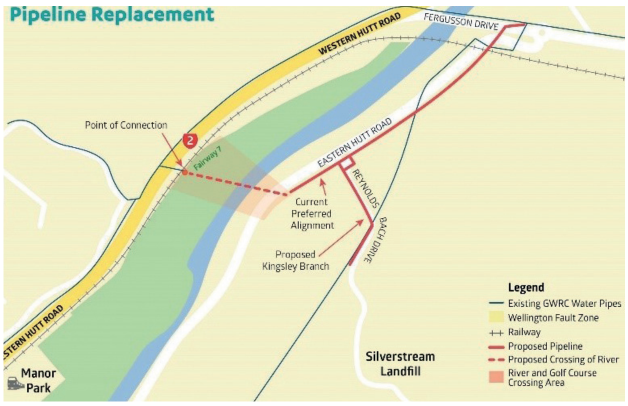
Carmichael to Johnsonville and Karori Pipeline

Project description:	This project involves: ◤ Construction of a new 1000mm CLS welded watermain between Carmichael Reservoir and a new pump station located near Omaroro Reservoir. ◤ A new pumping station to pump water from the cross harbour pipeline to Johnsonville. ◤ Construction of an 800mm CLS welded watermain between Omaroro Reservoir and Churchill Drive (green) with Wellington Fault crossing at Park Street, using open cavity below road and flexible joints to provide several metres of horizontal displacement 1150mm CLS welded from Churchill Drive to Johnsonville (purple) passing through and the strengthening of Johnsonville Tunnel (dashed purple). ◤ Upgrade to batter slopes along Grant, Lennel and Wadestown Road to prevent dropouts. ◤ Construction of 700mm CLS branch at the top of Churchill Drive (green), Wadestown. This project forms part of an existing project designed to establish a new bulk main from Porirua to Carmichael over the longer term, and get the existing Bulk Main off Moonshine Valley fault line.
Estimated cost:	**Capital cost: $247 million**
Rationale for potential inclusion:	The only remaining viable pipeline following an earthquake is installed below the Johnsonville-Karori road and has non-resilient joints every few metres (over 1,000 joints prone to failure in an event) which would require closure and excavation of a key transport route to repair. There is no resilient fault line crossing as the alternative pipeline and associated pump station will be largely destroyed at the current location outside the Wool Store on Hutt Road/Thorndon Quay.



Silverstream Bridge Pipeline Replacement Project

Project description:	Replacement of the Te Marua to Ngauranga pipeline where it crosses the Silverstream Road bridge and the Wellington Fault. The proposed pipeline replacement will be from the eastern end of the Silverstream Bridge, following the Eastern Hutt Road south, approximately 1km. It then crosses the Hutt River elevated on piers with large ball joints on each side of the fault permitting 5m of horizontal movement. After the Wellington Fault the pipeline will be buried, crossing the Manor Park golf course, the railway line and reconnecting to the existing pipeline on the western side of SH2. This project also involves replacement of the existing pipe that branches off supplying the Kingsley Pumping Station and the steel rising main from Kingsley Valley.
Estimated cost:	**Capital cost: $23 million**
Rationale for potential inclusion:	This project is currently scheduled for construction in 2019/ 2020 and will provide a more robust Wellington Fault crossing than the existing watermain crossing at Fergusson, Drive connecting the Te Marua River supplied system with the Waterloo Aquifer supplied system.



7.2.8 – Telecommunications project

Dedicated back up power for cell towers	
Project description:	This project involves the procurement and installation of permanent back-up generators (10-12kV) and fuel supply storage of 400-500L. If the site is not suitable for permanent installation, then readying the site. Also included in this project but not modelled in RiskScape and MERIT was the installation of generators at Vodafone and Spark sites. Approximately 40 sites across the region would be suitable for generator installation for each provider. Vodafone's sites have a similar installation cost to 2degrees', assuming resources consents were issued without challenge. Spark's network will have a slightly higher installation cost.
Estimated cost:	**Capital cost: $6.85 million ($11.65 million inclusive of Vodafone and Spark sites)**
Rationale for potential inclusion:	This will provide approximately two weeks of power before requiring re-fuelling by helicopter or road, if the electricity network has not been restored by this time. This project will ensure voice coverage is provided in most areas throughout the Wellington Region.

7.3 – RiskScape and MERIT

This section describes the damage and economic modelling used to assess the programmes. RiskScape and MERIT are the principal modelling tools used in the assessment.

RiskScape is a multi-hazard risk assessment tool developed by GNS Science and NIWA that estimates damage and direct losses for assets exposed to natural hazards. The modelling software combines spatial information on hazards, assets and asset vulnerability to quantify the impacts and estimate the number of casualties and displaced populations. Losses to physical infrastructure are calculated from the direct replacement costs of the damaged assets.

MERIT is an economic impact assessment that models the economic impact resulting from a loss of lifeline services.

RiskScape and MERIT are used to provide a combined damage loss assessment and economic impact analysis, giving a more comprehensive approach than either tool would in isolation (Figure 9). RiskScape outputs of damage are used to create service outage maps, which are an input to MERIT.

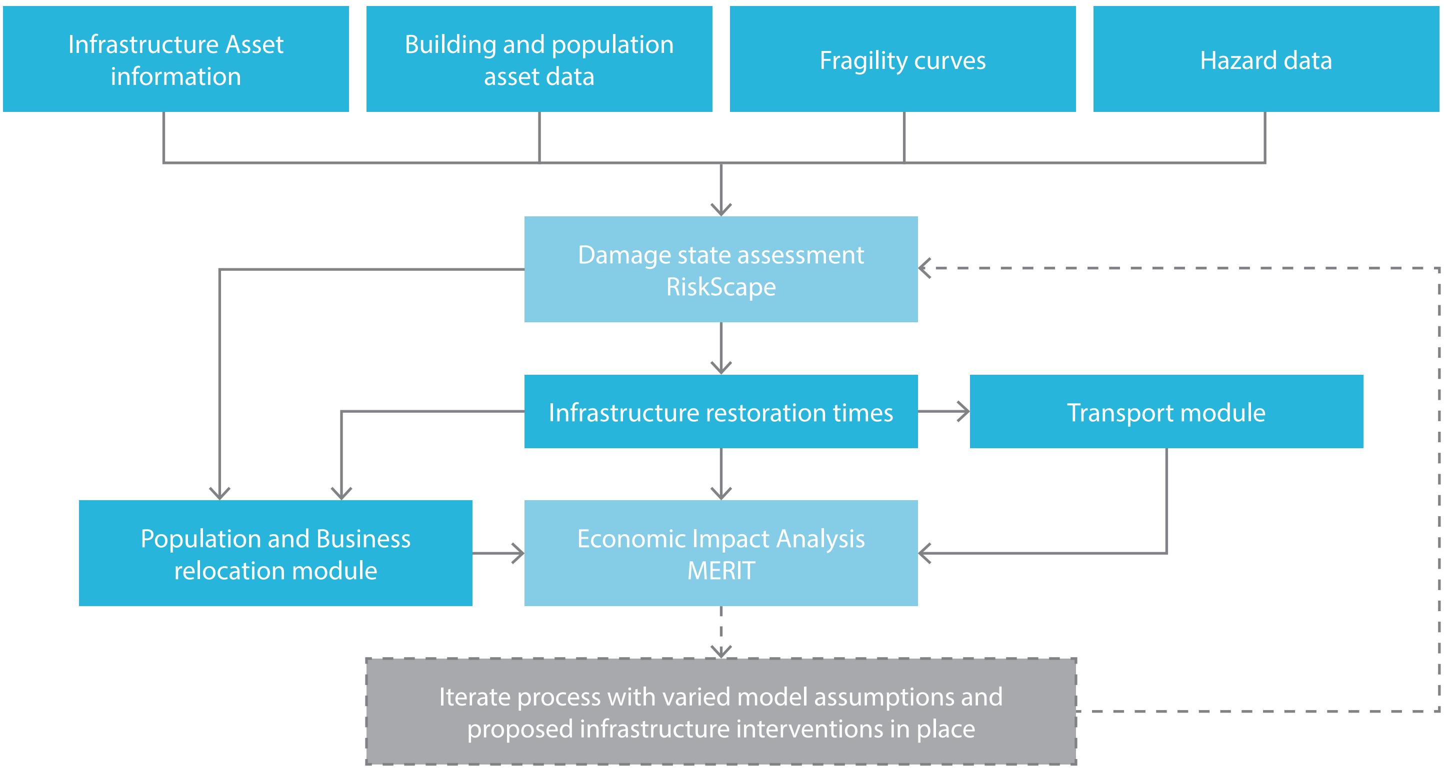


Figure 9: Linkages between the various stages of damage loss assessment and economic impact analysis

7.4 – Application

The modelling assessment was undertaken in three stages:

Stage 1: Base-Case Modelling – what is the damage and economic disruption expected should an earthquake occur tomorrow?

Stage 2: Intervention Modelling – what is the damage and economic disruption expected should the earthquake occur following the implementation of the short-list programmes?

Stage 3: Preferred Programme Modelling – what is the damage and economic disruption expected should the earthquake occur following the implementation of the preferred intervention programme?

The infrastructure types included in the modelling process were: road, rail, port, airport, electricity, telecommunications, potable water, wastewater, fuel, and gas. Damage to buildings was also modelled.

The supporting report: Wellington Resilience Programme Business Case: ***Lifelines Outage Modelling, GNS Science Consultancy Report*** *2017/236, December 2017* found in Appendix K.

7.5 – RiskScape

7.5.1 – Damage and Outage Modelling Framework

RiskScape uses a generic framework for estimating natural hazard loss (Figure 10). The model has three key input modules: asset, hazard and vulnerability.

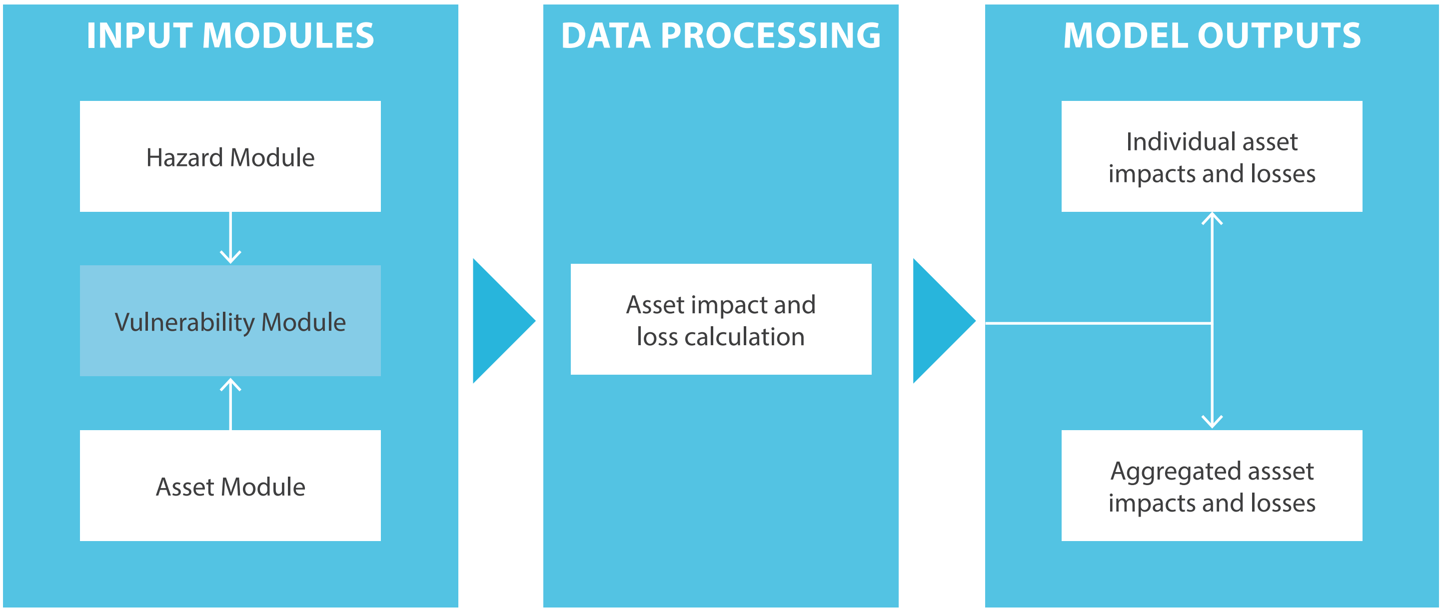


Figure 10: RiskScape Framework

Data or models represented in each module are combined in a 'loss' module to quantify asset impacts for a natural hazard event or scenario.

Appendix K contains information on the ***Lifelines Outage Modelling Report***.

7.6 – The MERIT Model

Economic impact modelling was carried out to assess the packaged infrastructure options. The modelling assessed the disruption impacts to the economy associated with the earthquake. The analysis relates to economic disruption, which reflects the ILM measure of net changes in GDP associated with a preferred investment programme as the top assessment metric with a 60% weighting.

The modelling used 'MERIT' (Modelling the Economics of Resilient Infrastructure Tool) developed in the 2012-16 MBIE funded Economics of Resilient Infrastructure (ERI) research programme. The full details of the economic approach are contained in the report: ***Wellington Resilience Programme Business Case, Modelling the Economics of Resilient Infrastructure Tool (MERIT) Assumptions Report,*** *m.e Research and Resilient Organisations, December 2017* (Appendix K).

The use of the MERIT model is a unique advancement for resilience studies of this kind. MERIT is an integrated spatial decision support system that enables a high-resolution assessment across space and through time of the economic consequences of infrastructure failure, business response, and recovery options.

Modelling of the recommended programme resulted in a **$6.16 billion reduction in GDP loss** following a 7.5 magnitude Wellington Fault event, assuming all projects included within the preferred programme have been implemented.

7.7 – Summary of Results

Economic modelling results for the base case and recommended investment programme show the cumulative net change in GDP against the no earthquake scenario. The results are related to the single 7.5 magnitude event only. Other events will also be mitigated by these infrastructure investments greatly increasing the economic value of the programmes.

The preferred programme represents a capital cost of around $3.9 billion dollars' worth of investment. Some of the programme items are very preliminary in scope and design definition. This estimate includes a cost of $1.06 billion for Petone to Grenada road link (taken as the median of the cost range supplied of $250 million - $2,200 million). At this stage the estimates should be taken as a high-level indicator of the likely magnitude of cost.

This study only assessed losses in GDP to the NZ economy. The cost of damages to buildings and private property were not considered.

Stage 1 of this PBC does not provide a cost benefit analysis (CBA) of individual projects or the programme as a whole. This will be undertaken for individual projects in subsequent business case stages once the lifeline organisations have the opportunity to further scope their initiatives.

In addition to the benefits associated with a reduction in GDP loss, many of the interventions in the preferred programme have associated co-benefits.

Table 8: Cumulative change in GDP for Preferred Programme ($2016 billion)

Lapsed Time Since Event	6 months		1 year		5 years	
Preferred Investment Scenario	**None**	**Preferred**	**None**	**Preferred**	**None**	**Preferred**
Wellington Region	-8.7	-5.7	-10.3	-6.3	-13.5	-8.0
Rest of NZ	-2.1	-1.7	-3.0	-2.2	-3.2	-2.6
Total NZ	-10.7	-7.4	-13.3	-8.4	-16.7	-10.5
Net Reduction in GDP Loss when compared to the No Investment Scenario						**$6.16B**

7.8 – Other Initiatives

In addition to the preferred programme, other measures are recommended to support the initial response and recovery phases. These are:

- Pre-consented emergency routes in place for overhead powerlines fast tracking the recovery phase, benefits of which were demonstrated after the Kaikoura and Christchurch earthquakes
- Changes to the Government Policy Statement on Land Transport (GPS) to enable faster funding of transport resilience improvements
- Incentivise electricity resilience investment or off-grid solutions.

7.9 – Programme Implementation

The preferred programme outlined in section 7.2 identifies the 25 resilience projects which, together, will reduce the potential GDP loss by $6.2bn, should a M7.5 Wellington Fault event occur. The modelling assumes all projects are complete. In reality the preferred programme will be implemented over many years.

Given the interdependencies between projects and the long lead-times for potential property acquisition, design and consenting, sequencing of the programme was undertaken in such a way that resilience benefits were maximised through co-ordinated investments. In order to do this the projects were bundled into three phases over a 20-year programme (phase 1 being years 1-7, phase 2 being years 8-14, and phase 3 being years 15-20) and prioritised against the following principles:

1. Projects were scheduled using expected durations and cost estimates obtained from lifeline organisations
2. Projects supporting an alternative (redundant) lifeline route were scheduled as a priority. Where no alternative route exists, strengthening works on the primary lifeline route were scheduled as a priority
3. Higher feasibility, lower cost projects were scheduled as a priority
4. Fuel, road and electricity projects were scheduled as a priority
5. Projects with a high complexity and cost were scheduled later in the programme to allow for appropriate planning
6. General strengthening works on the electricity and water distribution networks were phased evenly across the 20-year programme.

In deriving the preferred investment programme, importance was placed on the number of interdependencies across lifelines. As shown in Figure 11 below, road and fuel initiatives are the greatest enablers for other projects, and water, while critical itself, is most reliant on other lifelines. Intuitively this makes sense. A resilient water distribution network may withstand the earthquake well, but it won't function if electricity isn't available to pump water, and any areas which have failed will require road access, fuel for access vehicles and civil contractor equipment for repair.

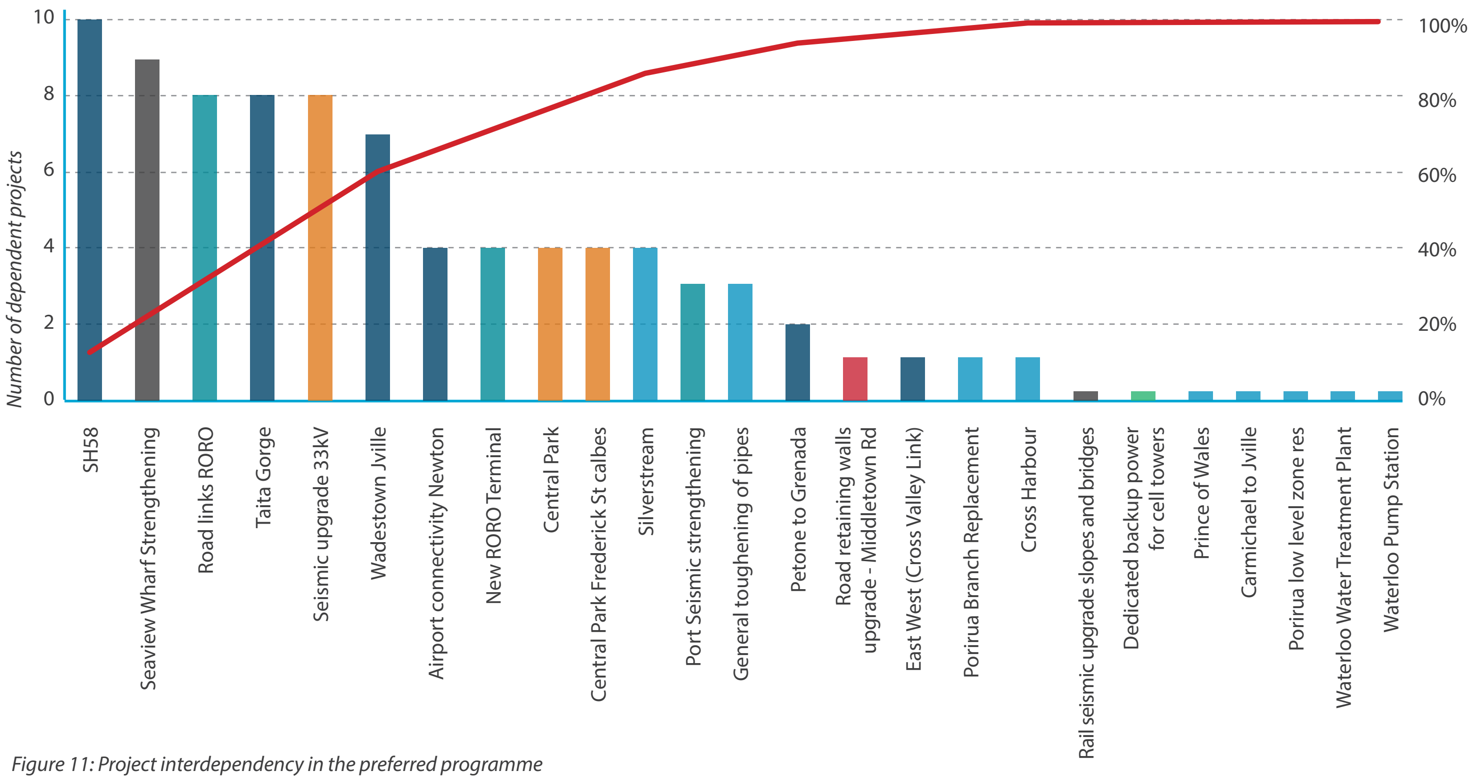


Figure 11: Project interdependency in the preferred programme

Figure 12 and Figure 13 below demonstrate the interdependencies between road and fuel resilience projects. SH2 between Petone and Ngauranga is critical to enable repairs to other lifeline infrastructure in the CBD and Wellington's economic recovery generally. Should this route be inaccessible (as is depicted by the red X in the diagram) many people will not be able to go to work, delaying the economic recovery for the region. In Figure 12 fuel, people, supplies and civil equipment are able to get to the CBD via an alternative route due to the combined efforts of four strengthening projects. Figure 13 demonstrates this via a second alternative route: the proposed Cross Valley Link and Petone to Grenada[14].

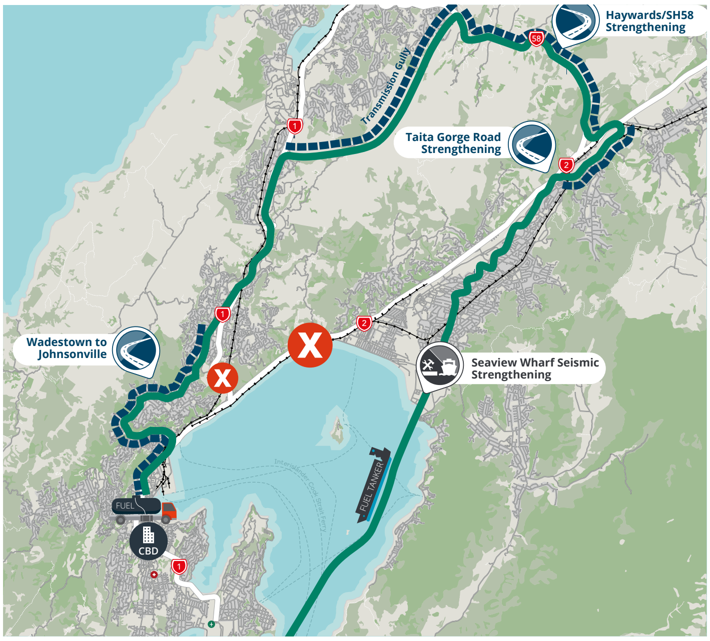


Figure 12: Access to fuel with Taita Gorge and SH58 Strengthening in place

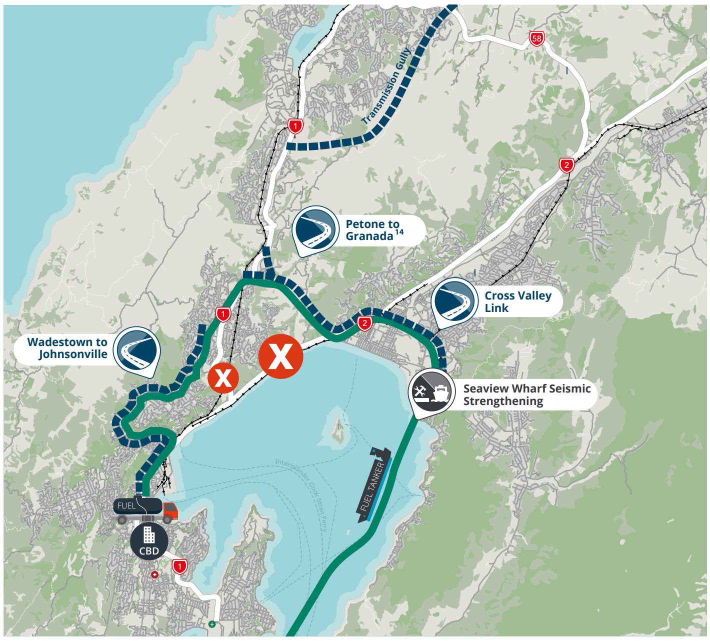


Figure 13: Access to fuel with Petone to Grenada and Cross Valley Link in place

This business case represents an opportunity to bring forward capital expenditure for resilience investment through prioritisation of resilience over other capital works projects or through additional funding streams.

It also represents an opportunity to co-ordinate across lifeline organisations and deliver a more resilient Wellington Region.

During Stage 2 of this PBC, the timings of this accelerated investment programme were re-confirmed with the respective lifeline organisations. An unaccelerated scenario in which some projects are not brought forward, i.e. the base case, was also tested in the Financial Case.

The recommended preferred investment programme is summarised in Table 9 and illustrated in Figure 14 on the following page.

Table 9: Project phasing summary

Phase	Lifeline	Projects	Outcome Achieved
PHASE 1 Years 0-7	Road / Fuel	SH58 Taita Gorge Wadestown to Johnsonville Seaview Wharf	A viable alternative route for fuel and people to get into the CBD.
	Road	Airport connectivity to Newtown	A viable alternative route for vehicles to get into the CBD from the airport
	Electricity	Central Park Substation Central Park to Frederick St Cable Seismic upgrade of cables and creation of 33kV rings (33% completed)	Single point of failure risk at Central Park substation lowered, and 33% of identified 33kV network strengthened.

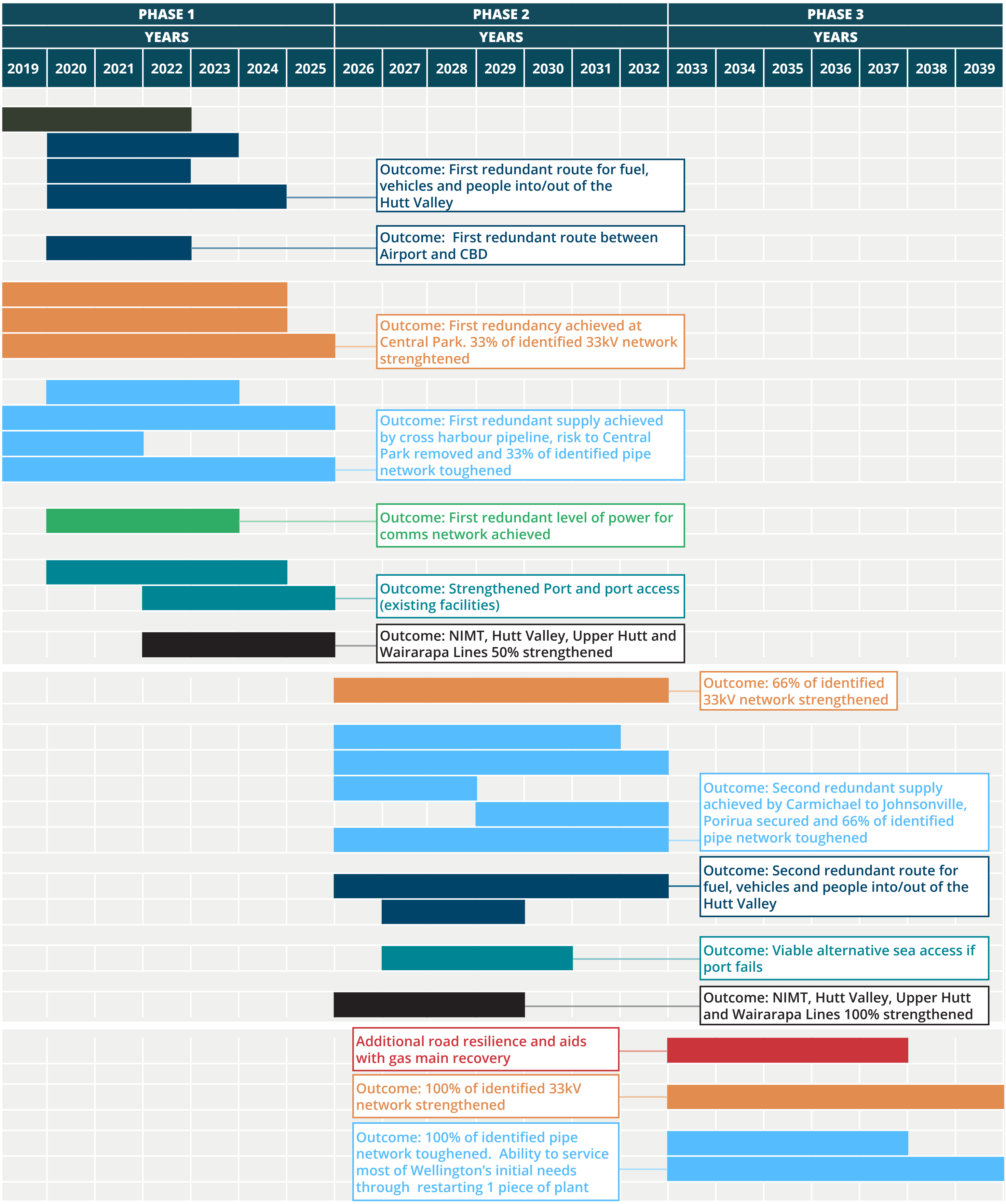
[14] *Petone to Grenada alignment shown is based on 2017 proposal. This option has been re-evaluated by the Transport Agency and is likely to differ from that demonstrated in this PBC*

Phase	Lifeline	Projects	Outcome Achieved
PHASE 1 Years 0-7	Water	Cross Harbour Pipeline Prince of Wales and Bell Road Reservoir Upgrade Silverstream Bridge Pipe Replacement Project General Toughening of identified pipes (33% completed)	A viable alternative water supply to Carmichael reservoir achieved via the cross-harbour link, water risk to the central park substation is removed and 33% of identified pipe network is toughened
	Communications	Dedicated backup power for cell towers	Alternative power for mobile telecommunications networks achieved
	Port / Road	Port Seismic Strengthening Better engineered links to the existing RORO terminal and port area	Strengthened port and port access (existing facilities)
	Rail	Seismic upgrades slopes and bridges (50% of identified rail strengthening programme completed)	50% Strengthened NIMT, Hutt Valley, Upper Hutt and Wairarapa lines
PHASE 2 Years 8-14	Electricity	Seismic upgrade of cables and creation of 33kV rings (66% completed)	66% of identified 33kV network strengthened
	Water	Carmichael to Johnsonville Porirua Branch Replacement Porirua Low Level Zone Reservoirs Waterloo Treatment Plant General Toughening of identified pipes (66% completed)	A second viable alternative water supply to CBD achieved, Porirua secured and 66% of identified pipes are toughened
	Road	Petone to Grenada Cross Valley Link	A second viable alternative route for fuel and people to get into the CBD
	Port	New RORO Terminal	A viable alternative sea access if strengthening undertaken at the port in Phase 1 fails. Location TBD.
	Rail	Seismic upgrades slopes and bridges (100% of identified rail strengthening programme completed)	100% Strengthened NIMT, Hutt Valley, Upper Hutt and Wairarapa lines
PHASE 3 Years 15-20	Road / Gas	Middleton Road retaining walls upgrade	Additional road resilience and aids with gas main recovery
	Electricity	Seismic upgrade of cables and creation of 33kV rings (100% completed)	100% of identified 33kV network strengthened
	Water	Waterloo Pump Station Extension and new Pipeline from Waterloo to Haywards General Toughening of identified pipes (100% completed)	100% of identified pipes are toughened. Ability to meet most of Wellington's initial water needs through restarting a single plant

INTEGRATED PROGRAMME

	GROUP #	PROJECT GROUPING	ICON	PROJECTS
Primary infrastructure strengthened or alternative achieved	1	Road		Seaview Wharf strengthening
				SH58
				Taita Gorge
				Wadestown to Johnsonville
	2	Road		Airport connectivity to Newtown
	3	Electricity		Central Park
				Central Park to Frederick Street cables
				Seismic strengthening 33kV
	4	Water		Cross Harbour pipeline
				Prince of Wales and Bell Road reservoir upgrade
				Silverstream Bridge Pipeline replacement project
				General toughening of pipes
	5	Comms		Dedicated backup power for cell towers
	6	Port/Road		Port Seismic strengthening
				Better engineered road links to existing RORO terminal & port area
	7	Rail		Rail Seismic upgrade of slopes and bridges
Primary infrastructure strengthened or secondary alternative achieved	8	Electricity		Seismic strengthening 33kV
	9	Water		Carmichael to Johnsonville
				Porirua Branch replacement
				Porirua low level zone reserviors
				Waterloo Treatment Plant
				General toughening of pipes
	10	Road		Petone to Grenada
				Cross Valley Link
	11	Port		New RORO Terminal
	12	Rail		Rail seismic upgrade of slopes and bridges
Strengthening completed	13	Road/Gas		Middleton Road retaining walls upgrade
	14	Electricity		Seismic strengthening 33kV
	15	Water		Waterloo Pump Station extension and new pipeline from Waterloo to Haywards
				General toughening of pipes

Figure 14: Integrated lifelines investment programme



PHASE 1
YEARS
PHASE 2
YEARS
PHASE 3
YEARS
2019
2020
2021
2022
2023
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2025
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2027
2028
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2033
2034
2035
2036
2037
2038
2039
Outcome: First redundant route for fuel, vehicles and people into/out of the Hutt Valley
Outcome: First redundant route between Airport and CBD
Outcome: First redundancy achieved at Central Park. 33% of identified 33kV network strenghtened
Outcome: First redundant supply achieved by cross harbour pipeline, risk to Central Park removed and 33% of identified pipe network toughened
Outcome: First redundant level of power for comms network achieved
Outcome: Strengthened Port and port access (existing facilities)
Outcome: NIMT, Hutt Valley, Upper Hutt and Wairarapa Lines 50% strengthened
Outcome: 66% of identified 33kV network strengthened
Outcome: Second redundant supply achieved by Carmichael to Johnsonville, Porirua secured and 66% of identified pipe network toughened
Outcome: Second redundant route for fuel, vehicles and people into/out of the Hutt Valley
Outcome: Viable alternative sea access if port fails
Outcome: NIMT, Hutt Valley, Upper Hutt and Wairarapa Lines 100% strengthened
Additional road resilience and aids with gas main recovery
Outcome: 100% of identified 33kV network strengthened
Outcome: 100% of identified pipe network toughened. Ability to service most of Wellington's initial needs through restarting 1 piece of plant

Fuel Criticality

From early on in the project, fuel was identified as being absolutely critical in the response and recovery of the Wellington Region. Without fuel, machinery cannot clear roads, vehicles cannot access key infrastructure such as cell towers, electricity lines and substations and water infrastructure and people cannot travel within and outside the region. The reliance of the telecommunications network on fuel to run generators is significant and second only to having access to their network via roads.

Furthermore, it has been identified, and confirmed in the wake of the recent fuel line crisis in Auckland, that the Wellington Region is reliant on the Seaview Fuel Terminal, the Seaview Wharf and the fuel lines that run between the wharf and terminal. The crisis also emphasised the disruption to not only the region, but the whole country. In the event of a Wellington Fault rupture, the RiskScape modelling has confirmed that the fuel terminal may suffer minor damage and could be running reasonably quickly but the damage to the fuel line and wharf could prevent additional fuel supplies being shipped into the region. Together with the modelled level of land damage (liquefaction and subsidence) that is most likely to occur in the Petone and Hutt River areas, this will result in the fuel terminal being isolated from the other areas of the Wellington Region for a substantial length of time due to roads being impassable.

Hutt City Council has identified the Cross Valley Link project as having a resilience benefit because it could provide a more secure route between SH2 and the Seaview Fuel Terminal when compared to The Esplanade and Waione Street on the Petone foreshore.

Based on the findings to date and the relative unknowns in terms of the actual benefits of the Cross Valley Link project (because it has not been progressed to detailed investigation) it was agreed at the final workshop by the participating lifeline organisations to include the Cross Valley Link in the preferred programme with a recommendation to investigate an alternative fuel option outside this project. This “fuel option” could include alternative locations for the fuel terminal where there would be improved accessibility via Transmission Gully to the main areas of population and critical infrastructure and more substantial access could be possible via the sea.

8. The Financial Case

The financial case presents a high-level assessment of the potential affordability and funding of the preferred programme to improve infrastructure resilience. The financial case looks at both the accelerated investment programme and the unaccelerated, 'do-minimum' programme. It:

- Sets out the financial impact of the options and the expected costs to the lifeline utilities
- Outlines potential funding sources
- Discusses overall affordability of the options and the additional funding required to deliver the programme.

The complete list of recommended initiatives in the preferred programme with their indicative costs supplied to date and their owner(s) is presented in Table 10.

Table 10: Preferred Investment Programme initiative list

Lifeline Infrastructure	Preferred Investment Programme		
	Initiative Name	Owner	Indicative Cost
Roads	Wadestown to Johnsonville seismic strengthening	WCC	$20M
	SH58/Haywards seismic upgrades from Transmission Gully to Hutt Valley	NZTA, HCC, PCC	$24M
	Taita Gorge Access	HCC	$2.5M
	Cross Valley Link[15]	HCC	$65M
	Petone to Grenada[16]	NZTA	$1,062M (median of range supplied)
	Better engineered road links to existing RORO Terminal and port area	NZTA, CentrePort	$71M
	Improve resilience of airport connectivity to city network via Newtown	WCC	$10M
	Middleton Road retaining walls upgrade	WCC, Gas	$50M
Fuel	Seaview Wharf seismic strengthening including pipeline	CentrePort and fuel partners	$10M + $25 M wharf strengthening costs
Sea Ports	Port Seismic Strengthening	CentrePort	$312M
	New RORO terminal with more resilient link to SH1	CentrePort, KiwiRail, Blue Bridge and GWRC	$250M

[15] *Special Note Regarding the Cross Valley Link –This option has been included as a proxy for improving fuel links to ensure the resilience necessity is captured. As part of future detailed work, there could be alternative preferable solutions to achieve the necessary fuel supply objectives.*

[16] *The link has been the subject of a recent review of both its design and cost. An update will be required for this project.*

Lifeline Infrastructure	Preferred Investment Programme		
	Initiative Name	**Owner**	**Indicative Cost**
Electricity	Central Park Substation improved resilience	Transpower, WE*	$40M
	Seismic upgrade of cables and creation of 33kV Rings	WE*	$160M
	Central Park to Frederick St cables replacement	WE*	$5M
Water	Cross Harbour Pipeline	WW	$139M
	Prince of Wales and Bell Road Reservoir upgrade	WW	$78M
	Carmichael to Johnsonville and Karori Pipeline	WW	$247M
	General water supply toughening	WW	$654M
	Porirua Branch Replacement & Emergency Pumping Plant	WW, PCC	$33M
	Porirua Low Level Zone Reservoirs	WW, PCC	$25M
	Waterloo Pump Station Extension and New Pipeline from Waterloo to Haywards	WW	$126M
	Waterloo Water Treatment Plant Liquefaction Mitigation Project	WW	$2M
	Silverstream Bridge Pipeline Replacement Project	WW	$23M
Rail	Rail seismic upgrade of slopes and bridges	KiwiRail	$100M
Telecommunications	Dedicated backup power for cell towers	Vodafone, Spark, 2degrees	$12M

The outcomes of the financial case are contained within the report titled: ***Wellington Lifeline Project Financial Case**, EY, September 2019* (Appendix N).

The key findings are:

- The whole of life programme costs (capex and initial opex) are estimated to be $5.3b. While this is a very large figure, it should be acknowledged that these are not all new costs. Many of these initiatives already feature in the long-term capital plans of Wellington's infrastructure providers
- The initial capital expenditure of $3.9b is the largest single component of the programme cost (73%)
- Estimated revenue generated from the initiatives themselves is small ($25.3m)
- The estimated funding for the programme comes to $1.9b, covering 36% of the programme cost. Of this:
  - $400m is committed to the programme
  - $1.5b is committed contingent on certain requirements being met
- **There is a significant funding shortfall of $3.4b**
- The funding shortfall for Phase 1 of the programme (Years 0 - 7) is $580m. This phase, contains the highest priority initiatives that deliver the greatest benefit and upon which other initiatives depend.

9. The Commercial and Management Cases

9.1 – Outlining the commercial strategy

In a programme business case, it is customary to outline the commercial case – broadly what services would be required and how they would be procured and the management case – covering an outline project plan, risk management and programme and business assurance arrangements.

In this instance, it is not possible to provide such an outline owing to the wide diversity both of the projects in the combined programme and of the responsible organisations themselves. It will be up to each responsible lifeline organisation to develop their commercial and management cases. It is important to note, however, that each responsible organisation is a well-established entity accustomed to procuring and managing the types of projects identified in the programme. Indeed, many of the projects represent business-as-usual for the organisations except that this business case demonstrates the value from those projects happening sooner than they might otherwise.

10. Next Steps

To date Stage 1 'Demonstration of Benefits' and Stage 2 'Financing and Timing' have been completed. In the preceding pages the PBC has demonstrated that completing the programme of works identified will significantly improve Wellington's economic recovery following major earthquake. It has also proposed an optimised schedule that would deliver the work in a co-ordinated and timely manner.

The funding and affordability have been outlined in the financial case, which has demonstrated that significant additional funding is required in order to implement the accelerated programme and realise resilience benefits sooner.

Next steps for the PBC involve taking the outcomes of Stage 1 and Stage 2 back to individual lifeline organisations and to local and central government. The aim of this is to generate an imperative to take action.

All of the lifeline organisations involved will need to develop their commercial and management cases and respond to this call to action.

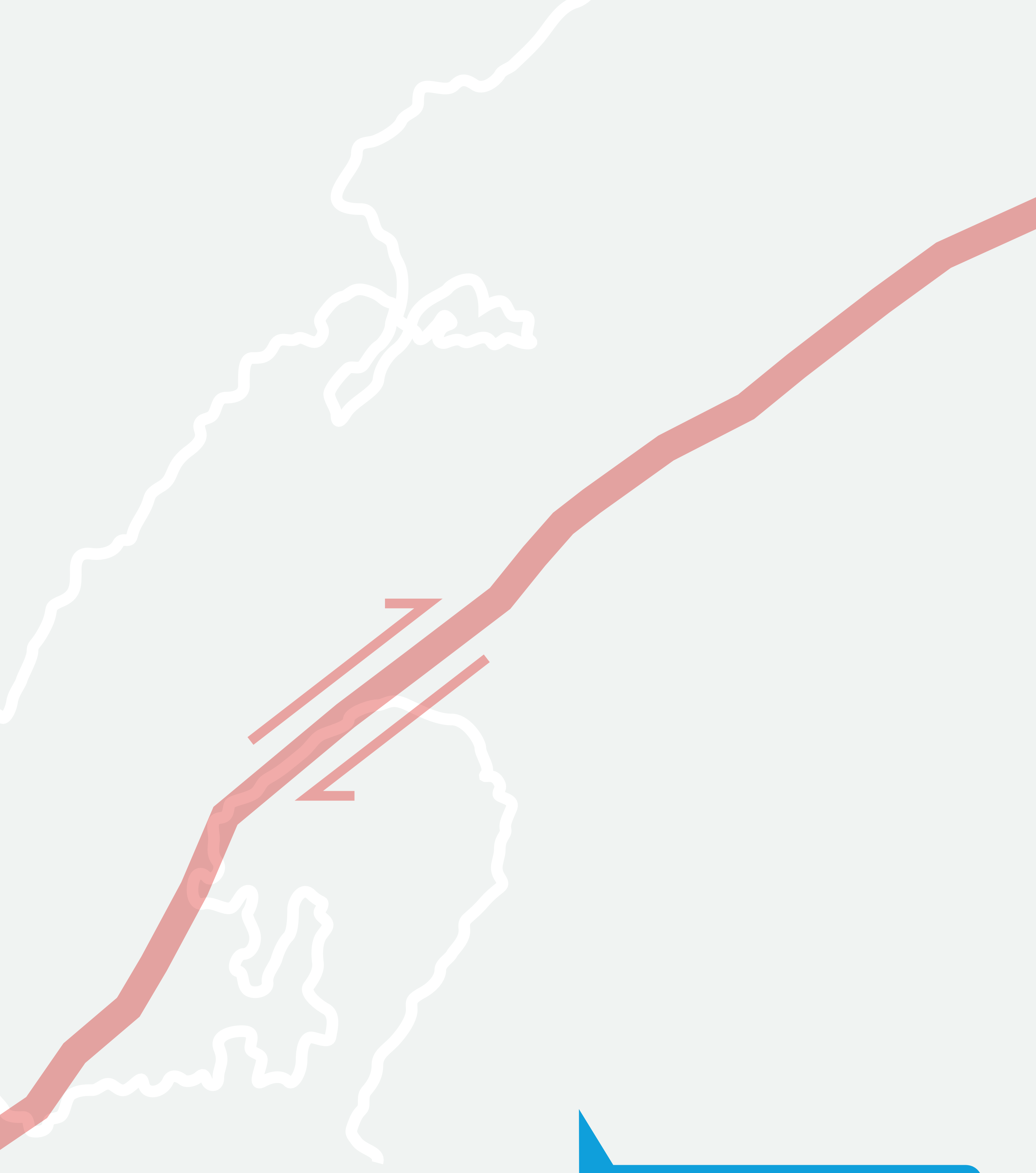
It is clear that a coalition across local and central government and the private sector will be required to progress this step and address the funding shortfall.

New funding mechanisms will need to be worked out over forthcoming years by the lifeline entities and will require the community's understanding and support. The public conversations must be fully informed and honest about the consequences of inaction.

Given the national economic value of this investment, this coalition will benefit from central government leadership because the ultimate economic and social cost of catastrophic failure following a major event is borne by the Crown.

Glossary of Abbreviations

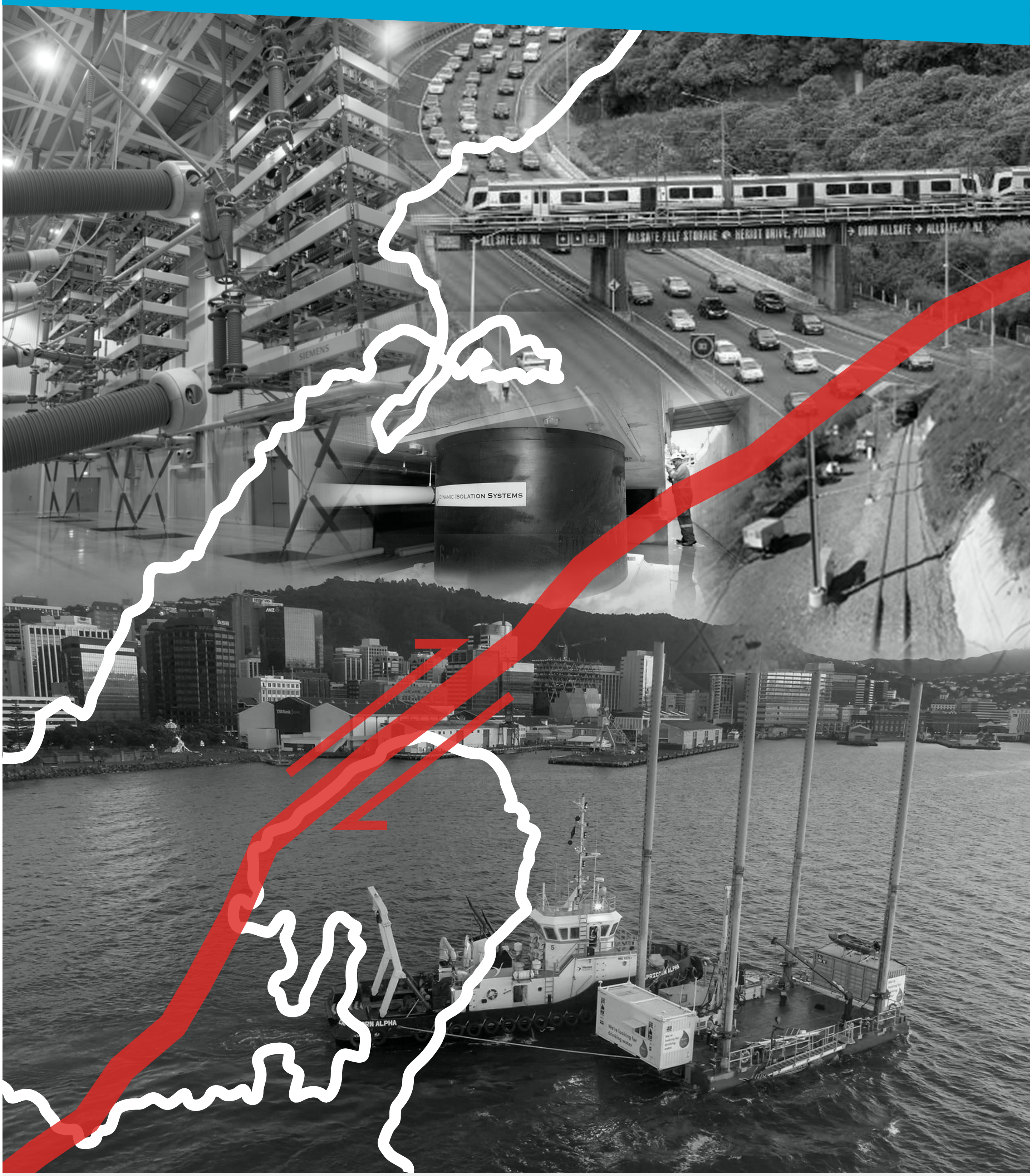
BAU	Business As Usual
BERL	Business and Economic Research Limited
BBC	Better Business Case
CBA	Cost Benefit Analysis
CBD	Central Business District
CDEM	Civil Defence Emergency Management
CGE	Computable General Equilibrium
CLS	Concrete Lined Steel
ERI	Economics of Resilient Infrastructure
GaWC	Globalization and World Cities
GDP	Gross Domestic Product
GNS	Geological and Nuclear Science Ltc.
GPS	Government Policy Statement on Land Transport
GPs	General Practitioner
GXP	Grid Exit Point
HILP	High Impact Low Probability
ILM	Investment Logic Map
KPI	Key Performance Indicator
KV	Kilovolt
LoS	Level of Service
LSN	Liquefaction Severity Number
MCA	Multi-Criteria Assessment
MCDEM	Ministry of Civil Defence and Emergency Management
ME	Market Economics
MERIT	Modelling the Economics of Resilient Infrastructure Tool
ML	Megalitres
MMI	Modified Mercalli Intensity shaking
MOH	Ministry of Health
MOT	Ministry of Transport
NIMT	North Island Main Trunk
NIP	National Infrastructure Plan 2015
NZ	New Zealand
RORO	Roll On Roll Off
PBC	Programme Business Case
PGA	Peak Ground Acceleration
RLTP	Regional Land Transport Plan
RMA	Resource Management Act 1991
RSPs	Retail Service Providers
SH1	State Highway 1
SH2	State Highway 2
SH58	State Highway 58
TG	Transmission Gully
UH	Upper Hutt
VfM	Value for Money
WCC	Wellington City Council
WE*	Wellington Electricity
WeLG	Wellington Lifelines Group
WRRAG	Wellington Region Resilience Acceleration Group
WRRCoG	Wellington Regional Resilience Coordination Group



WELLINGTON LIFELINES

REGIONAL RESILIENCE PROJECT

APPENDICES



WELLINGTON LIFELINES
REGIONAL RESILIENCE PROJECT

WELLINGTON LIFELINES PROJECT

Protecting Wellington's Economy Through Accelerated Infrastructure Investment Programme Business Case

Appendix A

Supporting Information (MMaI)

Table A-1 Average return period of earthquake shaking using the Modified Mercalli Intensity scale for an average Wellington site

MMI Level	Average Return Period	Example Outcomes of Intensity of Earthquake Shaking		
		People	Infrastructure, Structures and Fittings	Environment
MMI 7	*~30 years*	Felt by all. General alarm. Difficulty experienced in standing. Noticed by motorcar drivers who may stop.	Furniture moves. Fragile contents of buildings are damaged. Damage to windows, suspended ceilings, and tiled rooves. Un-reinforced walls crack; brick veneers and plaster or cement-based linings are damaged. Unbraced architectural features and ornaments fail. Un-reinforced domestic chimneys are damaged, often falling from roof-line.	Small slides of granular materials, with small rock-falls from steep slopes and cuttings. Instances of settlement of unconsolidated or wet, or weak soils. Some fine cracks appear in sloping ground. A few instances of liquefaction (i.e. small water and sand ejections).
MMI 8	*~120 years*	Severe shaking felt. Alarm may approach panic. Steering of motorcars greatly affected.	Heavy Furniture is overturned. Poorly constructed structures are heavily damaged; some collapse. Structures of ordinary construction are damaged some with partial collapse. Reinforced structures are damaged in some cases. Houses not secured to foundations may move. Un-reinforced domestic chimneys are damaged to low levels. Some damage to underground services.	Tree branches are broken. Cracks appear on steep slopes and in wet ground. Small to moderate slides in roadside cuttings and unsupported excavations. Small water and sand ejections and localised lateral spreading adjacent to streams, canals and lakes.

MMI Level	Average Return Period	Example Outcomes of Intensity of Earthquake Shaking		
		People	**Infrastructure, Structures and Fittings**	**Environment**
MMI 9	*~400 years*	Violent shaking felt. Panic.	Poorly constructed structures are destroyed. Structures of ordinary construction are heavily damaged, some collapse. **Reinforced structures** are damaged; with partial collapse, or distortion. Some damage or permanent distortion to well-built modern structures. Houses not secured to foundations are shifted off. Underground services are damaged.	Cracking of ground is conspicuous. Landsliding is general on steep slopes. Liquefaction effects are more widespread, with large lateral spreading.
MMI 10	*~1350 years*	Extreme shaking felt. Panic.	Poorly and ordinary constructed structures are destroyed or heavily damaged. **Reinforced structures** are damaged; with partial collapse or distortion. Well-built modern structures may have moderate damage. Underground services are severed.	Landslides are widespread; with large rock masses displaced on steep slopes Liquefaction effects are widespread and severe. Harbour and river water is thrown onto land.

Appendix B
Earlier Studies and their Findings

Previous studies set the scene for the current business case and highlight how imperative it is that the business case addresses outstanding issues and helps make the region more resilient for the good of the New Zealand economy and people of the region. They show work to date, and gaps to address.

Lifeline response priorities: 7 April 2015[16]

The Lifeline Response priorities paper represents the outcome of a WeLG project to create a framework for the prioritisation of lifeline restoration during and following an emergency. The framework was used to identify which facilities should be prioritised for response. The project also had the objective to "inform the risk reduction and resilience enhancements of the region's lifeline utilities". As such, the project very much formed a starting point for the current business case.

The paper observed that the framework "is necessarily high-level due to the complexity of attempting to balance various priorities and interdependencies"; it uses the MCDEM prioritisation framework as its basis. This PBC aims to assist in exploring some of that complexity.

Lifeline utilities restoration times for metropolitan Wellington following a Wellington fault earthquake[17]

This report acted as a catalyst for significant further investigation and investment by highlighting the restoration times – and how much greater they are than may generally be perceived. As stated in the Foreword by the WeLG Chair "The contents of this report make sober reading. The complexities of restoring essential services after a severe earthquake are considerable and the job will not be achieved quickly. There is much at stake. Not only does the region comprise 11 per cent of the country's population, but it also generates 15 per cent of its GDP. Wellington is the seat of government and the transport hub between North and South islands. Many organisations have their national headquarters in the capital's CBD so that a severe earthquake would affect operations far beyond the city" (page 5).

The report focuses on likely restoration times for key lifeline utility services following a major earthquake involving a rupture of the Wellington Fault. Accordingly, it is based on the same core scenario as the present business case and the identified restoration times help represent a starting point (or base case).

The report was based on studies completed just prior to the release of the WeLG report, and based on the expert opinions of the lifelines staff at the time. It only touched upon interdependency issues between lifeline sectors at a relatively light level.

The report included the restoration times (under a set of necessary but reasonable assumptions) for most utilities. Refer to Table 1. As can be seen, the time to restore services will result in significant disruption to the people and organisations based in Wellington.

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[16] *Wellington lifelines group/Wellington Region Emergency management Office/Wairarapa Engineering Lifelines Association 7 April 2015*

[17] *Report to the Wellington CDEM Group Joint Committee from the Wellington Lifelines Group, November 2012*

Table B-1: Summary of operational level of service as determined by a 2012 WeLG report

Utility Type	Time to restore operational level of service (dependent on location)
Gas	60 – 80 days
Power	20 – 50 days
Water	20 – 65 days
State Highway connections	SH2 Horokiwi - 8-16 weeks recovery time SH1 between Pukerua Bay and Paekakariki - up to 4 months recovery time (with Transmission Gully it is estimated it would cut restoration time down to 40 days) SH58 Haywards – likely 3 months recovery time SH2 Rimutaka Hill Road - extensive recovery time
Rail network	Similar to state highways in common locations, except the Rimutaka Hill Tunnel itself may be relatively unaffected, access to the portals of the tunnel is likely to be heavily affected.

Appendix C
Summary of Strategic Documentation

Guide to the National CDEM Plan 2015

The *Guide to the National CDEM Strategy* constitutes an effective cohesive strategy, which has four goals:

- **Goal 1**: increase community awareness, understanding, preparedness, and participation in respect of CDEM
- **Goal 2**: reduce the risks from hazards to New Zealand
- **Goal 3**: enhance New Zealand's capability to manage emergencies
- **Goal 4**: enhance New Zealand's capability to recover from emergencies.

This programme business case is a major contribution towards Goal 4 and will be expected to contribute to Goal 2.

The National CDEM Plan 2015 and Guide are supported by three supporting plans issued by the Director of CDEM. One is the *Wellington Earthquake National Initial Response Plan*, discussed below.

Lifeline utilities

The CDEM Strategy and Guide refer specifically to Lifeline utilities as entities that provide infrastructure services to the community such as water, wastewater, transport, energy, and telecommunications. The guide notes that Lifeline utilities have responsibilities for planning and coordinating in a way that enables the continuation of these services in an emergency, with assistance from CDEM Groups, MCDEM, and other relevant government agencies and regulatory bodies.

The Guide states that Lifeline utilities have duties under section 60 of the Act.

Every Lifeline utility identified in Schedule 1 must:

a) Ensure that it is able to function to the fullest possible extent, even though this may be at a reduced level, during and after an emergency

b) Make available to the Director of CDEM in writing, on request, its plan for functioning during and after an emergency.

Consistency of this business case with the guide and act

The preparation of this business case for WeLG on behalf of the lifeline organisations is important in helping them to fulfil their statutory responsibilities especially concerning *reduction* and *planning cooperatively*.

Guide to the National CDEM Plan 2015 – supporting information

The Guide further comments that Lifeline utilities are primarily responsible for the reduction of outage risks, for example, by the location and installation of assets consistent with local hazard conditions. Lifeline utilities are also primarily responsible for preparing readiness arrangements for emergency responses when outages occur.

Role of lifeline utilities during reduction and readiness

To help fulfil their duties under section 60 of the Act, all lifeline utilities are to—

a) Develop business continuity plans to:

i) Identify critical assets and business processes, assess their vulnerabilities, and undertake appropriate actions to reduce the risks they face

ii) Outline response and recovery arrangements, including appropriate contracting arrangements with key suppliers

b) Focus on both reduction and readiness, including planning co-operatively with—

i) Other lifeline utilities (whether or not in the same sector), especially those on which they are dependent; and

ii) Relevant government agencies

iii) CDEM Groups; and

c) Regularly test and exercise their response arrangements and participate in the National CDEM Exercise Programme.

Reduction

The Guide defines reduction as identifying and analysing risks to life and property from hazards, taking steps to eliminate those risks if practicable, and, if not, reducing the magnitude of their impact and the likelihood of their occurrence to an acceptable level. The objective of reduction is to take preventive steps to avoid or mitigate adverse consequences.

The principles underlying reduction are to:

d) Achieve acceptable levels of risk through sustainable and practicable reduction measures to provide the best long-term solutions; and

e) Reduce the risks to communities from hazards

Lifeline utilities and CDEM: Director's guideline for lifeline utilities and civil defence emergency management groups (DGL 16/14)

This document (http://www.civildefence.govt.nz/assets/Uploads/publications/dgl-16-14-Lifeline-Utilities-and-CDEM-Groups.pdf) notes, in Section 2.1 that lifeline utilities need to "consider the service delivery expectations and service delivery capacity for a range of disruptions. Each lifeline utility needs to determine the optimal level of service that meets their obligations, and plan for the delivery of this level of service."

Resource Management Act

Section 6 of the Resource Management Act 1991 (RMA) sets out matters of national importance that decision-makers must recognise and provide for in various circumstances.

Section 6 of the RMA has recently been amended to add '*the management of significant risks from natural hazards*'. The intent of this change is to provide an explicit mandate for decision-makers to manage significant risks from all natural hazards (as defined in section 2 of the RMA) as part of any Part 2 assessment.

These changes came into force on 19 April 2017.

National level aims for resilience

The current action to develop a business case to reduce the economic cost of a major event affecting Wellington aligns to the wider government aims for resilience in New Zealand.

This business case proposal is being developed as part of an integrated approach, which has been Government-coordinated with separate but inter-connected streams. These streams of work have looked at actions that can be taken to enhance resilience within one month, between one month and six months and beyond six months – this business case. The catalyst for developing the de facto strategy was the Kaikoura Earthquake of November 2016.

An urgent review of the Wellington Earthquake National Initial Response Plan by the Ministry of Civil Defence and Emergency Management (MCDEM) confirmed that the Wellington Region faces a unique set of risks and vulnerabilities that provide a sound basis for added central government attention. They included:

- The high possibility that a significant seismic event would result in the Wellington Region being cut off from the rest of the country for a significant period of time (months)
- The vulnerability of the transportation network (port, roads, airport, rail)
- The large at-risk population
- The large number of critical central government processes that are completely or mainly reliant on functioning Wellington lifelines.

Government established the Wellington Region Resilience Acceleration Group (WRRAG) to provide for greater central and local government collaboration to accelerate aligned planning, investment and delivery.

The actions for the *one to six-month period* have been under the banner of the Wellington Regional Resilience Coordination Group (WRRCoG). Its aims were to:

- Catalyse and secure a step change in regional resilience (readiness + risk reduction)
- Fast track investment to enable the step change
- Coordinate and monitor short-term activities that contribute to the step change
- Review effectiveness of current arrangements and tools currently in place to support regional resilience; and make suggestions for improvements if required (including post-event system capability and capacity).

This business case rounds out the integrated planning, addressing the period beyond six months.

National Infrastructure Plan[18] (NIP)

The NIP contains numerous references to the need for New Zealand's infrastructure to be more resilient, both in a general sense, and specifically against seismic events.

These references include a favourable assessment of Wellington Water taking a regional approach to a step change for strengthening resilience – including seismic resilience (p. 31) and the need for asset management practices to include a stronger understanding of the resilience of infrastructure networks at a national, regional and local level (p. 47).

The NIP's Action Plan covers a range of measures to strengthen resilience including that lifelines progress initiatives to improve resiliency in NZ.

Emergency Relocation of Executive Government and Parliament Plan

The *Emergency Relocation of Executive Government and Parliament Plan*[19] adopted in 2014 provides for the continuation of government (in Auckland). The Plan is based on nine assumptions concerning the level of assumed functionality of key infrastructure and lifeline utilities such as transport links and roading networks, power, drinking water, wastewater and telecommunications.

Wellington Resilience Strategy

The draft Wellington Resilience Strategy[20] was adopted at the Wellington City Council Strategy Committee on 9 February 2017. Its coverage is wide including goals: "People are connected, empowered and feel part of a community", "Decision making at all levels is integrated and well informed" and "Our homes and natural and built environments are healthy and robust". It therefore encompasses lifelines infrastructure within a wider compass with three especially relevant actions: "Review Wellington Lifelines Group", "Invest in water and sewage resilience and awareness" and "Integrate resilience into transport projects" (p. 17).

Under Review of Wellington Lifelines Group the Strategy refers to this project. It notes that "In partnership with Wellington Lifelines Group (WeLG), we will better communicate the vulnerabilities of our city's lifelines to leaders and decision makers to prompt and prioritise action". (p. 67)

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[18] *The Thirty Year New Zealand Infrastructure Plan 2015, New Zealand Government*

[19] *See http://www.civildefence.govt.nz/assets/Uploads/Cabinet-paper-emergency-relocation-plan.pdf*

[20] *Wellington Resilience Strategy – Draft Strategy 25 January 2017*

Figure C-1: Resilient Wellington mural (Source: WCC Wellington Resilience Strategy, Wellington City Council)

Government Policy Statement on Land Transport

The draft Government Policy Statement on Land Transport (GPS[21]) has the Objective: A land transport system that is resilient. (p. 9)

It aims for the Result: Improved network resilience at the most critical connections.

The GPS notes that it is important for economic growth and productivity that the network is resilient at the most critical points. The most critical points were determined by considering three factors:

- The route's importance (for roads this is linked to its role as per the One Road Network Classification system) and the availability of appropriate alternative routes
- The risk of transport disruption
- The performance of any system (transport or non-transport) in response to a disruptive event.

GPS 2018 gives priority to investment that improves resilience on routes to which disruptions pose the highest economic and social costs. This includes investment to improve resilience to high impact but low probability events.

GPS 2018 supports the development of regional plans and system approaches to improve resilience, and provide targeted investment for improving resilience risk through recognition of interdependencies between lifeline networks. It also supports investment for the best solutions on the most critical transport routes, in particular for regions with only one viable land transport route in and out. This includes the recovery of the transport system for urban areas such as Auckland, Wellington and Christchurch, which are vulnerable to high impact low probability natural events.

The NZ Transport Agency's strategy

The NZ Transport Agency's Statement of Intent states: "The resilience of the land transport network and its ability to recover from planned and unexpected events and return to providing the required level of service for customers requires careful planning, investment and management. We will improve our understanding of what resilience means in relation to 'one network' and sharpen our investment and planning tools to ensure we have the resources to address it. We will also consider what resilience means in relation to all roading network assets, services, systems and relationships"[22].

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[21] *Government Policy Statement on Land Transport draft (for engagement) February 2017 2018/19 – 2027/28*

[22] *NZ Transport Agency Statement of Intent 2014–18, p. 23*

Wellington Regional Land Transport Plan (RLTP)

The Wellington RLTP contains a significant section on resilience, which addresses both High Probability, Low Impact and High Impact, Low Probability events. The latter are defined in the RLTP as including a significant magnitude earthquake (7+), major volcanic eruption or a tsunami.

The RLTP gives the key resilience problem for Wellington's regional transport network as:
Regional infrastructure that is vulnerable to disruption by unplanned events is potentially resulting in an unacceptable cost of severance and restricted ability to recover over time.

The priority action areas are:

"The development of business cases in relation to the region's resilience issues will help to determine the best resilience solutions and packages and will help to guide the priority order in which projects should be undertaken."

Individual lifelines planning

Each lifeline provider is at a different stage in developing their individual asset management and resilience plans. This section gives a brief snapshot of a limited number of the plans to illustrate typical content and some of the issues being faced by lifeline organisations, as well as a summary of the status of the plans as known at May 2017. Knowing the status of present plans provides the starting point for a central aim of the business case – to enhance and better integrate all organisations' planning (and delivery) of enhanced resilience.

The councils with their wider responsibilities and tight statutory framework generally have well-documented plans. As described above (S. 4.6) Wellington City Council has a comprehensive resilience strategy.

The degree of planning and documentation among the utilities is very variable. In some cases, it may be that there is significant planning that has occurred, but it is not known publicly for reasons of commercial sensitivity.

Upper Hutt City Council

Typically for the councils, Upper Hutt City Council has an Infrastructure Strategy[24] whichcontains references to increasing resilience in respect of multiple assets. It comments that "Well maintained infrastructure located in the right place and provided for at the right time, with sufficient capacity and **resilience** is critical to the economic prosperity, and social well-being of people living and working in Upper Hutt (emphasis added, p. 3). Similarly, it notes that a purpose of its services is "Ensuring our community is resilient to change as a result of foreseen and unforeseen events – natural hazards, climate change, changes in demand" (p.3). In the specific section on Resilience of Infrastructure Assets (p. 8) specific vulnerabilities are identified affecting the water supply reticulation network, the roading network and a number of bridges with a commitment for upgrading.

Wellington Water

Wellington Water is a good example of a lifeline organisation that has taken a systematic approach to resilience. It has produced strategic cases for water supply and wastewater. The water supply example identified problems relating to the multiple crossings of numerous fault lines by the metropolitan water supply; the likelihood of long-term outages as a result of the state of the network and ground conditions; the linear configuration of the supply network and the expectation of metropolitan area utilities being disrupted. The strategic case also sets out the expected benefits, strategic responses and desired outcomes. The conclusion from the strategic case was the need to do more to enable Wellington Water to comply with the CDEM Act.

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[23] *Wellington Regional Land Transport Plan 2015 p. 119 – p. 124*

[24] *Infrastructure Strategy, 2015 – 2045, Upper Hutt City Council, January 2015*

[25] *Water Supply Resilience Strategic Case, Wellington Water, August 2015*

Wellington Electricity

Wellington Electricity is among the better publicly documented of the Lifeline Organisations[26]. It is an example of a lifeline organisation that is well aware of its need to address resilience and is taking active steps to do so. Nevertheless, it reports there is currently no additional funding for resilience expenditure, and budget for any resilience work comes out of the annual capex budget (page 100).

During 2016 Wellington Electricity studied options to improve the overall resiliency of the network for HILP events (such as a major earthquake). Together with Wellington Water, Wellington Electricity engaged with regionally critical consumers, focusing on learning the requirements of each of these consumers and getting a better understanding of their requirements after a severe disaster event, including backup power and water storage capabilities.

NZTA

The Transport Agency is well advanced with its resilience planning[27], having developed a national programme business case, undertaken research on its value[28] and developed multiple areas of policy and guidance[29]. Of particular interest is the way that resilience has been addressed for major projects with, for example, the Transmission Gully business case has a very specific objective: *to to provide an alternative strategic link for Wellington that improves regional network resilience and route security*.

All lifelines

The councils have reasonably complete and integrated infrastructure plans that address resilience. NZTA has advanced planning to enhance the resilience of the state highway network. Five out of the remaining 17 lifeline organisations are known to have some form of plan. Therefore, there are 12 organisations where the plans do not exist or are kept confidential and are unlikely to be integrated across the sector.

[26] *Wellington Electricity 10 Year Asset Management Plan 1 April 2017 - 31 March 2027*

[27] *State Highway Network Resilience National Programme Business Case*

[28] *Research Report 614 Establishing the value of resilience*

[28] *https://www.nzta.govt.nz/assets/Highways-Information-Portal/Technical-disciplines/Resilience/Resilience-project/Resources-and-information/Resilience-strategic-case-best-practice-and-insights-Final.pdf*

Appendix D

Investment Logic Map

PROBLEM	BENEFIT	INVESTMENT OBJECTIVES

PROBLEM

Uniquely Vulnerable Capital (70%)

A challenging geography, highly concentrated economic activity in CBD & very low infrastructure redundancy makes the NZ Capital uniquely vulnerable to a shock event resulting in economic & social risks for the region & country

Historically Low Value & Priority Placed on Resiliency (30%)

Historically low value placed on resilience, unclear expectations and lack of alignment/ priority for investment in the NZ Capital results in inaction with increased economic & social risks for the region & country

BENEFIT

NZ Inc

Significantly reduced risk to New Zealand's economy (60%)

KPI1: Reduced Predicted NZ Economic Loss

KPI2: Reduced Predicted Recovery Period

People

Safer People and More Resilient Community (20%)

KPI1: Reduced Recovery Period

KPI2: Reduced Population Loss

KPI3: Reduced Community Isolation

KPI4: Reduced Disease Risk

Government

Optimisde Strategic Lifelines Investment (20%)

KPI1: Finalised Investment Plan

KPI2: Aligned Central / Local Government

KPI3: Reduced Recovery Costs

INVESTMENT OBJECTIVES

Significantly reduce the risk to NZ economy from shock events affecting Lifeline Services in the Wellington Region (60%)

Reduce the safety risk to people living in the Wellington region from shock event affecting Lifeline Services (10%)

Make the Wellington Regional Community more resilient against the effect of a shock event affecting Lifeline Services (10%)

Optimise the combined investment in Wellington Lifeline Services (20%)

INVESTMENT KPI	MEASURE	BASELINE	TARGET
Reduced Predicted NZ Economic Loss	GDP/Vfm	TBC (Me/GNS)	NZ GDP Loss <10% VfM interventions +ve (ME/GNS)
Reduced Predicted Recovery Period	80% Normal Trade Level	TBC	1 month
	Lifelines Operational Service Restoration Time *Power, water, food, health (GPs) transport, schools, telcos (Chorus, RSPs) etc*	As per Lifelines Report *Lifelines restoration LoS*	1 week *1 week is generic placeholder – likely to vary by lifeline*
Reduced Predicted Population Loss	Population Loss % in X months	TBC	TBC
Reduced Predicted Community Isolation Period	7 Islands Critical Connection Restoration Time	TBC *eg Highways Lifelines LoS agreements*	1 week
Reduced Predicted Safety Risk from Infrastructure Failure	Infrastructure Related Deaths & SI	TBC	TBC
Reduced Predicted Risk of Major Disease Outbreak	MOH Measures	TBC	TBC
Finished Combined Investment Plan	Whole of Linelines Agreement	Doesn't Exist	Exists (66% of lifeline orgs)
	Individual Lifeline Long Term Plans	Not Included	Included (66% lifeline orgs)
Agreed Co-Funding Plan with Central Govternment	Co-Funded Plan Agreed	Doesn't Exist	Exists
Reduced Predicted Recovery Costs	Lifelines Operational Recovery Costs	TBC	TBC

Appendix E
About Wellington Lifelines Group

The Wellington Lifelines Group (or WeLG) was established in 1993 to co-ordinate the physical risk management activities of Wellington utility and transport service providers.

Members of the Wellington Lifelines Group are:

- CentrePort Limited
- Porirua City Council
- GNS Science
- Powerco
- Greater Wellington Regional Council
- Transpower
- Hutt City Council
- Upper Hutt City Council
- Kapiti Coast District Council
- Wellington City Council
- KiwiRail
- Wellington Electricity Lines Ltd
- NZ Transport Agency
- Wellington International Airport Ltd
- Nova Energy
- Wellington Water

The Wellington Lifelines Group works with its members to:

- Learn from each other and co-ordinate activities
- Facilitate discussion, particularly on hazard understanding and risk reduction measures on the Wellington Region's infrastructure
- Identify the effects of hazards on infrastructure, and to mitigate against those effects
- Facilitate increased understanding of the interdependencies between infrastructure organisations
- Develop best practice approaches to risk reduction, readiness, response and recovery for lifelines
- Maintain awareness of the importance of lifelines, and of reducing their vulnerabilities.

The stakeholders for the lifeline organisations are their customers, and in some cases shareholders or ratepayers, and the Government.

Appendix F

Initial Option List

Option status	On / Off Checkbox	Committed / Future	Function	Lifeline Sector	Option Name	Option Detail	Location of Control	Resilience Pathway
Complete	☑	Committed	Enables recovery (return to BAU)	Electricity	Seismic Upgrade	Seismic upgrade of all 33kV buried cables. Note that this represents the opportunity for an accelerated programme to implement this initiative sooner.	Region-wide	Robustness
Complete	☑	Future	Protection of infrastructure capital	Rail	NIMT geotech seismic upgrade	NIMT seismic upgrade of slopes (including outside of tunnels and other locations).	Region-wide	Robustness
Complete	☐	Future	Protection of infrastructure capital	Rail	Hutt geotech seismic upgrade	Hutt Valley seismic upgrade of slopes (including outside of tunnels and other locations).	Region-wide	Robustness
Not to be scored	☑	Future	Enable effective rescue/response/sustenance	Rail	Implement additional ground sensors	Finer net of ground sensors to guide level of response (rail network)	Region-wide	Recovery
Not to be scored	☐	Committed	Enable effective rescue/response/sustenance	Rail	Post-quake workforce	Wellington Metro rail infrastructure staff integrated into a post quake road/civil contractor workforce.	Region-wide	Recovery
Complete	☐	Future	Enables recovery (return to BAU)	Seaport	Port seismic strengthening - major works	(Higher cost option) Carry out full seismic upgrade of the Thorndon Container area to allow operations to be available 'within days' of an event. Note that this is included as it is important to national GDP	Wellington City	Robustness
Complete	☐	Future	Enables recovery (return to BAU)	Seaport	Seismic upgrade of the Thorndon Container area (minor)	(Lower cost option) Install edge protection around the Thorndon container wharf, to allow container and log operations to operate within 2-4 weeks after a major event.	Wellington City	Robustness
Complete	☐	Future	Enables recovery (return to BAU)	Seaport	New RORO terminal	Development of a new RORO terminal at a new (unspecified) location. Note that a (dolphin) mooring may also be required.	Wellington City	Redundancy
Complete (NB/MC)	☑	Future	Enables recovery (return to BAU)	Seaport	Roading connections to port	Resilience of ferry terminal connectivity to roading and city networks. Ensure that future ferry terminal developments have resilient connections to city and highways. ie. invest in improved resilience of roading network through to ferry terminals to improve recovery time for national freight task. Also, for immediate recovery, identify options for emergency roading solutions to access wharves after event.	Wellington City	Robustness
Not to be scored	☐	Future	Enable effective rescue/response/sustenance	Seaport	Coastal shipping	Coastal shipping routes N-S due to break in transport network (rail/port/roads). Note additional coastal capacity can be quickly supplied by incumbent operators to meet demand. South to North flows more problematic than North to South.	Region-wide	Redundancy
Complete	☐	Future	Enables recovery (return to BAU)	Seaport	New RORO terminal at Kaiwharawhara	Upgrade of Interislander / Kaiwharawhara terminal to create a resilient RORO terminal for Cook Strait ferries, including ground resilience. Note that a (dolphin) mooring may also be required.	Wellington City	Robustness
Not to be scored	☑	Future	Enable community sufficiency <7-days	Seaport	Mobile welfare stations	Use ships as mobile welfare stations (cruise ships). Cruise ships are self contained towns, including fresh water, sanitation, power and high capacity comms. Having discussions with the 3 major cruise firms about emergency charter capability could be worthwhile. Major cruise groups are Carnival, Norwegian and MSC, all of which have Sydney based operations.	Wellington City	Recovery
Not to be scored	☑	Future	Enables recovery (return to BAU)	Seaport	Alternative ferry connection point SI	Alternative ferry connection point(s) in South Island	Region-wide	Redundancy
Not to be scored	☑	Future	Enable effective rescue/response/sustenance	Communications	Shipping satcoms as comms hubs	Use shipping satcoms as comms hubs. Note high capacity satcoms can be installed on ships (potentially including cell phone call routing capability). Would there be interest in contributing towards providing this on Cook Strait ferries as backup capability?	Wellington City	Recovery
Complete	☐	Future	Enable effective rescue/response/sustenance	Seaport	Emergency RORO facility at Seaview	RORO facility at Seaview to allow access in an emergency. Note that a (dolphin) mooring may also be required.	Lower Hutt	Redundancy
Not to be scored	☑	Future	Enable effective rescue/response/sustenance	Seaport	Barges from WC to Seaview	Cross harbour connection for transport of goods and people - berthing locations. Consider smaller infrastructure for cross harbour vessels to feed Hutt valley, such as Sealink Auckland vehicle ferries and landing craft type vessels from Marlborough. Consider pre-positioning cargo barges in Wellington that could be used for this. Passenger only options would also help in evacuation scenarios.	Wellington City	Recovery
Complete (NB/MC)	☐	Future	Enable effective rescue/response/sustenance	Airport	Resilience of airport connectivity to city network via Newtown	Resilience of airport connectivity to roading and city networks via Newtown (due to additional local connectivity benefits)	Wellington City	Robustness
Not to be scored	☐	Future	Enables recovery (return to BAU)	Seaport	Taking ships post-event	Legislation to enable taking ships post-event. Agreement between Govt. and shipping companies.	Region-wide	Governance
Not to be scored	☐	Committed	Protection of infrastructure capital	Roads	Land Transport Government Policy Statement	Changes to the Government Policy Statement on Land Transport to make funding of resilience improvements faster	Region-wide	Governance
Complete	☑	Future	Protection of infrastructure capital	Roads	Akatarawa, Moonshine	Upgrade critical rural roads at Akatarawa and Moonshine. Upgrade to a 50k road including landslide protection works.	Upper Hutt	Robustness
Complete	☐	Future	Enable effective rescue/response/sustenance	Liquid fuel	Back-up diesel stores	Backup diesel storage in Ngaio Gorge. Includes replacing the tanks, improving access, fittings, spares, generator, gravity fed equipment, loading/unloading facilities, and slope stabilisation.	Wellington City	Redundancy
Not to be scored	☐	Future	Enable effective rescue/response/sustenance	Liquid fuel	Mobile fuel tankers	Mobile fuel tanks (tankers) at Seaview. Would be brought in post-event so considered an emergency response. Tankers are easily chartered, consider providing basic infrastructure to buoy moor in harbour with floating or fixed discharge lines.	Lower Hutt	Recovery
Complete	☑	Future	Protection of infrastructure capital	Liquid fuel	Move Seaview fuel terminal	Move one Seaview fuel terminal 'up hill' to Gracefield (away from liquefaction and tsunami prone area). May be issues with siting and legal requirements regarding distance.	Lower Hutt	Robustness
Complete	☑	Future	Enable effective rescue/response/sustenance	Gas	Readying point solution conversion to LPG	Enable primary gas users (hospitals and hotels) to be able to convert to LPG	Region-wide	Redundancy
Complete (NB/MC)	☑	Future	Protection of infrastructure capital	Seaport	Seismic upgrade of Seaview wharf	Carry out a seismic upgrade of the Seaview wharf.	Lower Hutt	Robustness
Not to be scored	☑	Future	Enable effective rescue/response/sustenance	All Infrastructure	Disaster recovery storage	Distributed disaster recovery storage locations for critical spares, materials, machines and fuel.	Region-wide	Governance
Complete	☐	Future	Protection of infrastructure capital	Communications	Harden communications network	Identify and then protect critical telco facilities and cable routes.	Region-wide	Robustness

Option status	On / Off Checkbox	Committed / Future	Function	Lifeline Sector	Option Name	Option Detail	Location of Control	Resilience Pathway
Complete	☐	Future	Enables recovery (return to BAU)	Communications	Redundant submarine fibre cables	Redundant submarine fibre cables into Wellington.	Region-wide	Redundancy
Complete (NB/MC)	☐	Future	Protection of infrastructure capital	Communications	Supersite network	Development of 'Supersite' network with coverage/capacity requirements defined by users, with all telco's participation - defined KPIs	Region-wide	Robustness
Not to be scored	☑	Committed	Enables recovery (return to BAU)	Communications	Data sharing	Greater collaboration across Telco's with detailed mutual aid agreements and information sharing on capability.	Region-wide	Recovery
Complete	☐	Future	Enable effective rescue/response/sustenance	Communications	Dedicated back-up power for cell towers	Improved response capability policy: dedicated portable / off-grid power generation (e.g. solar powered cell sites)	Region-wide	Governance
Not to be scored	☐	Future	Enable effective rescue/response/sustenance	Communications	Microwave/satellite links	Redundant microwave/satellite links to other cities and outside NZ	Region-wide	Redundancy
Not to be scored	☑	Future	Enable effective rescue/response/sustenance	Communications	Network redundancy	More diverse cable routes across the region.	Region-wide	Redundancy
Complete	☐	Future	Protection of infrastructure capital	Electricity	Central Park Substation - Improved Resilience	Reduce risk of Cntral Park outage	Wellington City	Redundancy
Complete	☐	Future	Enables recovery (return to BAU)	Electricity	Increase WE interconnectedness	Increase WE interconnectedness of MV network between Transpower sites (e.g. Vector and Orion)	Region-wide	Redundancy
Not to be scored	☑	Committed	Enables recovery (return to BAU)	Communications	Radio access networks (RAN)	Ability for mobile networks to share infrastructure cloud RAN	Region-wide	Redundancy
Not to be scored	☐	Committed	Protection of infrastructure capital	Electricity	Transpower supply points	Ensure AC Transpower supply points have N-I security.	Region-wide	Robustness
Complete (NB/MC)	☑	Future	Protection of infrastructure capital	Communications	Building resilience of telco facilities	Ensure all telco facilities are IL4 rated to 100% including fitout of services. Specifically consider Spark* Featherston St.	Region-wide	Robustness
Complete	☑ ☑	Future	Protection of infrastructure capital	All Infrastructure	EQ building code amendments	Increase building IL to prevent closed off CBD affecting power, comms, gas. (Outcome could also be achieved by a policy decision to relocate / not locate infrastructure in EQ-prone buildings.)	Region-wide	Robustness
Not to be scored	☑	Future	Enables recovery (return to BAU)	Other	Higher building standards	Mandate higher building standards, particularly in the CBD, with the recognition that this will reduce recovery time.	Wellington City	Robustness
Not to be scored	☐	Future	Enable community sufficiency <7-days	Electricity	Off-grid solutions (C+I)	Solar power for all key buildings (battery)	Region-wide	Redundancy
Not to be scored	☑	Future	Enable effective rescue/response/sustenance	Seaport	Evacuation facilities (tender)	Jetties to evacuate people (to reduce demand on lifeline services).	Wellington City	Recovery
Not to be scored	☐	Future	Reduction of Life/injury risk	Water distribution network	Fire suppression	Incentivise / mandate home fire suppression systems (like on planes and other vehicles)	Region-wide	Governance
Complete	☑	Committed	Enables recovery (return to BAU)	Water distribution network	Cross harbour pipeline	Cross harbour pipeline or bores. Note that this is committed in the LTP, so this option represents an acceleration of the programme.	Lower Hutt - Wellington City	Redundancy
Complete	☐	Future	Enable effective rescue/response/sustenance	Water distribution network	Prince of Wales and Bell Road II Reservoir	Prince of Wales and Bell Road II Reservoir: additional water reservoir(s). Feeds hospital and meets Newton potable water needs. Coupled with cross harbour pipeline / bores and associated pumpstations / pipe work.	Wellington City	Robustness
Complete	☐	Future	Enables recovery (return to BAU)	Potable water	Whakatiki dam	Construct the Whakatiki dam (built to SOLVE guidelines). Less need to cross the WF. Includes bulkwater pipeline and pumping.	Upper Hutt	Robustness
Not to be scored	☐	Future	Enables recovery (return to BAU)	All Infrastructure	BCP	All lifelines to develop and test business continuity plans (BCPs), which include alternate locations and communications plans. Establish a common BCP objective using 15022301 framework across all utilities.	Region-wide	Governance
Not to be scored	☐	Future	Reduction of Life/injury risk	Gas	Gas EQ shut off valves	Gas EQ shut off valves in homes (stop fires)	Region-wide	Governance
Not to be scored	☐	Future	Enable community sufficiency <7-days	Waste water	Policy to implement off-grid solutions for residential developments	Policy to implement off-grid solutions for residential developments (could be regulated or via grants). Needs to be applicable to apartments as well as residential homes	Region-wide	Governance
Not to be scored	☐	Future	Enable effective rescue/response/sustenance	Other	Solid waste disposal	Pre-defined solid waste disposal sites	Region-wide	Recovery
Complete	☐	Future	Enable community sufficiency <7-days	Waste water	Ablution facilities across schools	Policy to implement off-grid public facilities (at schools or CDEM centres)	Region-wide	Recovery
Not to be scored	☐	Future	Enable community sufficiency <7-days	Potable water	Saltwater soap	Making salt water soap available	Region-wide	Recovery
Complete (post-workshop)	☐	Committed	Enable community sufficiency <7-days	Water distribution network	Emergency water infrastructure	Emergency water infrastructure located in communities: bladders, mini-bores. Note that this represents the opportunity for an accelerated programme to implement this initiative sooner.	Region-wide	Recovery
Not to be scored	☐	Future	Enable community sufficiency <7-days	Potable water	Building requirements to mandate emergency water supplies	Building requirements to mandate emergency water supplies for homes and businesses	Region-wide	Governance
Not to be scored	☑	Future	Enable effective rescue/response/sustenance	Communications	Priority users	National database of priority mobile users to allow operators to invoke access class feature, giving those users network access during congested periods	Region-wide	Governance
Complete	☐	Future	Enables recovery (return to BAU)	Communications	Diversified handovers	All telco service providers required/mandated to build/operate diverse handovers between networks	Region-wide	Redundancy
Not to be scored	☐	Future	Protection of infrastructure capital	Electricity	Regulatory Incentivisation for resilience	Lower regulatory hurdle/barriers for electricity resilience	Region-wide	Governance
Not to be scored	☐	Future	Enable effective rescue/response/sustenance	All Infrastructure	Emergency consents	Emergency consents in place prior to event	Region-wide	Governance
Complete	☐	Future	Enable effective rescue/response/sustenance	Electricity	Duplicate spares for repair	Stockpiles of repair materials and replacement inventory (poles and wires). Greater than commercially justified by SOE.	Region-wide	Recovery
Not to be scored	☐	Future	Enable community sufficiency <7-days	Other	Resilience hubs	Community shelters pre-stocked. Consider marae as resilience hubs.	Region-wide	Governance
Not to be scored	☑	Future	Protection of infrastructure capital	Other	Tsunami defences	Improve robustness of defences against tsunami	Region-wide	Robustness

Option status	On / Off Checkbox	Committed / Future	Function	Lifeline Sector	Option Name	Option Detail	Location of Control	Resilience Pathway
Complete (post-workshop)	☑	Committed	Protection of infrastructure capital	Water distribution network	Pipe resilience	Toughen pipes at critical locations as part of AMP. Note that this represents the opportunity for an accelerated programme to implement this initiative sooner.	Region-wide	Robustness
Not to be scored	☑	Future	Enables recovery (return to BAU)	Water distribution network	KC-DC pipeline	Construct KC-DC pipeline	Kapiti	Redundancy
Not to be scored	☑	Committed	Protection of infrastructure capital	Water distribution network	AMP	Map fragility of network to prioritise asset management works in the context of community needs	Region-wide	Robustness
Not to be scored	☑	Future	Enable community sufficiency <7-days	All Infrastructure	Education	Household resilience education allow more time for infrastructure repairs	Region-wide	Recovery
Not to be scored	☑	Future	Enable community sufficiency <7-days	Electricity	Inverters to households	Inverters to households to allow freezers to be powered.	Region-wide	Recovery
Not to be scored	☐	Future	Enable effective rescue/response/sustenance	Other	Recovery workers	Pre-agree process for providing access and facilities for recovery workforce (e.g. accommodation, visas).	Region-wide	Governance
Not to be scored	☐	Future	Enable community sufficiency <7-days	Potable water	Off-grid solutions for commercial developments	Policy to implement off-grid solutions for commercial developments (could be regulated or via grants).	Region-wide	Governance
Not to be scored	☐	Future	Enable community sufficiency <7-days	Electricity	Off-grid solutions (Residential)	Incentivise solar and battery systems	Region-wide	Redundancy
Not to be scored	☐	Future	Enable effective rescue/response/sustenance	All Infrastructure	P2G resilience hub	Combined P2G emergency management communications hub	Lower Hutt	Governance
Complete	☑	Committed	Protection of infrastructure capital	Electricity	Replace high risk 33kV cables in liquefaction zones	Replace high risk 33kV cables in liquefaction zones. Note that this represents the opportunity for an accelerated programme to implement this initiative sooner.	Wellington City	Robustness
Not to be scored	☑	Future	Enable community sufficiency <7-days	Electricity	Generators	Generators at all critical sites	Region-wide	Redundancy
Not to be scored	☐	Future	Enable community sufficiency <7-days	Potable water	Micro grid	Micro grid co-located with water services for first 12-20 weeks	Region-wide	Recovery
Not to be scored	☐	Future	Enables recovery (return to BAU)	Liquid fuel	Alternative power of rail network	Long term - Change rail rolling stock to hybrid self powered or similar, so no OH reliance (Bombardier fuel cell commuter)	Region-wide	Robustness
Not to be scored	☑	Future	Enable effective rescue/response/sustenance	Other	NZDF	Strategic reserve of Defence Force construction equipment to supplement commercial	Region-wide	Governance
Not to be scored	☑	Future	Enable community sufficiency <7-days	Other	Drone delivered supplier	Investigate food and water deliveries by drone	Region-wide	Recovery
Not to be scored	☑	Future	Enable effective rescue/response/sustenance	Electricity	Ship power	Short term - Shore connection for export of ship power. ARATERE is a diesel electric ship with around 16MW of installed generation at 3.3KV and 50Hz. If there was a shore power connection available, then ARATERE could be used as a power supplier. Other ferries would have around 2MW of generation available. Provision of shore power connections is possible during future ferry terminal upgrades.	Wellington City	Recovery
Not to be scored	☑	Future	Enables recovery (return to BAU)	Seaport	Deeper shipping channel	Deeper shipping channel and berth pockets (to allow for rise of sea floor in fault event)	Wellington City	Redundancy
Complete	☑	Future	Enables recovery (return to BAU)	Roads	Takapu link	Takapu link between P2G RTG - to duplicate single road link between Tawa and Linden (SH1). Note that it was reported that the existing route is not necessary not resilient at present.	Tawa-Porirua	Redundancy
Not to be scored	☑	Future	Protection of infrastructure capital	Rail	Pukerua Bay - Paekakariki Tunnels	Move railway off the cliff face (2 tunnels) Pukerua Bay - Paekakariki	Kapiti	Robustness
Complete	☑	Committed	Protection of infrastructure capital	Roads	SH58 Resilience	SH58 resilience TG to Haywards Hill slope stability (rock anchors, drainage, etc). Note that safety works are committed, but this option provides for specific resilience measures to be added to the programme.	Lower Hutt - Tawa / Porirua	Robustness
Complete	☑	Committed	Enable effective rescue/response/sustenance	Roads	Ngauranga to Petone shared pathway	Wellington to Hutt cycleway: buffer to the ocean; allows straightening of rail line. This assessment assumes that the path will be built to the standard that it could allow heavy vehicle access after an emergency, but a narrower option could be considered as part of the CBA.	Lower Hutt - Wellington City	Redundancy
Complete	☑	Future	Enable effective rescue/response/sustenance	Roads	Belmont Regional Park link	Limited upgrade to existing track through Belmont Regional Park.	Lower Hutt	Redundancy
Complete	☐	Future	Enable effective rescue/response/sustenance	Roads	Cross Valley Link	Hutt Valley 'East-West connection'. New road connecting Lower Hutt east to west. Allows more resilient access to fuel depots. 2-4 lane.	Lower Hutt	Redundancy
Complete	☐	Future	Protection of infrastructure capital	Roads	Rimutaka Hill Road resilience	SH2 Rimutaka Hill road resilience improvements. Retain below the carriageway, with limited slope stability above the carriageway.	Upper Hutt	Robustness
Complete	☐	Future	Protection of infrastructure capital	Roads	Ngauranga Gorge resilience	SH1 Ngauranga Gorge accelerated resilience. Package of works including southern rail bridge and Hutt Rd. Includes slope stabilisation in Ngauranga Gorge.	Wellington City	Robustness
Complete	☑	Future	Enables recovery (return to BAU)	Roads	Petone to Grenada	Petone to Grenada new road link. Assuming cuts are designed to be resilient to rockfall risks.	Lower Hutt - Wellington City	Redundancy
Not to be scored	☐	Future	Enables recovery (return to BAU)	Roads	Bridge Lower Hutt to Miramar	Bridge Lower Hutt to Miramar	Lower Hutt	Redundancy
Complete (NB/MC)	☐	Committed	Protection of infrastructure capital	All Infrastructure	Thorndon Overbridge resilience	Thorndon Overbridge: when the bulk watermain in the area is replaced/renewed, causing a lot of excavation/disruption, investigate possibilities for rationalising buried infrastructure or mitigating risk in this specific area. Note that there is already an emergency access plan in place.	Wellington City	Robustness
Not to be scored	☐	Future	Protection of infrastructure capital	Rail	Wellington rail central infrastructure depot	Move Wellington rail central infrastructure depot off the active known fault line(s) and raise above sea level	Wellington City	Robustness
Complete	☑	Future	Enable effective rescue/response/sustenance	Rail	Alternate control centre	Alternative rail network control (outside GWR).	Region-wide	Redundancy
Not to be scored	☑	Future	Enables recovery (return to BAU)	Seaport	RORO hovercraft	Supplement ferries with giant RORO hovercraft	Wellington City	Recovery

Option status	On / Off Checkbox	Committed / Future	Function	Lifeline Sector	Option Name	Option Detail	Location of Control	Resilience Pathway
Not to be scored	☑	Future	Enable effective rescue/response/sustenance	Seaport	Shore power	Shore power connections to receive power from ships. ARATERE is a diesel electric ship with around 16MW of installed generation at 3.3KV and 50Hz. If there was a shore power connection available, then ARATERE could be used as a power supplier. Other ferries would have around 2MW of generation available. Provision of shore power connections is possible during future ferry terminal upgrades.	Wellington City	Recovery
Not to be scored	☑	Future	Enable effective rescue/response/sustenance	Seaport	Ferry terminal at Hongoeka Bay	Alternate Interislander ferry terminal at Hongoeka Bay	Tawa-Porirua	Redundancy
Not to be scored	☑	Future	Enable effective rescue/response/sustenance	Potable water	Desalination Plant	Desalination to provide water supply to city	Wellington City	Redundancy
Not to be scored	☑	Future	Enables recovery (return to BAU)	Seaport	Relocate port	Relocate port to more resilient location/s	Region-wide	Robustness
Complete	☑	Future	Protection of infrastructure capital	Rail	Rimutaka Rail Link	Strengthen portals and slope stabilisation from Featherston to Upper Hutt to provide Rimutaka Link prior to road opening (therefore redundancy v robustness)	Upper Hutt - Wairarapa	Redundancy
Complete	☑	Future	Enable effective rescue/response/sustenance	Airport	Runway improvement	Strengthen southern part of the existing runway to allow jet propelled craft in/out (including sewer network)	Wellington City	Robustness
Not to be scored	☑	Future	Enables recovery (return to BAU)	Other	Recovery masterplanning	Undertake masterplanning to guide better redevelopment post event.	Region-wide	Governance
Complete (NB/MC)	☑	Future	Enables recovery (return to BAU)	Seaport	Aotea Wharf	Redevelopment of general purpose wharf for logging freight and cruise facilities.	Wellington City	Robustness
Not to be scored	☐	Future	Enables recovery (return to BAU)	Rail	Electrify to Featherston	Electrify to Featherston (70km) and build back up CBD in Wairarapa	Region-wide	Redundancy
Complete	☑	Future	Protection of infrastructure capital	Water distribution network	Porirua Branch Replacement	Porirua Branch Replacement: the branch replacement is required as the existing pipeline will suffer severe damage due to age, materials and joint type	Tawa / Porirua	Robustness
Complete	☐	Future	Enable effective rescue/response/sustenance	Potable water	Porirua Emergency Pumping Plant	Porirua Emergency Water Pumping Facility (requires branch replacement also)	Tawa / Porirua	Recovery
Complete	☐	Future	Protection of infrastructure capital	Potable water	Porirua low level zone reservoir upgrades	Reservoir upgrades: supports supply to Kenepuru reservoir and wider Porirua zones not initially served until reticulation is restored. Supplies Kenepuru hospital.	Tawa / Porirua	Robustness
Complete (post-workshop)	☑	Future	Enable community sufficiency <7-days	Waste water	Provision of buckets for a two-bucket home toilet system	Provision of buckets for a two-bucket home toilet system	Region-wide	Recovery
Not to be scored	☐	Future	Enables recovery (return to BAU)	Water distribution network	Fire insurance	Mandatory insurance requirement to receive cover for fires when no alternative means of firefighting results in significant fires throughout city	Region-wide	Governance
Complete	☐	Future	Enables recovery (return to BAU)	Electricity	Emergency Overhead Cable routes	Emergency Overhead Cable routes	Region-wide	Recovery
Not to be scored	☑	Future	Enable effective rescue/response/sustenance	Electricity	Post-event survey	Improve ability to survey the power line network after an event which will speed up decision making to prioritise work - CDEM will control Helicopter access	Region-wide	Recovery
Not to be scored	☐	Future	Enable effective rescue/response/sustenance	All Infrastructure	Upscale Regional Transport Response Team	Upscale Regional Transport Response Team	Region-wide	Governance
Not to be scored	☐	Future	Enable effective rescue/response/sustenance	Other	Mobile surgical facilities	Establishment of deployable In-Patient Surgical Facilities	Region-wide	Recovery
Not to be scored	☐	Committed	Enable effective rescue/response/sustenance	Roads	Supply agreements	Collate and confirm we have knowledge of plant availability in areas of critical need. Clarifications of MoU's in place for all projects and quarries etc.	Region-wide	Governance
Not to be scored	☐	Committed	Enable effective rescue/response/sustenance	Roads	Contraflow gates	Installation of contraflow gates to allow flexibility of lane use on key roads.	Region-wide	Recovery
Complete	☐	Future	Enables recovery (return to BAU)	Water distribution network	Carmichael to Johnsonville & Karori Pipeline	Carmichael to Johnsonville & Karori Pipeline. Delivers circa 70 day reduction in time to restore water services. Assumed to be a strengthening project of an existing pipeline.	Wellington City	Robustness
Complete	☐	Future	Enables recovery (return to BAU)	Water distribution network	Pump station extension at Waterloo	Pump station extension at Waterloo	Lower Hutt	Robustness
Complete	☑	Future	Enables recovery (return to BAU)	Water distribution network	New pipeline from Waterloo to Haywards	New pipeline from Waterloo to Haywards	Lower Hutt	Redundancy
Complete	☑	Future	Enable effective rescue/response/sustenance	Roads	Taita Gorge Access	Strengthen road network in central Hutt Valley (Silverstream to Taita Gorge and the Hutt Valley Hospital area and possibly Eastern Hutt Bridge)	Lower Hutt	Robustness
Complete	☑	Future	Enable effective rescue/response/sustenance	Water distribution network	Critical customer network	Connect critical customers to the strategic pipes. Where strategic pipes are not present establish network isolation valves and isolation plans allowing early reestablishment of supply	Region-wide	Robustness
Complete	☑	Future	Enables recovery (return to BAU)	Potable water	Reservoir for Airport and Miramar Peninsula	Build water reservoir for Airport and Miramar Peninsula	Wellington City	Redundancy
Not to be scored	☑	Future	Protection of infrastructure capital	Roads	Thorndon Overbridge/Aotea Quay	Options for propping Thorndon Bridge to enable bridge restoration within one week of major earthquake (7.5+). Work would include ensuring props are stored in close proximity to the bridge. Investigate option to use gabion baskets to improve resilience of SH1 Thorndon Bridge/Aotea Quay off-ramp and pier, in partnership with CentrePort.	Wellington City	Robustness
Not to be scored	☐	Committed	Enables recovery (return to BAU)	Roads	Peka Peka to Otaki	Includes provision of a second, more resilient, crossing over the Otaki River	Kapiti	Redundancy
Not to be scored	☑	Future	Enables recovery (return to BAU)	Roads	Otaki to North of Levin	Improvements to state highway network - scope of works currently being defined. Likely to include new bridge structures.	Kapiti	Redundancy
Complete	☑	Future	Protection of infrastructure capital	Roads	Shell Gully - embankment and structure strengthening	Complete strengthening work to anchor embankment adjacent to pier. Requires other aspects of route resilience (Terrace Tunnel). Potentially best alternate route to the airport.	Wellington City	Robustness
Complete	☐	Future	Protection of infrastructure capital	Roads	Johnsonville to Wadestown	Seismic strengthening of retaining walls on Churchill Drive and Wadestown Road. Seen as key access to hospital.	Wellington City	Robustness

Option status	On / Off Checkbox	Committed / Future	Function	Lifeline Sector	Option Name	Option Detail	Location of Control	Resilience Pathway
Complete	☑	Committed	Enables recovery (return to BAU)	Roads	Transmission Gully	To be included in the base case	Kapiti - Porirua	Redundancy
Complete	☑	Future	Protection of infrastructure capital	Roads	Grays Road improvement	Flood protection works to improve connection	Tawa / Porirua	Redundancy
Complete	☑	Future	Protection of infrastructure capital	Roads	East-West Bridge Seismic Upgrades	East-West Connection bridge seismic upgrades.	Lower Hutt	Robustness
Complete	☑	Future	Enable effective rescue/response/sustenance	Seaport	RORO Pontoon	Mobile RORO facility with the ability to be located against any viable wharf in the harbour area.	Region-wide	Redundancy
Updated (post-workshop)	☐	Future	Enable effective rescue/response/sustenance	Seaport	Burnham Wharf replacement	Replacement of Burnham wharf with a new wharf facility including futureproofing for future emergency RORO use. This option will also require a complete replacement of the aviation fuel infrastructure. Both the wharf and the fuel infrastructure are nearing the end of their design life – with no further upgrades or strengthening planned.	Wellington City	Redundancy
Complete (post-workshop)	☐	Future	Enables recovery (return to BAU)	Electricity	Connection between substations in Wellington (160MW)	Connection between substations in Wellington (160MW)	Region-wide	Robustness
Complete (post-workshop)	☑	Future	Protection of infrastructure capital	Roads	Middleton Rd retaining walls upgrade	Upgrade retaining walls on Middleton Rd between Tawa and Johnsonville	Lower Hutt - Tawa / Porirua	Robustness
Complete (post-workshop)	☐	Future	Protection of infrastructure capital	Seaport	Strengthening of RORO facilities in the Port	Strengthening of RORO facilities in the Port	Wellington City	Robustness
Complete (post-workshop)	☑	Future	Enable effective rescue/response/sustenance	Seaport	Alternate ship mooring point	Alternate ship mooring point	Wellington City	Redundancy
Complete (post-workshop)	☑	Future	Enable effective rescue/response/sustenance	Potable water	Waterloo Water Treatment Plant Liquefaction Mitigation Project	Assessment of the options to mitigate liquefaction of the ground and implementation of the preferred option. Mitigation options include ground improvement or additional support for the structure.	Lower Hutt	Robustness
Complete (post-workshop)	☑	Future	Protection of infrastructure capital	Water distribution network	Silverstream Bridge Pipeline Replacement Project	Replacement of the Te Marua to Ngauranga pipeline where it crosses the Silverstream road bridge and the Wellington Fault	Upper Hutt	Robustness
Complete (post-workshop)	☑	Committed	Enables recovery (return to BAU)	Electricity	CPK – Frederick Street cables replacement	Replacement of the cables between Central Park Substations and Frederick Street Zone Sub-Station with cross-linked polyethylene (XLPE). This option is scheduled for implementation under WE*'s ongoing cable replacement programme and therefore has been included to accelerate funding.	Wellington City	Robustness
Complete (post-workshop)	☑	Future	Enables recovery (return to BAU)	Electricity	Replacement of fluid filled cables in the network	Replacement of all the remaining fluid filled cables in the network approximately 100km worth	Region-wide	Robustness

Appendix G
Options Not Assessed

The following tables contain the rationale behind why options were not carried through the shortlisting process. These options were either removed completely from further consideration or retained and described as being complementary or as enablers of other infrastructure options.

1. Those withdrawn entirely because they were duplicates, too generic or were considered infeasible:

Lifeline	Option	Justification
Roads	Bridge between Lower Hutt and Miramar	This option was considered infeasible
	Installation of contraflow gates for flexibility of lane use	This option was not considered a resilience measure against large shock events. The option has funding already committed
	Otaki to North of Levin	Outside the geographic remit of this business case
Rail	Electrify to Featherston	Not considered a resilience measure
	Pukerua Bay and Paekakariki tunnels for rail	Considered infeasible
	Move Wellington Rail Central Infrastructure Depot	This option would not directly address the network risks that would prevent it from operating post event
	Change rolling stock to hybrid to reduce reliance on overhead electrical supply	Not considered feasible as a resilience project
Seaport	Alternative connection point on the South Island	This option will be considered within other RORO options
	Legislation to enable re-purposing ships post-event	Considered a governance option outside of the remit of this business case
	Deeper shipping channel/berths to allow for sea floor rise in fault event	Not considered justifiable under a resilience mandate
	RORO Hovercraft to supplement ferries	Not seen as realistic as these craft will still require boarding and alighting facilities and ferries already exist
	Ferry terminal at Hongoeka Bay	This option had previously been explored and considered infeasible
	Relocate port to a more resilient location	Considered infeasible as a resilience proposal

Lifeline	Option	Justification
	Infrastructure for barges from Wellington City to Seaview	This option has been superseded by Road and RORO options
Water	Kapiti Coast Pipeline	This option was not sufficiently specified and without underlying benefits to justify development
	Asset Management Plan fragility mapping	This is considered business as usual for Wellington Water
	Fire Insurance – mandatory requirement to receive cover when no firefighting means are available	Outside the remit of this business case
	Policy to implement off-grid solutions for commercial developments	Outside the remit of this business case
	Micro-grid co-located with water services for the first 12-20 weeks	This option was not sufficiently specified and without underlying benefits to justify development
	Desalination Plant	Not considered feasible given the high operation and maintenance costs associated with desalination
Wastewater	Policy to implement off-grid solutions for residential developments	Outside the remit of this business case
Electricity	Ensure AC Transpower supply points have N-I security.	This already exists
	Off-grid solutions (C+I) for all key buildings	Outside the remit of this business case
	Generators at all critical sites	This option was not sufficiently specified
	Improve ability to survey powerlines post event	Outside the remit of this business case
	Increase WE Interconnectedness	This option was replaced by a specific 160MW interconnection option between substations
Communications	Data sharing agreements across mobile providers	Outside the remit of this business case
	Cloud RAN infrastructure sharing across mobile providers	Outside the remit of this business case
	Redundant microwave/satellite links	Considered infeasible
	More diverse cable routes across the region	This option was not sufficiently specified and without underlying benefits to justify development.
	Harden comms networks along escape routes	This option was not sufficiently specified and the locations of temporary houses will depend on the nature and location of the fault event
	National database of priority mobile users	Outside the remit of this business case and is considered an emergency response option

Lifeline	Option	Justification
Other	Disaster recovery storage	This option was not sufficiently specified and is covered under individual options in water, power and transport infrastructure types
	Business Continuity Plans	Outside the remit of this business case
	Emergency consents in place	This idea was not seen as sufficiently specified compared to similar themes in the business case
	Household resilience education	Outside the remit of this business case
	Combined P2G emergency management communications hub	Outside the remit of this business case
	Upscale Regional Transport Response Team	Outside the remit of this business case
	Tsunami defences	This option was not specified and has been addressed more specifically in other options
	Pre-defined solid waste disposal sites	This option was not sufficiently specified – sites available depend on transport accessibility
	Drone delivered food supplies	Both outside the remit of this business case and considered infeasible
	Recovery master planning	Outside the remit of this business case

2. Those options that are exclusively part of the initial response phase and do not to address the longer-term recovery and return to BAU phase:

Lifeline	Option	Justification
Rail	Implement additional rail ground sensors to guide response	Assessed as a recovery option
	Post-quake workforce	This option was considered outside the remit of this business case and also is considered a recovery option
Seaport	Coastal shipping	This option is considered to be an operational response that will occur anyway. Additional coastal shipping capacity can be quickly supplied following a shock event
	Jetties to evacuate people (to reduce demand on lifeline services)	Considered to be an emergency response option
	Use ships as mobile welfare stations	Considered to be an emergency response option
Fuel	Mobile floating fuel tanks	Considered to be an emergency response option
Water	Incentivise / mandate home fire suppression system	Considered to be a short term recovery option
	Making saltwater soap available	Considered to be a short term recovery option

Lifeline	Option	Justification
Gas	Earthquake shut-off valves installed to prevent fires	Considered to be an immediate emergency response option
Electricity	Inverters in households to power freezers	Considered to be a short term recovery option
Communications	Shipping Satcoms as communications routing hub	Considered to be an immediate emergency response option
Other	Mobile deployable surgical facilities	Considered an emergency response option
	Pre-stocked community shelters	Considered an emergency response option

3. Those not scored but retained as options currently being pursued.

Lifeline	Option	Justification
Roads	Peka Peka to Otaki	This option is currently being pursued

4. Those not scored as they are governance options that support or enable the outcomes of the other infrastructure options

Lifeline	Option	Justification
Roads	Changes to the Government Policy Statement on Land Transport to make funding of resilience improvements faster	This option is a governance option that that enables the transport options to be realised
	Supply agreements for materials and plant	Memoranda of Understanding already exist
Water	Building requirements to mandate emergency water supplies for new homes and businesses	This option is considered a governance option
Electricity	Regulatory incentivisation for resilience investment	
	Incentivise residential off-grid solutions	
Other	Pre-agreed recovery worker facilities plan	
	Strategic Reserve of NZDF construction equipment	
	Higher building standards in the CBD	
	Earthquake building code amendments	

Appendix H

Programme Options Development and Analysis

Appendix H: Programme Options Development and Analysis

H1 Programme Development

This appendix supports Section 7 of the PBC. It further explains how two possible programmes of options were developed to address the problems identified in the Strategic Case. It records the long list of options which were developed through workshops with lifelines organisations and subject matter experts. Further, it describes the process by which these options were generated, assessed against the investment objectives using a multi criteria analysis tool and packaged into three alternate programmes for refinement and testing with the stakeholder group, which reduced the programmes to two. How the agreed two alternative programmes were then tested and a preferred programme selected is covered in detail in the next section.

Initially, three draft programmes were developed that represented de facto low, medium and high investment.

The potential programmes were presented to lifelines organisations, councils and DPMC representatives at a workshop on 20 July 2017 as a starting point to establish the programme alternatives that would be taken forward for testing in RiskScape and MERIT (see below). At this workshop, participants moved several options that previously sat in the medium programme, down to the lower investment programme to reflect their criticality. The programmes were refined and subsequently it was agreed that two programmes would be taken forward to the detailed analysis stage. Maps of the interventions proposed for these programmes can be found in Appendix J.

The commercial viability of the various port and the fuel terminal options was raised as an issue by participants. Although the ease of implementation was assessed to a minor degree in the MCA, options considered not commercially viable were not automatically excluded at this stage in the assessment. Further discussion on the commercial viability of options, especially those for which there are competing providers in the market, such as fuel companies and Cook Strait ferry providers, were undertaken with the lifeline organisations individually following the workshop. From these discussions, the preferred ferry and fuel options were included in each programme alternative.

An assessment of the individual options making up each programme is provided below. MCA scores were used as a 'first-cut' for assessing the viability and responsiveness of individual projects, rather than a basis for programme allocation. The MCA score for each option in the resultant programmes can be found in Appendix I.

H1.1 Base Case

The base case was established as the base-line against which the efficacy of the improvement programmes could be tested. It included TG, which is three years into its six-year construction phase and has been included in the base case. TG is considered a 'game changer' providing resilient access deep into the region. As well as being a commitment, with large amounts of earthworks already completed and plant on-site it was clear that TG will be able to function as a through route following an earthquake, providing a critical transport connection for bringing in fuel and supplies to the region from the north. It therefore was considered as part of the base case.

H1.2 Projects common to both programmes

The following projects were common to both programme alternatives. Six of the projects are committed by lifelines organisations for future construction, and therefore were automatically selected for all programme alternatives. The remaining projects were considered 'must-dos' for the Wellington Region as they are enablers of other lifelines recoveries. For the projects which were included in the final recommended programme, they have simply been named here, with a more detailed description provided in Section 7.2 of the PBC.

- **Seaview Wharf seismic strengthening**
- **Wadestown to Johnsonville – seismic strengthening**
- **Middleton Road retaining walls upgrade**
- **SH58/Haywards Resilience Improvements from Transmission Gully to Hutt Valley**
- **Taita Gorge Access – strengthening road network**
- **Port Seismic Strengthening – major works**
- **New RORO Terminal**
- **Central Park Substation – improved resilience**
- **Central Park to Frederick Street cables replacement**
- **Cross Harbour Pipeline**
- **General water supply toughening acceleration**
- **Porirua Branch Replacement & Emergency Pumping Plant**
- **Porirua Low Level Zone Reservoirs**
- **Waterloo Pump Station extension and new pipeline from Waterloo to Haywards**
- **Waterloo Water Treatment Plant liquefaction project**
- **Prince of Wales and Bell Road Reservoir Upgrade**
- **Carmichael to Johnsonville and Karori Pipeline**
- **Silverstream Bridge Pipeline Replacement Project**
- **Dedicated back up power for cell towers**

And projects subsequently excluded:

Ngauranga Gorge Accelerate Resilience – slope stabilisation	
Project description:	This project involves the stabilisation of slopes along SH1 through either cut backs and reducing batters or providing protection from landslides.
Estimated cost:	**Capital cost: $3 million**
Rationale for potential inclusion:	It is assumed that all the potentially weak slopes through the Ngauranga Gorge will be stabilised ensuring the road remains open following an earthquake event and providing access through to Johnsonville, Tawa and Porirua.

Ngauranga to Petone Shared Pathway	
Project description:	Construction of a 4m wide shared path between Petone and Ngauranga on the Seaward side of the railway line. Additional reclamation will be required to what has been previously reclaimed. The works also involve building a new seawall. Enhanced options also include straightening of the railway line at selected locations. Furthermore, enhancements to the road could include additional

Ngauranga to Petone Shared Pathway	
	lanes or relocating the road further away from the toes of the steep slopes which are prone to failures during earthquakes.
Estimated cost:	**Capital cost: $85 million**
Rationale for potential inclusion:	The shared path can be used for access following an event away from the steep and unstable hills which SH2 runs close to. The reclamation and new sea wall will be constructed to a higher design standard than the existing wall hence improving its resilience in a quake events plus severe storm events.

Burnham Wharf replacement	
Project description:	Replacement of Burnham Wharf with a new seismically resilient wharf facility including futureproofing for future emergency RORO use. This project will require a complete replacement of the aviation fuel infrastructure also as it is near the end of its design life.
Estimated cost:	**Capital cost: not costed**
Rationale for potential inclusion:	Burnham Wharf provides a facility for ships carrying aviation fuel to dock and fill up the fuel tanks located nearby. 20 tanker trucks per day would be required to bring the equivalent volume of fuel from Seaview for airport operations. The reclamation beside Burnham Wharf is likely to liquefy or spread. These effects may result in severe structural damage to the wharf which is 1920s era reinforced concrete with low ductility and in a deteriorated state. Improving the resilience of the wharf and fuel infrastructure is essential to ensuring the airport can continue to operate following a quake event.

Emergency water infrastructure in communities	
Project description:	Emergency water infrastructure located in communities: bladders, mini-bores.
Estimated cost:	**Capital cost: $30 million**
Rationale for potential inclusion:	This project has been committed and therefore this represents the opportunity for an accelerated programme to implement this initiative sooner. It is included as a complementary project that allows more people to remain in the region and work on the recovery.

Ablution facilities across schools	
Project description:	Provision of pit latrines (or similar) at those schools that are likely to be emergency assistance centres.
Estimated cost:	**Capital cost: $20 million**
Rationale for potential inclusion:	This project will be a community facility that can used to sustain society in the short to medium term after a shock event. It will also ensure self-sufficiency at schools to enable them to reopen as soon as possible following a quake and the associated school communities can remain.

Provision of buckets for a two bucket home toilet system	
Project description:	Provision of two bucket system for separation of solid and liquid human waste and on site storage. The system will cost each household approximately $210 each.
Estimated cost:	**Capital cost: nil**

Provision of buckets for a two bucket home toilet system	
Rationale for potential inclusion:	This project will ensure self-sufficiency for the period immediately following a quake while the wastewater distribution networks are being repaired.

Readying point solution LPG supplies	
Project description:	This project involves conversion of connections and vapourisers for critical customers (hospitals, prisons and similar facilities) from reticulated natural gas supply to tanked LPG supply. The connections would take 7 days and then the LPG would be supplied via Isotainer (container based LPG tanks of which approximately 20 are available in NZ) which would be trucked into Wellington (via road or RORO). Other customers that rely on gas (e.g. restaurants, hotels) could also be converted from reticulated natural gas to LPG and supplied with small LPG tanks. This would be a short conversion process and then tanks would be trucked in from outside the region.
Estimated cost:	**Capital cost: $2 million**
Rationale for potential inclusion:	This project will support the recovery period following a major shake.

H1.3 Lower Investment Level Programme

This programme is made up of the smaller scale projects (both in size and cost) and includes those projects listed in H1.2 above as well as:

- **Minor Rail Seismic Upgrade of slopes and structures – NIMT Line and Hutt Valley Line,** and

Hutt River bridges strengthening	
Project description:	Potential strengthening of any bridge across the Hutt River to add redundancy and robustness
Estimated cost:	**Capital cost: not specified**
Rationale for potential inclusion:	The Hutt River is a major obstacle to connectivity in the valley where having multiple bridges available could be an asset.

H1.4 Higher Investment Level Programme

This programme is made up of the larger scale projects that require the higher investment levels. These projects are typically the larger infrastructure new builds or upgrades which, prior to modelling, are believed to provide higher infrastructure resilience than those in the Lower Investment Programme. These are in conjunction with the projects in H1.2 above as well as:

- **Cross Valley Link**
- **Petone to Grenada**
- **Better engineered road links to existing RORO Terminal and port area**
- **Resilience of airport connectivity to city network via Newtown**
- **Seismic upgrade of 33kV buried cables,** and

Major Rail Seismic Upgrade of slopes and structures – NIMT Line and Hutt Valley Line	
Project description:	Seismic upgrading of structures and slopes along the NIMT, Hutt Valley Line, Upper Hutt Line and Wairarapa Line – major investment
Estimated cost:	**Capital cost: $100 million (notional)**
Rationale for potential inclusion:	This project would allow freight and commuter trains to be back running earlier and with greater reliability.

Replacement of fluid filled cables in the network	
Project description:	Replacement of all the remaining fluid filled cables in the network with XLPE cables to improve their resilience to ground movements. Approximately 100km of replacements required.
Estimated cost:	**Capital cost: $160 million**
Rationale for potential inclusion:	This project has been previously identified in WE*'s Asset Management Plan. This project has been included in the programme to potentially accelerate its implementation rather than waiting for cables to reach the end of their life before requiring replacement.

H2 Analysis - RiskScape and MERIT

This section describes in more detail the damage and economic modelling used to assess the programmes.

H2.1 RiskScape

Damage and Outage Modelling Framework

RiskScape uses a generic framework for estimating natural hazard loss (Figure H-1). The model has three key input modules: asset, hazard and vulnerability.

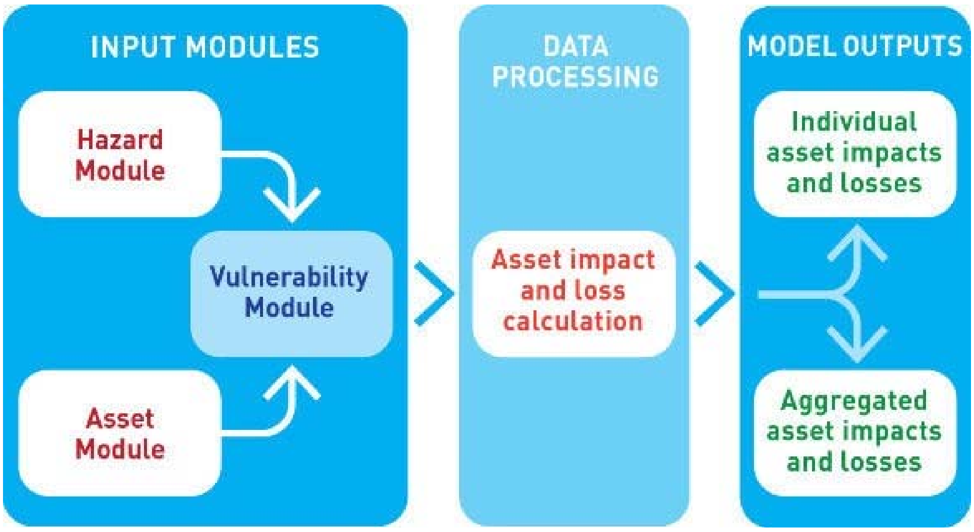

Figure H-15: RiskScape Framework

Data or models represented in each module are combined in a 'loss' module to quantify asset impacts for a natural hazard event or scenario (Table H-1).

Table H-1: RiskScape module definitions

Module	Data or Model Type	Definition
Hazard	Hazard Layer	A series of spatial representations of the severity of each of the phenomena generated by a hazard event or scenario.
Asset	Asset Layer	The spatial distribution of assets and their attributes.
Vulnerability	Vulnerability Model	The suite of functions that derive direct and indirect losses from the severity of imposed hazard action for each asset class
Loss	Aggregation Layer	Spatial information about areas or locations for calculating loss values.

By following a typical RiskScape workflow (e.g. Figure H-1) an event was defined and the relevant asset modules created using data provided by participating lifelines organisations. Any gaps in data were filled using expert engineering judgement. Using these asset modules, and the relevant hazard modules, individual asset exposure was defined based on the spatial extent and hazard intensity of each risk. A vulnerability module was then used to define the relationship between hazard intensity and the probability of reaching or exceeding a suite of damage states, based on an asset's exposure and its specific attributes. By applying a random weighted distribution, each asset is assigned a single damage state.

With each model run, individual asset impact distribution will vary, however the aggregated regional impacts remain roughly the same.

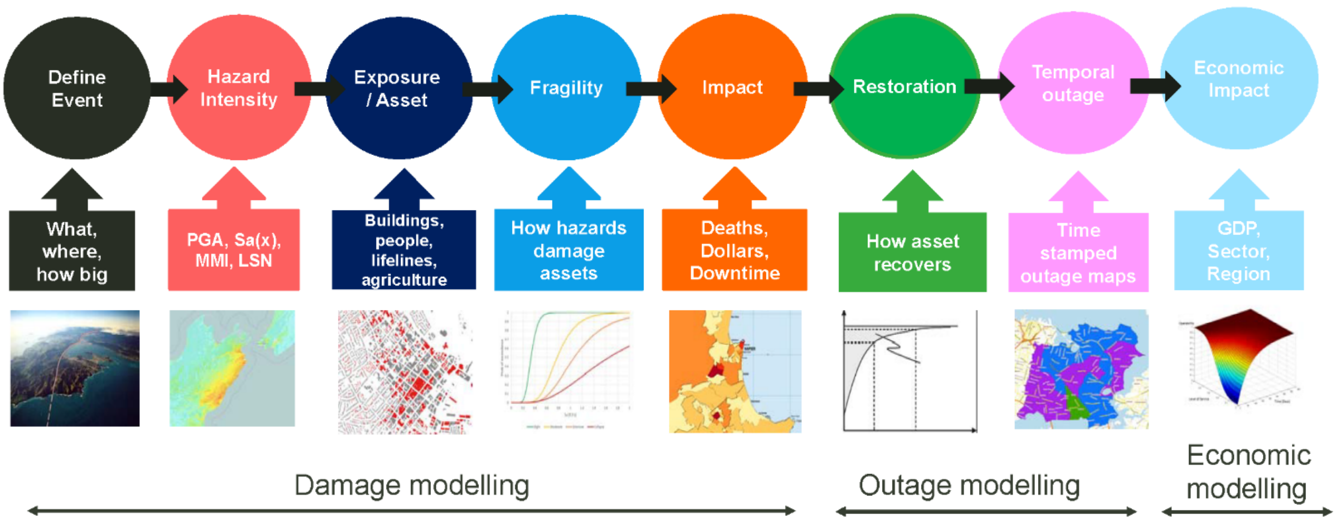

Figure H-2: Workflow of RiskScape modelling for temporal outage of lifelines

In collaboration with lifeline organisations, restoration models were then developed, to understand the outages experienced by users of the lifeline service. This was done using quantitative, logic based or network connectivity approaches, or a combination of all three. The restoration models define credible component-based outage times and a region wide, logic-based restoration strategy for each lifeline sector.

In collaboration with lifeline organisations, sector specific coverage zones were defined. Network or component-specific dependencies were defined for a logic based approach for assigning zone-based network outages. Mesh-blocks (the smallest geographical units which are used by Statistics New Zealand for data collection) were used to standardise outage zones across each sector's network coverage zones.

The results were presented to participating lifeline organisations to ensure credible outage times, with calibrations made if necessary.

Once outage information was established for individual sectors, time delays due to interdependencies with other sectors were added. In this context 'interdependencies' is taken to refer to the critical links between components of different infrastructure systems. In the modern world, critical infrastructure can be extremely vulnerable to the effects of outages and resultant cascade effects that cause the impacts of outages to spread far beyond the original scope of the initiating problem. Here, interdependencies were considered at quite a coarse level since the detailed consideration and modelling of interdependencies on a city scale is outside of the scope of this work. As a result, information on interdependencies was gained through the expert knowledge of the lifeline operators. Table H-2 shows how interdependencies have been accounted for in outage time calculations.

Table 112: Interdependencies accounted for in outage time calculations

Sector	Interdependencies accounted for
Road	None
Rail	None
Port	Road
Airport	Road
Fuel	Road
Electricity	Road
Telecommunications	Road, electricity/fuel
Potable water	Road, electricity/fuel
Wastewater	Road, electricity/fuel, potable water
Gas	Road

GIS analysis was used to create outage information and maps. Time (days), spatial (meshblock), and service level (on or off) data was used as inputs to the MERIT model. This information was presented on maps, using time bands rather than actual numbers of days, so that outage information could be compared across maps and sectors.

Natural Hazard Scenario

Of three scenarios considered, a single M7.5 Wellington Fault earthquake event (fault rupture, ground shaking, liquefaction, landslides, lateral spreading and subsidence) was selected by the project team for modelling, based on information gathered during the Business Behaviours workshops held early in the project[30]. This scenario represents a major impact event while still allowing for a credible recovery of the region. This scenario is well researched and commonly used for insurance and business continuity planning. This event has a probability of occurrence of 10% in the next 100 years but is also the dominant contributor to the 1 in 500-year earthquake hazard which is used to define the seismic loading levels for the building code for Importance Level 2 buildings (i.e. general multi-story commercial and residential buildings). The scenario consisted of a single mainshock and aftershocks were not considered.

The Wellington Fault scenario has many of the same characteristics as other large earthquakes that could occur in the Wellington Region, including earthquakes on the Ohariu Fault to the west of Wellington, the Wairarapa Fault to the east of Wellington and the Hikurangi Subduction Zone. Similar characteristics would include the level of ground shaking, the number of landslides and the distribution of liquefaction. This means that any intervention measures to mitigate the impacts from these hazards in a Wellington Fault earthquake will also have benefits for these other scenarios. Furthermore, by designing resilience measures to mitigate the impact from a 'maximum credible' scenario such as the Wellington

[30] see Brown, C., Seville, E., (2017) *Wellington Lifelines Resilience Project Programme Business Case: Business Behaviours Workshops, April 2017*, Resilient Organisations

Fault earthquake, the benefits from the interventions will also minimise the impact from smaller, more frequent earthquakes that occur in the region, or larger events that occur at greater distances (e.g. Alpine Fault earthquake).

The intervention projects will also provide benefits for other natural hazards not considered in this specific scenario including rainfall induced landslides, flooding and tsunami. Further, many of the interventions would provide additional resilience for the networks under business-as-usual by providing additional redundancy or strengthening of various network components.

The fault rupture hazard that was modelled is specific to the Wellington Fault.

Hazard Models

The hazards considered are described in Table H-3:

Table H-3: Hazard models

Hazard	Description	Measurement Unit(s)
Fault rupture	Zone of deformation related to fault rupture	Hazard Footprint
Ground shaking intensity	Ground shaking from earthquake	Peak Ground Acceleration (PGA), Moment Magnitude Intensity
Liquefaction	Liquefaction from ground shaking	Liquefaction Severity Number (LSN), Liquefaction Susceptibility
Lateral Spreading	Lateral spread from ground shaking and liquefaction	Probability of occurrence
Landslide	Landslide footprint generated from ground shaking	Volume (m^3)
Subsidence	Mean co-seismic subsidence generated by fault movement	Hazard footprint

Appendix K contains information on the Lifelines Modelling.

H2.2 The MERIT Model

Economic impact modelling was carried out to assess the packaged infrastructure projects. The modelling assessed the disruption impacts to the economy associated with the earthquake. The analysis relates to economic disruption which reflects the ILM measure of net changes in GDP associated with a preferred investment programme as the top assessment metric with a 60% weighting.

The modelling used 'MERIT' (Modelling the Economics of Resilient Infrastructure Tool) developed in the 2012-16 MBIE funded Economics of Resilient Infrastructure (ERI) research programme. The full details of the economic approach are contained in the report: Wellington Resilience Programme Business Case, Modelling the Economics of Resilient Infrastructure Tool (MERIT) Assumptions Report, m.e Research and Resilient Organisations, December 2017 (Appendix L)

The use of the MERIT model is a unique advancement for resilience studies of this kind. MERIT is an integrated spatial decision support system that enables a high-resolution assessment across space and through time of the economic consequences of infrastructure failure, business response, and recovery options.

Central to MERIT is a multi-sectoral, multi-regional and fully dynamic economic model, designed to imitate the core features of a Computable General Equilibrium (CGE) model. CGE models tend to be the favoured approach and 'state-of-the-art' in modelling of regional and national-level economic impacts.

Among the advantages of these types of models are the whole-of-economy coverage, the capture of induced impacts and 'general equilibrium' impacts.

Although MERIT incorporates the core features of a CGE model, it differs from a standard CGE model in that it is formulated as a System Dynamics model using finite difference equations. This is an innovative extension to economic modelling undertaken in part to improve its ability to capture the impacts of events over time. MERIT is a simulation model, acknowledging that in meeting these constraints there is a transition pathway through which the economy must pass. MERIT is particularly appropriate for natural hazard events as it can directly account for out-of-equilibrium dynamics that often emerge in a disrupted economy.

Once information is transformed into appropriate inputs and MERIT is run, it can produce a variety of indicators to help assess economic impacts of an infrastructure outage in aggregate and by industry. The model can thus not only be used to assess the economic consequence of a natural hazard event resulting from infrastructure failure, but also to inform resilience-building and investment initiatives.

The MERIT modelling calculates economic impacts over a 5-year timeframe following a quake event, assuming that the event takes place at the present time. A 5-year time frame was selected for the modelling as it was considered a balance between two competing considerations: (1) covering a period sufficiently long to capture some of the ongoing consequences of the disruption, and (2) recognising that the further out in time from the event, the greater the uncertainty in outcomes. It is quite likely that the impacts of the event will continue to be felt long after five years, for example through population movement, business relocation, and the ongoing implications of lost income flow, and to the extent that this occurs, the reported results will underestimate the impacts. Over time, however, there are other dynamics that may play out and which are highly uncertain and contentious, for example whether there may be community and policy initiatives to 're-invent Wellington', or the extent to which the rebuild activities provide some possibilities to put in place more modern and better capital.

It is also important to recognise that following a large disruption event, the period of rebuild activities may be quite significant and be responsible for stimulating economic activity. Based on the Christchurch experience, relatively little rebuild would be expected to take place in the first few years after the event. A large portion of rebuild activity is likely to be funded by international transfers via insurance/reinsurance, but some will be funded privately and via local/central government. As much of the reconstruction will relate to non-infrastructure property rebuild, particularly commercial and residential buildings, it is likely to occur regardless of the infrastructure resilience-enhancing investments that are the focus of this study. The economic consequences of rebuild activities have been deliberately excluded from the modelling, in line with the focus on reducing the negative consequences of economic disruption following a major event, particularly as a result of loss of infrastructure service provision.

Details on how the suite of MERIT tools was developed, how it works, and previous applications are provided in the references of the Assumptions Report (Appendix L).

Applying MERIT to Wellington

To apply MERIT to the Wellington Fault earthquake scenario, the first step was to evaluate any modifications required. To do this, a series of workshops with stakeholders were held to understand how sensitive the Wellington economy would be to infrastructure and other disaster disruptions. Each workshop explored how disaster disruptions (infrastructure and community disruptions) could affect Wellington's habitability, liveability and business viability. Economic tipping points and key enablers and barriers to a successful Wellington post-disaster recovery were also explored.

To fully capture the consequences of the event, it was necessary to develop a set of bespoke models for this project, mostly addressing aspects of transportation and tourism disruption as well as the propensity for people and business relocation and the effects of isolation. Overall, the following drivers of economic system change following a major earthquake event were incorporated into the MERIT modelling process (Figure H-3).

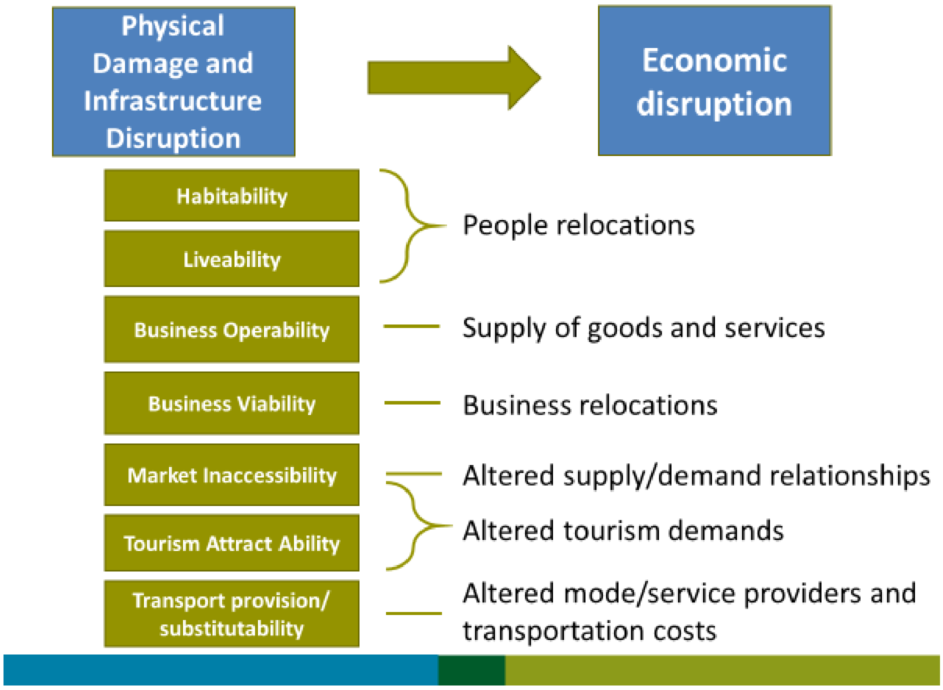

Figure H-3: Drivers of Recovery included in the Wellington Fault Earthquake Scenario Modelling

Model Linkages and Assumptions

The core task in undertaking the MERIT modelling was to translate descriptions of infrastructure damage and other forms of physical disruption into estimates of economic impacts. A variety of modelling steps were undertaken to provide a set of time-dependent parameters (e.g. GIS maps) that could be used as inputs to the economic model.

Figure provides an overall scheme of the MERIT modelling process. The mathematical procedures that make up the modelling process were grouped into a series of 'models', some of which have underlying sub-components or 'modules'. For example, the Dynamic Economic Model is the core economic model constructed within the System Dynamics modelling language, and is underpinned by several modules that cover Enterprises, Factors, Capital, Labour, and so on. The Business Behaviours Model and Population Relocation Model are the other two modules that make up the core components of the MERIT toolkit. The information that flows between these models is depicted in Figure H-4. The Business Behaviours Model calculated the 'operability' of different economic industries, across time, and given differing combinations of infrastructure service and other types of disruption. The industry operability parameters were incorporated directly within the Dynamic Economic Model, to modify the 'as normal' levels of productivity within each economic industry.

The Assumptions Report in Appendix L provides a detailed explanation on the assumptions underpinning the modelling.

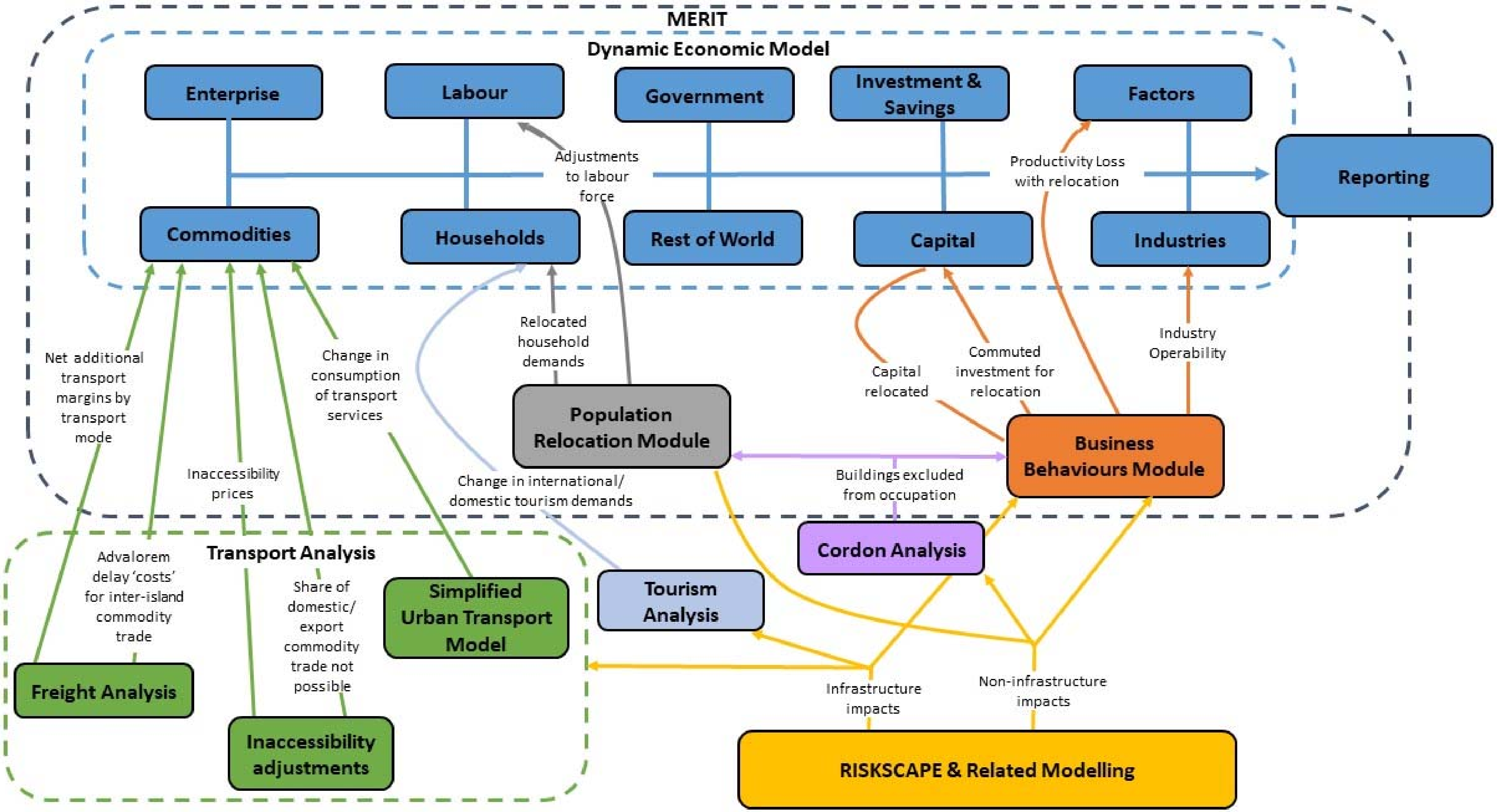

Figure H-4: Interlinkages between the MERIT suite of tools, transport analysis, cordon analysis, tourism analysis and RiskScape

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Cordon Analysis

Two types of cordons were created to identify buildings excluded from occupation. The first, represented the initial cordon put in place while clean-up of debris, assessment of buildings and such activities occur. It was assumed to be a relatively large area at first, given the nature of the event and the need to first establish appropriate information on damage. The second cordon concentrated on individual buildings that could not be occupied for a relatively long basis using direct information on buildings provided by RiskScape. This information was used as an input into the Population Relocation Module and Business Behaviours Module.

Tourism Analysis

For tourism, the findings from the Christchurch and Kaikōura quake experience were used as a starting point for estimating the likely shifts in tourism demands. After the February 2011 quake, most potential visitors chose not to travel to Christchurch, and instead travelled to other parts of the country or avoided travel to New Zealand altogether. In the case of a Wellington fault event, it was assumed that regardless of the level of infrastructure resilience, there would be a similar type of outcome.

Table H-4 provides a summary of the estimates used of the likely changes in tourism demands from one week to five years after the event.

Table H-4: Background Change in Tourism Demands after Major Quake

		1 week	1 month	3 months	6 months	1 year	2 years	5 years
Wellington Region	Domestic	-20%	-20%	-18%	-17%	-16%	-9%	-5%
Rest of New Zealand	Domestic	0.5%	0.5%	0%	0%	0%	0%	0%
Wellington Region	International	-66%	-53%	-52%	-51%	-51%	-46%	-34%
Rest of New Zealand	International	2%	3%	3%	3%	3%	4%	3%

A unique feature of Wellington is that it is the origin of, and destination for, ferries linking the North and South Islands. A portion of the Wellington tourism market is thus directly dependent on its role as the 'gateway to and from the South Island'. Drawing on statistical sources, it was estimated that approximately one quarter of all international tourism demands in Wellington, and just less than 20% of domestic tourism demands, are directly dependent on this gateway role. It was therefore assumed that these shares of tourism demand can only be realised with operation of the ferries, as well as access to the ferry terminal from out of the Wellington Region.

Another significant feature of the Wellington scenario, which was not experienced in the Christchurch event, is the level of inaccessibility that will be generated for the city due to the damage to road and rail links. For the period over which Wellington is effectively isolated due to transport disruptions, the better analogy was the Kaikōura quake, as the Kaikōura township suffered similar isolation.

To reflect the inaccessibility of Wellington City for visitors, demand by tourists for goods and services produced within Wellington city was set to zero, up until access to central Wellington was restored.

Because accessibility was restored sooner under the investment packages, the loss of demand in Wellington Region returned to the background level sooner in Table H-5 compared to Table H-6.

Table H-5: Change in Tourism Demands Incorporating Ferry and Road Disruptions – No Investment Package

		1 week	1 month	3 months	6 months	1 year	2 years	5 years
Wellington Region	Domestic	-92%	-92%	-92%	-23%	-16%	-10%	-5%
Rest of New Zealand	Domestic	2%	2%	2%	1%	0%	0%	0%

Wellington Region	International	-97%	-96%	-96%	-56%	-53%	-47%	-34%
Rest of New Zealand	International	4%	6%	7%	4%	4%	4%	3%

Table H-6: Change in Tourism Demands Incorporating Ferry and Road Disruptions – Investment Packages included.

		1 week	1 month	3 months	6 months	1 year	2 years	5 years
Wellington Region	Domestic	-92%	-92%	-25%	-22%	-13%	-9%	-5%
Rest of New Zealand	Domestic	2%	2%	1%	0.5%	0%	0%	0%
Wellington Region	International	-97%	-96%	-57%	-55%	51%	46%	-34%
Rest of New Zealand	International	4%	6%	4%	4%	4%	4%	3%

Population Relocation Module

For a Wellington Fault earthquake scenario, a major driver of economic impacts and recovery was assumed to be the potential movement of people away from the Wellington Region, i.e. population relocation. The analysis of population relocation was undertaken by identifying four separate phases of population movement: emergency evacuation, strategic evacuation, shelter relocation, and voluntary flight. These reflect the complex drivers that might 'push' people to move away from the Wellington Region, and then to attract them back into the region as key milestones in the recovery are achieved (Figure H-5).

Figure H-5: Components within the Population Relocation Module.

For the economic modelling, the primary outcome of changes in population was changes in the location of labour resources and changes in the distribution of demand for goods and services.

In terms of labour force changes, the Dynamic Economic Model incorporated two economic regions: Wellington and Rest of New Zealand. To ensure that the movement of people between regions resulted in a change in the distribution of demand for goods and services, a portion of the household income account for Wellington Region was relocated to the rest of New Zealand household income account.

Business Behaviours Model

The original Business Behaviours model was developed based largely on data arising out of the 2011 Canterbury Earthquake event. At the start of the project a review was undertaken to determine the types of modifications that would be necessary, to allow for the differences in the nature and extent of impacts faced under the Wellington event. Key changes made were to incorporate the new Population Relocation Model with two principal additions: modification of the original 'operability' curves, and inclusion of business relocations.

The modelling and assumptions for the extensions both relied on classifying business/industries into subcategories to reflect the different infrastructure needs and capacities for adaption of different industry groups.

The MERIT Business Behaviours Model took information on infrastructure and non-infrastructure disruptions, and calculated the level of 'operability' achieved by each business/industry compared to business-as-usual operability. To reflect that businesses are adaptive to situations, full operability generally returns over time, however the more severe the level of disruption, and the longer the duration, the greater the initial fall in operability and the longer the recovery period. The operability curves described the rate at which normal levels of productivity in an industry fell, and then returned to normal.

One of the most significant differences between the Canterbury experience and the Wellington fault scenario was the expected level of inaccessibility to the Wellington transport network, which was never faced in Canterbury. Not only would this severely limit the delivery of goods, abilities of staff to get to work, and customers to access services, it would severely limit the options available to organisations to adapt and cope to the disruption. Another major aspect of the Wellington scenario was that some infrastructure types have much longer outage times over much of the city. For example, electricity and communications were generally restored relatively quickly in Christchurch, but in the case of Wellington, very long outage times would restrict organisations from taking up some of the more common adaptation options (e.g. working at home, remotely).

Within the Business Behaviours model, a new business relocation component was developed to model the relocation of businesses from the region. This reflects the assumption that some businesses may choose to relocate some, or all, of their operations to outside of the Wellington Region, over and above adjustments made owing to reduced demand from population movements.

To estimate the proportion of businesses relocating within each of the studied industry groups they were assigned a 'business viability' score at each location, see Table H-7. The overall score assigned was the highest score for which at least two categories were fulfilled. Within these tables accessibility issues for businesses at several different levels were considered – the time taken to restore access from their location to the rest of New Zealand, time to restore access to their 'local centre', and time taken to restore access from their location to the Wellington CBD. The Assumptions Report in Appendix L contains full details of how business viability was assessed across all industry groups.

Table H-7: Business viability assumptions for businesses in the office-based services category

Business Viability						
Factor	**A**	**B**	**C**	**D**	**E**	**F**
Unusable commercial property across region	<5%	5-10%	10-20%	20-30%	30-80%	80-100%
Disruption of one or more of water, electricity, or communications (including data) at business premises level*	Disruption <1 week	Disruption 1-4 weeks	Disruption 4-12 weeks	3-6 months lack of adequate services	6-12 months lack of adequate services	>12 months lack of adequate services
Access to 'local CBD' – Wellington, Porirua, Upper Hutt and Lower Hutt (include fuel limitations) (N/A for Kapiti Coast district, Masterton, Carterton, South Wairarapa)	Full access to zone	Zone isolated for up to 1 week	Zone isolated 1-4 weeks	Zone isolated for 4-8 weeks	Zone isolated for 8-12 weeks	Zone isolated for more than 12 weeks
Access to Wellington CBD (include fuel limitations)	Full	Access restored within 2 weeks	Access restored 2- 6 weeks	Access restored 3-12 weeks	Access restored 3-6 months	Access restricted over 6 months
Access by road out of the region (include fuel limitations)	Full	Access restored within 4 weeks	Access restored 4- 12 weeks	Access restored 3-6 months	Access restored 6-12 months	Access restricted over 12 months

% business leave region	0%	2.5%	5%	10%	20%	40%
*Note: it is assumed that sufficient emergency water and food supplies are available for those that choose to stay. Their provision is likely to be inconvenient (walk to water, food rations etc) and this factors into the estimated relocation proportions.						

The Business Behaviours model interfaces with the main economic model via a series of "operability" curves. The method for calculating operability for industries was highly spatial, generating unique results for each meshblock and 41 industry types. The operability curves at each location were weighted by the relative number of employees at each location. The process was undertaken twice, once for businesses that remained in the Wellington Region, and once for those that relocated outside of the region.

Transportation Model

The transportation modelling covered three separate themes: freight, inaccessibility, and urban transportation (Figure H-4). These are discussed in detail in in the Assumption Report in Appendix L.

H3 Summary of Results

Economic modelling results, (Table H-8), for the base case and the two investment programme alternatives, show the cumulative net change in GDP against the no earthquake scenario. The results are related to the single 7.5 magnitude event only. Other events will also be mitigated by these infrastructure investments greatly increasing the economic value of the programmes.

Table H-8: Cumulative change in GDP from no earthquake scenario ($2016 billion)

Lapsed Time Since Event	6 months			1 year			5 years		
Investment Scenario	**None**	**Lower**	**Higher**	**None**	**Lower**	**Higher**	**None**	**Lower**	**Higher**
Wellington Region	**-8.7**	**-5.9**	**-5.4**	-10.3	-6.6	-6.1	-13.5	-8.5	-7.8
Rest of NZ	-2.1	-1.7	-1.6	-3.0	-2.1	-2.0	-3.2	-2.3	-2.2
Total NZ	-10.7	-7.5	-7.0	-13.3	-8.7	-8.1	**-16.7**	**-10.9**	**-10.0**
Net Reduction in GDP Loss when compared to the No Investment Scenario								**$5.8B**	**$6.7B**

In summary, the GDP summary losses to NZ after five years equate to:

$16.7 billion – No Investment

$10.9 billion – Lower Level Investment

$10.0 billion – Higher Level Investment.

The higher investment programme reduces the net change in GDP by approximately $900 million more than the lower investment programme. These additional savings can be attributed to:

- Electricity being established sooner across the region – providing greater opportunities for work activities to be conducted from home or at new sites, and a faster return to normal levels of productivity.
- Slightly fewer people are expected to relocate
- Reduced transport costs within the region.

Both programmes also contained interventions that were not able to be modelled in RiskScape and MERIT as they were not going to produce a significant impact on the outage maps, but were included in the programmes as they may have an impact on the network as a whole or facilitate other projects. The rationale for their inclusion in each programme is included in their individual descriptions in Section 7.2 in the PBC.

H4 Programme Overview

The RiskScape and MERIT modelling results for both programmes were presented to lifelines organisations at a workshop. There were seven projects that differed between the two programmes. In order to identify which initiatives best achieved the investment objectives, the MCA scores for each of the seven projects were revisited to help determine the preferred way forward.

The resulting preferred programme, subject to formal confirmation, is essentially a hybrid of the two alternative programme options. It was identified that one initiative: *160MW interconnectedness between substations* was a duplicate of another: *Central Park to Frederick Street cables replacement*, and hence was also removed from the programme.

Four projects were subsequently removed from the core programme following discussion with the Steering Group either because they relate principally to recovery – the wastewater and gas projects or because their efficacy is uncertain – the *Ngauranga to Petone Shared Pathway*.

Table H-9: Preferred investment programme impact on outage times and identified co-benefits.

Lifeline Infrastructure	Preferred Investment Programme and Indicative Costs		
	Initiative Name	Identification of Co-benefits	Impact on Outage Times
Roads	**Wadestown to Johnsonville route** - seismic strengthening of retaining walls etc	Resilience ONLY initiative	Yes – assessed using Roading Manager knowledge and experience
	SH58 Haywards seismic upgrades from TG to Hutt Valley (in addition to committed safety upgrades)	Resilience ONLY initiative	Yes – assessed using Roading Manager knowledge and experience
	Taita Gorge Access - strengthen road network on eastern side of Hutt Valley	Resilience ONLY initiative	Yes – assessed using Roading Manager knowledge and experience
	Cross Valley Link - new road connecting across the valley and providing connection from SH2 to Seaview/fuel	Primarily a traffic flow improvement project with resilience included	Yes – assessed using Roading Manager knowledge and experience
	Petone to Grenada - new road link from Hutt Valley to SH1 (inclusive of resilience enhancements)	A traffic flow improvement project with resilience enhancements	Yes – assessed using Roading Manager knowledge and experience
	RORO better engineered road links to port – seismic improvements to the 'skew rail bridge' (SH1 just south of Ngauranga), providing a road ramp from SH1 southbound to Kaiwharawhara (InterIslander area) and improving the performance on Aotea Quay	Resilience ONLY initiative	Yes – assessed using Roading Manager knowledge and experience
	Improve resilience of airport connectivity to city networks via Newtown	Resilience ONLY initiative	Yes – assessed using Roading Manager knowledge and experience
	Middleton Road retaining walls upgrade	Resilience ONLY initiative	No – assists with protection of utilities through corridor
Fuel	**Seaview Wharf seismic strengthening** including pipeline	Resilience ONLY initiative	Yes – assessed using expert knowledge
Sea Ports	**Port Seismic Strengthening** (ground improvements and major works to container terminal)	Resilience ONLY initiative	Yes – assessed using expert knowledge

	New RORO terminal	Primarily a project intended to improve RORO facilities.	Yes – assessed using expert knowledge
Electricity	**Central Park Substation improved resilience** - Creation of new CPK2 site close to the existing substation	This is a resilience ONLY initiative, however it would provide benefits in mitigating against minor power outages too.	Yes – modelled in RiskScape
	Seismic upgrade of 33kV buried cables - Eastern Wellington 33kV ring (Frederick, Hataitai, Evans Bay, Ira St) and Lower Hutt 33kV ring	These cables will be replaced by WE* as part of their normal maintenance renewals. The project represents earlier upgrading.	Yes – modelled in RiskScape
	Central Park to Frederick Street cables replacement	These cables will be replaced by WE* as part of their normal maintenance renewals. The project represents earlier replacement.	Yes – modelled in RiskScape
Water	**Cross Harbour Pipeline**	Resilience ONLY initiative	Yes – assessed using expert knowledge
	Prince of Wales and Bell Road Reservoir Upgrade	This is a resilience initiative, however it would provide benefits in providing additional water storage in the Central Wellington area.	Yes – assessed using expert knowledge
	Carmichael to Johnsonville and Karori Pipeline	Resilience ONLY initiative	Yes – assessed using expert knowledge
	General Water Supply Toughening	Resilience ONLY initiative. The project represents earlier upgrading.	Yes – modelled in RiskScape
	Porirua Branch Replacement & Emergency Pumping Plant	Resilience ONLY initiative	Yes – assessed using expert knowledge
	Porirua Low Level Zone Reservoirs	This is a resilience initiative, however it would provide benefits in providing additional water storage in the Porirua area.	Yes – assessed using expert knowledge
	Waterloo Pump Station Extension and New Pipeline from Waterloo to Haywards	Resilience ONLY initiative	Yes – assessed using expert knowledge
	Waterloo Water Treatment Plant Liquefaction Mitigation Project	Resilience ONLY initiative	Yes – assessed using expert knowledge
	Silverstream Bridge Pipeline Replacement Project	Resilience ONLY initiative	Yes – assessed using expert knowledge

Rail	**Rail seismic upgrade of slopes and structures** - NIMT Line, Hutt Valley Line and Upper Hutt (UH) to Wairarapa (WL) (Lower Investment)	Resilience ONLY initiative	Yes – assessed using expert knowledge
Telecommunications	**Dedicated backup power for cell towers**	Resilience ONLY initiative	Yes – assessed using expert knowledge

Should an event occur before all of the initiatives are implemented the full potential benefit from investment may not be realised, owing to the interdependence between lifelines.

The loss of potential value to the Wellington and New Zealand economy, from an event, decreases with the preferred programme (**Table H-10**). The loss of industry value to Wellington is significantly improved from the base case. For example, the loss to the Financial and Business Services and Government, Education and Health Service sectors is reduced by $2.2 and $1.3 billion respectively (net of the base case).

Table H-10: Accumulated loss of industry value added for the Preferred Programme ($\$_{2016}$ NZ mil)

	Industry	2 Months			6 Months			1 Year			2 Years			3 Years			5 Years		
		Wellington	Rest of NZ	Total NZ	Wellington	Rest of NZ	Total NZ	Wellington	Rest of NZ	Total NZ	Wellington	Rest of NZ	Total NZ	Wellington	Rest of NZ	Total NZ	Wellington	Rest of NZ	Total NZ
1	Agriculture	-10	30	20	-10	50	40	-20	60	40	-20	30	20	-20	10	-10	-20	-20	-40
2	Other primary	-10	0	0	-10	-10	-20	-10	10	-10	-10	10	-10	-10	-10	-20	-20	-40	-50
3	Manufacturing	-190	70	-130	-290	0	-290	-290	10	-280	-290	-30	-320	-280	-70	-350	-280	-150	-430
4	Utilities & communications	-150	30	-120	-210	-30	-240	-230	-70	-310	-270	-130	-400	-290	-170	-460	-340	-270	-610
5	Construction	-150	-80	-230	-430	-570	-1,000	-340	-200	-540	-230	250	20	-190	540	340	-80	1,200	1,130
6	Trade and hospitality	-340	-140	-470	-550	-530	-1,080	-600	-790	-1,390	-660	-950	-1,620	-720	-1,080	-1,800	-830	-1,500	-2,320
7	Transport & storage	-120	-210	-330	-300	-460	-760	-440	-670	-1,120	-620	-620	-1,240	-730	-540	-1,270	-830	-520	-1,360
8	Financial & business services	-1,000	60	-940	-1,650	50	-1,600	-1,820	70	-1,750	-1,920	240	-1,680	-1,990	440	-1,550	-2,110	820	-1,290
9	Government, education and health services	-800	40	-760	-1,400	-20	-1,420	-1,520	-190	-1,710	-1,630	-360	-1,990	-1,720	-420	-2,130	-1,830	-480	-2,310
10	Other services	-230	130	-110	-450	90	-360	-520	60	-470	-610	-10	-620	-700	-90	-790	-850	-380	-1,230
11	Other value added	-180	-60	-230	-390	-270	-660	-490	-430	-920	-600	-630	-1,230	-680	-810	-1,490	-790	-1,200	-1,990
	Total	**-3,180**	**-120**	**-3,300**	**-5,690**	**-1,700**	**-7,390**	**-6,280**	**-2,160**	**-8,440**	**-6,870**	**-2,200**	**-9,070**	**-7,340**	**-2,200**	**-9,540**	**-7,970**	**-2,540**	**-10,510**

Appendix I

Programme Alternative Multi-criteria Assessments

			Understand the Function / Service					Impact and Tolerance to Outage						Challenge	
			Option Characterisation					Impact on Operational Level of Service			Public Health and Safety Impacts			Efficacy in the Context of Challenge	
	On / Off Checkbox	Committed / Future	Lifeline Sector	Option Name	Option Detail	Location of Control	Resilience Pathway	Self Sufficiency (<7 days)	Response and Recovery	Return to BAU	Direct Public Health Benefits	Indirect Public Heath Benefits	Safety Risk	Spatial Efficacy	Resilience Dividend
Description	To select options to assess within each	Dropdown to select if options are committed or	Dropdown of lifelines sectors.	Free text for option short name.	Free text summary of the option (may link to other sources to allow this to be kept short).	The location for implementation of the option (categorised as a dropdown to create consistency).	Dropdown list (robustness, redundancy, recovery, governance).	(seven point scale -3-3).	Initial steps required by lifelines utilities to achieve a 'survival' level of operation (seven point scale -3-3).	Initiatives that help move from recovery to BAU or lessen the impact of an event so that return to BAU is faster (seven point scale -3-3)	(seven point scale -3-3).	(seven point scale -3-3).	7-point scale (to allow identification of options which impact life / injury risk	3-point scale to indicate if the intervention will likely be effective in a local location (based on location of control),	Does the option create resilience to other challenges (not included elsewhere) e.g. climate change.

Option status	On / Off Checkbox	Committed / Future	Lifeline Sector	Option Name	Option Detail	Location of Control	Resilience Pathway	Self Sufficiency (<7 days)	Response and Recovery	Return to BAU	Direct Public Health Benefits	Indirect Public Heath Benefits	Safety Risk	Spatial Efficacy	Resilience Dividend
Complete	☑	Committed	Electricity	Seismic Upgrade	Seismic upgrade of all 33kV buried cables. Note that this represents the opportunity for an accelerated programme to implement this initiative sooner.	Region-wide	Robustness	0	3	3	0	2	0	Regional	N
Complete	☑	Future	Rail	NIMT geotech seismic upgrade	NIMT seismic upgrade of slopes (including outside of tunnels and other locations).	Region-wide	Robustness	0	1	3	0	1	2	Regional	y
Complete	☑	Future	Rail	Hutt geotech seismic upgrade	Hutt Valley seismic upgrade of slopes (including outside of tunnels and other locations).	Region-wide	Robustness	0	0	3	0	1	2	Regional	y
Complete	☑	Future	Seaport	Port seismic strengthening - major works	(Higher cost option) Carry out full seismic upgrade of the Thorndon Container area to allow operations to be available 'within days' of an event. Note that this is included as it is important to national GDP	Wellington City	Robustness	0	2	3	0	0	1	Regional	Y
Complete (NB/MC)	☑	Future	Roads	Better engineered road connections to port	Resilience of ferry terminal connectivity to roading and city networks. Ensure that future ferry terminal developments have resilient connections to city and highways. ie. invest in improved resilience of roading network through to ferry terminals to improve recovery time for national freight task. Also, for immediate recovery, identify options for emergency roading solutions to access wharves after event.	Wellington City	Robustness	0	2	3	0	0	0	Regional	Y
Complete	☑	Future	Seaport	New RORO terminal at Kaiwharawhara	Upgrade of Interislander / Kaiwharawhara terminal to create a resilient RORO terminal for Cook Strait ferries, including ground resilience. Note that a (dolphin) mooring may also be required.	Wellington City	Robustness	0	2	3	0	0	1	Regional	Y
Complete (NB/MC)	☑	Future	Roads	Resilience of airport connectivity to city network via Newtown	Resilience of airport connectivity to roading and city networks via Newtown (due to additional local connectivity benefits)	Wellington City	Robustness	0	2	1	0	1	0	Regional	N
Complete	☑	Future	Gas	Readying point solution conversion to LPG	Enable primary gas users (hospitals and hotels) to be able to convert to LPG	Region-wide	Redundancy	2	1	1	2	1	0	Regional	Y
Complete (NB/MC)	☑	Future	Seaport	Seismic upgrade of Seaview wharf	Carry out a seismic upgrade of the Seaview wharf.	Lower Hutt	Robustness	0	2	2	0	1	0	Regional	N
Complete	☑	Future	Communications	Dedicated back-up power for cell towers	Improved response capability policy: dedicated portable / off-grid power generation (e.g. solar powered cell sites)	Region-wide	Governance	2	3	2	0	1	0	Regional	Y
Complete	☑	Future	Electricity	Central Park Substation - Improved Resilience	Reduce risk of Cntral Park outage	Wellington City	Redundancy	0	3	3	0	2	0	District	N
Complete	☑	Committed	Water distribution network	Cross harbour pipeline	Cross harbour pipeline or bores. Note that this is committed in the LTP, so this option represents an acceleration of the programme.	Lower Hutt - Wellington City	Redundancy	0	3	3	2	0	0	Regional	Y
Complete	☑	Future	Water distribution network	Prince of Wales and Bell Road II Reservoir	Prince of Wales and Bell Road II Reservoir: additional water reservoir(s). Feeds hospital and meets Newton potable water needs. Coupled with cross harbour pipeline / bores and associated pumpstations / pipe work.	Wellington City	Robustness	0	3	2	2	0	1	Regional	Y
Complete	☑	Future	Waste water	Ablution facilities across schools	Policy to implement off-grid public facilities (at schools or CDEM centres)	Region-wide	Recovery	3	2	0	3	0	0	Regional	Y
Complete (post-workshop)	☑	Committed	Water distribution network	Emergency water infrastructure	Emergency water infrastructure located in communities: bladders, mini-bores. Note that this represents the opportunity for an accelerated programme to implement this initiative sooner.	Region-wide	Recovery	3	2	0	3	0	0	Regional	Y
Complete (post-workshop)	☑	Committed	Water distribution network	General water supply toughening	Toughen pipes at critical locations as part of AMP. Note that this represents the opportunity for an accelerated programme to implement this initiative sooner.	Region-wide	Robustness	0	2	2	3	0	0	Regional	Y
Complete	☑	Committed	Roads	SH58 Resilience	SH58 resilience TG to Haywards Hill slope stability (rock anchors, drainage, etc). Note that safety works are committed, but this option provides for specific resilience measures to be added to the programme.	Lower Hutt - Tawa / Porirua	Robustness	0	2	2	0	1	1	Regional	Y
Complete	☑	Committed	Roads	Ngauranga to Petone shared pathway	Wellington to Hutt cycleway: buffer to the ocean; allows straightening of rail line. This assessment assumes that the path will be built to the standard that it could allow heavy vehicle access after an emergency, but a narrower option could be considered as part of the CBA.	Lower Hutt - Wellington City	Redundancy	0	2	2	0	1	1	Regional	N
Complete	☑	Future	Roads	Cross Valley Link	Hutt Valley 'East-West connection'. New road connecting Lower Hutt east to west. Allows more resilient access to fuel depots. 2-4 lane.	Lower Hutt	Redundancy	0	1	1	0	1	0	Local	Y
Complete	☑	Future	Roads	Ngauranga Gorge resilience	SH1 Ngauranga Gorge accelerated resilience. Package of works including southern rail bridge and Hutt Rd. Includes slope stabilisation in Ngauranga Gorge.	Wellington City	Robustness	0	2	3	0	1	2	Regional	Y
Complete	☑	Future	Roads	Petone to Grenada	Petone to Grenada new road link. Assuming cuts are designed to be resilient to rockfall risks.	Lower Hutt - Wellington City	Redundancy	0	2	3	0	1	0	Regional	Y
Complete	☑	Future	Water distribution network	Porirua Branch Replacement	Porirua Branch Replacement: the branch replacement is required as the existing pipeline will suffer severe damage due to age, materials and joint type	Tawa / Porirua	Robustness	0	3	2	2	0	0	District	N
Complete	☑	Future	Potable water	Porirua Emergency Pumping Plant	Porirua Emergency Water Pumping Facility (requires branch replacement also)	Tawa / Porirua	Recovery	0	3	1	3	0	0	District	Y
Complete	☑	Future	Potable water	Porirua low level zone reservoir upgrades	Reservoir upgrades: supports supply to Kenepuru reservoir and wider Porirua zones not initially served until reticulation is restored. Supplies Kenepuru hospital.	Tawa / Porirua	Robustness	0	3	2	2	0	0	District	Y
Complete (post-workshop)	☑	Future	Waste water	Provision of buckets for a two-bucket home toilet system	Provision of buckets for a two-bucket home toilet system	Region-wide	Recovery	2	2	0	3	0	0	Regional	Y
Complete	☑	Future	Water distribution network	Carmichael to Johnsonville & Karori Pipeline	Carmichael to Johnsonville & Karori Pipeline. Delivers circa 70 day reduction in time to restore water services. Assumed to be a strengthening project of an existing pipeline.	Wellington City	Robustness	0	3	1	2	0	0	District	N

	On / Off Checkbox	Committed / Future	Lifeline Sector	Option Name	Option Detail	Location of Control	Resilience Pathway	Self Sufficiency (<7 days)	Response and Recovery	Return to BAU	Direct Public Health Benefits	Indirect Public Heath Benefits	Safety Risk	Spatial Efficacy	Resilience Dividend
	Understand the Function / Service							Impact and Tolerance to Outage						Challenge	
	Option Characterisation							Impact on Operational Level of Service			Public Health and Safety Impacts			Efficacy in the Context of Challenge	
Description	To select options to assess within each	Dropdown to select if options are committed or	Dropdown of lifelines sectors.	Free text for option short name.	Free text summary of the option (may link to other sources to allow this to be kept short).	The location for implementation of the option (categorised as a dropdown to create consistency).	Dropdown list (robustness, redundancy, recovery, governance).	(seven point scale -3-3).	Initial steps required by lifelines utilities to achieve a 'survival' level of operation (seven point scale -3-3).	Initiatives that help move from recovery to BAU or lessen the impact of an event so that return to BAU is faster (seven point scale -3-3)	(seven point scale -3-3).	(seven point scale -3-3).	7-point scale (to allow identification of options which impact life / injury risk	3-point scale to indicate if the intervention will likely be effective in a local location (based on location of control),	Does the option create resilience to other challenges (not included elsewhere) e.g. climate change.

Option status	On / Off Checkbox	Committed / Future	Lifeline Sector	Option Name	Option Detail	Location of Control	Resilience Pathway	Self Sufficiency (<7 days)	Response and Recovery	Return to BAU	Direct Public Health Benefits	Indirect Public Heath Benefits	Safety Risk	Spatial Efficacy	Resilience Dividend
Complete	☑	Future	Water distribution network	Waterloo Pump Station extension	Pump station extension at Waterloo	Lower Hutt	Robustness	0	3	3	3	0	0	District	Y
Complete	☑	Future	Water distribution network	New pipeline from Waterloo to Haywards	New pipeline from Waterloo to Haywards	Lower Hutt	Redundancy	0	3	3	3	0	0	District	Y
Complete	☑	Future	Roads	Taita Gorge Access	Strengthen road network in central Hutt Valley (Silverstream to Taita Gorge and the Hutt Valley Hospital area and possibly Eastern Hutt Bridge)	Lower Hutt	Robustness	0	2	2	0	2	0	Regional	Y
Complete	☑	Future	Roads	Wadestown to Johnsonville	Seismic strengthening of retaining walls on Churchill Drive and Wadestown Road. Seen as key access to hospital.	Wellington City	Robustness	0	3	2	0	2	1	District	Y
Updated (post-workshop)	☑	Future	Seaport	Burnham Wharf replacement	Replacement of Burnham wharf with a new wharf facility including futureproofing for future emergency RORO use. This option will also require a complete replacement of the aviation fuel infrastructure. Both the wharf and the fuel infrastructure are nearing the end of their design life – with no further upgrades or strengthening planned.	Wellington City	Redundancy	0	2	0	0	1	0	Regional	Y
Complete (post-workshop)	☑	Future	Electricity	Connection between substations in Wellington (160MW)	Connection between substations in Wellington (160MW)	Region-wide	Robustness	1	3	2	0	2	0	Regional	Y
Complete (post-workshop)	☑	Future	Roads	Middleton Rd retaining walls upgrade	Upgrade retaining walls on Middleton Rd between Tawa and Johnsonville	Lower Hutt - Tawa / Porirua	Robustness	0	3	2	0	2	1	District	Y
Complete (post-workshop)	☑	Future	Potable water	Waterloo Water Treatment Plant Liquefaction Mitigation Project	Assessment of the options to mitigate liquefaction of the ground and implementation of the preferred option. Mitigation options include ground improvement or additional support for the structure.	Lower Hutt	Robustness	0	3	3	3	0	0	District	N
Complete (post-workshop)	☑	Future	Water distribution network	Silverstream Bridge Pipeline Replacement Project	Replacement of the Te Marua to Ngauranga pipeline where it crosses the Silverstream road bridge and the Wellington Fault	Upper Hutt	Robustness	0	3	3	3	0	0	District	N
Complete (post-workshop)	☑	Committed	Electricity	CPK – Frederick Street cables replacement	Replacement of the cables between Central Park Substations and Frederick Street Zone Sub-Station with cross-linked polyethylene (XLPE). This option is scheduled for implementation under WE*'s ongoing cable replacement programme and therefore has been included to accelerate funding.	Wellington City	Robustness	0	3	3	0	2	0	District	N
Complete (post-workshop)	☑	Future	Electricity	Replacement of fluid filled cables in the network	Replacement of all the remaining fluid filled cables in the network approximately 100km worth	Region-wide	Robustness	0	3	3	0	2	0	Regional	N

Development of Controls							Value of Resilience								
Implementation							Indirect Benefits				Indirect Costs				
Ease of Implementation	Time to Implementation	Reliance on Other Options	Enables Other Outcomes	Lead Agency	Partner Agencies	Stakeholders	Environmental	Social	Cultural	Economic	Environmental	Social	Cultural	Economic	TOTAL MCA
4-point scale to document the ease of implementation of an option.	Dropdown to indicate if the options could be delivered in: - Short term, less-than 1-year - Mid term, 1-10 years	y/n to indicate there are interdependencies to take into consideration	4-point scale to document the ability to enable other outcomes. Including how many options, the scale of the	Who is responsible for taking an option forward.	Who is responsible for supporting the lead agency in taking an option forward.	An indication of agencies or groups who would need to be consulted.	H, M, L based on NZTA research consequence matrix (to be amended for WLG).	H, M, L based on NZTA research consequence matrix (to be amended for WLG).	H, M, L based on NZTA research consequence matrix (to be amended for WLG).	H, M, L based on NZTA research consequence matrix (to be amended for WLG).	H, M, L based on NZTA research consequence matrix (to be amended for WLG).	H, M, L based on NZTA research consequence matrix (to be amended for WLG).	H, M, L based on NZTA research consequence matrix (to be amended for WLG).	H, M, L based on NZTA research consequence matrix (to be amended for WLG).	

Ease of Implementation	Time to Implementation	Reliance on Other Options	Enables Other Outcomes	Lead Agency	Partner Agencies	Stakeholders	Environmental	Social	Cultural	Economic	Environmental	Social	Cultural	Economic	TOTAL MCA
1	Long-term	Y	3	WE	ComCom, MBIE		None	None	None	L	L	None	None	None	0.74
2	Mid-term	Y	2	Kiwirail	NZTA, GWRC		None	None	None	L	L	None	None	None	0.60
1	Mid-term	Y	1	Kiwirail	NZTA, GWRC		None	None	None	L	L	None	None	None	0.41
3	Mid-term	Y	0	CentrePort, GWRC	Horizons		None	None	None	M	L	None	None	None	0.47
3	Mid-term	Y	1	GWRC	CentrePort, NZTA	Horizons	None	L	None	L	L	L	None	None	0.54
1	Mid-term	Y	3	CentrePort, GWRC	Kiwirail, NZTA, Horizons		None	None	None	H	H	L	L	None	0.71
3	Mid-term	Y	1	GWRC	NZTA		None	L	None	L	L	L	None	None	0.45
1	Short-term	Y	1	DHB, MBIE			None	None	None	None	None	None	None	None	0.37
3	Mid-term	Y	2	CentrePort	Fuel companies		M	None	None	L	L	None	None	None	0.60
2	Mid-term	Y	2	MBIE	Telcos		L	None	None	L	L	None	None	None	0.65
1	Mid-term	N	3	Transpower / WE	Transpower / WE	ComCom, MBIE	None	None	None	L	L	None	None	None	0.74
2	Mid-term	y	0	WCC	WW, GWRC		L	None	None	L	L	None	L	None	0.48
1	Mid-term	Y	0	WCC	WW, GWRC	DHB	None	None	None	L	L	L	None	None	0.41
2	Mid-term	N	0	WW	Councils, MoEdu, Regional Public Health	WREMO	M	None	None	L	L	None	L	None	0.34
3	Mid-term	N	0	WW	Councils		None	None	None	L	L	None	None	None	0.37
2	Mid-term	Y	0	WW	Councils		None	None	None	None	L	None	None	None	0.37
2	Mid-term	N	3	NZTA	HCC	Transpower, WW	None	None	None	L	M	None	L	None	0.67
1	Mid-term	N	2	NZTA	HCC, GWRC, WCC	Kiwirail, WW	L	M	None	L	H	None	M	None	0.54
1	Mid-term	Y	3	HCC	NZTA	GWRC	None	M	None	L	L	M	None	None	0.53
3	Mid-term	N	1	NZTA, WCC	Kiwirail		None	None	None	L	None	None	None	None	0.58
2	Mid-term	N	3	NZTA	WCC, HCC, GWRC		None	L	None	H	M	L	L	None	0.74
1	Mid-term	Y	1	WW		GWRC, PCC, HCC	None	None	None	L	L	None	None	None	0.49
3	Mid-term	Y	1	WW		GWRC, PCC, HCC	None	None	None	L	L	None	None	None	0.52
1	Mid-term	N	1	WW		CC DHB, GWRC, PCC, HCC	None	None	None	L	L	None	None	None	0.49
3	Short-term	Y	0	WW	MBIE		L	None	None	None	None	None	None	None	0.34
2	Mid-term	N	0	GWRC	WW, WCC		None	None	None	L	L	None	None	None	0.38

Development of Controls							Value of Resilience								
Implementation							Indirect Benefits				Indirect Costs				
Ease of Implementation	Time to Implementation	Reliance on Other Options	Enables Other Outcomes	Lead Agency	Partner Agencies	Stakeholders	Environmental	Social	Cultural	Economic	Environmental	Social	Cultural	Economic	TOTAL MCA
4-point scale to document the ease of implementation of an option.	Dropdown to indicate if the options could be delivered in: - Short term, less-than 1-year - Mid term, 1-10 years	y/n to indicate there are interdependencies to take into consideration	4-point scale to document the ability to enable other outcomes. Including how many options, the scale of the	Who is responsible for taking an option forward.	Who is responsible for supporting the lead agency in taking an option forward.	An indication of agencies or groups who would need to be consulted.	H, M, L based on NZTA research consequence matrix (to be amended for WLG).	H, M, L based on NZTA research consequence matrix (to be amended for WLG).	H, M, L based on NZTA research consequence matrix (to be amended for WLG).	H, M, L based on NZTA research consequence matrix (to be amended for WLG).	H, M, L based on NZTA research consequence matrix (to be amended for WLG).	H, M, L based on NZTA research consequence matrix (to be amended for WLG).	H, M, L based on NZTA research consequence matrix (to be amended for WLG).	H, M, L based on NZTA research consequence matrix (to be amended for WLG).	

Ease of Implementation	Time to Implementation	Reliance on Other Options	Enables Other Outcomes	Lead Agency	Partner Agencies	Stakeholders	Environmental	Social	Cultural	Economic	Environmental	Social	Cultural	Economic	TOTAL MCA
2	Mid-term	N	0	WW		GWRC, HCC, UHCC	None	None	None	L	L	None	None	None	0.49
2	Mid-term	N	0	WW		GWRC, HCC, UHCC	None	None	None	L	L	None	None	None	0.49
3	Mid-term	N	3	HCC	NZTA, GWRC	UHCC	None	None	None	L	L	None	None	None	0.70
3	Mid-term	Y	2	WCC	NZTA		L	None	None	L	L	None	None	None	0.67
1	Mid-term	Y	2	CentrePort	GWRC, WCC		None	None	None	M	M	L	L	None	0.44
1	Mid-term	Y	2	WE		Transpower, ComCom, MBIE	None	None	None	L	L	L	None	None	0.60
3	Mid-term	Y	2	WCC	NZTA		L	None	None	L	L	None	None	None	0.67
3	Mid-term	Y	0	WW		GWRC, HCC, UHCC	None	None	None	L	None	None	None	None	0.52
3	Mid-term	N	0	WW		GWRC, UHCC	L	None	None	L	L	None	None	None	0.52
2	Mid-term	N	3	Transpower / WE	Transpower / WE		None	None	None	L	L	None	None	None	0.77
1	Long-term	Y	3	WE	ComCom, MBIE		None	None	None	M	L	None	None	None	0.75

	On / Off Checkbox	Committed / Future	Lifeline Sector	Option Name	Option Detail	Location of Control	Resilience Pathway	Self Sufficiency (<7 days)	Response and Recovery	Return to BAU	Direct Public Health Benefits	Indirect Public Heath Benefits	Safety Risk	Spatial Efficacy	Resilience Dividend
	Understand the Function / Service							Impact and Tolerance to Outage						Challenge	
	Option Characterisation							Impact on Operational Level of Service			Public Health and Safety Impacts			Efficacy in the Context of Challenge	
Description	To select options to assess within each	Dropdown to select if options are committed or	Dropdown of lifelines sectors.	Free text for option short name.	Free text summary of the option (may link to other sources to allow this to be kept short).	The location for implementation of the option (categorised as a dropdown to create consistency).	Dropdown list (robustness, redundancy, recovery, governance).	(seven point scale -3-3).	Initial steps required by lifelines utilities to achieve a 'survival' level of operation (seven point scale -3-3).	Initiatives that help move from recovery to BAU or lessen the impact of an event so that return to BAU is faster (seven point scale -3-3)	(seven point scale -3-3).	(seven point scale -3-3).	7-point scale (to allow identification of options which impact life / injury risk	3-point scale to indicate if the intervention will likely be effective in a local location (based on location of control),	Does the option create resilience to other challenges (not included elsewhere) e.g. climate change.

Option status	On / Off Checkbox	Committed / Future	Lifeline Sector	Option Name	Option Detail	Location of Control	Resilience Pathway	Self Sufficiency (<7 days)	Response and Recovery	Return to BAU	Direct Public Health Benefits	Indirect Public Heath Benefits	Safety Risk	Spatial Efficacy	Resilience Dividend
Complete	☑	Future	Rail	NIMT geotech seismic upgrade	NIMT seismic upgrade of slopes (including outside of tunnels and other locations).	Region-wide	Robustness	0	1	3	0	1	2	Regional	y
Complete	☑	Future	Rail	Hutt geotech seismic upgrade	Hutt Valley seismic upgrade of slopes (including outside of tunnels and other locations).	Region-wide	Robustness	0	0	3	0	1	2	Regional	y
Complete	☑	Future	Seaport	Port seismic strengthening - major works	(Higher cost option) Carry out full seismic upgrade of the Thorndon Container area to allow operations to be available 'within days' of an event. Note that this is included as it is important to national GDP	Wellington City	Robustness	0	2	3	0	0	1	Regional	Y
Complete	☑	Future	Seaport	New RORO terminal at Kaiwharawhara	Upgrade of Interislander / Kaiwharawhara terminal to create a resilient RORO terminal for Cook Strait ferries, including ground resilience. Note that a (dolphin) mooring may also be required.	Wellington City	Robustness	0	2	3	0	0	1	Regional	Y
Complete	☑	Future	Gas	Readying point solution conversion to LPG	Enable primary gas users (hospitals and hotels) to be able to convert to LPG	Region-wide	Redundancy	2	1	1	2	1	0	Regional	Y
Complete (NB/MC)	☑	Future	Seaport	Seismic upgrade of Seaview wharf	Carry out a seismic upgrade of the Seaview wharf.	Lower Hutt	Robustness	0	2	2	0	1	0	Regional	N
Complete	☑	Future	Communications	Dedicated back-up power for cell towers	Improved response capability policy: dedicated portable / off-grid power generation (e.g. solar powered cell sites)	Region-wide	Governance	2	3	2	0	1	0	Regional	Y
Complete	☑	Future	Electricity	Central Park Substation - Improved Resilience	Reduce risk of Cntral Park outage	Wellington City	Redundancy	0	3	3	0	2	0	District	N
Complete	☑	Committed	Water distribution network	Cross harbour pipeline	Cross harbour pipeline or bores. Note that this is committed in the LTP, so this option represents an acceleration of the programme.	Lower Hutt - Wellington City	Redundancy	0	3	3	2	0	0	Regional	Y
Complete	☑	Future	Water distribution network	Prince of Wales and Bell Road II Reservoir	Prince of Wales and Bell Road II Reservoir: additional water reservoir(s). Feeds hospital and meets Newton potable water needs. Coupled with cross harbour pipeline / bores and associated pumpstations / pipe work.	Wellington City	Robustness	0	3	2	2	0	1	Regional	Y
Complete	☑	Future	Waste water	Ablution facilities across schools	Policy to implement off-grid public facilities (at schools or CDEM centres)	Region-wide	Recovery	3	2	0	3	0	0	Regional	Y
Complete (post-workshop)	☑	Committed	Water distribution network	Emergency water infrastructure	Emergency water infrastructure located in communities: bladders, mini-bores. Note that this represents the opportunity for an accelerated programme to implement this initiative sooner.	Region-wide	Recovery	3	2	0	3	0	0	Regional	Y
Complete (post-workshop)	☑	Committed	Water distribution network	General water supply toughening	Toughen pipes at critical locations as part of AMP. Note that this represents the opportunity for an accelerated programme to implement this initiative sooner.	Region-wide	Robustness	0	2	2	3	0	0	Regional	Y
Complete	☑	Committed	Roads	SH58 Resilience	SH58 resilience TG to Haywards Hill slope stability (rock anchors, drainage, etc). Note that safety works are committed, but this option provides for specific resilience measures to be added to the programme.	Lower Hutt - Tawa / Porirua	Robustness	0	2	2	0	1	1	Regional	Y
Complete	☑	Committed	Roads	Ngauranga to Petone shared pathway	Wellington to Hutt cycleway: buffer to the ocean; allows straightening of rail line. This assessment assumes that the path will be built to the standard that it could allow heavy vehicle access after an emergency, but a narrower option could be considered as part of the CBA.	Lower Hutt - Wellington City	Redundancy	0	2	2	0	1	1	Regional	N
Complete	☑	Future	Roads	Ngauranga Gorge resilience	SH1 Ngauranga Gorge accelerated resilience. Package of works including southern rail bridge and Hutt Rd. Includes slope stabilisation in Ngauranga Gorge.	Wellington City	Robustness	0	2	3	0	1	2	Regional	Y
Complete	☑	Future	Water distribution network	Porirua Branch Replacement	Porirua Branch Replacement: the branch replacement is required as the existing pipeline will suffer severe damage due to age, materials and joint type	Tawa / Porirua	Robustness	0	3	2	2	0	0	District	N
Complete	☑	Future	Potable water	Porirua Emergency Pumping Plant	Porirua Emergency Water Pumping Facility (requires branch replacement also)	Tawa / Porirua	Recovery	0	3	1	3	0	0	District	Y
Complete	☑	Future	Potable water	Porirua low level zone reservoir upgrades	Reservoir upgrades: supports supply to Kenepuru reservoir and wider Porirua zones not initially served until reticulation is restored. Supplies Kenepuru hospital.	Tawa / Porirua	Robustness	0	3	2	2	0	0	District	Y
Complete (post-workshop)	☑	Future	Waste water	Provision of buckets for a two-bucket home toilet system	Provision of buckets for a two-bucket home toilet system	Region-wide	Recovery	2	2	0	3	0	0	Regional	Y
Complete	☑	Future	Water distribution network	Carmichael to Johnsonville & Karori Pipeline	Carmichael to Johnsonville & Karori Pipeline. Delivers circa 70 day reduction in time to restore water services. Assumed to be a strengthening project of an existing pipeline.	Wellington City	Robustness	0	3	1	2	0	0	District	N
Complete	☑	Future	Water distribution network	Waterloo Pump Station extension	Pump station extension at Waterloo	Lower Hutt	Robustness	0	3	3	3	0	0	District	Y
Complete	☑	Future	Water distribution network	New pipeline from Waterloo to Haywards	New pipeline from Waterloo to Haywards	Lower Hutt	Redundancy	0	3	3	3	0	0	District	Y
Complete	☑	Future	Roads	Taita Gorge Access	Strengthen road network in central Hutt Valley (Silverstream to Taita Gorge and the Hutt Valley Hospital area and possibly Eastern Hutt Bridge)	Lower Hutt	Robustness	0	2	2	0	2	0	Regional	Y
Complete	☑	Future	Roads	Wadestown to Johnsonville	Seismic strengthening of retaining walls on Churchill Drive and Wadestown Road. Seen as key access to hospital.	Wellington City	Robustness	0	3	2	0	2	1	District	Y
Updated (post-workshop)	☑	Future	Seaport	Burnham Wharf replacement	Replacement of Burnham wharf with a new wharf facility including futureproofing for future emergency RORO use. This option will also require a complete replacement of the aviation fuel infrastructure. Both the wharf and the fuel infrastructure are nearing the end of their design life – with no further upgrades or strengthening planned.	Wellington City	Redundancy	0	2	0	0	1	0	Regional	Y

			Understand the Function / Service					Impact and Tolerance to Outage						Challenge	
			Option Characterisation					Impact on Operational Level of Service			Public Health and Safety Impacts			Efficacy in the Context of Challenge	
	On / Off Checkbox	Committed / Future	Lifeline Sector	Option Name	Option Detail	Location of Control	Resilience Pathway	Self Sufficiency (<7 days)	Response and Recovery	Return to BAU	Direct Public Health Benefits	Indirect Public Heath Benefits	Safety Risk	Spatial Efficacy	Resilience Dividend
Description	To select options to assess within each	Dropdown to select if options are committed or	Dropdown of lifelines sectors.	Free text for option short name.	Free text summary of the option (may link to other sources to allow this to be kept short).	The location for implementation of the option (categorised as a dropdown to create consistency).	Dropdown list (robustness, redundancy, recovery, governance).	(seven point scale -3-3).	Initial steps required by lifelines utilities to achieve a 'survival' level of operation (seven point scale -3-3).	Initiatives that help move from recovery to BAU or lessen the impact of an event so that return to BAU is faster (seven point scale -3-3)	(seven point scale -3-3).	(seven point scale -3-3).	7-point scale (to allow identification of options which impact life / injury risk	3-point scale to indicate if the intervention will likely be effective in a local location (based on location of control),	Does the option create resilience to other challenges (not included elsewhere) e.g. climate change.

Option status	On / Off Checkbox	Committed / Future	Lifeline Sector	Option Name	Option Detail	Location of Control	Resilience Pathway	Self Sufficiency (<7 days)	Response and Recovery	Return to BAU	Direct Public Health Benefits	Indirect Public Heath Benefits	Safety Risk	Spatial Efficacy	Resilience Dividend
Complete (post-workshop)	☑	Future	Electricity	Connection between substations in Wellington (160MW)	Connection between substations in Wellington (160MW)	Region-wide	Robustness	1	3	2	0	2	0	Regional	Y
Complete (post-workshop)	☑	Future	Roads	Middleton Rd retaining walls upgrade	Upgrade retaining walls on Middleton Rd between Tawa and Johnsonville	Lower Hutt - Tawa / Porirua	Robustness	0	3	2	0	2	1	District	Y
Complete (post-workshop)	☐ ☑	Future	Potable water	Waterloo Water Treatment Plant Liquefaction Mitigation Project	Assessment of the options to mitigate liquefaction of the ground and implementation of the preferred option. Mitigation options include ground improvement or additional support for the structure.	Lower Hutt	Robustness	0	3	3	3	0	0	District	N
Complete (post-workshop)	☑	Future	Water distribution network	Silverstream Bridge Pipeline Replacement Project	Replacement of the Te Marua to Ngauranga pipeline where it crosses the Silverstream road bridge and the Wellington Fault	Upper Hutt	Robustness	0	3	3	3	0	0	District	N
Complete (post-workshop)	☑	Committed	Electricity	CPK – Frederick Street cables replacement	Replacement of the cables between Central Park Substations and Frederick Street Zone Sub-Station with cross-linked polyethylene (XLPE). This option is scheduled for implementation under WE*'s ongoing cable replacement programme and therefore has been included to accelerate funding.	Wellington City	Robustness	0	3	3	0	2	0	District	N
	☐														

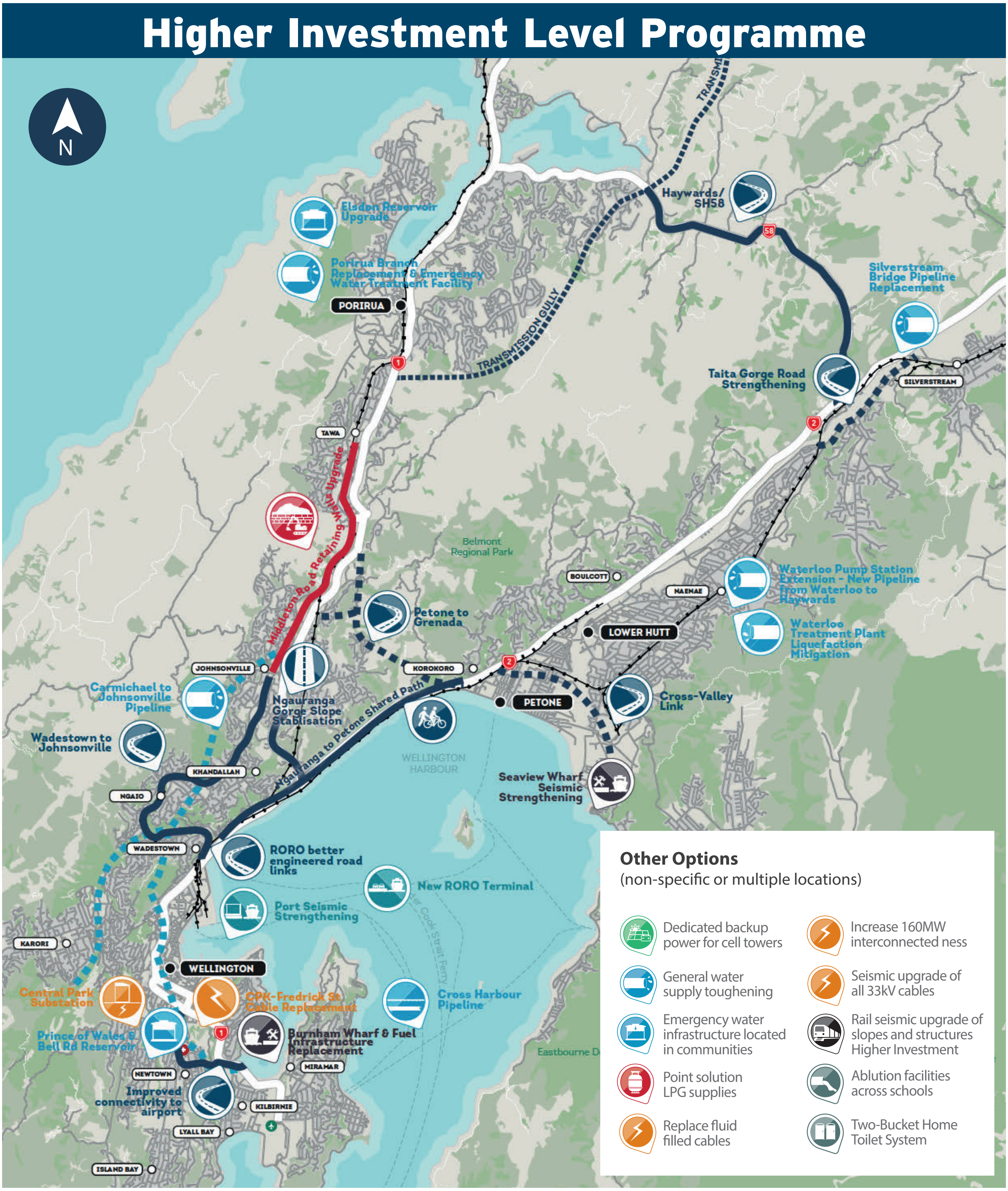
Development of Controls							Value of Resilience								
Implementation							Indirect Benefits				Indirect Costs				
Ease of Implementation	Time to Implementation	Reliance on Other Options	Enables Other Outcomes	Lead Agency	Partner Agencies	Stakeholders	Environmental	Social	Cultural	Economic	Environmental	Social	Cultural	Economic	TOTAL MCA
4-point scale to document the ease of implementation of an option.	Dropdown to indicate if the options could be delivered in: - Short term, less-than 1-year - Mid term, 1-10 years	y/n to indicate there are interdependencies to take into consideration	4-point scale to document the ability to enable other outcomes. Including how many options, the scale of the	Who is responsible for taking an option forward.	Who is responsible for supporting the lead agency in taking an option forward.	An indication of agencies or groups who would need to be consulted.	H, M, L based on NZTA research consequence matrix (to be amended for WLG).	H, M, L based on NZTA research consequence matrix (to be amended for WLG).	H, M, L based on NZTA research consequence matrix (to be amended for WLG).	H, M, L based on NZTA research consequence matrix (to be amended for WLG).	H, M, L based on NZTA research consequence matrix (to be amended for WLG).	H, M, L based on NZTA research consequence matrix (to be amended for WLG).	H, M, L based on NZTA research consequence matrix (to be amended for WLG).	H, M, L based on NZTA research consequence matrix (to be amended for WLG).	
Ease of Implementation	Time to Implementation	Reliance on Other Options	Enables Other Outcomes	Lead Agency	Partner Agencies	Stakeholders	Environmental	Social	Cultural	Economic	Environmental	Social	Cultural	Economic	TOTAL MCA
2	Mid-term	Y	2	Kiwirail	NZTA, GWRC		None	None	None	L	L	None	None	None	0.60
1	Mid-term	Y	1	Kiwirail	NZTA, GWRC		None	None	None	L	L	None	None	None	0.41
3	Mid-term	Y	0	CentrePort, GWRC	Horizons		None	None	None	M	L	None	None	None	0.47
1	Mid-term	Y	3	CentrePort, GWRC	Kiwirail, NZTA, Horizons		None	None	None	H	H	L	L	None	0.71
1	Short-term	Y	1	DHB, MBIE			None	None	None	None	None	None	None	None	0.37
3	Mid-term	Y	2	CentrePort	Fuel companies		M	None	None	L	L	None	None	None	0.60
2	Mid-term	Y	2	MBIE	Telcos		L	None	None	L	L	None	None	None	0.65
1	Mid-term	N	3	Transpower / WE	Transpower / WE	ComCom, MBIE	None	None	None	L	L	None	None	None	0.74
2	Mid-term	y	0	WCC	WW, GWRC		L	None	None	L	L	None	L	None	0.48
1	Mid-term	Y	0	WCC	WW, GWRC	DHB	None	None	None	L	L	L	None	None	0.41
2	Mid-term	N	0	WW	Councils, MoEdu, Regional Public Health	WREMO	M	None	None	L	L	None	L	None	0.34
3	Mid-term	N	0	WW	Councils		None	None	None	L	L	None	None	None	0.37
2	Mid-term	Y	0	WW	Councils		None	None	None	None	L	None	None	None	0.37
2	Mid-term	N	3	NZTA	HCC	Transpower, WW	None	None	None	L	M	None	L	None	0.67
1	Mid-term	N	2	NZTA	HCC, GWRC, WCC	Kiwirail, WW	L	M	None	L	H	None	M	None	0.54
3	Mid-term	N	1	NZTA, WCC	Kiwirail		None	None	None	L	None	None	None	None	0.58
1	Mid-term	Y	1	WW		GWRC, PCC, HCC	None	None	None	L	L	None	None	None	0.49
3	Mid-term	Y	1	WW		GWRC, PCC, HCC	None	None	None	L	L	None	None	None	0.52
1	Mid-term	N	1	WW		CC DHB, GWRC, PCC, HCC	None	None	None	L	L	None	None	None	0.49
3	Short-term	Y	0	WW	MBIE		L	None	None	None	None	None	None	None	0.34
2	Mid-term	N	0	GWRC	WW, WCC		None	None	None	L	L	None	None	None	0.38
2	Mid-term	N	0	WW		GWRC, HCC, UHCC	None	None	None	L	L	None	None	None	0.49
2	Mid-term	N	0	WW		GWRC, HCC, UHCC	None	None	None	L	L	None	None	None	0.49
3	Mid-term	N	3	HCC	NZTA, GWRC	UHCC	None	None	None	L	L	None	None	None	0.70
3	Mid-term	Y	2	WCC	NZTA		L	None	None	L	L	None	None	None	0.67
1	Mid-term	Y	2	CentrePort	Horizons, GWRC, WCC		None	None	None	M	M	L	L	None	0.44

Development of Controls							Value of Resilience									
Implementation							Indirect Benefits				Indirect Costs					
Ease of Implementation	Time to Implementation	Reliance on Other Options	Enables Other Outcomes	Lead Agency	Partner Agencies	Stakeholders	Environmental	Social	Cultural	Economic	Environmental	Social	Cultural	Economic	TOTAL MCA
4-point scale to document the ease of implementation of an option.	Dropdown to indicate if the options could be delivered in: - Short term, less-than 1-year - Mid term, 1-10 years	y/n to indicate there are interdependencies to take into consideration	4-point scale to document the ability to enable other outcomes. Including how many options, the scale of the	Who is responsible for taking an option forward.	Who is responsible for supporting the lead agency in taking an option forward.	An indication of agencies or groups who would need to be consulted.	H, M, L based on NZTA research consequence matrix (to be amended for WLG).	H, M, L based on NZTA research consequence matrix (to be amended for WLG).	H, M, L based on NZTA research consequence matrix (to be amended for WLG).	H, M, L based on NZTA research consequence matrix (to be amended for WLG).	H, M, L based on NZTA research consequence matrix (to be amended for WLG).	H, M, L based on NZTA research consequence matrix (to be amended for WLG).	H, M, L based on NZTA research consequence matrix (to be amended for WLG).	H, M, L based on NZTA research consequence matrix (to be amended for WLG).	

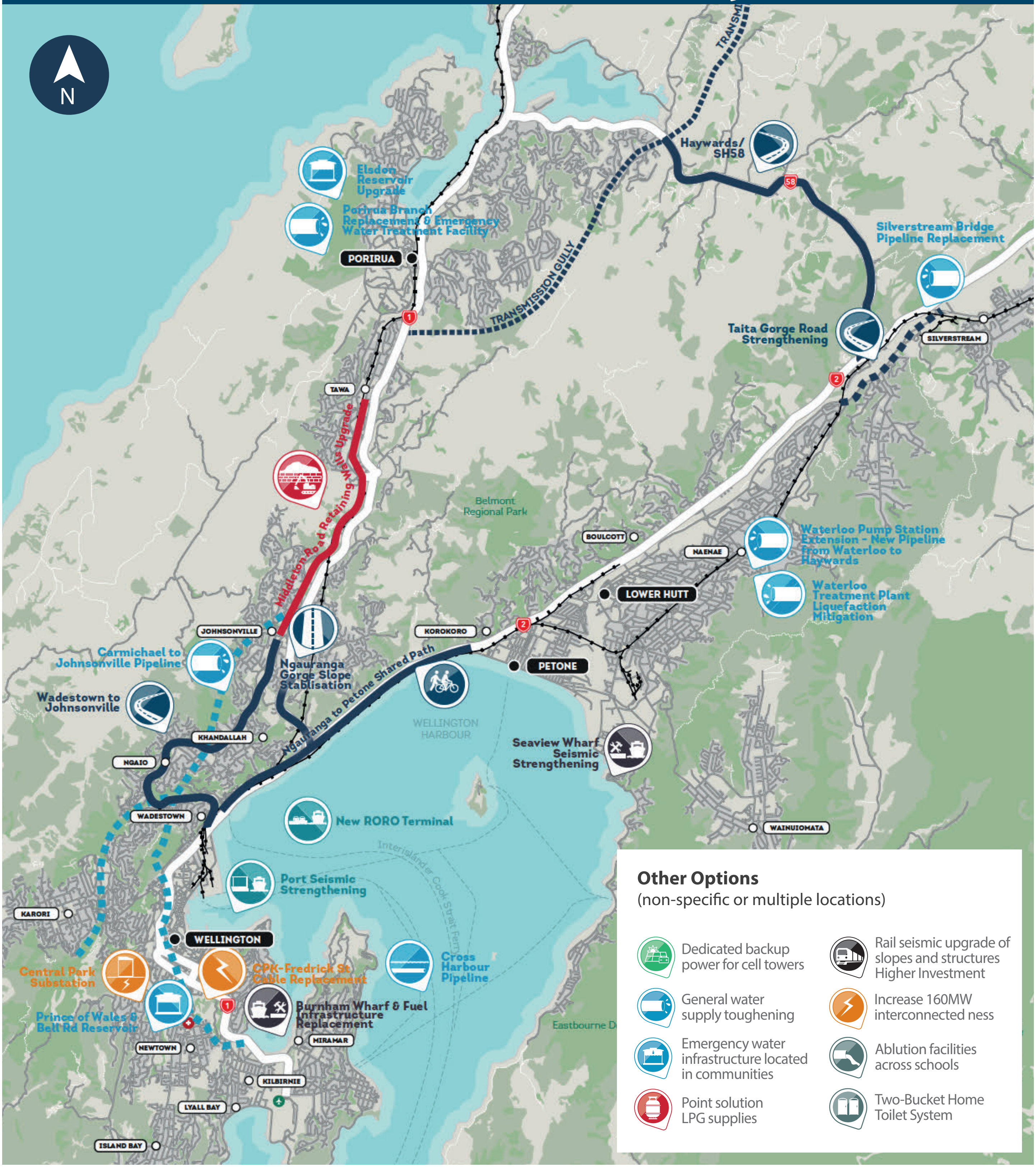
Ease of Implementation	Time to Implementation	Reliance on Other Options	Enables Other Outcomes	Lead Agency	Partner Agencies	Stakeholders	Environmental	Social	Cultural	Economic	Environmental	Social	Cultural	Economic	TOTAL MCA
1	Mid-term	Y	2	WE		Transpower, ComCom, MBIE	None	None	None	L	L	L	None	None	0.60
3	Mid-term	Y	2	WCC	NZTA		L	None	None	L	L	None	None	None	0.67
3	Mid-term	Y	0	WW		GWRC, HCC, UHCC	None	None	None	L	None	None	None	None	0.52
3	Mid-term	N	0	WW		GWRC, UHCC	L	None	None	L	L	None	None	None	0.52
2	Mid-term	N	3	Transpower / WE	Transpower / WE		None	None	None	L	L	None	None	None	0.77

Appendix J

Programme Alternative Maps



Lower Investment Level Programme



Other Options
(non-specific or multiple locations)

- Dedicated backup power for cell towers
- General water supply toughening
- Emergency water infrastructure located in communities
- Point solution LPG supplies
- Rail seismic upgrade of slopes and structures Higher Investment
- Increase 160MW interconnected ness
- Ablution facilities across schools
- Two-Bucket Home Toilet System

Appendix K

Lifelines Outage Modelling (RiskScape)

Wellington Resilience Programme Business Case: Lifelines Outage Modelling

E. Grace (comp)

GNS Science Consultancy Report 2017/236
December 2017

GNS SCIENCE
TE PŪ AO

DISCLAIMER

This report has been prepared by the Institute of Geological and Nuclear Sciences Limited (GNS Science) exclusively for and under contract to Greater Wellington Regional Council (GWRC) for the purpose of delivery of a Programme Business Case to Treasury which identifies the vulnerabilities of the Wellington Region's utility networks and the economic costs and benefits of increasing resilience. Unless otherwise agreed in writing by GNS Science, GNS Science accepts no responsibility for any use of or reliance on any contents of this report by any person other than GWRC and Treasury and shall not be liable to any person other than GWRC, on any ground, for any loss, damage or expense arising from such use or reliance.

BIBLIOGRAPHIC REFERENCE

Grace E, compiler. 2018. Wellington Resilience Programme business case: lifelines outage modelling. Lower Hutt (NZ): GNS Science. 75 p. (GNS Science consultancy report; 2017/236).

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EXECUTIVE SUMMARY

GNS Science, Market Economics and Resilience Organisations have undertaken damage and economic modelling to provide an evidence-base for the assessment of infrastructure programmes to improve Wellington's resilience to a major earthquake event. The outputs of the modelling are being used by Aurecon to inform the writing of a business case for infrastructure investment on behalf of the Wellington Lifelines Group.

A Mw7.5 Wellington Fault earthquake event and associated perils (fault rupture, ground shaking, liquefaction, landslides, lateral spreading, subsidence) was used to assess damage and economic disruption to the following infrastructure types: road, rail, port, airport, electricity, telecommunications, potable water, wastewater, fuel, and gas. Damage to buildings was also modelled. This modelling produced damage under the base-case: what is the damage and economic disruption expected should an earthquake occur tomorrow with current infrastructure? Two further stages of modelling were also undertaken:

1. Intervention Modelling – what is the damage and economic disruption expected should the same earthquake occur following the implementation of either of two separate infrastructure intervention programmes (two separate sets of results)? and
2. Preferred Programme Modelling – what is the damage and economic disruption expected should the same earthquake occur following the implementation of a preferred intervention programme?

The modelling tools RiskScape and MERIT were used. Workshops with lifeline providers were held to determine the extent of damage expected to the networks and the restoration strategies of the lifelines given that damage. This information was used to create temporal service outage maps that show the level of lifeline service expected throughout the region over time. These service outage maps were fed into MERIT, the economic model, which calculated a range of economic parameters including the change in GDP out to 5 years from the event as a measure of the disruption to the economy.

This report sets out the assumptions in the damage modelling and outage map creation process, and presents the final outage maps from each of the three stages of modelling. A companion report sets out the assumptions in the MERIT modelling process (Smith N., Brown C., McDonald G., Seville E., Ayers M., Kim J. 2017: *Wellington Resilience Programme Business Case: Modelling the Economics of Resilient Infrastructure Tool (MERIT) Assumptions Report*). Both this report and the companion MERIT report inform the business case report being prepared by Aurecon (Allard, J., Kenworthy, C. 2017: *Programme Business Case for Infrastructure Investment to Ensure the Wellington Region can Rebound after a Major Earthquake*).

1.0 INTRODUCTION

1.1 BACKGROUND

The Wellington Lifelines Group is running a process to prepare a Programme Business Case for investment in the resilience of Wellington's infrastructure. As part of this process, GNS Science, Market Economics and Resilience Organisations have undertaken damage and economic modelling to provide an evidence-base for the assessment of investment programmes. The outputs of the modelling are being used by Aurecon to inform the writing of the business case.

The Programme Business Case process has been run by Aurecon and has generally involved working with the lifeline organisations to identify infrastructure investment objects, generate a list of infrastructure investment projects, shortlist those projects and arrange them into infrastructure investment programmes, select a preferred programme of infrastructure investment to be included in the business case, and finally, write the Programme Business Case.

The modelling process has occurred in parallel to the business case process and has informed decisions made by lifeline organisations as the process has progressed. The modelling involved three stages:

> **Stage 1: Base-Case Modelling** – what is the damage to infrastructure and buildings and economic disruption expected should an earthquake occur tomorrow with the current infrastructure?
>
> **Stage 2: Intervention Modelling** – what is the damage and economic disruption expected should the same earthquake occur following the implementation of either of two separate infrastructure intervention programmes? This stage produced two separate sets of results, one for a higher investment programme and one for a lower investment programme. The programmes modelling were the result of the Aurecon-led business case process.
>
> **Stage 3: Preferred Programme Modelling** – what is the damage and economic disruption expected should the same earthquake occur following the implementation of a preferred infrastructure intervention programme? The programme modelled in this stage was that selected by the lifeline organisations as the preferred infrastructure investment programme. The programme was a middle-ground between the higher and lower investment programmes, including all the projects from the lower investment programme and some of the projects from the higher investment programme.

These three sets of results allow comparisons to be made, so that the impact of the intervention programmes can be assessed in the business case.

More detail of the business case process can be found in the business case document prepared by Aurecon (Allard, J., Kenworthy, C. 2017: *Programme Business Case for Infrastructure Investment to Ensure the Wellington Region can Rebound after a Major Earthquake*)

1.2 OVERVIEW OF MODELLING TOOLS

RiskScape and MERIT (Modelling the Economics of Resilient Infrastructure Tool) are the key tools used in the damage and economic assessment.

RiskScape is a multi-hazard risk assessment tool developed by GNS Science and NIWA that estimates damage and direct losses for assets exposed to natural hazards. The modelling software combines spatial information on hazards (e.g. earthquake, tsunami, flood), assets (e.g. buildings, lifeline infrastructure, people) and asset vulnerability to quantify the impacts on physical assets, as well as estimating the number of casualties and displaced populations. Losses to physical infrastructure are calculated from the direct replacement costs of the damaged assets.

MERIT is an economic impact assessment tool developed by GNS Science, Market Economics and Resilient Organisations that models the economic impact resulting from a loss of lifeline services (i.e. due to water, power, roading outages etc.). The resulting economic impact is measured in terms such as GDP at risk, employment at risk, income etc., across a variety of different economic sectors (e.g. education, retail, commercial, industrial) and over different time periods (days, weeks, months, years).

RiskScape and MERIT are used together to provide a combined damage loss assessment and economic impact analysis, giving a more comprehensive approach than either tool would in isolation (Figure 1.1). RiskScape outputs of damage, in conjunction with information on restoration strategies, are used to create temporal service outage maps, which are an input to the MERIT model.

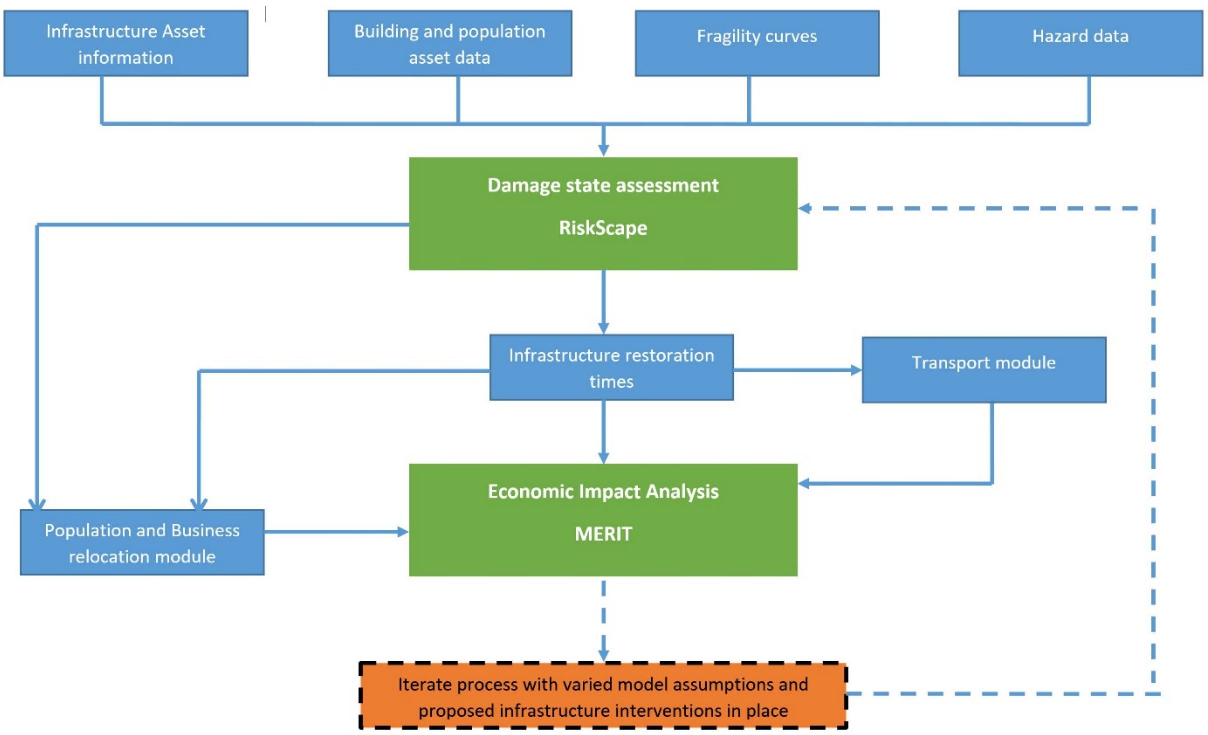


Figure 1.1 Linkages between the various stages of damage loss assessment and economic impact analysis for the Wellington Resilience PBC.

1.3 SCOPE OF MODELLING

The infrastructure types included in the modelling process were: road, rail, port, airport, electricity, telecommunications, potable water, wastewater, fuel, and gas. Damage to buildings was also modelled.

For the purposes of this project, the area of investigation is part of the Wellington Region, defined as the Kapiti Coast, Porirua, Wellington, Lower Hutt and Upper Hutt districts.

One hazard event was used for the modelling: a Mw7.5 Wellington Fault earthquake event and associated perils (fault rupture, ground shaking, liquefaction, landslides, lateral spreading, subsidence). Two other hazard scenarios had been considered: a Mw8.4 (approx.) subduction earthquake, and a weather event (storm/flooding, landslides) based on a Wahine storm event adjusted for climate change. However, based on information gathered during the Business Behaviours workshops held early in the project (see Brown, C. et al), these two other scenarios were found to be inappropriate as the basis for the project (too disruptive and not disruptive enough, respectively), and the project team selected the Wellington Fault event. This event is described in more detail in section 3.0 of this report.

Two types of outputs were provided by the modelling:

1. Temporal service outage maps
2. Figures for loss in GDP

The temporal service outage maps, created using a combination of RiskScape and GIS analysis, show the time taken for services to be fully restored across the study area. These were produced for each infrastructure type. These outage maps are used as an input to the MERIT model. The figures for loss of GDP, produced by MERIT, are provided up to five years after the event. As stated in section 1.1, the modelling was undertaken in three stages. There were therefore three sets of outputs, one for each stage.

1.4 SCOPE OF THIS REPORT

GNS Science was engaged to undertake damage and economic modelling part of the project. This report sets out the assumptions in the damage modelling and outage map creation process, and presents the final outage maps from each of the three stages of modelling. A companion report sets out the assumptions in the MERIT modelling process (Smith N. et al)). Both this report and the companion MERIT report inform the business case report being prepared by Aurecon.

The remainder of this report describes the damage and outage modelling framework for creating the temporal service outage maps, the hazard scenario used, the specific hazard modules used, and the specific network, or network component modelling assumptions used to develop temporal service outage maps under the Base-Case, Intervention Programmes, and Preferred Programme.

2.0 DAMAGE AND OUTAGE MODELLING FRAMEWORK

2.1 OVERVIEW OF PROCESS

There were three key steps in the process of creating the temporal service outage maps, which can be summarised as follows:

1. Data gathering: The modelling relied on network and asset data provided by the lifeline organisations. Significant work was required in some instances to cleanse data, fill gaps and prepare it for the modelling process, requiring specialised GIS analysis.
2. Damage modelling: This process took the network and asset data and built models, developed and applied fragility functions to the different components, prepared hazard models, and applied the hazard models to the network models to generate damage information (damage states for each component). This process used a combination of RiskScape and GIS analysis.
3. Outage map creation: In collaboration with lifelines organisations, restoration strategies were explored and the time taken for restoration of full service was calculated. This process used a mixture of quantitative, logic based, and network connectivity approaches, and specialist GIS analysis.

The outputs of this process were temporal service outage maps and information, which were used as inputs to the MERIT model for economic disruption analysis.

Further information about RiskScape, the damage modelling process, and the outage map creation process follows.

2.2 RISKSCAPE BACKGROUND

RiskScape uses a generic framework for estimating natural hazard impacts and losses (Figure **2.1**). The model has three key input modules: asset, hazard and vulnerability. Data or models represented in each module are combined in a 'loss' module to quantify asset impacts for a natural hazard event or scenario (Table 2.1).

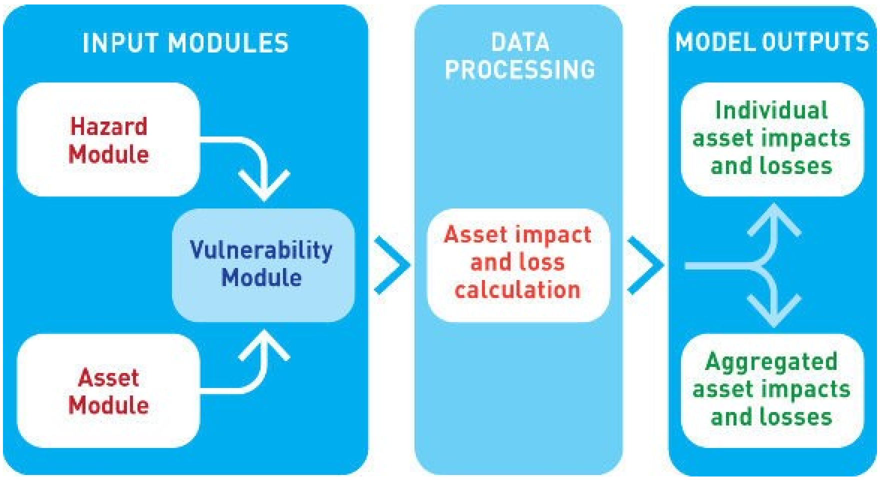


Figure 2.1 RiskScape Framework.

Table 2.1 RiskScape module definitions.

Module	Data or Model Type	Definition	Format
Hazard	Hazard Layer	A series of spatial representations of the severity of each of the phenomena generated by a hazard event or scenario.	Vector data or raster data
Asset	Asset Layer	The Spatial distribution of assets and their attributes.	Vector data
Vulnerability	Vulnerability Model	The suite of functions that derive direct and indirect losses from the severity of imposed hazard action for each asset class	Statistical function and/or set of rules (algorithm)
Loss	Aggregation Layer	Spatial information about areas or locations for calculating loss values.	Vector data

For this project, a typical modelling workflow (see Figure 2.2) was followed. Unless otherwise specified in this report, existing RiskScape hazard, asset, vulnerability and loss modules have been used. If calibrations were required to the existing modules, then a new module was created.

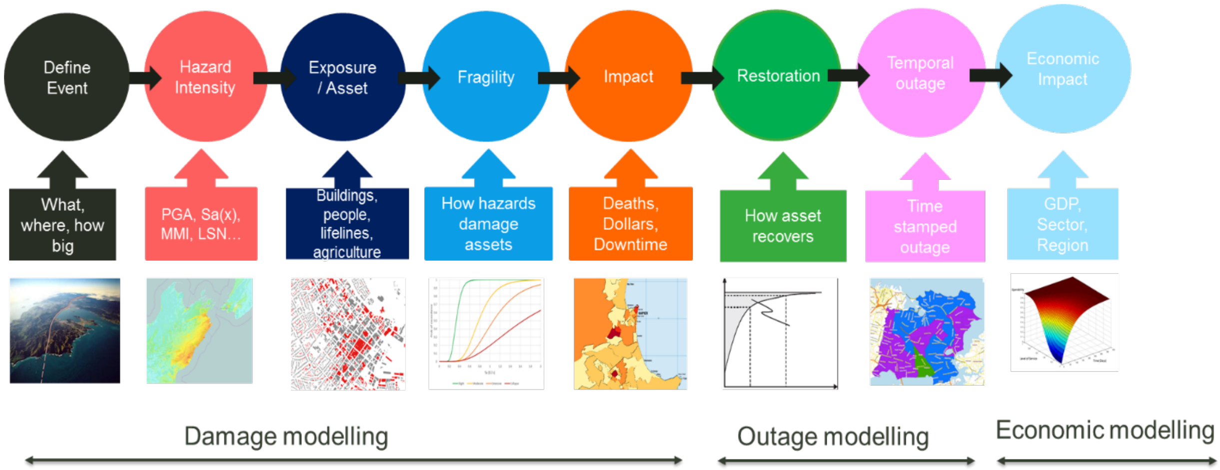


Figure 2.2 Workflow of modelling for temporal outage of lifelines.

2.3 DAMAGE MODELLING

Damage modelling for this project used GIS analysis and RiskScape and followed these steps:

1. An event was defined (see Section 3.0 of this report)
2. The relevant asset modules were created using data provided by participating lifelines operators. Any gaps in data were populated using expert engineering judgement.
3. Hazard modules were defined (see Section 4.0 of this report)
4. Using the asset modules created in Step 2 and the hazard modules created in Step 3, individual asset exposure was defined based on the spatial extent and hazard intensity of each peril.
5. A vulnerability module was then used (lognormal cumulative distribution function) to define the relationship between hazard intensity and the probability of reaching or exceeding a suite of damage states, based on an asset's exposure (Step 4) and specific attributes (e.g. age, function, material type) (Step 2).

6. By applying a random weighted distribution, each asset is assigned a single damage state. This impact approach represents a realistic distribution of damage for a single scenario. With each model run, individual asset impact distribution will vary, however the aggregated regional impacts remain roughly the same.
7. Impacts (i.e. damage) were presented to each participating lifeline provider to calibrate the model and if required the model was re-run until a credible impact scenario was achieved.

2.4 TEMPORAL SERVICE OUTAGE MAP CREATION

In collaboration with lifeline operators, restoration models were then developed, to understand the outages experienced by users of the lifeline service. This was done using quantitative, logic based or network connectivity approaches, or a combination of all three. The restoration models define credible component-based outage times and a regionwide, logic-based restoration strategy for each lifeline sector.

In collaboration with lifeline operators, sector specific coverage zones were defined. Any network or component-specific dependencies were defined to explore a logic based approach for assigning zone-based network outages. Mesh-blocks (the smallest geographical units which are used by Statistics New Zealand for data collection) were used to standardise outage zones across each sector's network coverage zones. The results were presented to participating lifeline providers to ensure credible outage times, with calibrations made if necessary.

Once outage information was established for individual sectors, time delays due to interdependencies with other sectors were added. In this context "interdependencies" is taken to refer to the critical links between components of different infrastructure systems. In the modern world, critical infrastructure can be extremely vulnerable to the effects of outages and resultant cascade effects that cause the impacts of outages to spread far beyond the original scope of the initiating problem. Here, interdependencies were considered at quite a coarse level since the detailed consideration and modelling of interdependencies on a city scale is outside of the scope of this work. As a result, information on interdependencies was gained through the expert knowledge of the lifeline operators. Table 2.2 shows how interdependencies have been accounted for in outage time calculations.

Table 2.2 Interdependencies accounted for in outage time calculations.

Sector	Interdependencies accounted for
Road	None
Rail	None
Port	Road
Airport	Road
Fuel	Road
Electricity	Road
Telecommunications	Road, electricity/fuel
Potable water	Road, electricity/fuel
Wastewater	Road, electricity/fuel, potable water
Gas	Road

GIS analysis was used to create outage information and maps. Time (days), spatial (meshblock), and service level (on or off) data was provided to the MERIT modellers. Representations of this information was presented on maps, using time bands rather than actual numbers of days, so that outage information could be compared across maps and sectors. This was considered useful by the project team for presenting the information in the business case workshops.

3.0 NATURAL HAZARD SCENARIO

Of three scenarios considered, a single Mw7.5 Wellington Fault earthquake event (fault rupture, ground shaking, liquefaction, landslides, lateral spreading, subsidence) was selected by the project team for modelling, based on information gathered during the Business Behaviours workshops held early in the project (see Brown, C., Seville, E., (2017) *Wellington Lifelines Resilience Project Programme Business Case: Business Behaviours Workshops, April 2017*, Resilient Organisations). This scenario represents a major impact event while still allowing for a credible recovery of the region. This scenario is well researched and commonly used for insurance and business continuity planning. This event has a probability of occurrence of 10% in the next 100 years but is also the dominant contributor to the 1 in 500-year earthquake hazard which is used to define the seismic loading levels for the building code for Importance Level 2 buildings (i.e. general multi-story commercial and residential buildings). The scenario consisted of a single main shock, and aftershocks were not considered.

The Wellington Fault scenario has many of the same characteristics as other large earthquakes that could occur in the Wellington region, including earthquakes on the Ohariu Fault to the west of Wellington, the Wairarapa Fault to the east of Wellington and the Hikurangi Subduction Zone. Similar characteristics would include the level of ground shaking, the number of landslides and the distribution of liquefaction. This means that any intervention measures to mitigate the impacts from these hazards in a Wellington Fault earthquake will also have benefits for these other scenarios. Furthermore, by designing resilience measures to mitigate the impact from a ‘maximum credible’ scenario such as the Wellington Fault earthquake, the benefits from the interventions will also minimise the impact from smaller, more frequent earthquakes that occur in the region, or larger events that occur at large distances (e.g. Alpine Fault earthquake). Resilience measures undertaken for earthquake may also mitigate losses to other hazard events such as flooding or rainfall induced landsliding. The fault rupture hazard that was modelled is specific to the Wellington Fault.

4.0 HAZARD MODELS

The following hazards were considered in the project (see Table 4.1):

- Ground shaking
- Liquefaction
- Lateral spreading
- Landslide
- Subsidence
- Fault rupture

Table 4.1 Hazard models used for Welling Resilience PBC modelling.

Hazard	Description	Measurement Unit(s)	Source
Fault rupture	Zone of deformation related to fault rupture	Hazard Footprint	(Berryman, 1990; Stirling *et al.*, 2012)
Ground shaking intensity	Ground shaking from earthquake	Peak Ground Acceleration (PGA), Moment Magnitude Intensity (MMI)	Worden *et al.*, 2012; Bradley, 2013
Liquefaction	Liquefaction from ground shaking	Liquefaction Severity Number (LSN), Liquefaction Susceptibility	Dellow, Perrin and Ries, 2015, MINERVA EQC loss model
Lateral Spreading	Lateral spread from ground shaking and liquefaction	Probability of occurrence	
Landslide	Landslide footprint generated from ground shaking	Volume (m^3)	(Sadashiva, King and Matcham, 2017)
Subsidence	Mean co-seismic subsidence generated by fault movement	Hazard footprint	Townsend *et al.*, 2016

The following perils were not included:

- **Fire following earthquak**e: The FFE earthquake model developed by (Cousins et al., 2012) was a prototype model for Wellington City. It was recommended by those authors that future work is needed to refine the ignition model as this is highly uncertain and is somewhat biased by only including ignition rates from earthquakes with fires. Work is underway as part of the 'Its Our Fault' project to review the ignition model and update the FFE model. This work is due for completion in 2018 so will not be ready for the WelRes project.
- **Tsunami:** modelling indicates that there will be searching and minor inundation around the harbour edges in a Wellington Fault earthquake. Given the relative minor inundation compared to the other hazards, and significant work required to include tsunami impacts, it is not modelled.

The hazard models included in the project are outlined in detail below.

4.1 FAULT RUPTURE MODEL

Fault rupture is defined as a deformation zone (Figure 4.1) around the fault trace. This model uses the mapped trace of the Wellington-Hutt Valley segment of the Wellington Fault and a buffer distance of 20-50 m, as was used in the recent Hazard Review for Hutt City Council (Townsend *et al.*, 2016). Unless otherwise specified, fault rupture is assumed to result in displacement and severing of all infrastructure components crossing the fault.

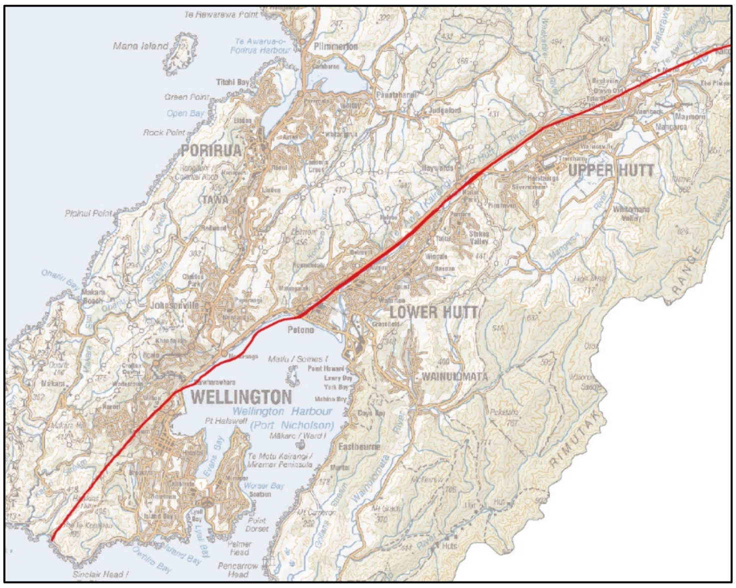


Figure 4.1 Map of location of Wellington-Hutt Valley Segment of the Wellington Fault (red) and deformation zone (Berryman, 1990; Stirling et al., 2012).

4.2 GROUND SHAKING

Ground shaking is estimated using the fault source model of the Wellington to Hutt Valley Fault as defined in the NZ National Seismic Hazard model (Stirling et al., 2012). Ground shaking is estimated across the region using the ground motion prediction equation (GMPE) of (Bradley, 2013) which is currently the preferred model (i.e. highest weighting) for active shallow crust fault sources. The ground shaking includes site amplification based on the site class map for Wellington developed during the ‘Its our Fault’ project (Perrin and Stephenson, 2010; Boon et al., 2011). Two ground shaking models are developed using the OpenQuake engine (an opensource earthquake hazard and risk modelling tool developed by the Global Earthquake Model): 1) A single ground motion field map of median ground shaking 2) 100 ground motion field realizations including uncertainty in the GMPE (both inter-event and intra-event) with the median model being used (Figure 4.2). To accommodate fragility models in Modified Mercalli Intensity Scale (MMI) the ground motion to intensity conversion equation (GMICE) of Worden et al., 2012 is used.

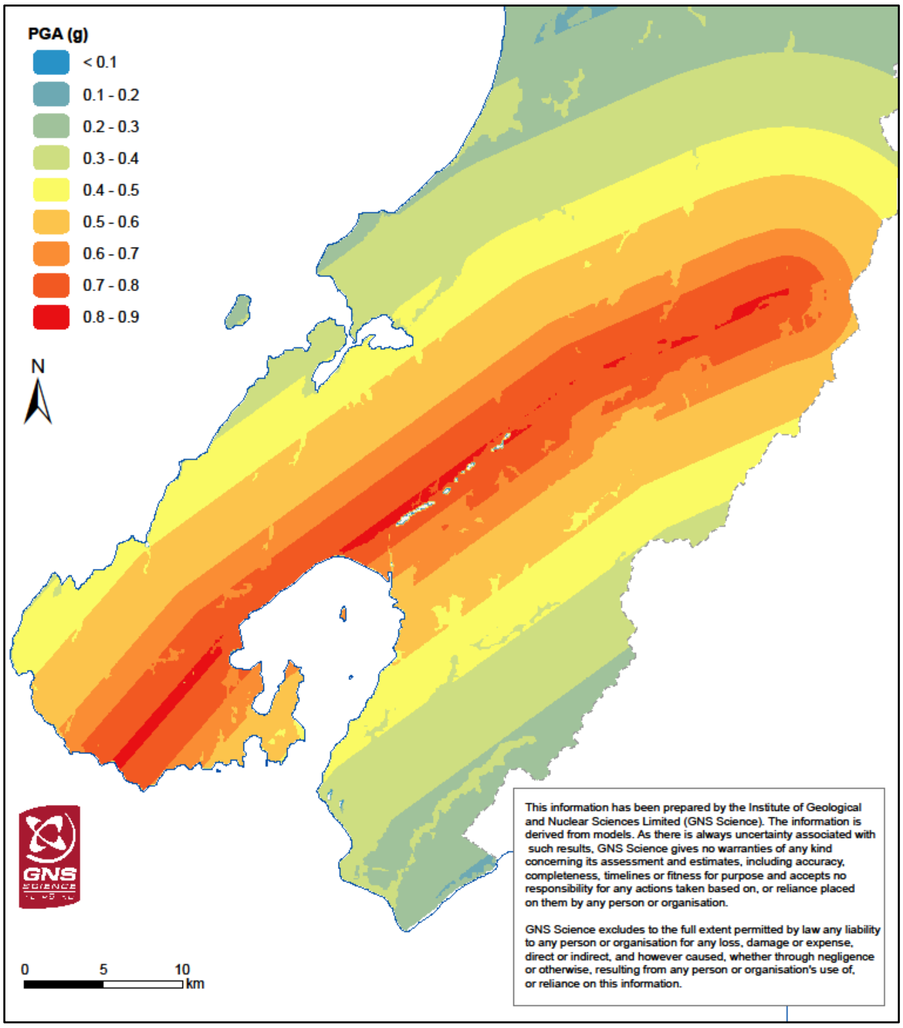


Figure 4.2 Peak Ground Acceleration (PGA) for Wellington Fault Scenario.

4.3 LIQUEFACTION

Liquefaction is represented by two models (both shown in Figure 4.3): 1) Liquefaction severity number (LSN) which is based on the magnitude of the earthquake and peak ground acceleration (PGA); 2) Liquefaction susceptibility which is a 5-level categorical layer which ranges from very low, low, moderate, high, very high, (Dellow, Perrin and Ries, 2015). Mean LSN was used for modelling. The LSN data is output from the EQC loss model 'MINERVA' using outputs from the development of the MINERVA Liquefaction Loss Model. LSN data is only available across residential areas of the Wellington City, Hutt City and Upper Hutt. Liquefaction vulnerability is incorporated into the relevant RiskScape vulnerability modules through a damage enhancement for LSN based functions and a shaking enhancement incorporated into liquefaction severity based functions.

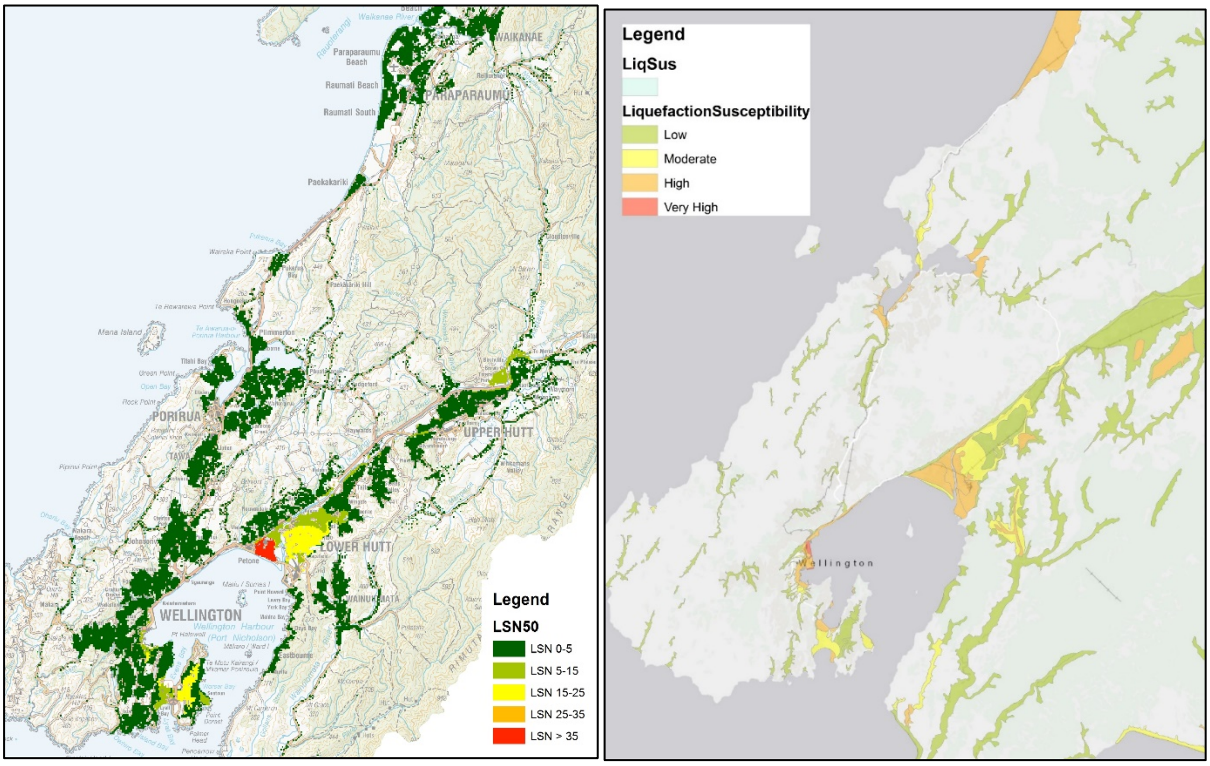


Figure 4.3 Mean LSN (left) and liquefaction susceptibility (right) values for the Wellington Fault scenario (Dellow, Perrin and Ries, 2015).

A separate liquefaction (LSN) model was developed specifically for this project, by combining liquefaction susceptibility with LSN to address gaps in the LSN model. The susceptibility values were assumed to be equivalent to LSN in that Low = LSN 0-16, Moderate = 17-25, High = >25. The few instances of Very High susceptibility are considered equivalent to 100% lateral spreading probability (see Section 4.4). This was applied exclusively to potable water and waste water assets, which are particularly susceptible to liquefaction and were not captured in either liquefaction model in isolation. A separate model again was developed specifically within this project for Kapiti Coast for modelling of potable and waste water assets. This used expert judgement to assign liquefaction susceptibility classes based on soil conditions.

4.4 LATERAL SPREADING

In most cases, lateral spreading is incorporated within the liquefaction LSN or susceptibility models. Separate lateral spreading models developed explicitly within the Wellington Resilience Project and use expert judgement to map susceptibility probability zones within Lower Hutt and Wainuiomata for use in potable and waste water modelling y (Figure 4.4).

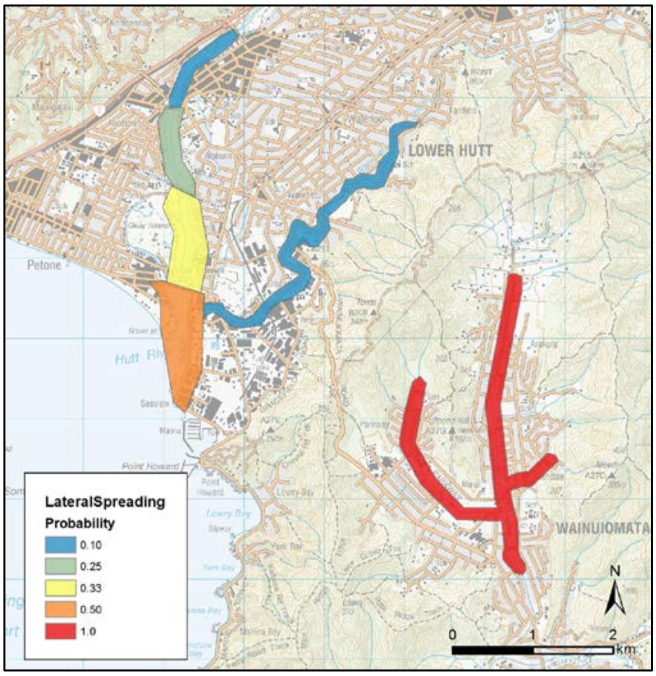


Figure 4.4 Map showing lateral spreading zones of varying occurrence probabilities in Lower Hutt and Wainuiomata.

4.5 LANDSLIDES

Landslides are explicitly modelled within the project. Slopes in the Wellington Region have been mapped and assigned a probability of failure (and size of failure) given a level of PGA. Landslides are then modelled stochastically based on the input PGA map provided from the ground shaking model. Landslides are modelled within the RiskScape NZTA tool which was designed to model landslide impacts to the roading network. Six realisations of landslide distribution were modelled and from these a typical representation, being the most commonly encountered in the six reviewed, was selected (Figure 4.5). A separate realisation was used for roads and rail which was more credible for those networks. Unless otherwise specified, landslides are assumed to result in the highest level of component damage.

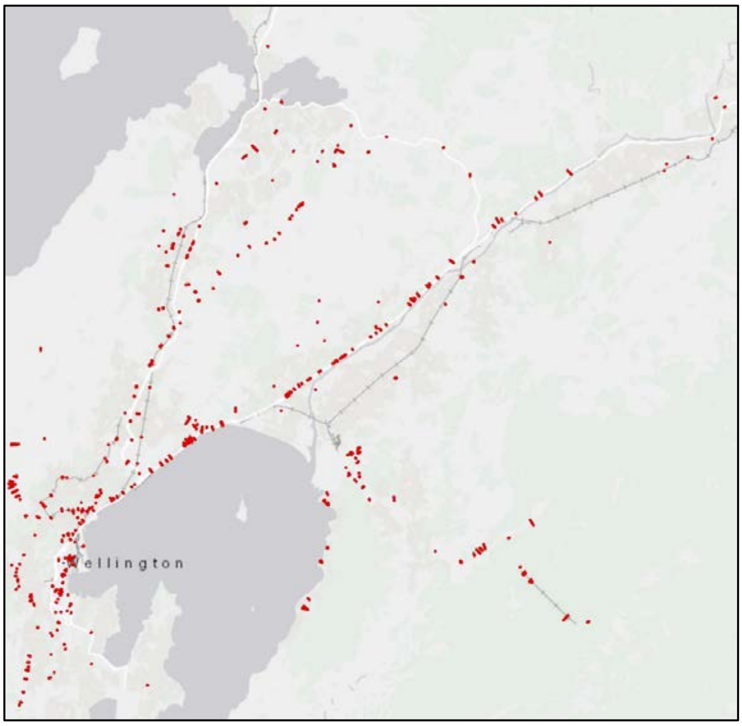


Figure 4.5 A single realisation of landslide distribution from the RiskScape NZTA Tool landslide model for the Wellington region. Landslides are shown in red.

4.6 CO-SEISMIC SUBSIDENCE

Subsidence caused by fault movements can result in some areas to be inundated by seawater. Subsidence hazard zones are defined as those where the estimated mean subsidence of the Wellington-Hutt Valley segment of the Wellington Fault is below MSL. This model is based on work from 'It's our Fault' and is derived from a range of geological datasets (Townsend *et al.*, 2016). The area modelled only includes the Hutt Valley (Figure 4.6). There has been little work to date on possible subsidence in Wellington City from a Wellington Fault earthquake and therefore cannot be included in the model. Unless otherwise specified, subsidence is assumed to result in the highest level of component damage.

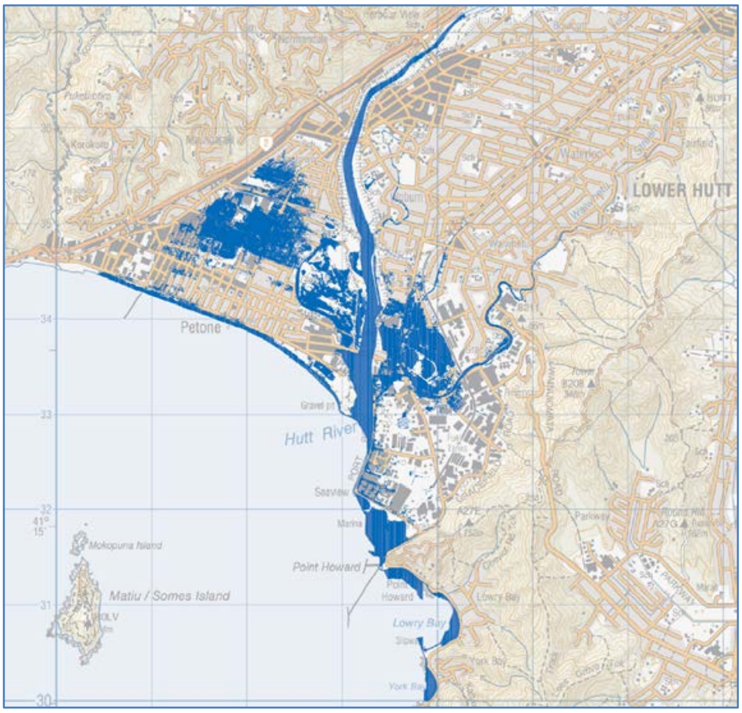


Figure 4.6 Estimated subsidence (dark blue) extent (areas below MSL) resulting from a M7.5 Wellington Fault earthquake (based on Townsend *et al.*, 2016).

5.0 TRANSPORTATION LIFELINES

5.1 ROADS

5.1.1 Asset Data

The road network within the study area was simplified into 24 transportation zones. The key linkage routes between these zones were used in the modelling. The zones and linkages were chosen based on expert judgement and pre-existing road hierarchies (Figure 5.1). The key linkages included New Zealand Transport Agency's (NZTA) ONRC road categories: all National, High Volume and Regional roads in the study area, and some arterial and collector roads. These routes are also identified in the 'Priority Roads' mapping exercise lead by the Wellington Regional Emergency Management Office (WREMO).

The key linkage routes were geographically represented within a segmented GIS layer with a set of attributes for each road segment that assigned appropriate fragility functions corresponding to the type of asset (i.e. bridges, tunnels or retaining walls).

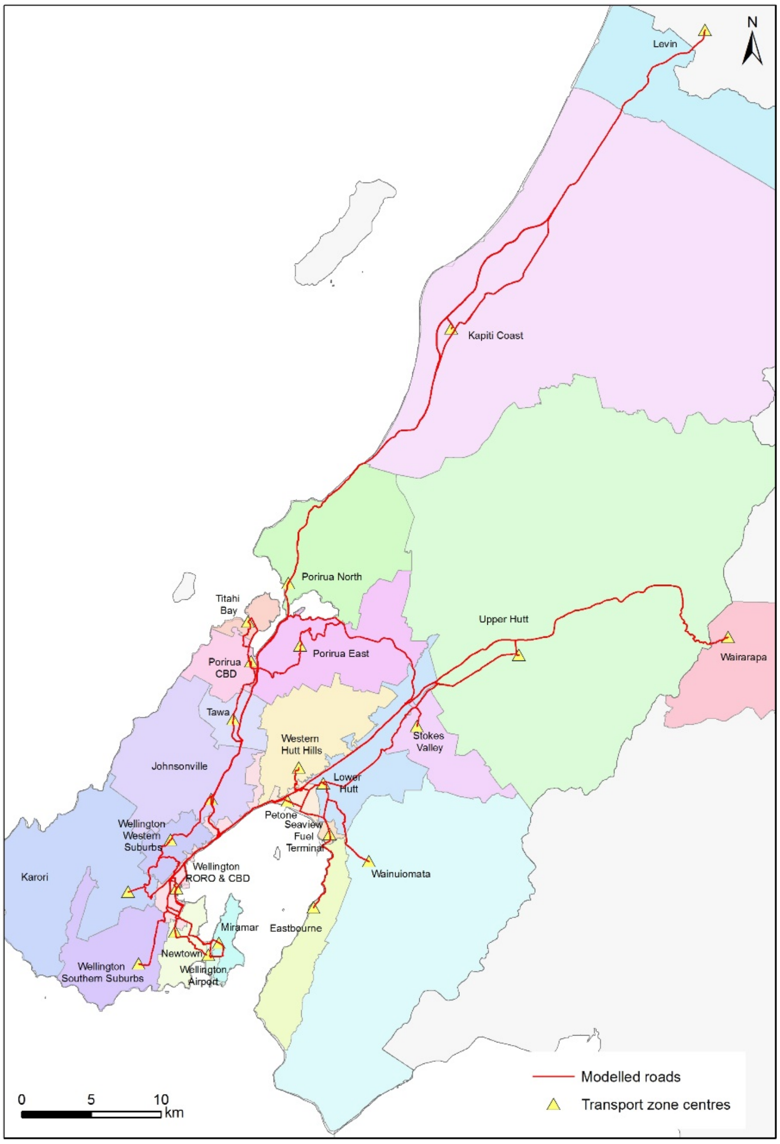


Figure 5.1 Transportation zones and routes selected for damage modelling.

5.1.2 Vulnerability and Impact Modelling

Impacts of the Wellington Fault earthquake on the road network was estimated using vulnerability models incorporated within the GNS-NZTA Road Risk Evaluation Tool (Sadashiva, King and Matcham, 2017). Past and recent earthquakes have shown that bridges, tunnels and retaining walls are the common road structures that are vulnerable to ground shaking, while significant damage to the road itself are also evident due to ground failure (e.g. liquefaction and surface fault rupture). Therefore, the above road assets (roads, bridges, retaining walls) were selected for damage modelling, and fragility functions previously developed (King et. al. 2015) were applied for such assets along the selected routes for this study. Where additional / detailed information on the assets were made available by the roading managers such information was also used for damage modelling.

Damage to one or more assets due to an earthquake can result in disruption to the normal traffic flow at any road segment. Table 5.1 outlines the Service Disruption Levels (SDL) adopted for this project. Figure 5.2 shows the road disruption map for the earthquake event considered for this project. The map shows the critical SDL for each road segment. For example, consider a road segment with a bridge and a tunnel; if the SDL due to bridge damage = 3, SDL due to tunnel damage is 2 and SDL due to damage to road itself is 4 (note these are critical SDL as a result of damages due to all considered perils associated with the event for each asset), then the final SDL reported for the road segment is the maximum SDL (= 4 in this example).

Table 5.1 Service Disruption Levels for all hazards (Sadashiva, King and Matcham, 2017).

Service Disruption Level	Disruption State	Extent of damage affecting	Likely damage characteristics
SDL0	None	None	None
SDL1	Minor	Fringe / shoulder	Requiring visual inspection & "patch-up" / clearing / cosmetic nature works due to any of following: (a) Debris deposition; (b) Slight settlement or minor offset of ground; (c) Minor damage to protection works such as a seawall; or (d) Minor abutment settlement, bridge expansion joint & bearing showing movement, hairline cracking and spalling to bridge elements / tunnel liner
SDL2	Moderate	Single lane	Requiring visual inspection & moderate amount of clearing works / repairing components (as required) due to any of the following: (a) Moderate volume of debris deposition; (b) Moderate settlement or ground offset; or (c) Cracking and spalling of bridge piers / tunnel liner exposing core, abutment backwall / wing wall cracking, anchor bolt damage, extensive cracking and spalling of shear keys, damage to restrainers, moderate offset of bearings
SDL3	Significant	Several lanes	Requiring detailed inspection & moderate – significant repair / stabilisation works, some rebuild / replacement may be required due to any of the following: (a) Significant volume of debris deposition, significant structural damage or collapse of short-medium high retaining walls; (b) Ripple distortion or loss of foundation support of carriageway; or (c) Bridge structural significantly compromised, tilting of substructure, approach slab rotation, joint seal failure, large spalls due to pounding, significant cracking and spalling in piers / abutment walls, large approach settlements, major ground settlement at a tunnel portal and/or extensive cracking of the tunnel liner
SDL4	Severe	Complete road closure	Requiring detailed inspection & significant repair / stabilisation works, most likely rebuild / replacement required due to any of the following: (a) Significant volume of debris / ashfall deposition; (b) Major settlement of ground; or (c) Bridge components damaged beyond repair, loss of bearing support / one or more spans dropped, foundation failure, excessive tilting and movement of abutments, culverts scoured, major cracking of tunnel liner which may include possible collapse, complete failure of a steep and / or a high retaining wall

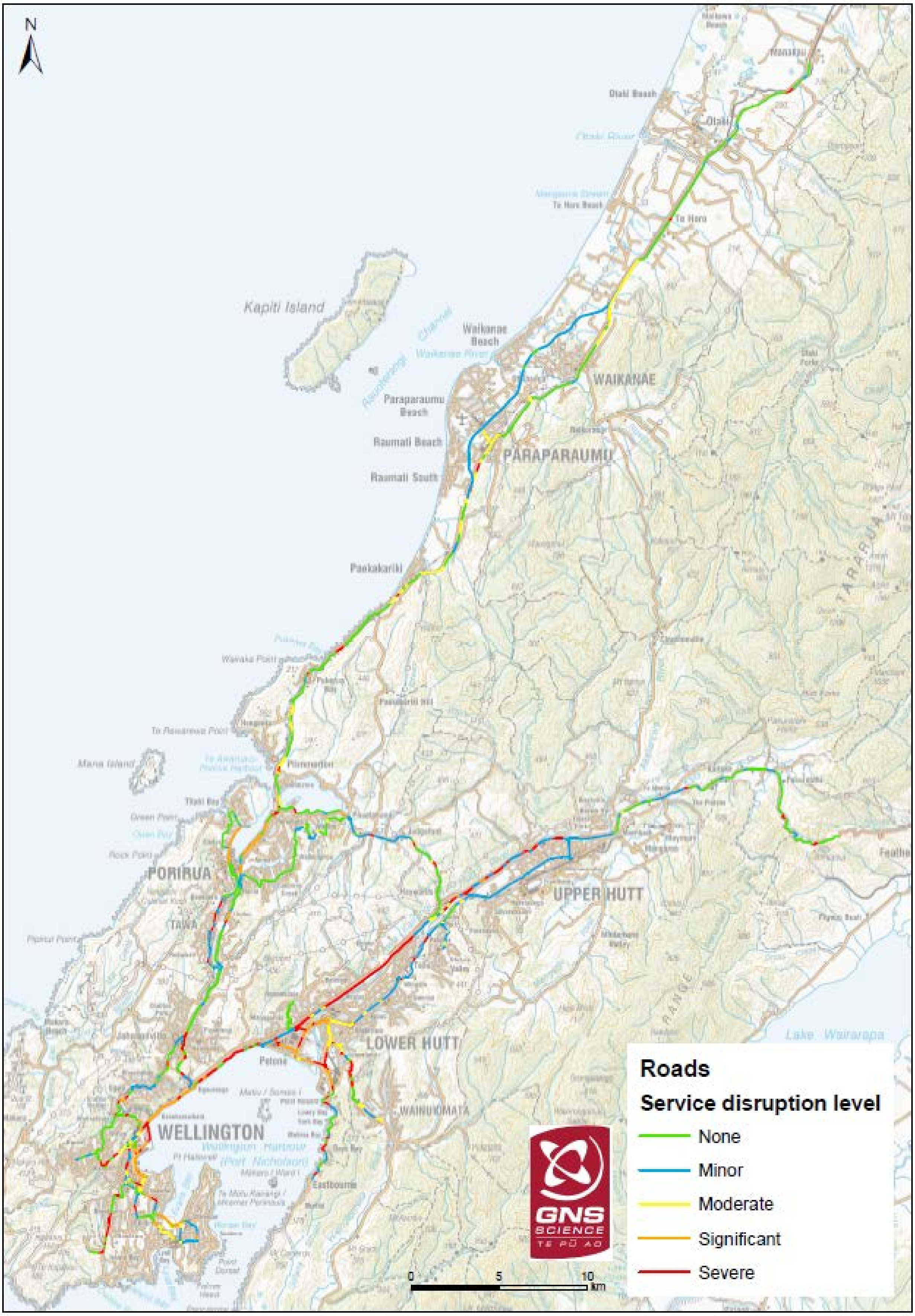


Figure 5.2 Service Disruption Level for modelled roads.

5.1.3 Base-Case Outages

The road disruption map (Figure 5.2) was reviewed by road managers during consultation on the restoration times for this project. Where an estimate of the times for providing access between the transportation zones was needed for roads not modelled by GNS, the Opus (OPUS, 2012) results for the alternate routes were also discussed and applied by the roading managers.

Restoration times were estimated for two types of service: response and recovery. Response service is used to show how long it takes to achieve access for emergency purposes. Recovery service is used to show how long it takes for usual service to be restored for the general public.

Table 5.2 & Table 5.3 show the likely restoration times for the key routes for the two levels of services (i.e. response and recovery) that were determined using expert opinion of the roading teams.

Table 5.2 Road zone outage times (days) for response.

	Levin	Kapiti Coast	Porirua North	Titahi Bay	Porirua CBD	Porirua East	Tawa 'CBD'	Johnsonville CBD	Wlgtn western suburbs	Karori	Wlgtn RORO& CBD	Newtown	Wlgtn southern suburbs	Wlgtn Airport	Miramar	Upper Hutt CBD	Stokes Valley	Western Hutt Hills	Lower Hutt	Petone	Wainuiomata	Seaview Fuel Terminal	Eastbourne	Wairarapa
Levin																								
Kapiti Coast	7																							
Porirua North	7	5																						
Titahi Bay	7	3	5																					
Porirua CBD	7	3	5	2																				
Porirua East	7	3	5	2	2																			
Tawa 'CBD'	7	3	5	2	1	2																		
Johnsonville CBD	7	7	7	7	7	7	7																	
Wlgtn Western Suburbs	7	7	7	7	7	7	7	3																
Karori	13	13	13	13	13	13	13	13	13															
Wlgtn RORO&CBD	10	10	10	10	10	10	10	10	10	13														
Newtown	14	14	14	14	14	14	14	14	14	14	14													
Wlgtn Southern Suburbs	10	10	10	10	10	10	10	10	10	13	14	14												
Wlgtn Airport	14	14	14	14	14	14	14	14	14	14	14	12	14											
Miramar	14	14	14	14	14	14	14	14	14	14	14	14	14	14										
Upper Hutt Cbd	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90									
Stokes Valley	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	7								
Western Hutt Hills	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	40	40							
Lower Hutt	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	7	3	40						
Petone	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	21	21	40	21					
Wainuiomata	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	10	10	40	10	21				
Seaview Fuel Terminal	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	10	10	40	10	21	10			
Eastbourne	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	30	30	40	30	30	30	30		
Wairarapa	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	90	90	90	90	90	90	90	90	

Table 5.3 Road zone outage times (days) for recovery.

	Levin	Kapiti Coast	Porirua North	Titahi Bay	Porirua CBD	Porirua East	Tawa 'CBD'	Johnsonville CBD	Wlgtn western suburbs	Karori	Wlgtn RORO& CBD	Newtown	Wlgtn southern suburbs	Wlgtn Airport	Miramar	Upper Hutt CBD	Stokes Valley	Western Hutt Hills	Lower Hutt	Petone	Wainuiomata	Seaview Fuel Terminal	Eastbourne	Wairarapa
Levin																								
Kapiti Coast	28																							
Porirua North	28	21																						
Titahi Bay	28	21	21																					
Porirua CBD	28	21	21	14																				
Porirua East	28	21	21	21	21																			
Tawa 'CBD'	28	21	21	14	7	21																		
Johnsonville CBD	97	97	97	97	97	97	97																	
Wlgtn western suburbs	97	97	97	97	97	97	97	93																
Karori	103	103	103	103	103	103	103	103	103															
Wlgtn RORO&CBD	100	100	100	100	100	100	100	100	100	103														
Newtown	104	104	104	104	104	104	104	104	104	104	104													
Wlgtn southern suburbs	104	104	104	104	104	104	104	104	104	104	104	104												
Wlgtn Airport	104	104	104	104	104	104	104	104	104	104	104	102	104											
Miramar	104	104	104	104	104	104	104	104	104	104	104	104	104	104										
Upper Hutt CBD	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120									
Stokes Valley	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	21								
Western Hutt Hills	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180							
Lower Hutt	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	21	14	180						
Petone	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	30	30	180	30					
Wainuiomata	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	49	49	180	49	49				
Seaview Fuel Terminal	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	42	42	180	42	42	49			
Eastbourne	138	138	138	138	138	138	138	138	138	138	138	138	138	138	138	138	138	180	138	138	138	138		
Wairarapa	28	28	28	28	28	28	28	97	97	103	100	104	104	104	104	120	120	180	120	120	120	120	138	

5.1.4 Intervention outages

Due to the nature of the intervention projects selected for this project (see below) it was decided after consultation with the respective roading teams that no explicit damage modelling of these projects was necessary. It was assumed that the proposed works will undergo detailed engineering assessments, geotechnical investigations, meet current standard requirements etc., and risks identified will be addressed accordingly.

> ***Intervention projects:***
> ***Wadestown to Johnsonville route*** *- strengthening of supporting retaining walls and some engineering of major uphill slopes results in a reduction of outage time*
> ***Middleton Road retaining walls upgrade*** *– this link is not included in damage modelling and therefore has no effect on outage time for roads*
> ***Clifton Terrace On-ramp bridge slope stabilisation*** *- this link is not included in damage modelling and therefore has no effect on outage time for roads*
> ***Ngauranga Gorge Accelerated Resilience*** *– some slopes are proposed to be stabilised (minor works only), therefore this has no effect on outage time for roads*
> ***Ngauranga to Petone Shared Pathway and realign rail*** *- It was assumed that this initiative would not provide an access that would provide an economically viable access, so was not considered for input to the response or recovery matrices and therefore has no effect on outage times for roads*
> ***SH58 Haywards seismic upgrades from TG to Hutt Valley*** *- slope stabilisations of slopes above SH58 at Haywards Hill result in a reduction of outage times for respective zones*
> ***Taita Gorge Access Strengthening*** *– strengthening of a retaining wall (supporting the road) - results in a reduction of outage time*
> ***Hutt River Bridges Strengthening*** *– project already completed and strengthening works are not expected to withstand a Wellington fault rupture and therefore has no effect on road outage time*
> ***East West Link*** *– a new route including a new bridge across the Hutt river so resulting in a reduction to outage time*
> ***Petone to Grenada*** *- a new route resulting in a reduction to outage time*
> ***RORO better engineered road links to port*** *– some strengthening works to road network near port facility that is expected to result in a reduction to outage time*
> ***Improve resilience of airport connectivity to city networks via Newtown*** *– strengthening results in a reduction to road outage times*

The intervention projects had been arranged into two programmes. The effects to road outages from the two intervention programmes is summarised in Table 5.4 & Table 5.5.

Table 5.4 Low Investment road outage times (days) for response.

	Levin	Kapiti Coast	Porirua North	Titahi Bay	Porirua CBD	Porirua East	Tawa 'CBD'	Johnsonville CBD	Wlgtn western suburbs	Karori	Wlgtn RORO& CBD	Newtown	Wlgtn southern suburbs	Wlgtn Airport	Miramar	Upper Hutt CBD	Stokes Valley	Western Hutt Hills	Lower Hutt	Petone	Wainuiomata	Seaview Fuel Terminal	Eastbourne	Wairarapa
Levin																								
Kapiti Coast	7																							
Porirua North	7	5																						
Titahi Bay	7	3	5																					
Porirua CBD	7	3	5	2																				
Porirua East	7	3	5	2	2																			
Tawa 'CBD'	7	3	5	2	1	2																		
Johnsonville CBD	7	7	7	7	7	7	7																	
Wlgtn western suburbs	7	7	7	7	7	7	7	3																
Karori	13	13	13	13	13	13	13	13	13															
Wlgtn RORO&CBD	7	7	7	7	7	7	7	5	5	13														
Newtown	14	14	14	14	14	14	14	14	14	14	14													
Wlgtn southern suburbs	10	10	10	10	10	10	10	10	10	13	14	14												
Wlgtn Airport	14	14	14	14	14	14	14	14	14	14	14	12	14											
Miramar	14	14	14	14	14	14	14	14	14	14	14	14	14	14										
Upper Hutt CBD	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14									
Stokes Valley	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	7								
Western Hutt Hills	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40							
Lower Hutt	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	7	3	40						
Petone	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	40	21					
Wainuiomata	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	10	10	40	10	21				
Seaview Fuel Terminal	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	10	10	40	10	21	10			
Eastbourne	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	40	30	30	30	30		
Wairarapa	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	40	21	21	21	21	30	

Table 5.5 Higher Investment road outage times (days) for response.

	Levin	Kapiti Coast	Porirua North	Titahi Bay	Porirua CBD	Porirua East	Tawa 'CBD'	Johnsonville CBD	Wlgtn western suburbs	Karori	Wlgtn RORO& CBD	Newtown	Wlgtn southern suburbs	Wlgtn Airport	Miramar	Upper Hutt CBD	Stokes Valley	Western Hutt Hills	Lower Hutt	Petone	Wainuiomata	Seaview Fuel Terminal	Eastbourne	Wairarapa
Levin																								
Kapiti Coast	7																							
Porirua North	7	5																						
Titahi Bay	7	3	5																					
Porirua CBD	7	3	5	2																				
Porirua East	7	3	5	2	2																			
Tawa 'CBD'	7	3	5	2	1	2																		
Johnsonville CBD	7	7	7	7	7	7	7																	
Wlgtn western suburbs	7	7	7	7	7	7	7	3																
Karori	13	13	13	13	13	13	13	13	13															
Wlgtn RORO&CBD	7	7	7	7	7	7	7	5	5	13														
Newtown	14	14	14	14	14	14	14	14	14	14	14													
Wlgtn southern suburbs	10	10	10	10	10	10	10	10	10	13	14	14												
Wlgtn Airport	14	14	14	14	14	14	14	14	14	14	14	7	14											
Miramar	14	14	14	14	14	14	14	14	14	14	14	14	14	14										
Upper Hutt CBD	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15									
Stokes Valley	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	7								
Western Hutt Hills	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40							
Lower Hutt	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	7	3	40						
Petone	7	3	5	3	3	3	3	7	7	13	7	14	14	14	14	15	15	40	15					
Wainuiomata	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	7	7	40	7	15				
Seaview Fuel Terminal	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	7	7	40	7	15	7			
Eastbourne	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	40	30	30	30	30		
Wairarapa	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	40	21	21	21	21	30	

5.1.5 Preferred Programme Outages

The roading intervention projects selected for the preferred programme were the same as those included in the higher investment programme. The preferred programme outages for roads are therefore the same as those for the higher programme (Table 5.5).

5.2 RAIL

5.2.1 Assets

Damage modelling of the rail network followed a similar approach as taken for modelling the road network. A GIS layer of the rail network and accompanying attributes defining various rail assets were provided by KiwiRail. Figure 5.3 shows the different railway lines in the study area that provide freight and passenger services. Also shown are the other rail assets (i.e. tracks, bridges and tunnels) selected for damage modelling.

Figure 5.3 Railway assets modelled.

5.2.2 Vulnerability and Impact Modelling

Damage states for the selected rail assets was largely based on engineering judgement and further verified with KiwiRail.

Figure 5.4 shows the rail network damage state map for the earthquake event considered for this study. Similar to the road disruption map, the rail damage map shows the critical damage state for each track segment. A track segment is approximately 200m in length and may include other rail assets.

Figure 5.4 Modelled damage to the Wellington Region rail network.

5.2.3 Base-case Outages

Outage times (Table 5.6) were derived through consultation with KiwiRail staff for the base-case for both the services (i.e. freight and passenger) using the above damage state map.

Table 5.6 Rail network outage times for base case.

Service	Base Case
Freight	12-36 months
Interisland Rail Freight	24 -36 months
Passenger	36 - 42 months

5.2.4 Intervention Outages

No specific intervention project(s) were defined for the rail network. Instead, Aurecon (in consultation with KiwiRail) provided the likely restoration times (Table 5.7) as a result of rail seismic upgrades of slopes and structures (yet to be fully scoped at the time of writing this report) under low and high investment categories.

Table 5.7 Rail network outage times considering intervention programme.

Service	Low Investment	High Investment
Freight	9-36 months	6-30 months
Interisland Rail Freight	18-36 months	12-30 months
Passenger	39 months	33 months

5.2.5 Preferred Programme Outages

The rail intervention project selected for the preferred programme was the same as those included in the low investment programme. The preferred programme outages for rail are therefore the same as the low investment outages (Table 5.7).

5.3 Port

Outage times for the Port were developed through a series of workshops with Port Wellington. The hazard models were presented along with likely levels of damage to assets which were used to derive restoration times based on expert judgement.

5.3.1 Base-Case Outages

The dominant damage anticipated for the main CentrePort terminal at Thorndon was the fault displacement and liquefaction induced settlement/lateral spreading at the western end of the Aotea Wharf (adjacent to the Roll-on/Roll-off ferry terminal) and damage (settlement and lateral spreading) of the Thorndon Reclamation. (Note: the base case assumed that remedial work currently underway in stabilising the Thorndon Container Wharf and associated crane facilities was complete and provides liquefaction/settlement protection of that zone).

Restoration times for the return of function (fn) and return to full service (FS) (shown in red text in **Figure 5.5**) were determined during workshops with CentrePort, which included the refinement of damage estimations with intra-dependency considerations.

Interdependencies were determined during workshops with CentrePort staff and the relevant network restoration times were added.

Figure 5.5 Restoration times for port assets in Wellington. Red text is base-case outage times, blue text is intervention and preferred programme outages.

5.3.2 Intervention Outages

The primary mitigation measures proposed involved enhancing the resilience of the Roll-on/Roll-off ferry terminal and docking facility (including enhanced vehicular access from both the Motorway and the city) and the formation of liquefaction mitigation measures along Aotea Wharf. These projects were the same for the High and Low programmes.

The impact of these projects on outage times was determined through discussions with CentrePort. Outage times with these projects in place are shown in blue text in Figure 5.5.

5.3.3 Preferred Programme Outages

No new Port projects were included in the preferred programme. Rather, the same intervention projects from the low and high programmes were included in the preferred programme. Therefore, the outages for Port are the same as the high and low programmes (blue text in Figure 5.5).

5.4 AIRPORT

The evaluation of Wellington International Airport similarly involved meetings with the management team and discussion as to expectations of outage damage and recovery for each of the asset bundles shown in **Figure 5.6**. These bundles were loosely groups into runway, hardstanding areas and buildings (control tower, terminals, warehouse and hanger facilities).

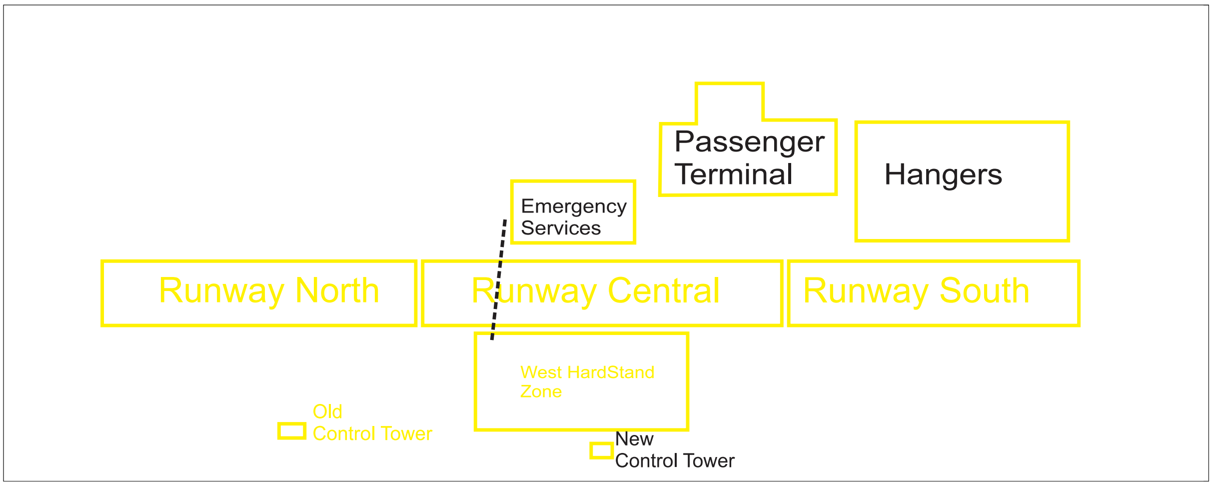


Figure 5.6 Asset bundles for Wellington International Airport.

5.4.1 Base-Case Outages

The base-case for the airport resulted in damage to the terminal buildings and hangers and to the south runway (where potential settlement has been identified). The shortened runway is anticipated being out of operation for 3 days with the extended runway disrupted for 3 months and return to full service in 6 months. The terminal buildings were also anticipated to be out of service for 3 months and return to full service after 6 months. Temporary facilities were recognised as available on the western hardstanding area, permitting the return of partial service (predominantly emergency and military flights) to be established after 3 days (from when suitable earthmoving equipment becomes available).

5.4.2 Intervention Outages

The intervention project selection and shortlisting process being run by Aurecon did not identify any projects relating to the airport.

5.4.3 Preferred Programme Outages

There were no additional projects relating to the airport included in the preferred programme. Therefore, the preferred programme outages for the Airport are the same as the Base-Case outages (Section 5.4.1).

6.0 UTILITIES LIFELINES

6.1 FUEL

6.1.1 Assets

Wellington region has three oil terminal storage facilities; Seaview, Kaiwharawhara, and Miramar. Seaview facilities provide service to the general population and businesses in the Wellington region; Kaiwharawhara facilities supply primarily to the Cook Strait ferry services; and Miramar storage facilities provide for Aviation purposes. Only the Seaview facilities, are considered for this project (**Figure 6.1**).

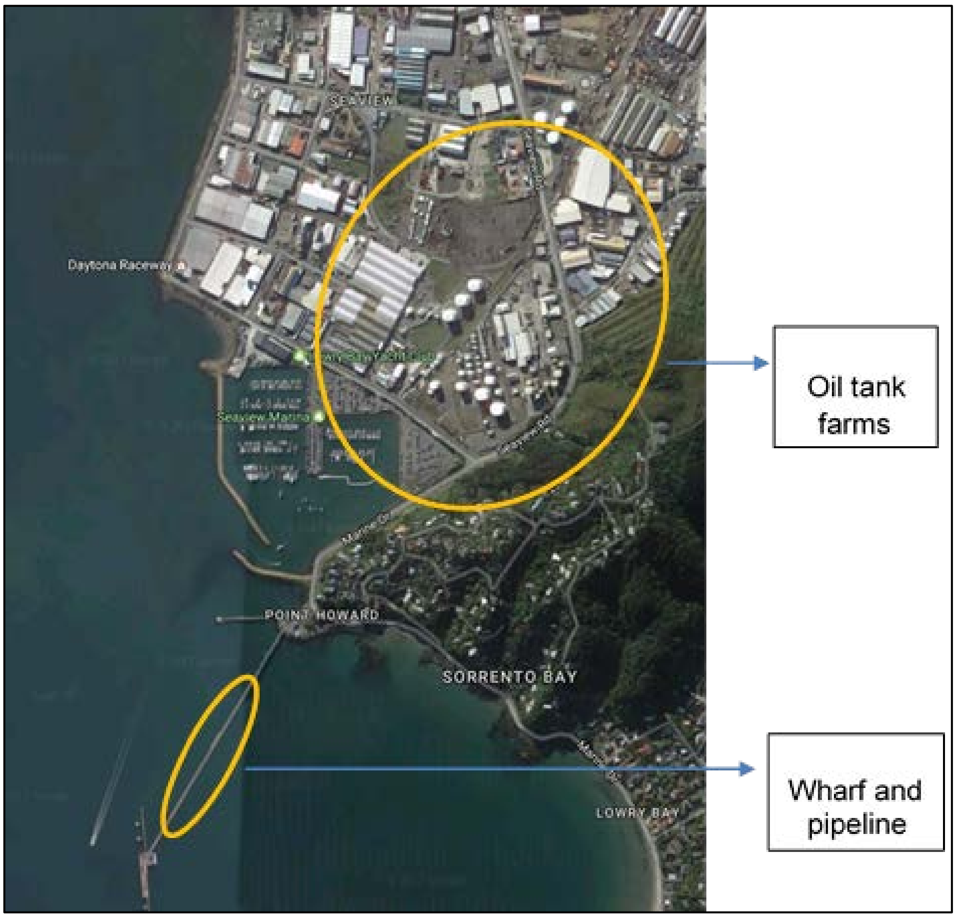


Figure 6.1 Seaview fuel storage facilities.

6.1.2 Vulnerability and Impact Modelling

We worked through the steps of the modelling framework (Section 2.0), based on expert judgement, to estimate direct damage to oil storage tanks and intake infrastructure such as pipelines and wharf for offloading fuel.

6.1.3 Base-Case Outages

Outage times are assigned by suburb for critical (as defined by Wellington Region CDEM Group, 2015) and general customers. For general customers, fuel can only be provided when the fuel intake facility at the wharf is restored, and when road access from Seaview is available. In our modelling service stations are assumed to be functional and to have 5 days of residual fuel available to customers. Availability of road access is considered as an interdependency for fuel supply. It is assumed that there are enough back-up facilities for their continued operation. The final outage times for fuel are shown in Figure 6.2.

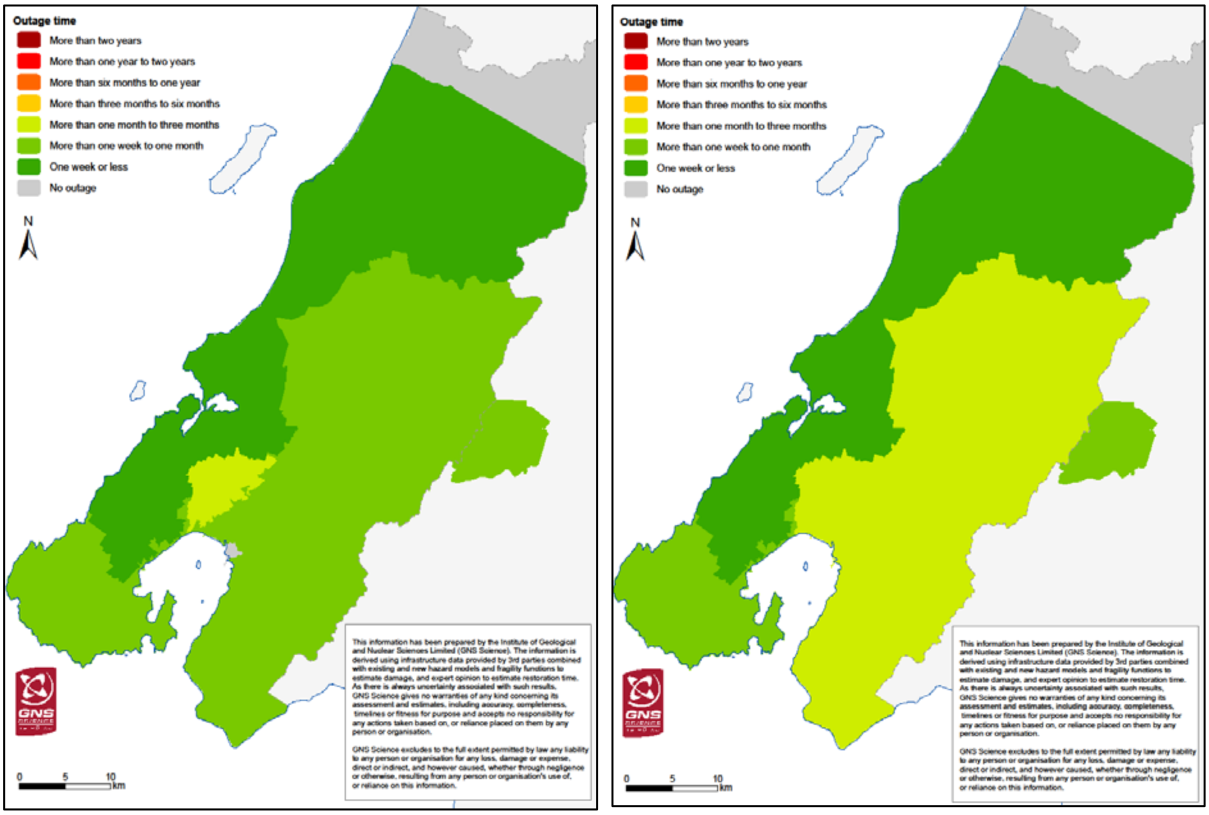


Figure 6.2 Outage map for fuel service to critical customers (left) and general customers (right) from the Seaview facility.

6.1.4 Intervention Outages

Only one intervention project was considered for fuel. This project was included in both intervention programmes. Damage modelling was not necessary for this project:

> ***Seaview Wharf seismic strengthening including pipeline*** *– strengthening results in the continued supply of fuel to tank farms making fuel available for both critical and general customers providing road access is available. When road access is restricted, critical customers are prioritised.*

It is assumed that the seismic strengthening would consider the impacts from lateral spread and subsidence on the Seaview wharf infrastructure including the pipeline. The updated outage times are presented in Figure 6.3.

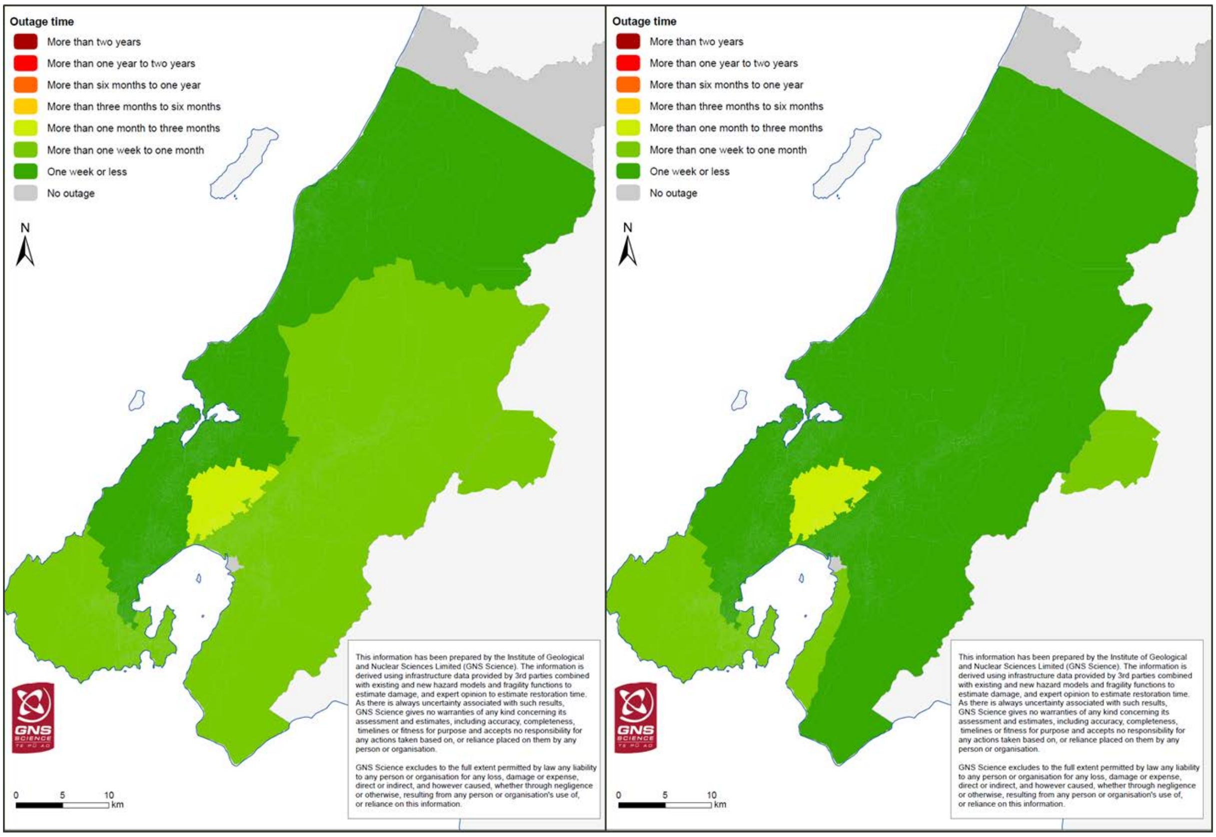


Figure 6.3 outage times for fuel service to critical and general customers with low investment interventions (left) and high investment interventions (right).

6.1.5 Preferred Programme Outages

There were no new fuel intervention projects included in the preferred programme. Therefore, the preferred programme outages for fuel are the same as the High Investment outages (Figure 6.3).

6.2 ELECTRICITY

6.2.1 Assets

The Wellington electricity network includes the national grid network and the local distribution networks. Detailed information of some electricity network data are listed in Table 6.1 below.

Table 6.1 Electricity network data used in the project.

Asset Type	Asset Attributes	Major Hazard Threat	Owners	Note
Transmission Structure	Location; Structural type (e.g. pi/single/triple pole, steel tower)	Landslide Fault Rupture	Transpower	With a degree of redundancy, a predominately overhead network, is expected to perform well in an earthquake (WeLG 2012)
National Grid (GXP)	Location; Voltage level; Construction type, age & condition	Shaking Liquefaction Landslide Fault Rupture	Transpower; WELL	
Zone Substation	Location; Voltage level; Construction type, age & condition	Shaking Liquefaction Landslide Fault Rupture	WELL; Electra	WELL has 27 zone substations in its subtransmission system (WELL AMP 2015)
33 kV Cable/Overhead Line	Location; Length; Voltage level; Material & age	Liquefaction Fault Rupture	Transpower; WELL; Electra	143 kM, or 70% of WELL's 33 kV distribution system are buried, which is prone to liquefaction (WeLG 2012, WELL AMP 2015)

Various sources of dataset have been used to develop electricity network exposure data, including Transpower, Wellington Electricity (WELL) and Electra. By considering the scope and timeframe of the project, along with the vulnerability of various asset types and available information, the following asset types were considered in this study:

Transmission Structure *– no classifications*
Substation *- classified by voltage level, construction type, age and condition*
Buried Cables *– classified by length, voltage level, and conduction material*
Overhead Cables *– no classifications*

6.2.2 Vulnerability and Damage Models

Impacts to the electricity network were modelled using RiskScape (see Section 2.0) using vulnerability models that are presented in Table 6.2. Overhead cables use transmission tower damage as a proxy for impacts, due to a lack of available vulnerability models for overhead cables. The definitions for damage states (DS) and recovery times are tabulated in Table 6.3 and were consulted with WELL.

Table 6.2 Electricity assets vulnerability models.

Asset Type	Hazards		
	Ground Shaking	**Liquefaction**	**Landslides, Fault Rupture, co-subsidence**
Substation (zone & GXP)	PGA: Federal Emergency Management Agency, 2015	LSN: (Rosser and Dellow,2015) and engineering judgement	Within Hazard foot print = DS4, not within hazard footprint = DS0 Where DS0 is ‘no damage’ and DS4 is ‘complete damage’
Cable	MMI: Lin, Nayyerloo and Zhang, 2016		
Transmission tower or pole	PGA: Xie *et al.*, 2012		

Table 6.3 Damage state and recovery time definitions.

Damage states and recovery time definition						
Method	Expert Judgement					
Typology	All Electricity Assets					
Hazard	Earthquake, Liquefaction, Landslide, Fault Rupture, Subsidence					
Intensity Parameter	Recovery Time					
Measure	days					
MV Substations Parameters						
RiskScape Damage State Application	DS0: None	DS1: Insignificant	DS2: Light	DS3: Moderate	DS4: Severe	DS5: Critical
Recovery Times	0	0	0	0	4	4
Application	Apply to Electricity Substations with Electricity Voltage Level > 66kV					
LV Substations Parameters						
RiskScape Damage State Application	DS0: None	DS1: Insignificant	DS2: Light	DS3: Moderate	DS4: Severe	DS5: Critical
Recovery Times	0	0	0	3	3	30
Application	Apply to Electricity Substations with Electricity Voltage Level < 66 kV					
Transmission Towers Parameters						
RiskScape Damage State Application	DS0: None	DS1: Insignificant	DS2: Light	DS3: Moderate	DS4: Severe	DS5: Critical
Recovery Times	0	0	0	0	2	2
Application	Apply values to Electricity Transmission Structures with Transmission Structure types: Steel Lattice, Aluminium Lattice.					
Transmission Poles Parameters						
RiskScape Damage State Application	DS0: None	DS1: Insignificant	DS2: Light	DS3: Moderate	DS4: Severe	DS5: Critical
Recovery Times	0	0	0	1	2	2
Application	Apply values to Electricity Transmission Structures with Transmission Structure types: Tubular Steel, Timber Monopole, Timber Double Pole, Timber Triple Pole, Reinforced Concrete, Reinforced Fibre Composite.					
Electricity Cables Parameters						
RiskScape Damage State Application	DS0: None	DS1: Insignificant	DS2: Light	DS3: Moderate	DS4: Severe	DS5: Critical
Recovery Times	0	0	0	11	16	16
Application	Apply to all Electricity Cables					

Substation buildings are modelled using the same methods as with buildings (see Section 7.1), with the final impact for each substation being assigned using a logic-based approach to define the critical damage state (i.e. the final impact is the worst damage level from plant components or building).

The damage ratio curve for buried cables as presented in Lin et al, 2016, was refined following workshops with the network providers (see Appendix A1.0), and a new vulnerability module created in RiskScape to reflect the more robust cable network in the Wellington region compared with that of Christchurch, on which the Lin et al. model is based on. Cables are segmented into approximately 50m lengths for modelling.

The final damage results for electricity components are presented in Figure 6.4.

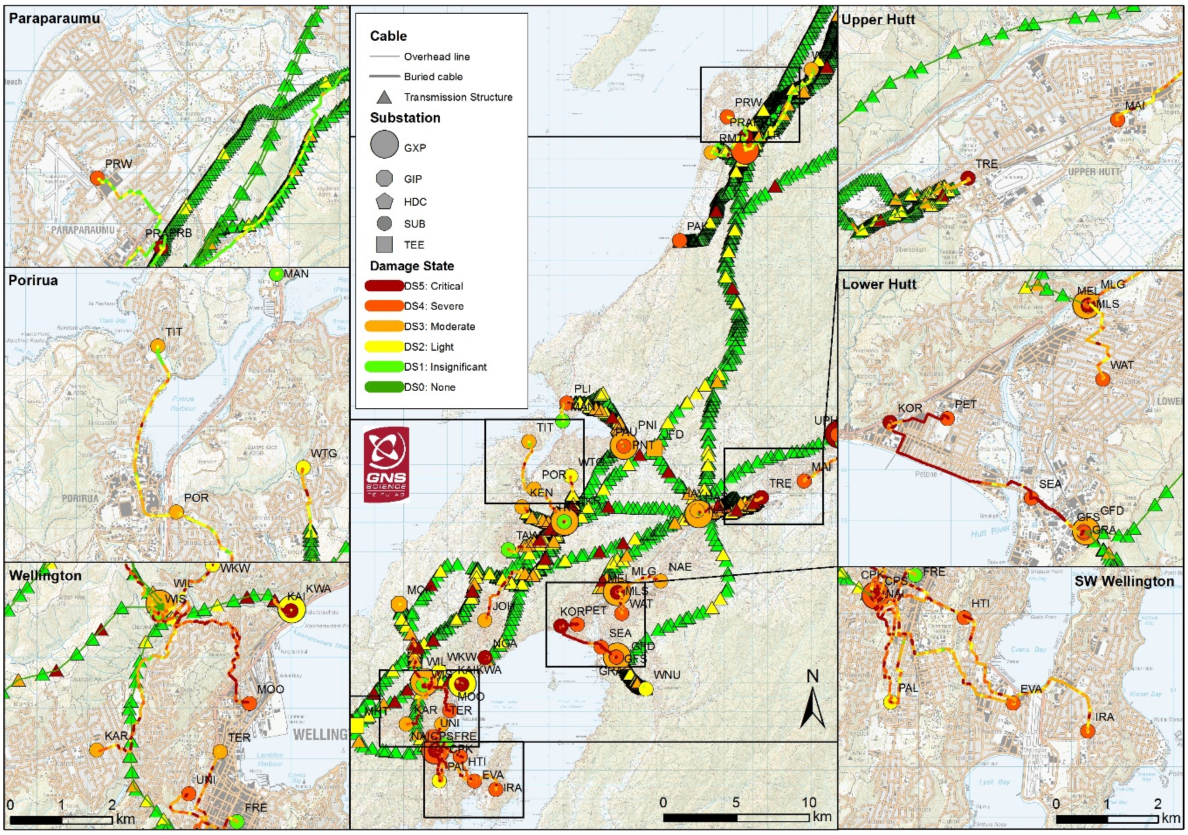


Figure 6.4 Modelled damage to the Wellington Region electricity network in the base case.

6.2.3 Base-Case Outages

The electricity network used an intra-dependent network connectivity analysis for outage calculation, with recovery (outage) times as listed in Table 6.2 for damaged components and a logic based recovery strategy approach (priority sites, resource availability etc.).

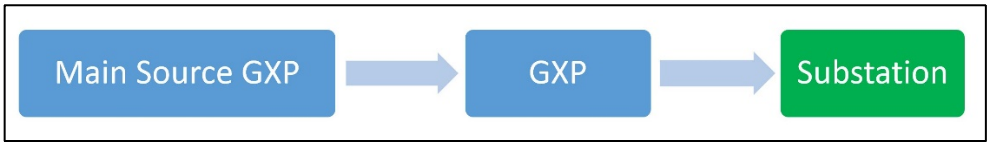


Figure 6.5 Electricity network components and component hierarchy (left to right).

Electricity network comprises different components as listed in Table 6.1. and they are connected in a specific hierarchy to supply electricity to the households. In Figure 6.5 the main source GXP (grid exit points with high voltage, say 220kV) may be connected to GXP of lower voltage, say 66 kV and then to a substation of 33 kV by means of transmission structures and overhead lines or buried cables. In our modelling, the distribution stations of 11 kV and the downstream components were not modelled individually but we considered their impact collectively as explained later in this section. This means that a failure in any one asset resulting in a failure of all downstream components. For cables, >= DS2 is assumed to be a break in connectivity. The outage time computation is based on the time required to restore the services, but not necessarily the time required to repair the damaged components. So, for example, when there are multiple points of damage, repairing the cable may not be viable and hence, alternate methods of restoring the service will be sought, such as constructing overhead power lines to bypass damaged assets. In this project, we considered all the resources for restoration are located in the Lower Hutt zone as suggested by WELL. So, for every substation zone, restoration of service depends on the number of days to get road access from the Lower Hutt zone.

The outage of service is computed for every zone substation area considering the damage status and recovery period of the components upstream of the damage point. The longest recovery time is chosen as the outage time. Following this process interdependency with roads is considered and outage times are derived for pre-established electricity coverage zones. A further 10 days is assumed for the restoration of local distribution components (which are not directly modelled for impacts). Final outage times are presented in Figure 6.6.

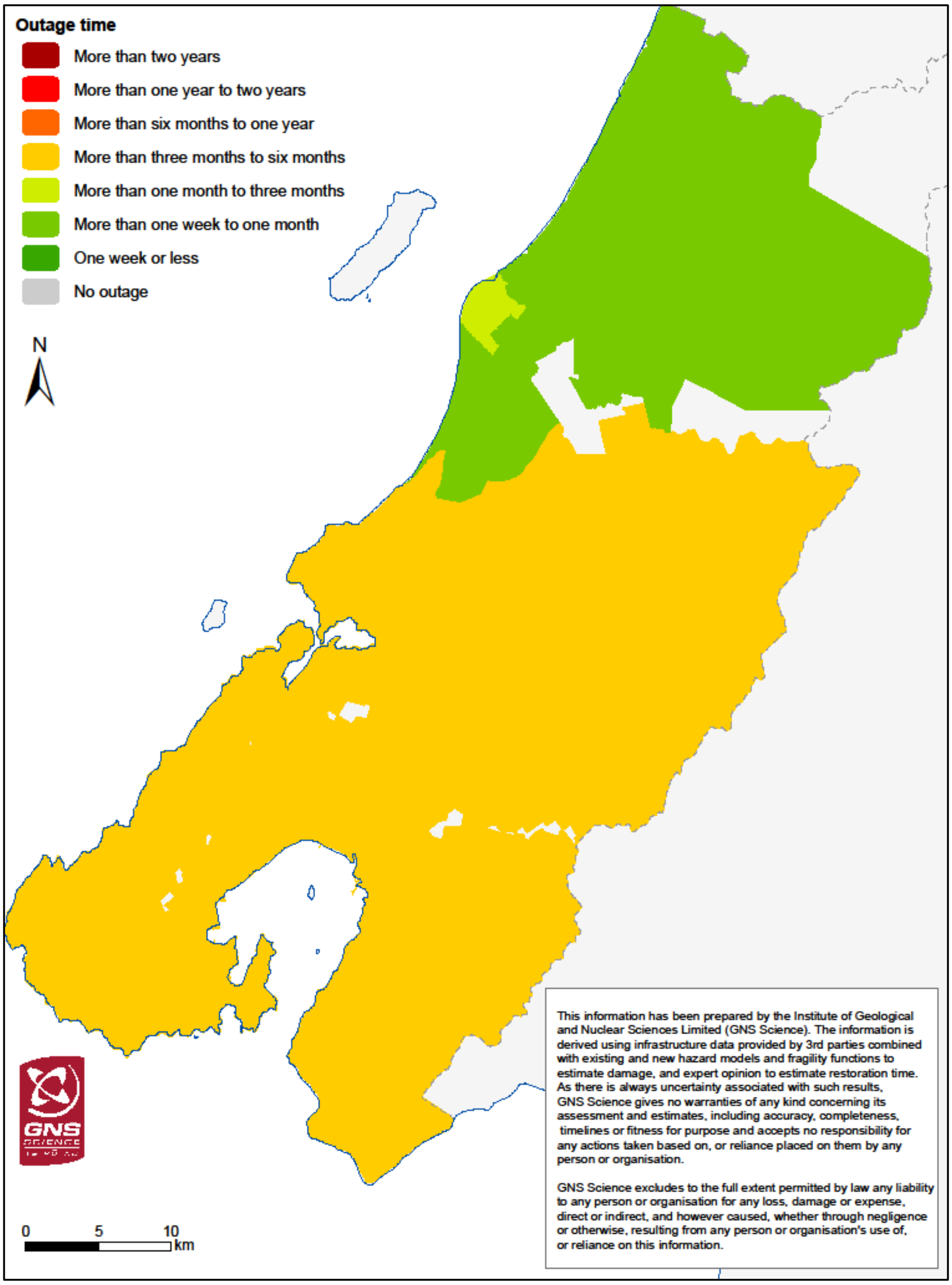


Figure 6.6 Outage map for electricity service for base-case scenario.

6.2.4 Intervention Outages

Intervention programmes for the electricity network were as follows:

Central Park Substation improved resilience *- New connection (cable) added to a new substation which is assumed to be designed to withstand damage associated with the modelled earthquake scenario.*

Emergency overhead powerlines *- Does not affect BAU assets and is therefore not modelled for damage. However, this does affect restoration and therefore outage time*

Increase 160MW interconnectedness between substations *- New lines are added between affected substations. They are assumed to be constructed with XLPE conduction material. Phase 2 modelling used a secondary damage curve specifically for XLPE cables. This was to reflect a lower rate of damage for a more resistant material type. BAU modelling did not use this for existing XLPE cables.*

Seismic upgrade of 33kV buried cables *- New cables, and therefore connections, are established in East Wellington and in Lower Hutt. Everything is assumed to be constructed with XLPE conduction material, and therefore use the new damage curve associated with this material type.*

CPK - Frederick St cables replaced under ongoing cable replacement programme *- New cables added between CPK and Frederic St. Everything assumed to be constructed with XLPE conduction material, and therefore use the new damage curve for this material type.*

Replacement of all fluid filled cables in network *- All buried cables in the network are assumed to be upgraded to XLPE conduction material type, if not already. Therefore, all cables use the new damage curve for this material type.*

With the consideration of these intervention programmes, updated network outage times are presented for low and high investment packages in Figure 6.7.

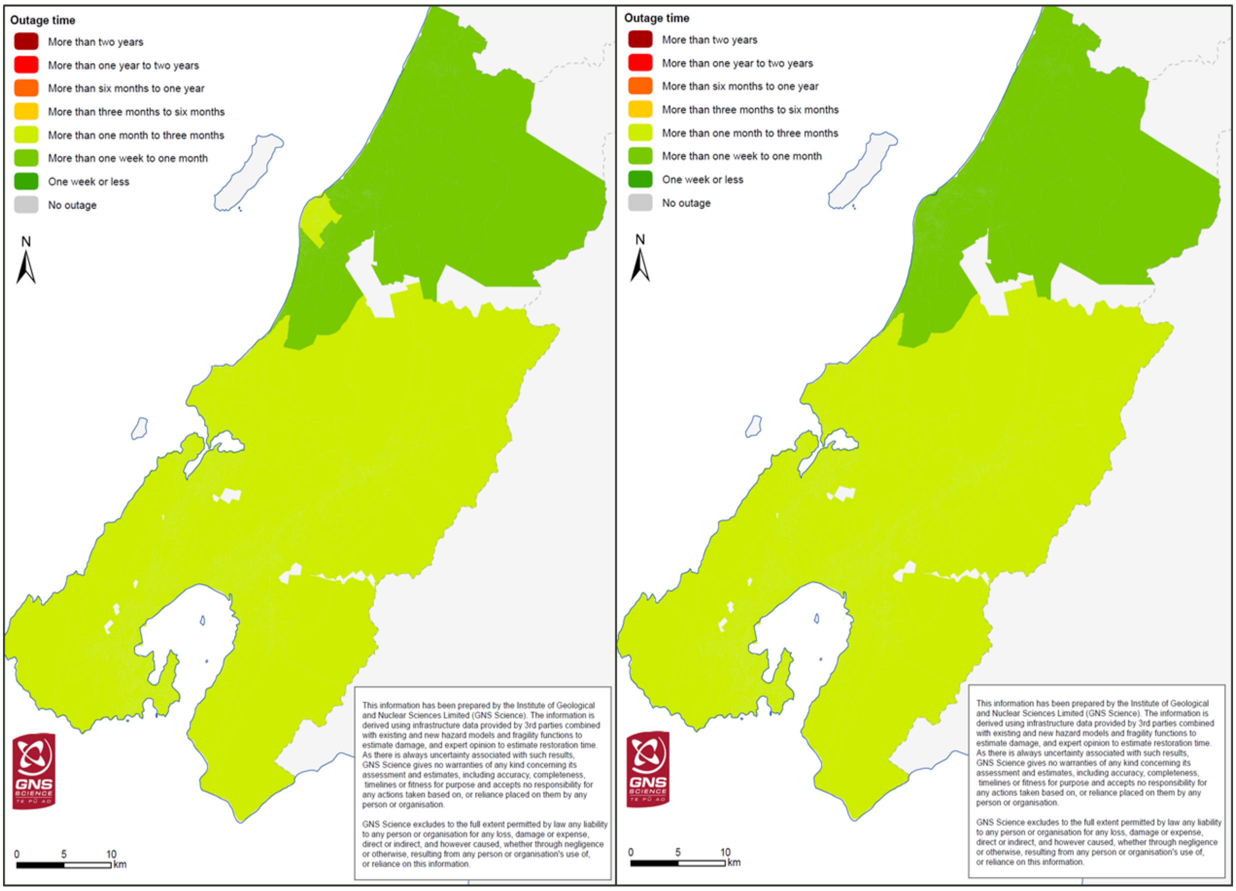


Figure 6.7 Updated electricity network outage for low (left) and high (right) investment programmes.

6.2.5 Outage associated with Preferred Investment Programme

Once the outage maps for low and high investment programmes were shared with the infrastructure providers, discussions were held to seek for opinion on a 'preferred programme'. It was decided to go with the 'high investment programme' but with 'Replacement of all fluid filled cables in network' excluded. The outage map of the 'preferred programme' is shown in Figure 6.8. The results of the 'preferred programme' resemble that of the 'low investment programme'; this is because of the large time bands used in the figure. However, the absolute number of days is less for the 'preferred programme' than that for the 'low investment'. The upgrade of the 33kv ring in Lower Hutt and Wellington City can potentially reduce the outage time for electricity supply, but the road outage time is much longer, delaying the final recovery of electricity supply.

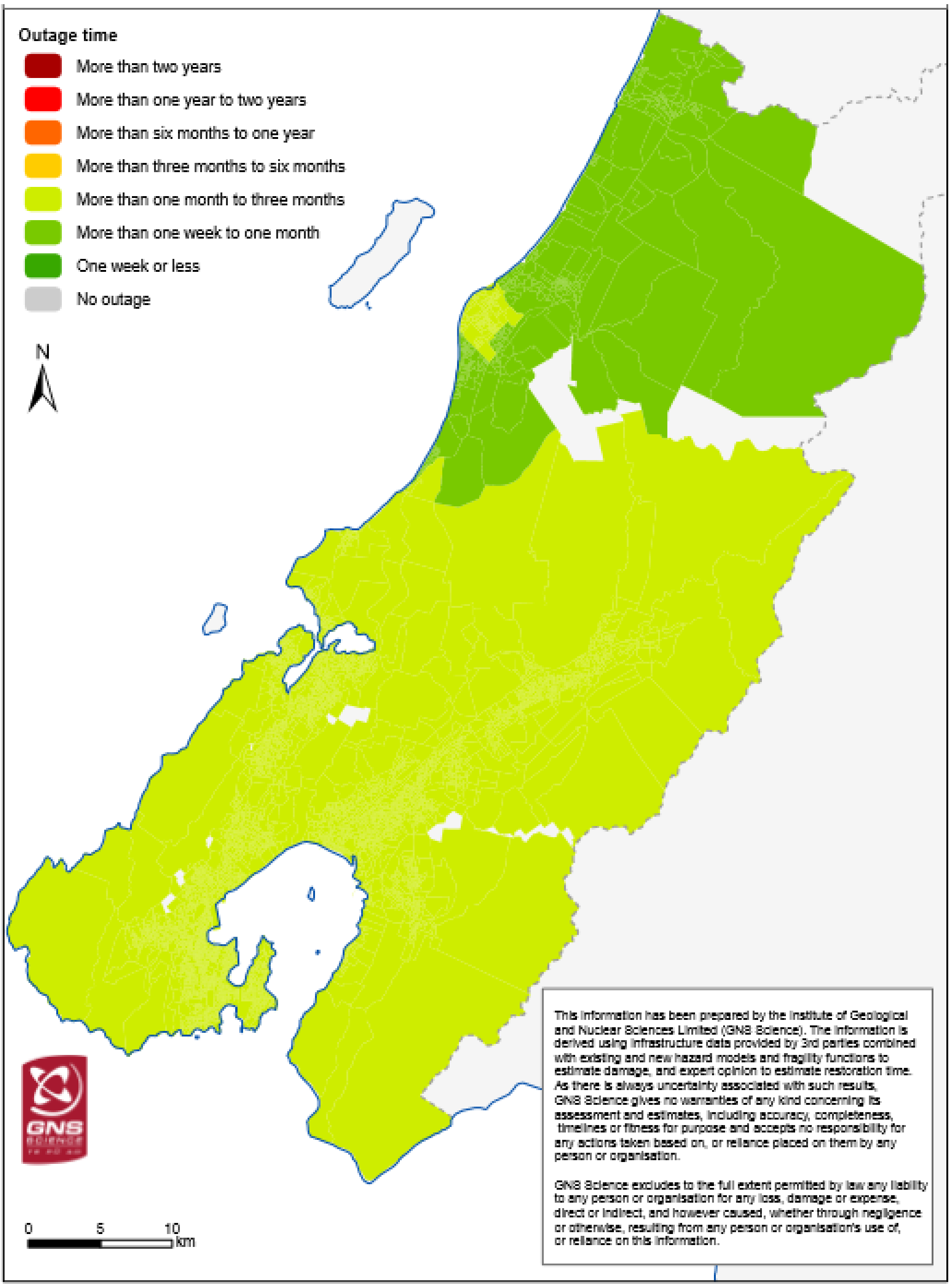


Figure 6.8 Updated electricity outage for preferred programme.

6.3 TELECOMMUNICATIONS

6.3.1 Asset Data

Telecommunications networks are comprised of infrastructure that provides users with landline, data and wireless (cellular) services. For example, i) Buildings: exchange house, ii) Equipment: the core of the exchanges themselves including cabling, cabinets, switch gear etc.

Infrastructure: component supports the exchange operations, typically back-up power generation (AC and DC), heating and ventilation equipment, water storage and distribution facilities, monitoring and control equipment, etc, iii) Cable: the buried distribution network within the Wellington CBD areas, and iv) cellular tower.

Various sources of dataset have been requested and will be used to develop telecommunication network exposure data. By considering the scope and timeframe of the project, along with the vulnerability of various asset types and available information, the asset types considered in this project are as follows:

> ***Exchange Buildings*** *– comprised of infrastructure components and equipment components, each classified by condition (sound, deficient) and housing, classified the same as non- infrastructure buildings (Section 7.1).*
> ***Buried Cables*** *– classified by type (primary, secondary). Only primary cables are considered for modelling*
> ***Cellular Towers*** *– no classifications. Note that only 132 cellular towers were considered in this project, as limited data was available.*

6.3.2 Vulnerability and impact modelling

Impacts to telecommunications components are modelled using RiskScape (see Section 2.0) using the vulnerability models presented in Table 6.4. Liquefaction impacts use the same LSN damage enhancements as electricity with exchange buildings, buried cables and cellular towers considered equivalent to substations, buried cables and transmission structures respectively (Section 6.2). The impacts to telecommunications components are presented in Figure 6.9.

Table 6.4 Telecommunications asset vulnerability models.

Asset Type	Hazards		
	Ground Shaking	**Liquefaction**	**Other Hazards**
Exchange Building	MMI: Nayyerloo and King, 2012	LSN: (Rosser and Dellow, 2015)	Within Hazard foot print = DS4, not within hazard footprint = DS0
Buried Cable	MMI: Nayyerloo and King, 2012	LSN: engineering judgement	
Cellular Towers	PGA: Xie *et al.*, 2012	LSN: engineering judgement	

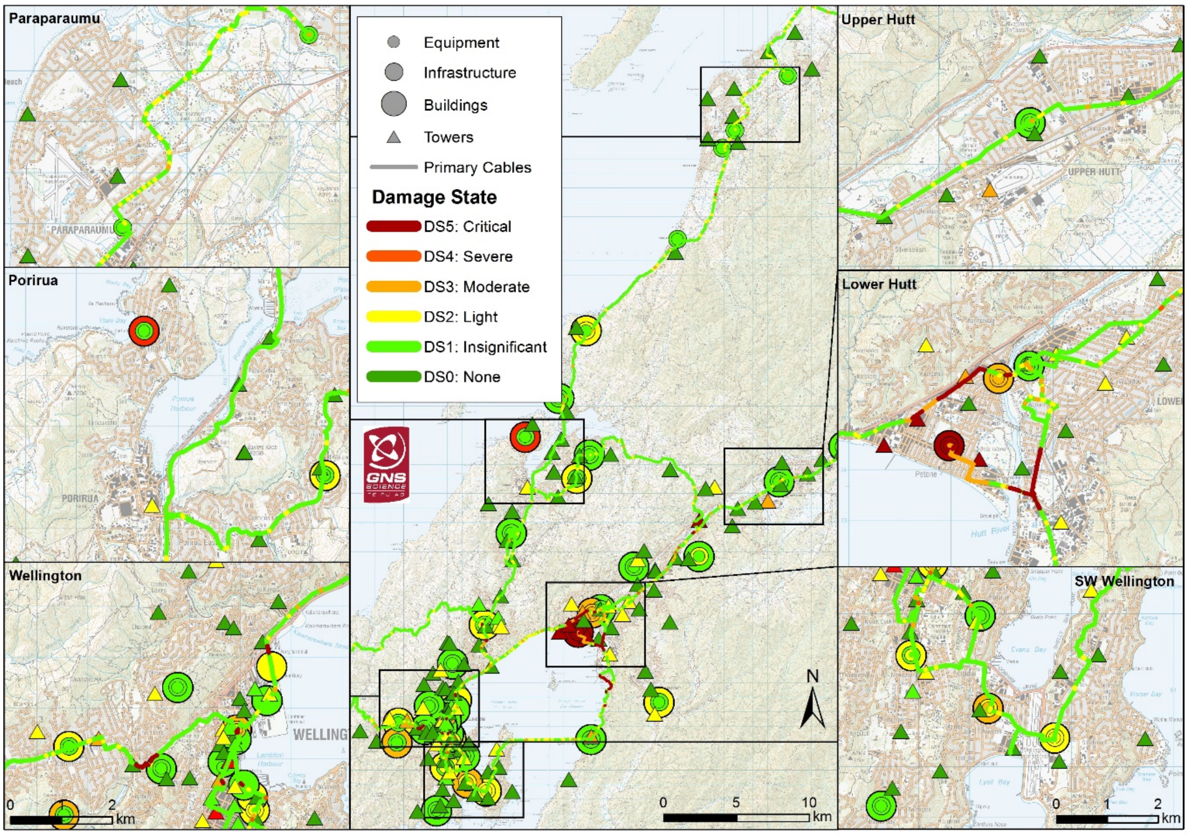


Figure 6.9 Modelled damage to the Wellington Region telecommunications network.

6.3.3 Base-Case Outages

Telecommunications outage times were derived as per the steps of the modelling framework (Section 2.0), which considered both repair times including dependency on electricity or fuel (whichever was available quickest to allow the exchange houses and cellular towers to operate to provide service) and road access. Outage times do not consider a customer's ability to receive network services (access to mobile phone charger, electricity to run computer etc.). The telecommunication providers indicated there would be helicopter access for fuel distribution, however this was not considered in the model. It is likely that most available helicopters would be deployed for disaster response purposes. Outage times for cellular towers attached to buildings considered the access of the associated building, based on its assigned damage state (Section 7.1). Separate outage times were derived for data, landline and cellular services, however when interdependencies were considered the outage times were similar (Figure 6.10).

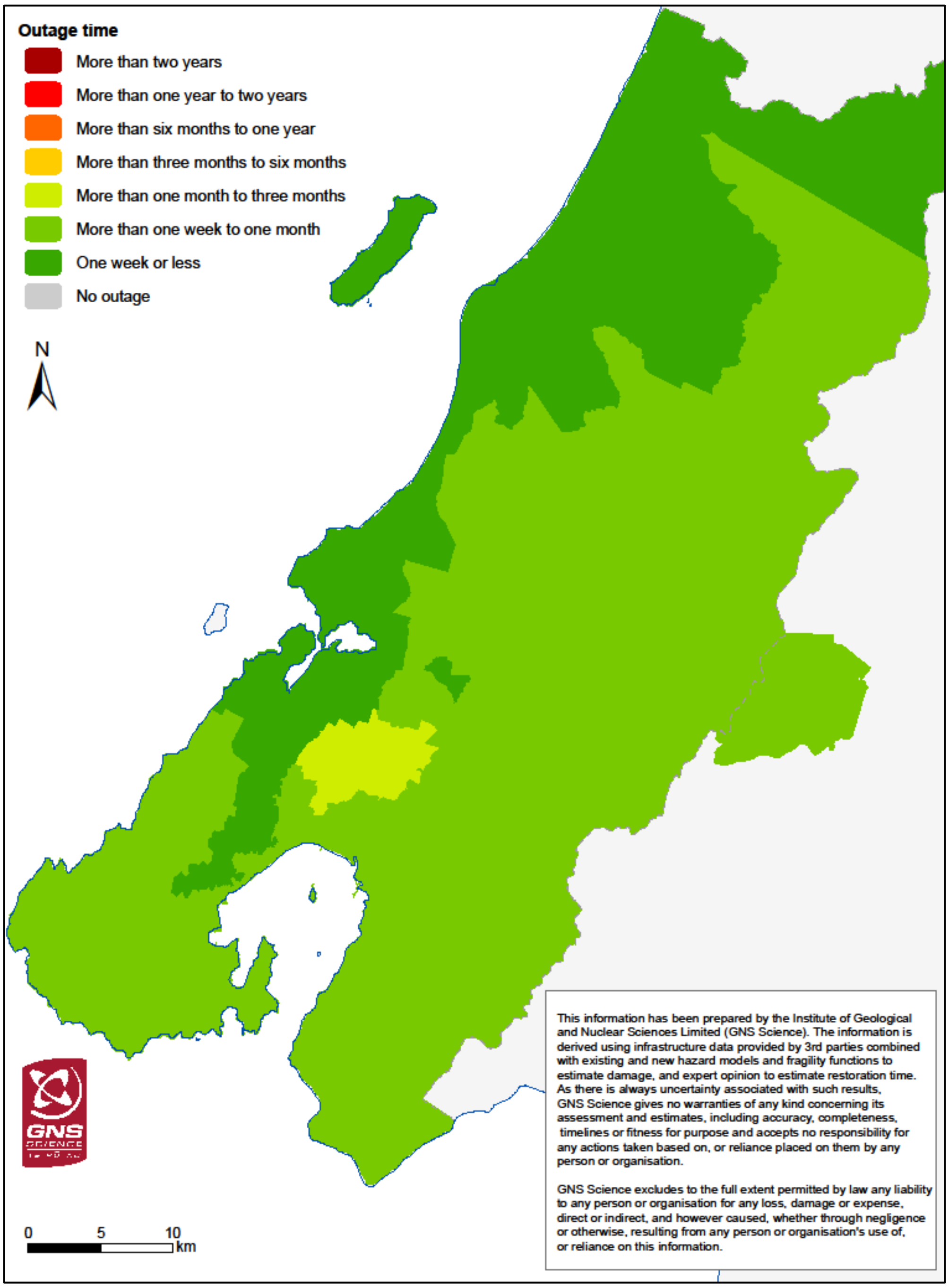


Figure 6.10 Outage times for telecommunication services (data, cellular and landline) in the base-case.

6.3.4 Intervention Outages

Only one intervention project was considered for the telecommunications network, and this was included in both programmes:

> ***Dedicated backup power for cell towers*** *- This programme did not affect the BAU assets and was therefore not modelled for damage, however this results in a reduction to outage times.*

The effects of this intervention project were equal, as with the base-case model, for all three aspects of telecommunication services (Figure 6.11). Though only one intervention project was considered, due to its dependency on electricity and fuel, the results for low and high investment programmes are different.

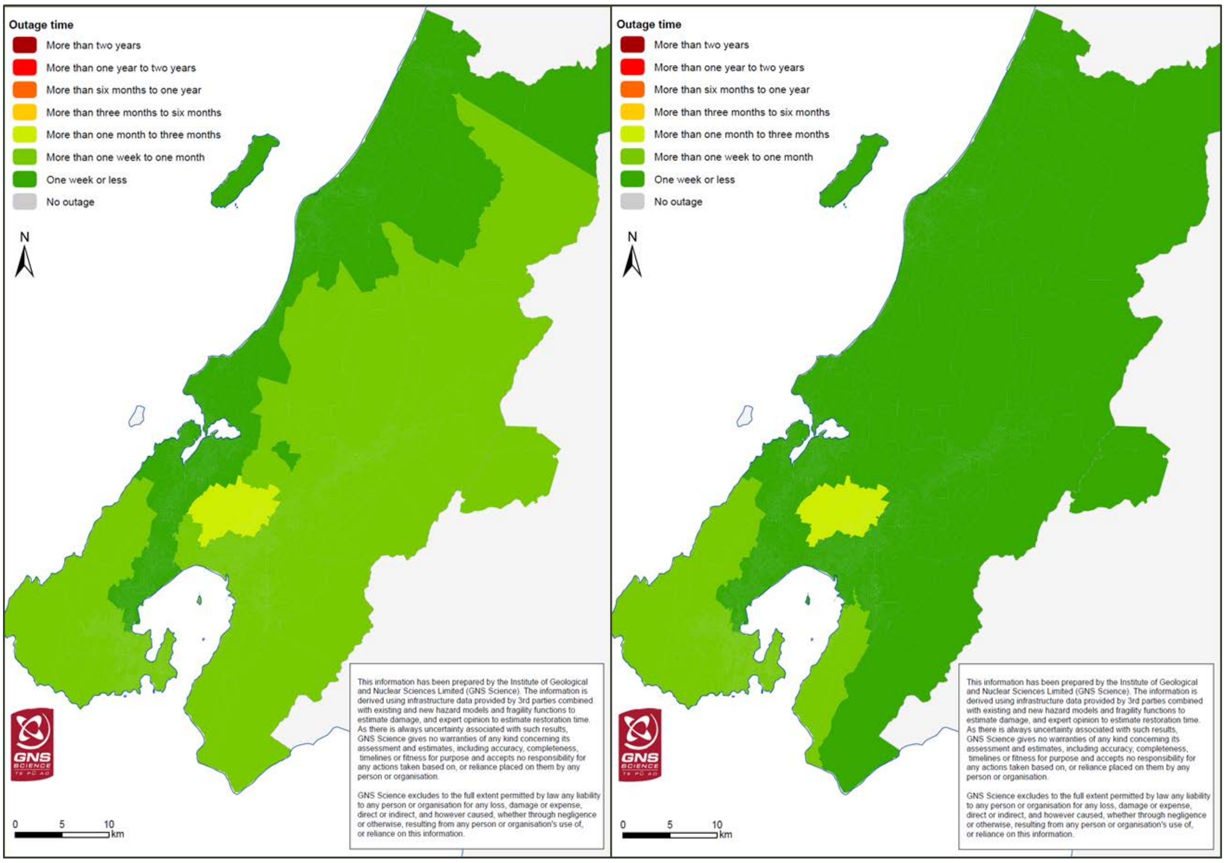


Figure 6.11 Outage times for telecommunication services (data, cellular and landline) for low (left) and high (right) investment programmes.

6.3.5 Preferred Programme Outages

The telecommunication intervention project was included in the preferred programme, with no new projects included. However, there was a change in the electricity sector projects included in the preferred programme. Because telecommunications are dependent on electricity, outage times for the three telecommunication services did changed under the preferred programme. Figure 6.12 shows the preferred programme outages for telecommunications.

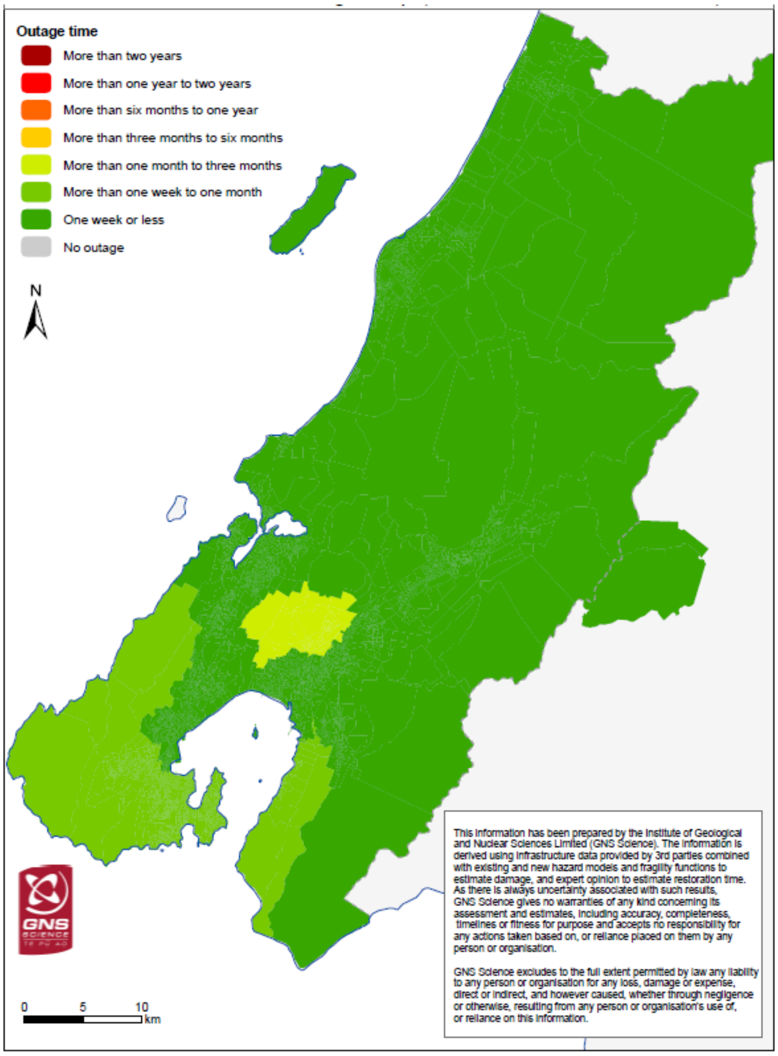


Figure 6.12 Outage times for telecommunication services (data, cellular and landline) for preferred programme.

6.4 WATER

6.4.1 Asset Data

For the Wellington Region water network (Figure 6.13), the following assets were considered:

> ***Treatment Plants*** *- classified by capacity, building material, foundation type and by seismic restraining level (anchored components, unanchored components).*
> ***Pump Stations*** *- classified by capacity, building material, foundation type and by seismic restraining level.*
> ***Wells*** *– no classification.*
> ***Reservoirs*** *– classified by material type (timber, steel, concrete or plastic depending on the size), capacity, seismic restraining (anchored or unanchored) and age.*
> ***Transmission Pipelines*** *– classified by class (bulk, mains-to-reservoir), diameter, material type, joint type, ductility and length.*
> ***Distribution Pipelines*** *– classified by class (mains, submains, reticulation), diameter, material type, joint type, ductility and length.*
> ***Pipe Tunnels*** *– no classification.*

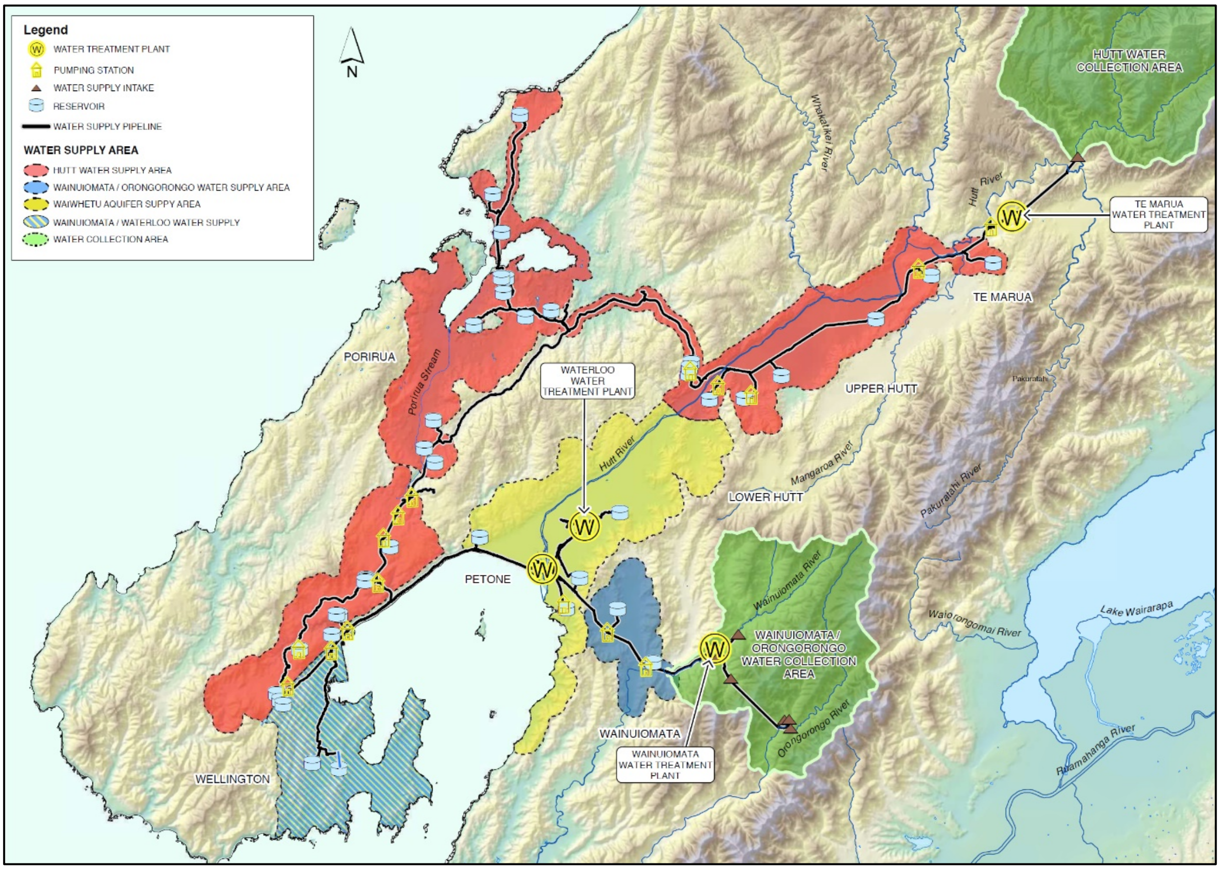


Figure 6.13 Greater Wellington Regional Council bulk water supply network (Greater Wellington Regional Council, 2014).

6.4.2 Vulnerability and Impact Modelling

Impacts to the water network were modelled using RiskScape (see Section 2.0) with the vulnerability models presented in Table 6.5. For pipelines, empirical functions that estimate repair rates due to ground shaking hazard intensity (MMI) and ground displacement (Fault rupture, landslide, liquefaction, co-seismic subsidence and lateral spreading) are used as opposed to lognormal cumulative distribution functions. This allows for a higher resolution of modelling than currently available pipe fragility function classifications would provide. Pipes are segmented into approx. 50m lengths. Most of the key components of the water networks including the treatment plants and pump stations consist of several sub-components. In these instances, the vulnerability functions are based on the probabilistic combinations of subcomponent damage functions using Boolean expressions (Federal Emergency Management Agency, 2015), which is a readily available and widely accepted approach. The impacts to water components are presented in Figure 6.14.

Table 6.5 Summary of potable water asset vulnerability models.

Asset Type	**Hazards**		
	Ground Shaking	**Liquefaction**	**Other Hazards**
Treatment Plants	PGA: Federal Emergency Management Agency, 2015	LSN: (Rosser and Dellow, 2015)	Within Hazard foot print = DS5: Critical Damage, not within hazard footprint = DS0: No Damage lateral spreading = WelRes PBC, Nayyerloo 2016
Pipelines	MMI: Transmission pipes = (Cousins, 2013). Distribution pipes = Nayyerloo, 2016	Transmission pipes = (Cousins, 2013) Distribution pipes = Nayyerloo, 2016	
Pump Stations	PGA: Federal Emergency Management Agency, 2015	(Rosser and Dellow, 2015)	
Wells	PGA: Federal Emergency Management Agency, 2015	(Dellow *et al.*, 2003)	
Reservoirs	PGA: Federal Emergency Management Agency, 2015	Assumed to be on non-liquefiable ground	
Pipe Tunnels	not considered	not considered	

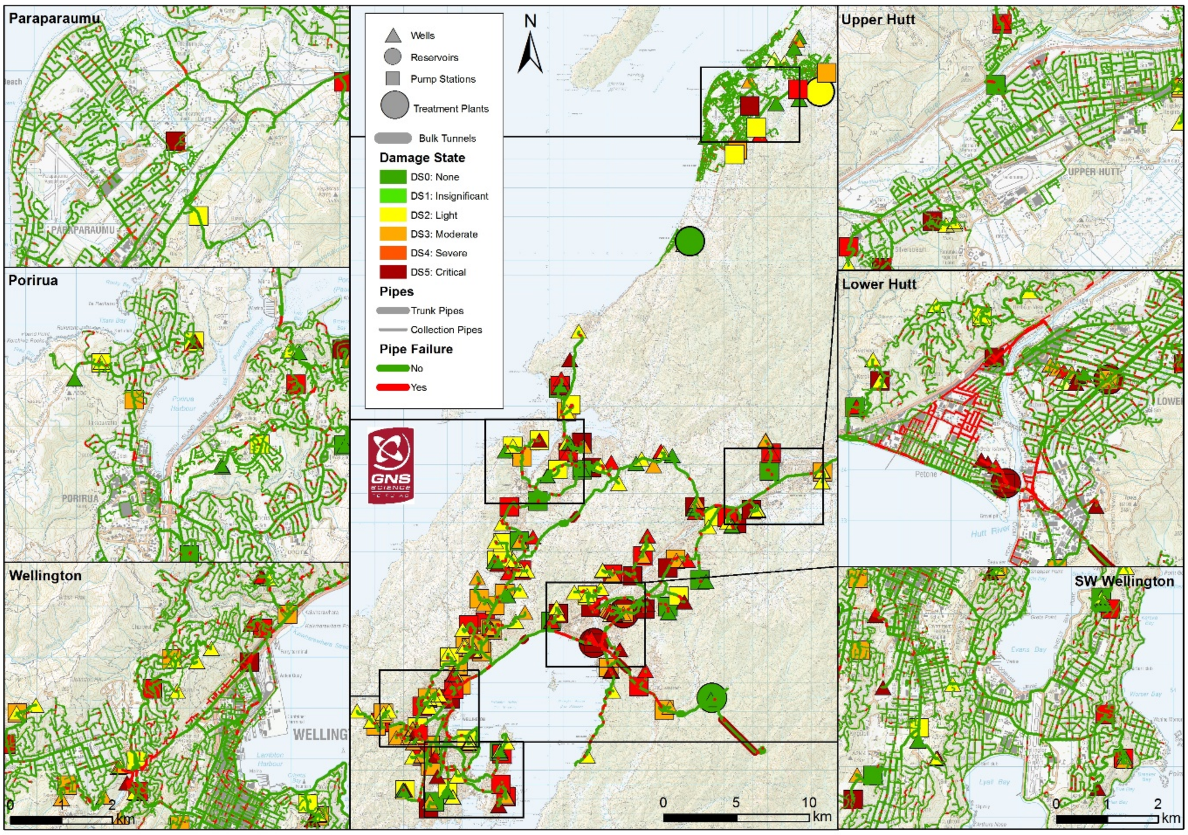


Figure 6.14 Modelled damage to the Wellington Region water network.

6.4.3 Base-Case Outages

Network outages were determined through a series of workshops with lifelines operators based on pre-defined coverage zones, as per the modelling framework (Section 2.0). Pipeline failures were manually tabulated for each zone, allowing worker crews to be assigned based on availability over time. This assumed a maximum of 10 available crews for transmission pipes from 6 weeks onwards. This assumption considers the time taken for workers to deal with their personal response to the event, as well as securing workers from outside of the directly impacted area. Restoration time was assumed to be 3.5 days per failure on the transmission network, beginning first at the four regional water sources. For the reticulation network, 30 repairs per day (for transmission and distribution combined), beginning at the completion of the transmission water network, was assumed. KCDC assumed 30 repairs per day based on the available workers with treatment facilities available after 6 months based on the modelled damage. Restoration per zone was defined as 80% of properties having service to at least the property boundary (which excludes laterals). For treated water, the repair times of treatment plants were added to the base restoration times. Network interdependencies considered electricity or fuel, and road access to calculate network outage (Figure 6.15).

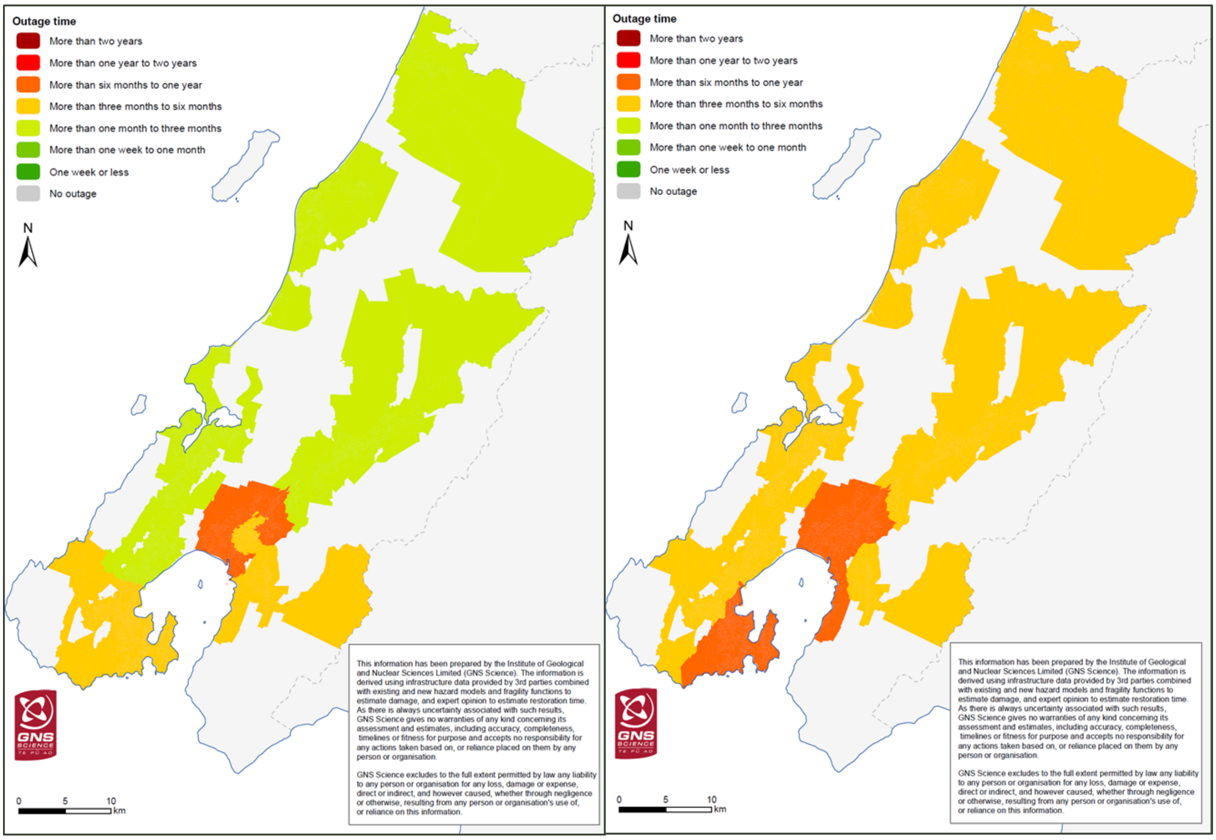


Figure 6.15 Outage map for non-potable (left) and potable (right) water services.

6.4.4 Intervention Outages

Intervention projects for the Water network were as follows:

> ***Cross Harbour Pipeline*** *– new pipeline connection assumed to extend inland just south of the Waterloo Treatment Plant. The pipe is assumed to be designed to withstand damage from a Wellington Fault event and therefore no damage modelling was required.*
>
> ***Prince of Wales and Bell Road Reservoir Upgrade*** *- assumed to be designed to withstand damage in the given scenario and no damage modelling was done. This programme is necessary for the functionality of the cross harbour pipeline programme.*
>
> ***Carmichael to Johnsonville and Karori Pipeline*** *- new transmission pipeline is added connecting Karori, Carmichael and Johnsonville. This pipe was assumed to be designed to withstand damage from a Wellington Fault event and was therefore not modelled for damage.*
>
> ***General Water Supply Toughening*** *- a 'critical' network of pipes was defined, made up of predominantly mains and mains – to – reservoirs. These were all assumed to be upgraded to ductile pipes, if not already, for damage modelling.*
>
> ***Porirua Branch Replacement & Emergency Water Treatment Facility*** *- new pipeline connection is added which is assumed to be designed to withstand any damage from this scenario and was therefore not modelled for damage. The emergency treatment plant has no spatial data, but is also assumed to designed to withstand damage from this scenario and would be operational immediately after the event, therefore, no damage was modelled for this asset. The emergency treatment plant had no effect on non-potable outage time, but meant that potable water was available as soon as the pipes are repaired to supply the area.*
>
> ***Elsdon Reservoir Upgrade*** *- This programme was not modelled in Phase 2, but is necessary for the Porirua branch replacement and emergency water treatment facility programme.*
>
> ***Waterloo Pump Station Extension*** *- this assumed that the Waterloo Treatment Facility would be operational immediately after the given event. This was not modelled for damage as the extension is assumed to be designed to withstand damage during this scenario. This had no effect on outage time for non-potable water, however it meant that potable water is available immediately after pipes are restored.*
>
> ***New Pipeline from Waterloo to Haywards*** *– a new pipe is added for bulk supply between Waterloo treatment plant and Haywards. This pipe was assumed to be designed to withstand damage in the given scenario and is therefore not modelled for damage.*
>
> ***Waterloo Water Treatment Plant Liquefaction Mitigation Project*** *– this is assumed to be designed to withstand the effects of a Wellington Fault event, therefore no damage modelling is necessary. This results in a reduction of outage time for potable water.*
>
> ***Silverstream Bridge Pipeline Replacement Project*** *– new pipe assumed to be designed to withstand the effects of a Wellington Fault event, therefore damage modelling is not necessary.*

All these projects were included in both intervention programmes.

New pipelines, all of which were not modelled for damage, are assumed to be operating after the event. This meant that any breaks on the existing network could be bypassed by the new pipes and were therefore removed from the total breaks for that zone's transmission supply. The upgraded 'critical network' was modelled the same as with base-case, resulting in reduced breaks.

The Cross Harbour Pipeline in conjunction with the strengthening of the Waterloo wells and treatment plant allowed for repair crews to be assigned to Miramar and South Wellington immediately following the restoration of bulk pipes between Waterloo treatment plant and Seaview. This method provides potable supply to the south of the region while supply is also sourced from the north. The strengthening of water treatment plants and the addition of an emergency plant in Porirua, meant that potable water was available across the region as soon as the water supply was restored through damaged pipe networks. This meant there was no difference in non-potable (untreated) and potable water outage times other than for Kapiti Coast pressure zones.

Once interdependencies with roads and electricity or fuel were considered, the outage times for non-potable and potable services were equal. The updated outage times are presented in Figure 6.16. Note that they are the same for both the low and high investment programmes.

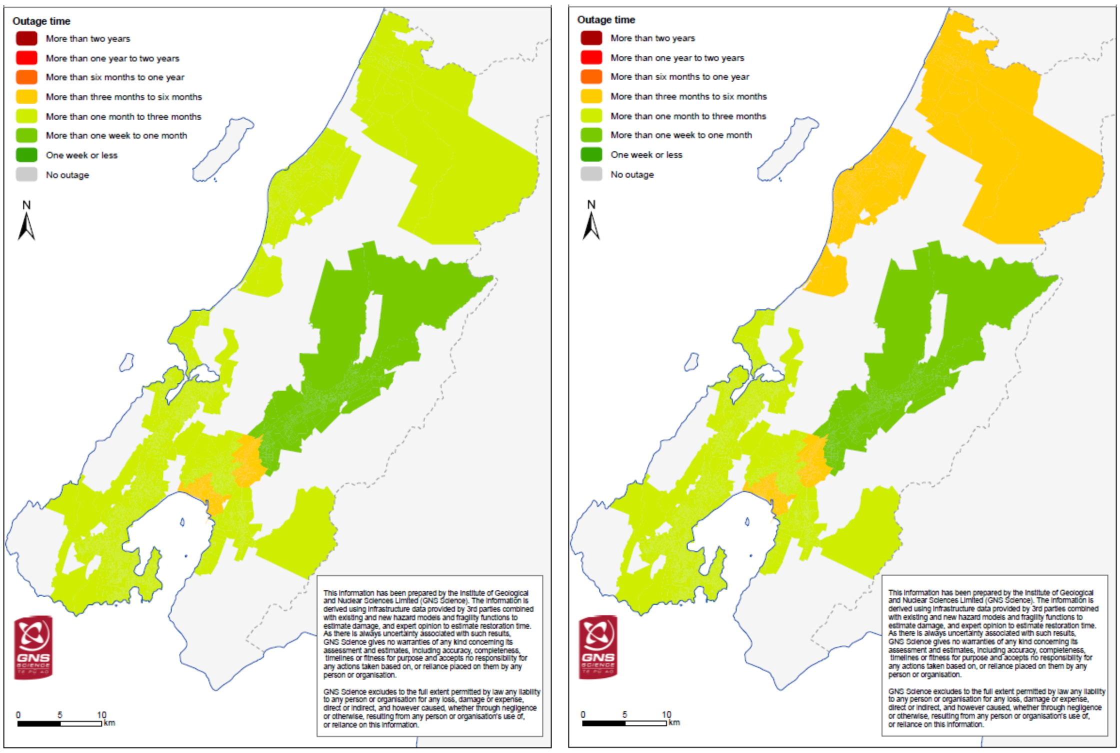


Figure 6.16 Outage map for non-potable (left) and potable (right) water services for low and high investment intervention programmes.

6.4.5 Preferred Programme Outages

While there was no change to the projects for potable water under the preferred programme, Wellington Water did request a change to the restoration strategy. A new method for crew allocation was used, which focused on bulk network repairs to connect zones as a priority, without repairing all breaks in one zone before moving to the next (which was the strategy under the base-case). This allowed for water supply to move through the region quicker before beginning work on the distribution network. The new restoration strategy also assumed an additional 10 repairs per day on the distribution pipe network compared with the base-case. The updated outage times are presented in Figure 6.17. While there has been a change in the raw numbers for the preferred programme, the timebands used in the outage maps means the maps do not show the difference.

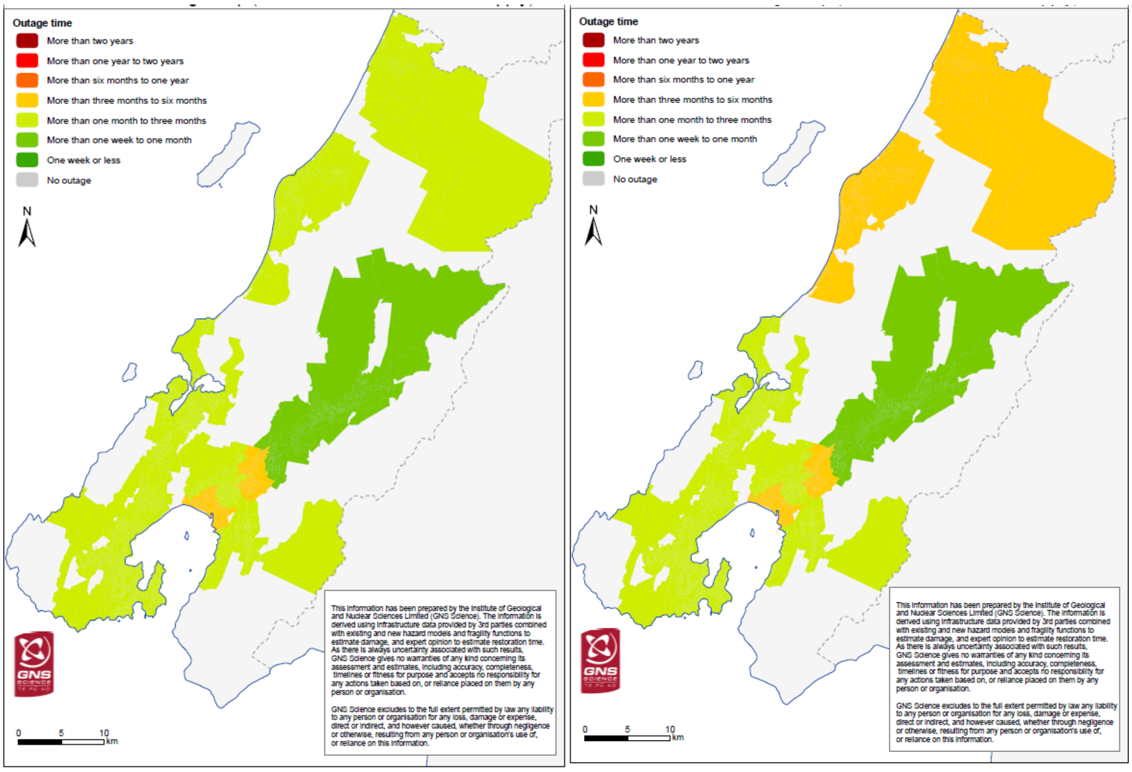


Figure 6.17 Outage map for non-potable (left) and potable (right) water services for the preferred programme.

6.5 WASTE WATER

For the Wellington Region waste water network, the following components were considered.

> ***Collection Pipelines*** *– classified by class (mains, submains, reticulation), diameter, material type, joint type, ductility and length*
> ***Interceptor Pipelines*** *- classified by diameter, age, material type, joint type, ductility and length.*
> ***Pump Stations*** *– classified by capacity, building material, foundation type and by seismic restraining level (anchored components, unanchored components)*
> ***Waste Water Treatment Plants*** *- classified by capacity, building material, foundation type and by seismic restraining level*

6.5.1 Vulnerability and Damage Modelling

Impacts to the waste water network were modelled using RiskScape (see Section 2.0) with the vulnerability models presented in Table 6.6. For pipe assets, empirical functions that estimate break rates (per km) due to ground shaking hazard intensity (MMI) and ground displacement (Fault rupture, landslide, liquefaction, co-seismic subsidence and lateral spreading) are used. The results of damage modelling are presented in Figure 6.18.

Table 6.6 Waste water assets vulnerability models.

Asset Type	Hazards		
	Ground Shaking	**Liquefaction**	**Other Hazards**
Treatment Plants	PGA: (Federal Emergency Management Agency, 2015)	LSN: (Rosser and Dellow, 2015)	Within Hazard foot print = DS4, not within hazard footprint = DS0 lateral spreading = Nayyerloo, 2016
Pipelines	MMI: Interceptors = (Cousins, 2013). Collection sewers = Nayyerloo, 2016	Bulk pipes = (Cousins, 2013). Others = Nayyerloo, 2016	
Lift Stations	PGA: (Federal Emergency Management Agency, 2015)	(Rosser and Dellow, 2015)	

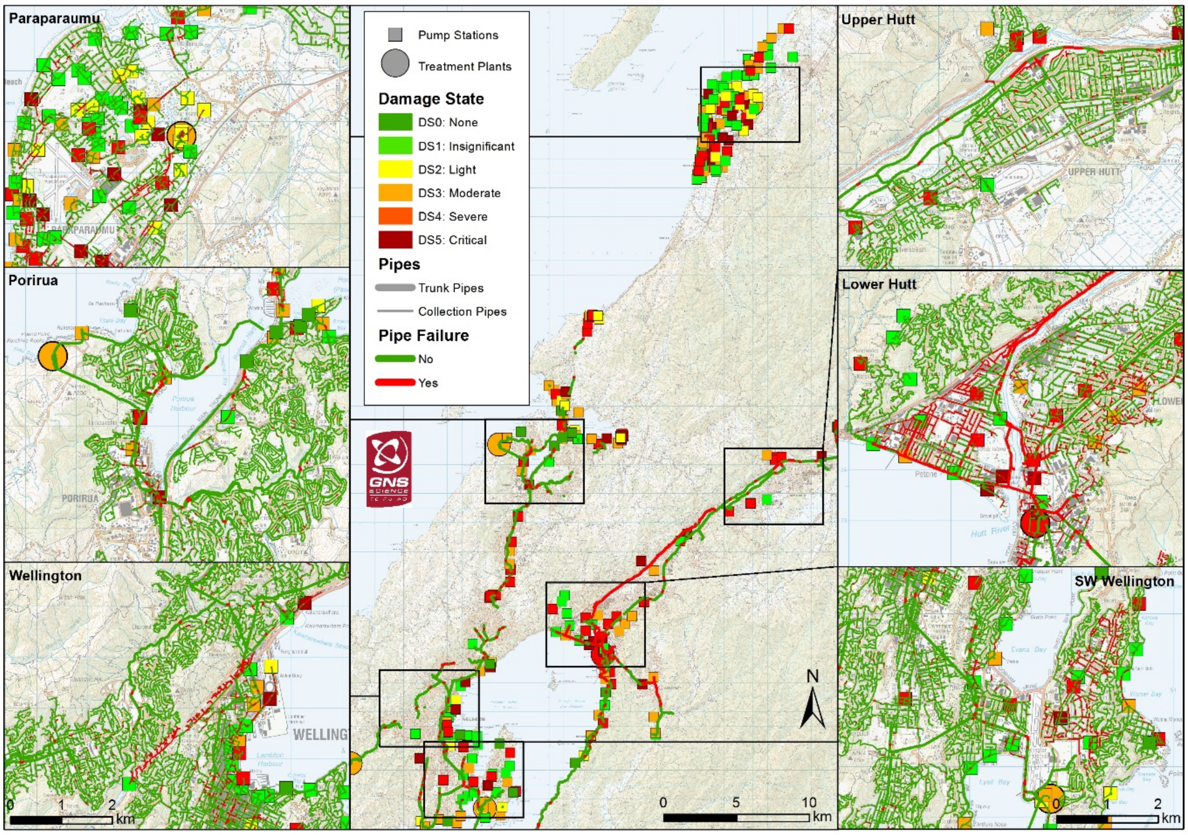


Figure 6.18 Modelled damage to the Wellington Region waste water network.

6.5.2 Base-Case Outages

Network outage times were derived through workshops with network providers, as per the modelling framework (Section 2.0). The focus was on finding watercourses for each catchment, which in an emergency situation are an acceptable means of wastewater discharge in order to bypass damaged assets and prevent overflow or backflow. Outage was assigned based on network damage and distance from nearest available watercourse. Lateral spreading and co-seismic subsidence were also considered in the workshops regarding flow reversal on gravity pipes. Separate restoration times were considered for collection (and discharge to nearest watercourse) and collection with treatment.

Network interdependencies were defined during workshops with network providers. Waste water considered electricity or fuel (for mobile pumps), water (>100 L per day per person required to keep network flowing) and road access. The restoration times of interdependent networks were applied to the waste water network restoration time (base outage) to determine network outage for treated and untreated services (Figure 6.19).

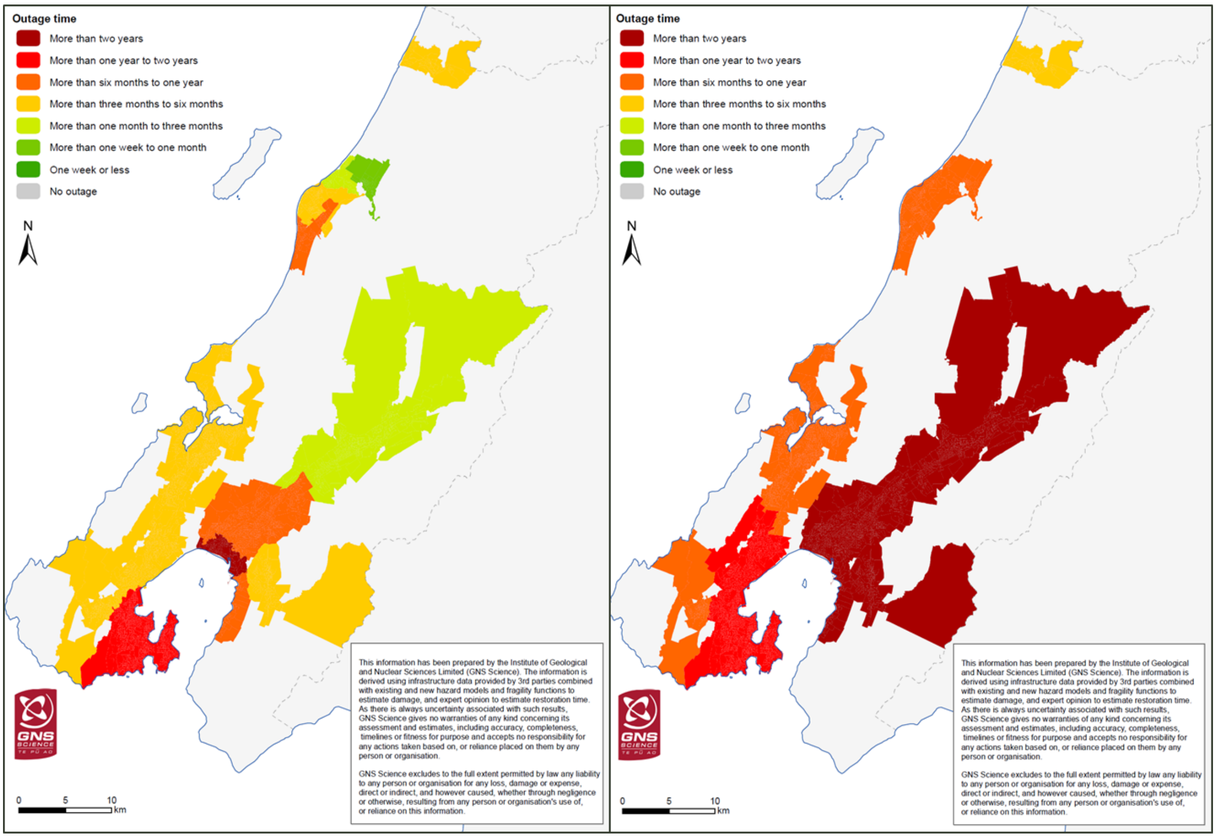


Figure 6.19 Outage times for waste water collection (left) and treatment (right) services.

6.5.3 Intervention Outages

No intervention programmes influenced damage or outage for the wastewater network, however a dependency on the water network resulted in a change to waste water outage times for intervention modelling (Figure 6.20). As interventions for the water network had no variation between low and high investment programmes, the waste water outage times are also equal for both.

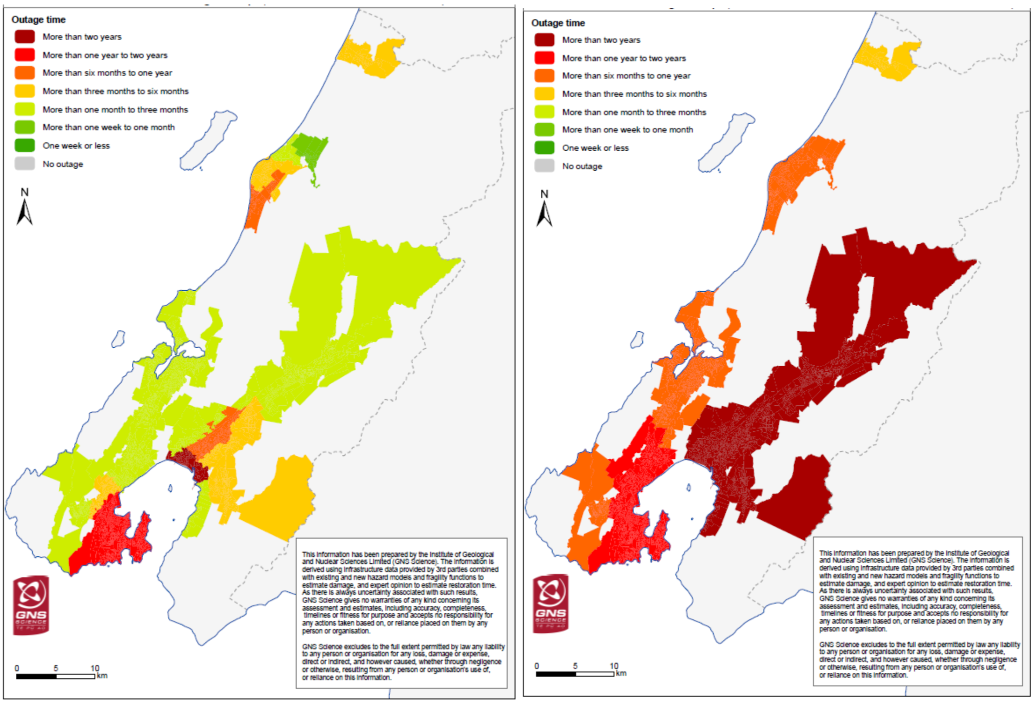


Figure 6.20 Outage times for waste water collection (left) and treatment (right) for low and high investment programmes.

6.5.4 Preferred Programme Outages

Although there were no new wastewater intervention projects included in the preferred programme, wastewater is dependent on potable water, and there were changes made to the potable water outages under the preferred programme. Figure 6.21 shows the preferred programme outages for wastewater.

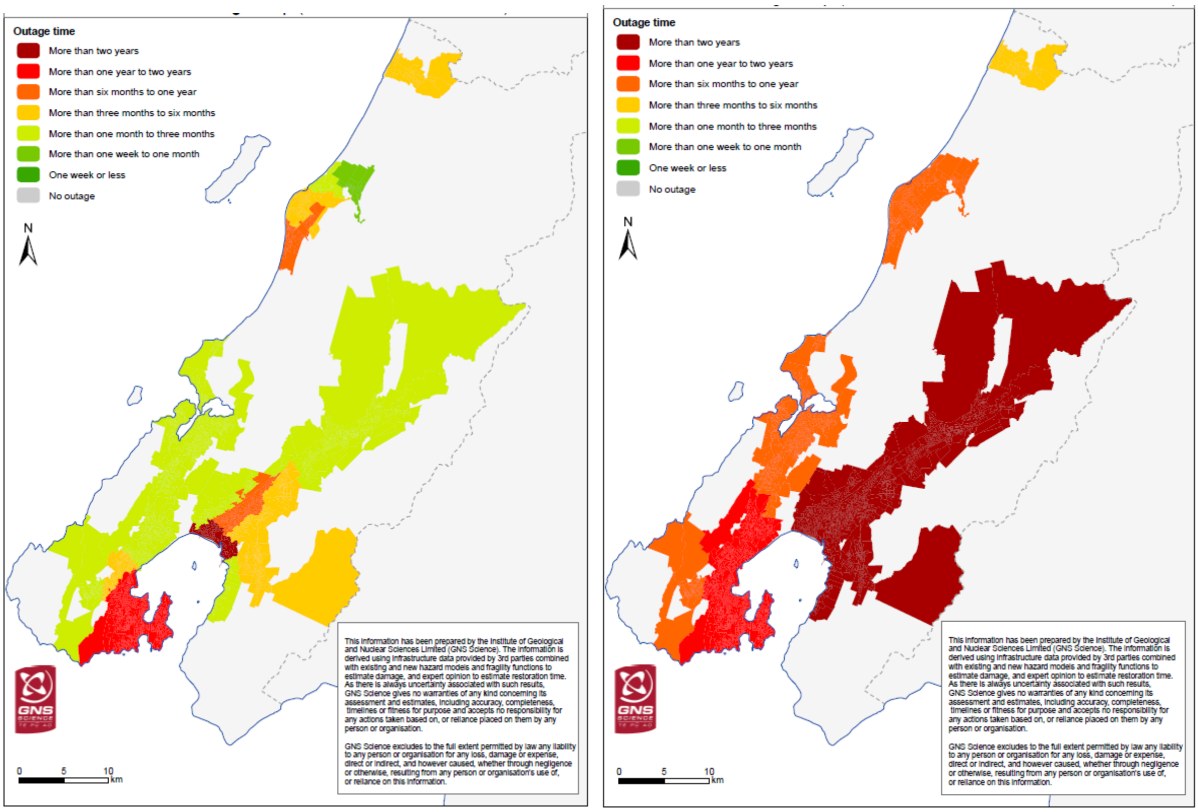


Figure 6.21 Outage map for waste water collection (left) and treatment (right) for the preferred programme.

6.6 GAS

6.6.1 Asset Data

The Nova and PowerCo gas networks provide local distribution of gas across Wellington, Porirua, Hutt City and Upper Hutt. The Nova and PowerCo networks source gas from gates operated by First Gas who, in turn, distribute from Taranaki generation to the Wellington Region. First Gas assets were not considered for damage modelling as they are outside the affected area. The following components were considered:

> ***Local distribution pipes*** *– these are similar steel pipes with carbon fibre reinforcing and have a single classification*

Gas valves were not considered for damage modelling as they were deemed to be extremely robust.

Following meetings with Nova and PowerCo, both networks were found to have similar pipe types and were therefore grouped together for modelling.

6.6.2 Vulnerability and Impact Modelling

Impacts to the gas distribution network were modelled using RiskScape (see Section 2.0) using the vulnerability models presented in Table 6.5. For pipelines, empirical functions that estimate break rates due to ground shaking hazard intensity (MMI) and ground displacement (Fault rupture, landslide, and liquefaction) are used as opposed to lognormal cumulative distribution functions. Pipes are segmented into approximate 50m lengths across the network and all are defined as ductile piping.

Table 6.7 Summary of gas network asset vulnerability models.

Asset Type	Hazards		
	Ground Shaking	**Liquefaction**	**Landslide and Fault Rupture**
Pipelines	Distribution pipes = Nayyerloo, 2016	Distribution pipes = Nayyerloo, 2016	Within Hazard foot print = DS5: Critical Damage, not within hazard footprint = DS0:

Modelled damage to the gas pipeline network is presented in Figure 6.22.

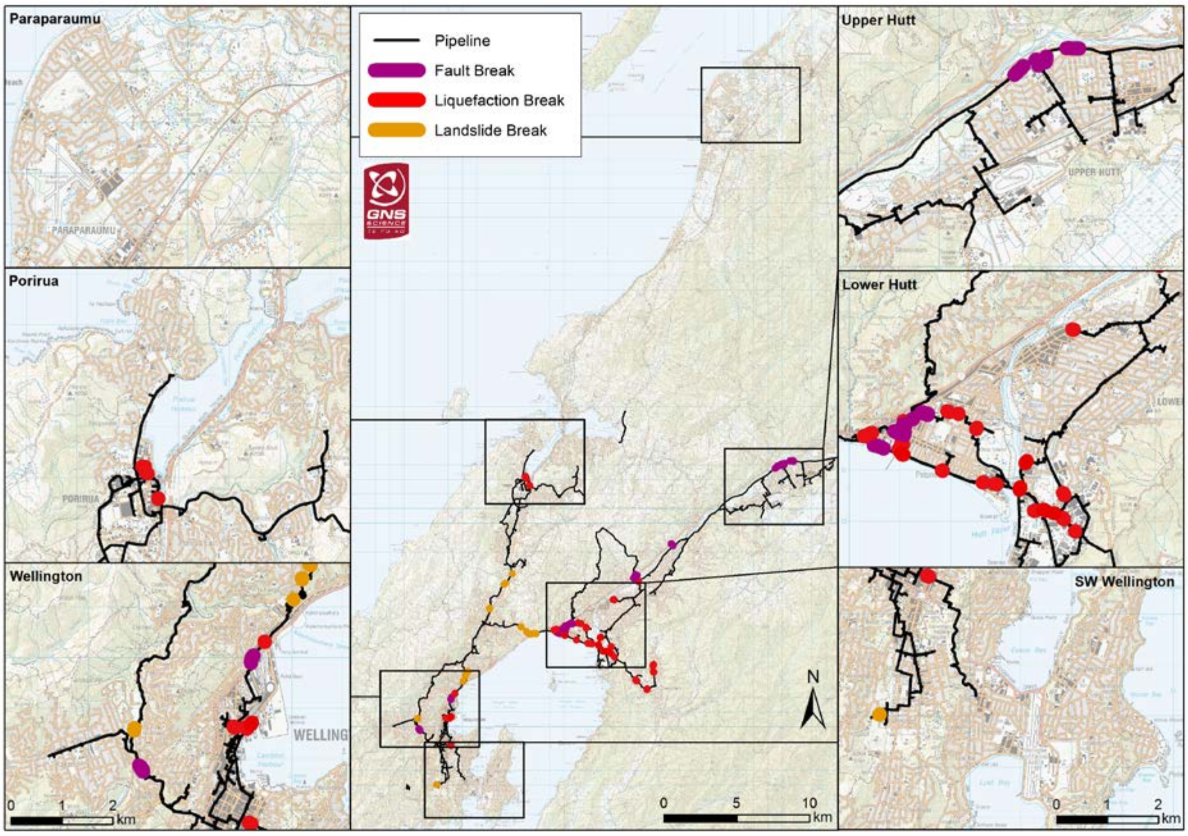


Figure 6.22 Modelled damage to the Wellington Region gas network.

6.6.3 Base-Case Outages

Network outages were estimated through a workshop with Nova and PowerCo engineers. Based on the pipe network break map, restoration strategies and times were defined by Nova and PowerCo. The gas network would be restored from the 'gate' (exit point of First Gas network) and then downstream to the customer. Each break would be isolated and the pipe would be replaced. Repair crews are typically based in Seaview, Lower Hutt, so outage was dependent on road access from Seaview to the break site, beginning with breaks closest to the gates. Repair times for each break were estimated at 4-7 days and breaks close together could be repaired simultaneously. Once interdependencies of roads were considered, the outage time for critical and general customers was similar (Figure 6.23).

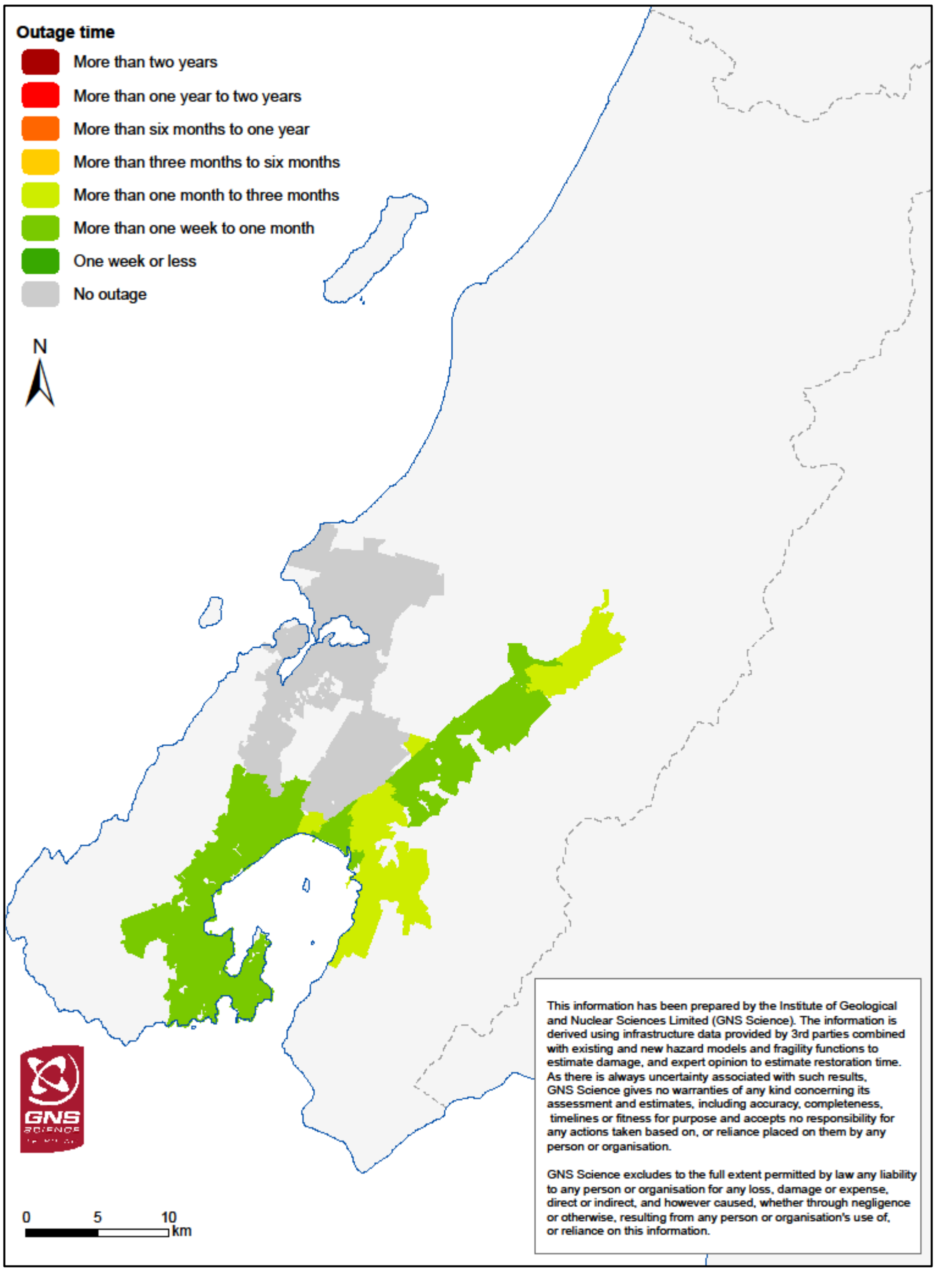


Figure 6.23 Outage times for gas to critical and general customers.

6.6.4 Interventions

Only one intervention project was considered for the gas network, and this was included in both programmes:

> ***Point solution conversion for LPG - Supplies for key activities including hospitals –*** *damage modelling not required*

This intervention project was aimed to reduce the disruption to critical users (e.g. hospitals etc) by using portable LPG supplies, for example through isotainers shipped on trucks or smaller LPG tanks. These are available outside of the region and therefore restoration of gas to these critical customers is the same time as road access is restored. The outage time for general customers is unchanged from the base case modelling. The outage times for low and high investment programmes were equal (Figure 6.24).

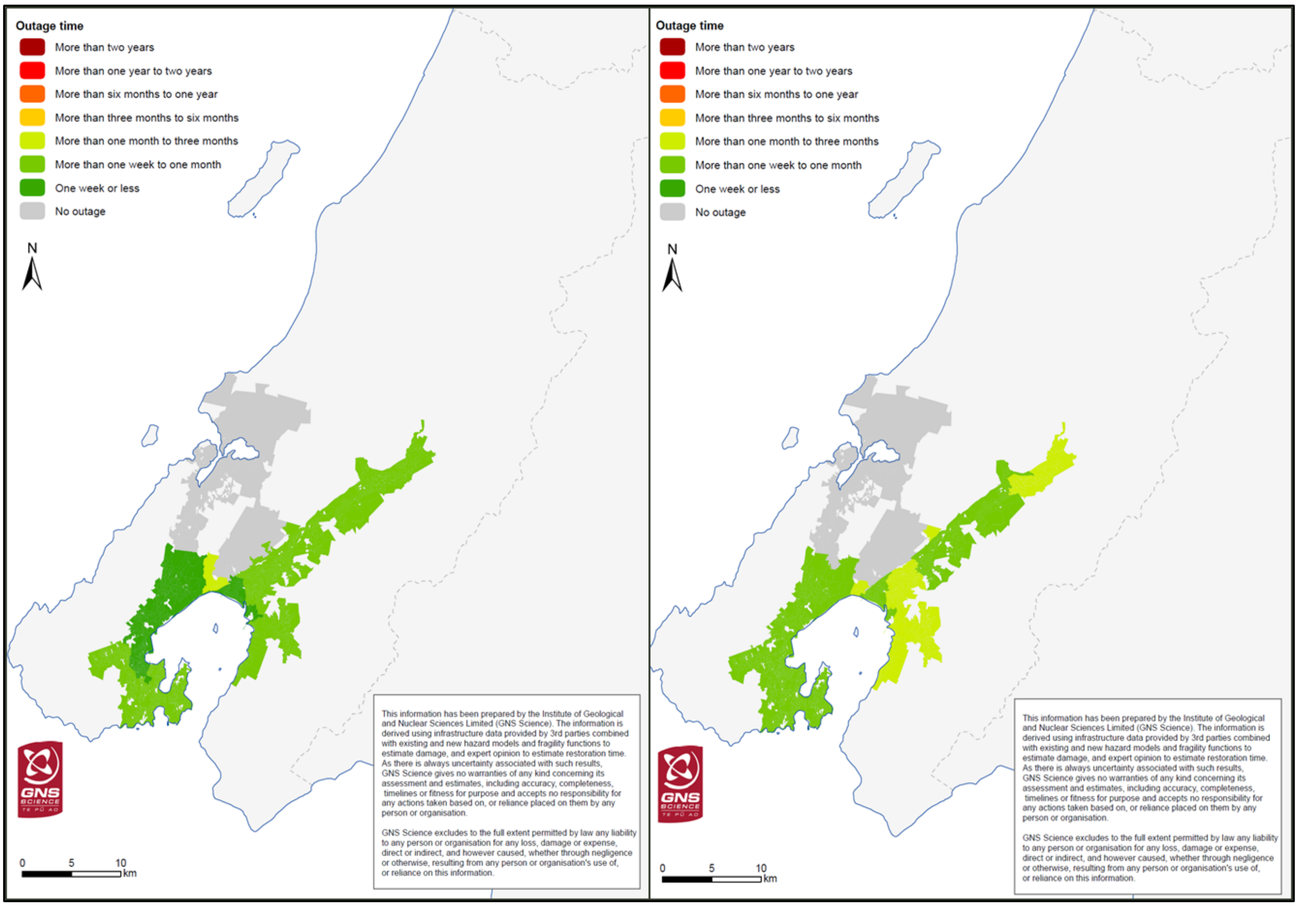


Figure 6.24 Outage times for gas to critical (left) and general (right) customers incorporating the intervention project to supply critical customers with bottled gas or isotainers.

6.6.5 Preferred Programme Outages

There were no new gas intervention projects added to the preferred programme. Therefore, the preferred programme outages for gas are the same as the High Investment outages (Figure 6.24).

7.0 NON-INFRASTRUCTURE

7.1 BUILDINGS

Buildings are generally considered the end-point of most infrastructure distribution networks. Building assets can also easily be linked to occupancy and economic value based on council rateable values and national census data. This provides the crucial link between the built and social environments which is a key input for MERIT economic loss modelling (see Section 1.2) in this project. In addition to direct losses, the MERIT-RiskScape linked economic loss model also requires outage times which, in the case of buildings, are defined by functional down-time (i.e. the number of days a building is not functional following the given hazard scenario).

7.1.1 Asset Data

In the case of this project, all occupied buildings in the Wellington Region were assumed to be included in the RiskScape asset repository. This includes residential, commercial, industrial, educational, utility, community, government, religious and emergency operations buildings. This database was unaltered for the study area. Buildings are classified by use category, earning potential, replacement cost, contents value, storeys, floor area, footprint area, occupancy, vehicle value, vehicles.

7.1.2 Impact modelling

Utilising RiskScape's vulnerability module for earthquakes and the Wellington Region buildings repository, direct impacts to building assets were modelled including the direct economic losses associated with building damage. The level of damage to structural and non-structural components of a building is described by one of five damage states**:** DS0: None (no damage), DS1: Insignificant (minor non-structural damage), DS2: Light (non-structural damage only), DS3: Moderate (repairable structural damage), DS4: Severe (irreparable structural damage), and DS5: Critical (structural integrity fails). The model was run for 10 scenario realisations at both night and day time scenarios, allowing for variations in population distribution. The direct impact results were provided for damage state (Figure 7.1), human displacement, human susceptibility, human losses and reinstatement costs.

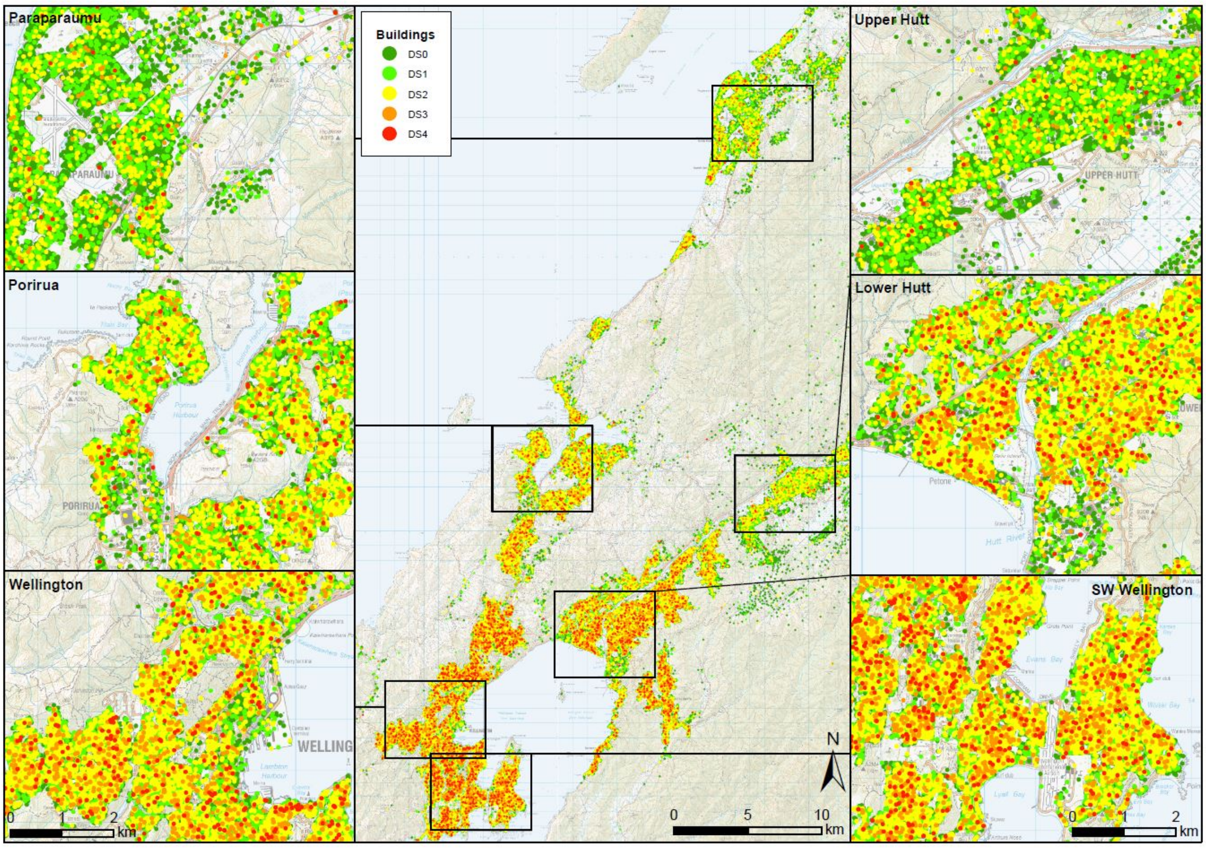


Figure 7.1 Modelled damage states for Wellington Region buildings.

7.1.3 Functional Down-time

The functional down-time of buildings are estimated using expert judgement and down times observed in the Canterbury Earthquake Sequence (2010-2011) that is conditional on damage state of the building. The availability of lifelines (e.g. electricity, water, and road access) to the building is also considered to estimate the final building down time. The MERIT economic loss model also requires building intra-dependency based on cordon zones that may be erected around the potential fallout zone of unstable buildings. A cordon zone was applied to the 10 sets of results for >= DS4 (Severe and Critical damage) buildings (Figure 7.2). The cordon zone distance was assumed to be half the building height, or the full building height for unreinforced masonry buildings. Building footprints were used and the cordon zone was calculated from the footprint edge. Building height was assumed to be 2.5m per storey.

Figure 7.2 Example of cordon zones (red) in Wellington CBD associated with > DS4 buildings for a single scenario realisation.

8.0 SUMMARY

Three stages of infrastructure damage and economic disruption modelling have been undertaken to provide an evidence-base for the assessment of infrastructure investment programmes identified by the Wellington Lifelines Group. The modelling process has produced a series of temporal service outage maps that show the time to restoration of full service following a Mw7.5 Wellington Fault earthquake event and associated perils (fault rupture, ground shaking, liquefaction, landslides, lateral spreading, subsidence), as well as economic disruption information, including figures for loss in GDP out to five years following the event. This information is to be used by Aurecon in a Programme Business Case for investment in the resilience of Wellington's infrastructure.

The outputs from the modelling process have been specifically produced for the Programme Business Case assessment, and are not necessarily appropriate for other uses by the lifeline organisations involved. However, the work done in this project can be built on, to produce appropriate information for more specific purposes, such as detailed analysis of network vulnerabilities or the impact of the staging of intervention projects on reducing GPD losses. Another positive outcome of the project is that further modelling can now be undertaken more efficiently than was possible before this project due to advances in modelling techniques developed as part of the project and supported by research funding.

9.0 ACKNOWLEDGMENTS

We would like to sincerely thank the lifeline organisations who contributed data, time and expertise to this project. We would like to thank the Richard Mowll for this facilitation and expert knowledge. And we would like to thank the Project Steering Group for providing valuable guidance and feedback on the modelling process.

We would like to thank Aurecon for their collaboration on this project.

We would like to thank Finn Scheele, Kelvin Berryman, and Michele Daly for their reviews of this report.

10.0 REFERENCES

Allard J, Kenworthy C. 2017. Programme business case for infrastructure investment to ensure the Wellington Region can rebound after a major earthquake. Wellington (NZ): Aurecon New Zealand Limited.

Berryman KR. 1990. Late Quaternary movement on the Wellington Fault in the Upper Hutt area. New Zealand Journal of Geology and Geophysics. 33(2):257–270.

Boon, D. Perrin ND, Dellow GD, Van Dissen RJ, Lukovic B. 2011. NZS1170.5:2004 site subsoil classification of Lower Hutt. In: Ninth Pacific Conference on Earthquake Engineering: Building an earthquake resilient society; 2011 Apr 14-16; Auckland, New Zealand. Auckland (NZ): 9PCEE. paper 013.

Bradley BA. 2013. A New Zealand-specific pseudospectral acceleration ground-motion prediction equation for active shallow crustal earthquakes based on foreign models. Bulletin of the Seismological Society of America. 103(3):1801–1822. doi:10.1785/0120120021.

Brown C, Seville E. 2017. Wellington Lifelines Resilience project programme business case: Business Behaviours Workshops, April 2017. Christchurch (NZ): Resilient Organisations.

Cousins WJ, Thomas G, Heron DW, Smith WD. 2012. Probabilistic modeling of post-earthquake fire in Wellington, New Zealand. Earthquake Spectra. 28(2):553-571. doi:10.1193/1.4000002.

Cousins WJ. 2013. Wellington without water: impacts of large earthquakes. Lower Hutt (NZ): GNS Science. 124 p. (GNS Science report; 2012/30).

Dellow GD, Perrin ND, Ries WF. 2015. Liquefaction hazard in the Wellington Region. Lower Hutt (NZ): GNS Science. 71 p. (GNS Science report; 2014/16).

Dellow GD, Barker PR, Beetham RD, Heron DW. 2003. A deterministic method for assessing the liquefaction susceptibility of the Heretaunga Plains, Hawke's Bay, NZ. In: Crawford S, Baunton P, Hargraves S. Geotechnics on the volcanic edge; 2003 Mar; Tauranga, New Zealand. Wellington (NZ): Institution of Professional Engineers New Zealand. p. 111-120. (Proceedings of technical groups; 30(1 GM)).

Federal Emergency Management Agency. 2015. Hazus–MH 2.1 technical manual : earthquake model. Washington (DC): Federal Emergency Management Agency Mitigation Division. 718 p. [accessed 2018 Mar 27]. https://www.fema.gov/media-library-data/20130726-1820-25045-6286/hzmh2_1_eq_tm.pdf.

Greater Wellington Regional Council. 2014. Wellington (NZ): Greater Wellington Regional Council; [accessed 2013 April 01]. http://www.gw.govt.nz/.

Lin S-L, Nayyerloo M, Zhang H. 2016. Seismic performance of buried cables during the Canterbury Earthquake Sequence. In: Australasian Earthquake Engineering Society Conference; 2016 Nov 25-27; Melbourne, Australia. Melbourne (AU): Australian Earthquake Engineering Society. paper 372.

Nayyerloo M, King AB. 2012. Assessment of earthquake risk: Chorus NZ. Lower Hutt (NZ): GNS Science. 37 p. (GNS Science consultancy report, 2012/247).

Perrin ND, Stephenson WR. 2010. Site class determinations (NZS 1170.5) in Wellington using borehole data and microtremor techniques. In: Earthquake prone buildings: how ready are we? 2010 NZEE Conference; 2010 Mar 26-28; Wellington, New Zealand. Wellington (NZ): New Zealand Society for Earthquake Engineering. paper 22, Figure 1.

Rosser BJ, Dellow GD. 2015. Assessment of liquefaction risk in the Hawke's Bay. Lower Hutt (NZ): GNS Science. 77 p. (GNS Science consultancy report; 2015/186).

Sadashiva VK, King AB, Matcham I. 2017. Exploring a risk evaluation tool for New Zealand State Highway Network National Resilience Project. In: 16th World Conference on Earthquake Engineering, 16WCEE; 2017 Jan 9-13; Santiago, Chile. Tokyo (JP): International Association for Earthquake Engineering. paper 3957.

Smith N, Brown C, McDonald G, Seville E, Ayers M, Kim J. 2017. Wellington Resilience Programme business case: Modelling the Economics of Resilient Infrastructure Tool (MERIT) assumptions report. Christchurch (NZ): Resilient Organisations.

Stirling MW, McVerry GH, Gerstenberger MC, Litchfield NJ, Van Dissen RJ, Berryman KR, Barnes P, Wallace LM, Villamor P, Langridge RM, et al. 2012. National seismic hazard model for New Zealand: 2010 update. Bulletin of the Seismological Society of America. 102(4):1514-1542. doi:10.1785/0120110170.

Townsend DB, Begg JG, Van Dissen RJ, Rhoades DA, Saunders WSA, Little TA. 2016. Estimating co-seismic subsidence in the Hutt Valley associated with rupture of the Wellington Fault. Bulletin of the New Zealand Society for Earthquake Engineering. 49(3):283-291.

Wellington Region CDEM Group. 2015. Wellington Region CDEM Group Fuel Plan 2015. Wellington (NZ): WREMO.

Worden CB, Wald DJ, Rhoades DA. 2012. Probabilistic relationships between ground-motion parameters and modified mercalli intensity in California. Bulletin of the Seismological Society of America. 102(1):204–221. doi:10.1785/0120110156.

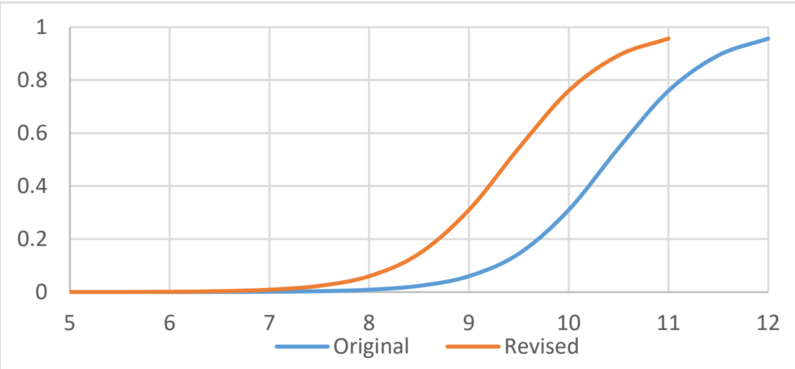
Xie L, Tang J, Tang H, Xie Q, Xue S. 2012. Seismic fragility assessment of transmission towers via performance-based analysis. In: 15th World Conference on Earthquake Engineering (15WCEE); 2012 Sep 24-28; Lisbon, Portugal. Kanpur (IN): NICEE. 10 p.

APPENDICES

A1.0 CALIBRATED VULNERABILITY MODELS FOR ELECTRICITY ASSETS

Table A2.1 Ground Shaking Vulnerability Model for Buried Electricity Cables.

Ground Shaking					
Reference	S.-L. Lin, M. Nayyerloo and Z. Zhang 2016, "Seismic Performance of Buried Electricity Cables during the Canterbury Earthquake Sequence", Australian Earthquake Engineering Society 2016 Conference, Nov 25-27, Melbourne, Australia				
Method	Empirical & expert Judgement				
Function	Logit (inverse of logarithm)				
Equation	$=1/(1+EXP(-(\beta_0 + \beta_1 * MMI)))$				
Function Example	https://en.wikipedia.org/wiki/Logistic_regression				
Typology	Buried Cable				
Damage Ratios	0.0 – 0.04	0.04 – 0.12	0.12 – 0.5	0.5 – 0.8	> 0.8
RiskScape Damage State	DS1: Insignificant	DS2: Light	DS3: Moderate	DS4: Severe	DS5: Critical
Hazard	Ground Shaking				
Intensity Parameter	**MMI**				



Revised Curve Parameters

MMI	Damage Ratio
5	0.0001840
5.5	0.000488
6	0.001292
6.5	0.003419
7	0.009013
7.5	0.023545
8	0.060087
8.5	0.144922
9	0.310026
9.5	0.543639
10	0.759511
10.5	0.893309
11	0.956893

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Appendix L

Modelling the Economics of Resilient Infrastructure Tool (MERIT) Assumptions Report

Wellington Resilience Programme Business Case

Modelling the Economics of Resilient Infrastructure Tool (MERIT) Assumptions Report

5th December 2017

m.e research

Resilient ORGANISATIONS

Wellington Resilience Programme Business Case

Modelling the Economics of Resilient Infrastructure Tool (MERIT) Assumptions Report

Prepared for

Wellington Lifelines Group

Date of this version: 05/12/2017

Report author(s): Nicola Smith, Charlotte Brown, Garry McDonald, Erica Seville, Morag Ayers, John Kim

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Glossary

CBD: Central Business District.

Census Area Unit (CAU): A geographic unit from Statistics New Zealand Census Area Unit Boundaries. The CAU is constructed by combining meshblocks and generally coincide with main or secondary urban areas. On average, CAUs within urban and rural areas normally contain a population of 3,000 to 5,000 and 500 to 2,000 respectively.

Computable General Equilibrium (CGE): A class of applied economic models typically used to illustrate an economy's responses to changes in policy, technology or other external shocks. Typically, CGE models recognise several types of economic agents (usually different types of industries, households and government), conceptualised as either profit or utility maximisers. Optimisation algorithms are employed to determine the set of prices for all commodities and factors of production that would prevail subject to selected constraints (e.g. all commodity and factor markets clear, and total income equals total expenditure for all agents).

GDP: Gross Domestic Product.

Households: New Zealand resident individuals and families, and Private Non-Profit Organisation (PNPO) serving households.

Meshblock: The smallest geographic unit for which statistical data is collected by SNZ. These vary in size depending on population. Rural meshblocks generally having a population of around 60 people, while urban meshblocks are roughly the size of a city block with approximately 110 people.

SAM: Social Accounting Matrices.

System Dynamics: A methodology for understanding certain kinds of dynamic systems. The methodology concentrates on mapping the feedback relationships between different components or relationships within a system, and simulating changes in systems over time.

TA: Territorial Local Authority.

1 Introduction

As part of the Wellington Resilience Programme Business case, economic impact modelling was carried out to assess packaged infrastructure options for improving Wellington's resilience to a 7.5 magnitude earthquake on the Wellington Fault. Specifically, the modelling assessed the disruption impacts to the economy associated with the quake. Our analysis is deliberately narrowed to *economic disruption* rather than consideration of losses of life or physical asset damage.[1] This reflects the desire of stakeholders for an economic analysis to support development of a resilience Programme Business Case (PBC). Importantly, the stakeholders, through a facilitated Intervention Logic Mapping (ILM) workshop, selected *net changes in GDP*[2] associated with a preferred investment programme as a key PBC assessment metric – giving it a 65% weighting. Our modelling used 'MERIT' (**M**odelling the **E**conomics of **R**esilient **I**nfrastructure **T**ool) developed in the 2012-16 MBIE funded Economics of Resilient Infrastructure (ERI) research programme.[3]

The purpose of this report is to describe the economic modelling and assumptions made during the analysis. The report is structured as follows:

Section 2 provides a brief description of the MERIT toolkit,

Section 3 describes how MERIT was applied to Wellington, and

Section 4 details the sub-models and key assumptions applied in the analysis.

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[1] The latter two however have been estimated by GNS Science.

[2] As measured against a business-as-usual counterfactual scenario.

[3] https://www.naturalhazards.org.nz/NHRP/Hazard-themes/Societal-Resilience/EoRI.

2 Modelling the Economics of Resilient Infrastructure Tool (MERIT)

MERIT is an integrated spatial decision support system that enables a high-resolution assessment across space and through time of the economic consequences of infrastructure failure, business response, and recovery options.

Central to MERIT is a multi-sectoral, multi-regional and fully dynamic economic model, intentionally designed to imitate the core features of a Computable General Equilibrium (CGE) model. CGE models tend to be the favoured approach and 'state-of-art' in modelling of regional and national-level economic impacts. Among the advantages of these types of models are the whole-of-economy coverage, the capture of not only indirect (i.e. so-called upstream and downstream multiplier effects generated through supply chains) and induced (i.e. as generated through household consumption) impacts, but also the 'general equilibrium' impacts (i.e. price changes, factor substitution and transformation).

Although MERIT incorporates the core features of a CGE model, it is important to note that it differs from a standard CGE model in that it is formulated as a System Dynamics model using finite difference equations. This is an innovative extension to economic modelling undertaken in part to improve our ability to capture the impacts of events over time. Standard economic models are 'equilibrium' models that describe conditions of demand for all commodities and factors when a set of pre-determined conditions are met i.e. supply equates to demand for commodities and factors, and income equates to expenditure for all economic agents. MERIT however is a simulation model, acknowledging that in meeting these constraints there is a transition pathway through which the economy must pass. MERIT is particularly useful when dealing with natural hazard events as it can directly account for out-of-equilibrium dynamics that often emerge in a disrupted economy.

Once information is transformed into appropriate inputs and MERIT is run, it can produce a variety of indicators to help us assess economic impacts of an infrastructure outage in aggregate and by industry. The model can thus not only be used to assess the economic consequence of a natural hazard event resulting from infrastructure failure, but also to inform on resilience-building and investment initiatives. The steps that are required to transform information on physical disruptions into appropriate input parameters can vary can from application-to-application, depending on the types of physical information provided, as well as the extent and nature of impacts arising out of the disruption event. Much of this report concentrates on describing the steps and assumptions that were necessary to model the specific Wellington 7.5 magnitude earthquake scenarios.

Details on how the suite of MERIT tools was developed, how it works, and previous applications are also provided in the following reports:

- Buxton, R.; Wright, K.C.; Daly, M.C.; Timar, L.; Mieler, D. (2014) *Single Infrastructure Failures: capturing outage information for MERIT - Modelling the Economics of Resilient Infrastructure Tool.* Economics of Resilient Infrastructure Research Report 2014/01. 56p.

- Seville, E., Stevenson, J., Brown, C., Giovinazzi, S., Vargo, J. (2014) *Disruption and Resilience: How Organisations coped with the Canterbury Earthquakes.* Economics of Resilient Infrastructure Research Report 2014/02, 45p.
- Smith, N.J., Zhang, Y., Cardwell, R., McDonald, G.W., Kim, J.-H., and Murray, C.F. (2015). *Development of a Social Accounting Framework for New Zealand*. Economics of Resilient Infrastructure Research Report 2015/01. 71p.
- Brown, C., Giovinazzi, S., Seville, E., Vargo, J., Stevenson, J.R. (2015) *Developing the Business Behaviours Module within MERIT*. Economics of Resilient Infrastructure Research Report 2015/02. 71p.- addendum added January 2016.
- Hatton, T., Seville, E., Brown, C., Stevenson, J.R. (2016) *Businesses and the Canterbury earthquakes: how do their experiences translate to other contexts?* Economics of Resilient Infrastructure Research Report 2016/01.
- Deligne, N.I.; Blake, D.M.; Davies, A.J.; Grace, E.S.; Hayes, J.; Potter, S.; Stewart, C.; Wilson, G.; Wilson, T.M. 2015. *Economics of Resilient Infrastructure Auckland Volcanic Field Scenario*, Economics of Resilient Infrastructure Research Report 2015/03. 151 p.
- Smith, N.J., Kim, J-H., and McDonald, G.W. (2016). *Auckland Water Outage Scenario: Modelling the Economic Consequences of Interruptions in Infrastructure Service using MERIT.* Economics of Resilient Infrastructure Research Report 2016/02. 23p. 4
- Kim, J-H., Smith, N.J., and McDonald, G.W. (2016). *Auckland Electricity Outage Scenario: Modelling the Economic Consequences of Interruptions in Infrastructure Service using MERIT* Economics of Resilient Infrastructure Research Report 2016/04. 30p.
- Cardwell, R.C., McDonald, G.W., and Smith, N.J. (2016). *Economic Impacts of a Hypothetical Lyttleton Port Outage:* A confidential report prepared for Lyttleton Port Company under the Economics of Resilient Infrastructure Research Programme. Takapuna, Market Economics Ltd.
- Smith, N.J.; McDonald, G.W.; Kim, J-H. (2016). *Economic Impacts of the State Highway 4 Outage – June 2015*, Economics of Resilient Infrastructure Research Report 2016/03. 15 p.
- Kim, J.-H.; N.J. Smith; G.W. McDonald (2016). *Economics of Resilient Infrastructure*, Economics of Resilient Infrastructure Research Report 2016/04. 30 p.
- Smith, N.J., Harvey, E., and McDonald, G.W. (2016). *Dynamic Economic Model. A technical report*. Economics of Resilient Infrastructure Research Report 2017/02. 109p.

3 Applying MERIT to Wellington

To apply the MERIT toolkit to a Wellington Fault earthquake scenario, we first needed to evaluate what, if any, modifications were required.

To do this, a series of workshops with key stakeholders were held to understand how sensitive the Wellington economy would be to infrastructure and other disaster disruptions. Each workshop explored how disaster disruptions (infrastructure and community disruptions) could affect Wellington's habitability, liveability and business viability. Economic tipping points and key enablers and barriers to a successful Wellington post-disaster recovery were also explored.

Details of the workshop process and outcomes are fully documented in the following report:

> Brown, C., Seville, E., (2017) *Wellington Lifelines Resilience Project Programme Business Case: Business Behaviours Workshops, April 2017*, Resilient Organisations.

Importantly, to fully capture the consequences of the Wellington Fault event, it was also necessary to develop a set of bespoke models for this project, mostly addressing aspects of transportation and tourism disruption as well as the propensity for people and business relocation. Although transport infrastructure disruptions are among the important disruptions potentially experienced by businesses, the transport components of infrastructure had generally not been included in the business behaviours modelling to date. Additionally, transportation disruptions generate other types of economic impacts, directly and indirectly. Transportation is thus generally tackled in MERIT modelling on a case-by-case basis depending on the nature and extent of impacts by the economic modelling team. Overall, the following key drivers of economic system change following a major earthquake event were identified, and incorporated into the MERIT modelling process (Figure 3.1).

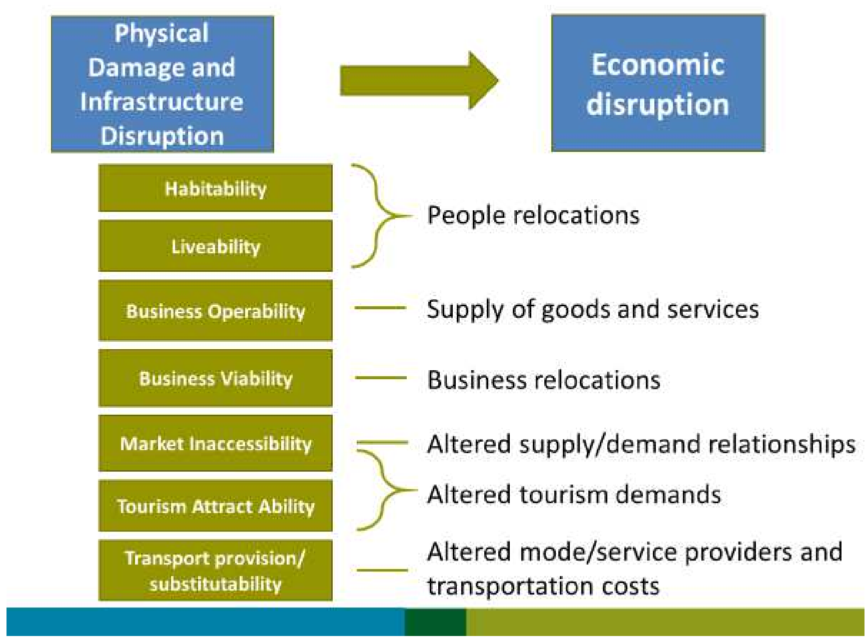

Figure 3.1 Drivers of Recovery included in the Wellington Fault Earthquake Scenario Modelling.

4 Model Linkages and Assumptions

The core task faced in undertaking the MERIT modelling is to translate descriptions of infrastructure damage and other forms of physical disruption, derived for the Wellington Fault earthquake scenario, into estimates of economic impacts. Here, the descriptions of infrastructure damage and other forms of physical disruption are provided by the RiskScape modelling team. For the most part this information could not be applied directly as inputs to the economic model. Instead, a variety of additional modelling steps, typically incorporating further information and assumptions are first undertaken to provide a set of time-dependent parameters (i.e. GIS maps) that could be used directly as inputs to the economic model.

Figure 4.1 provides an overall scheme of the MERIT modelling process. To assist in the conceptualisation, the mathematical procedures that make up the modelling process have been grouped into a series of 'models', some of which have underlying sub-components or 'modules'. For example, the Dynamic Economic Model is the core economic model constructed within the System Dynamics modelling language, and it is underpinned by several modules that cover Enterprises, Factors, Capital, Labour, and so on (see also Smith *et al*. (2016)). The Business Behaviours Model and Population Relocation Model are the other two modules that make up the core components of the MERIT toolkit. The key sets of information that flow between these models is also depicted in Figure 4.1. For example, the Business Behaviours Model (Brown *et al*., 2015) calculated the 'operability' of different economic industries, across time, and given differing combinations of infrastructure service and other types of disruption. Once calculated, the industry operability parameters were incorporated directly within the Dynamic Economic Model, to modify the 'as normal' levels of productivity within each economic industry.

In the following sections of this report we set out the key assumptions underpinning each model, and the derivation of the information that flows between each model. Please note that the entire modelling process was relatively complex with many steps, we concentrated only on describing aspects that were not already covered by the technical reports listed above.

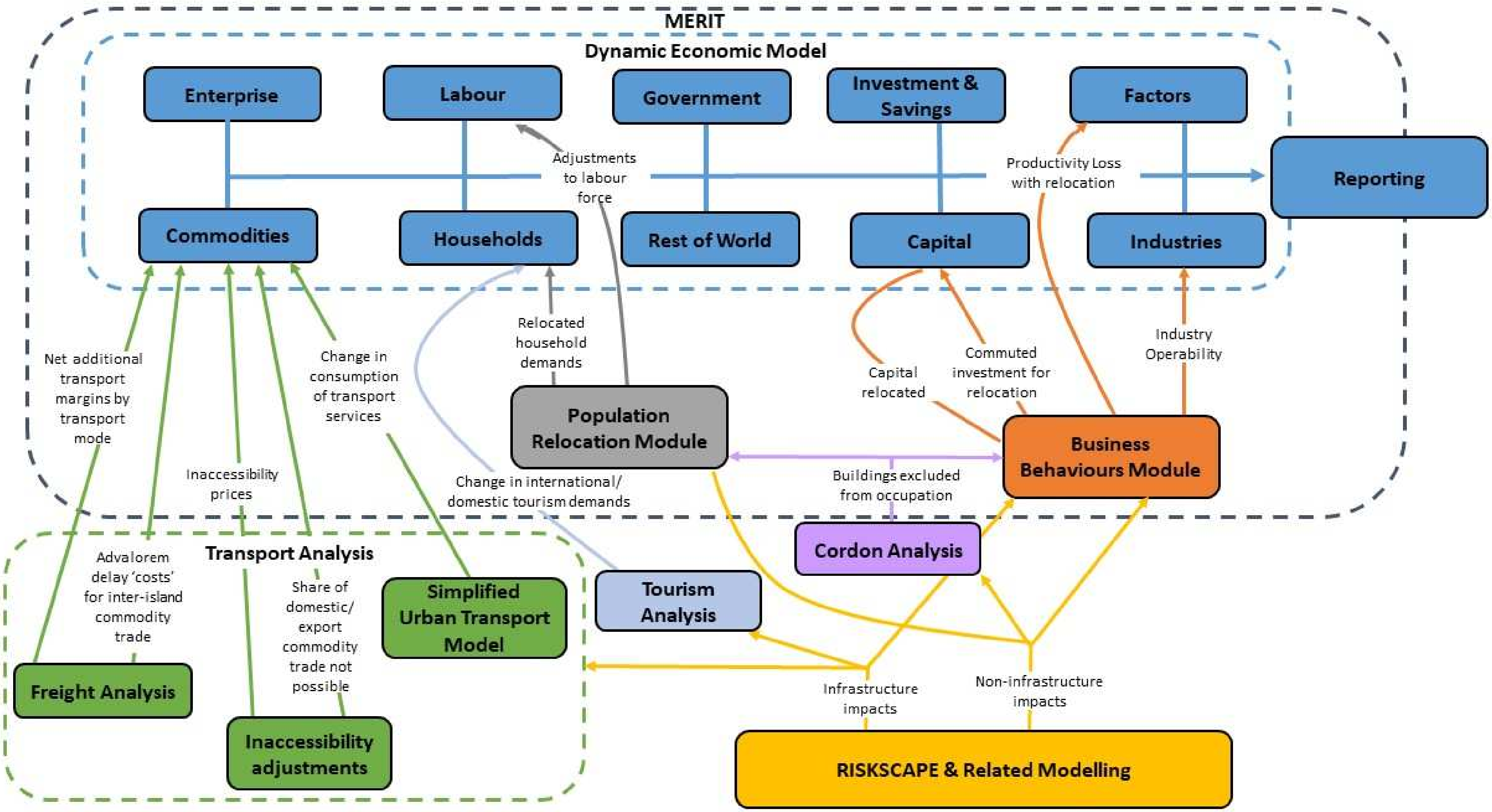

Figure 4.1. Interlinkages between the MERIT suite of tools, transport analysis, cordon analysis, tourism analysis and Riskscape.

4.1 RiskScape

Hazard modelling was carried out by GNS Science using the RiskScape model – a multi-hazard loss assessment tool developed by GNS Science and NIWA. RiskScape was used to quantify and map building and infrastructure damage and loss under the 7.5 magnitude Wellington Fault Earthquake scenario. RiskScape incorporates stochastic parameters, which means that outputs from the model can vary each time it is run. For this project RiskScape was run 10 times to produce estimates of the number of deaths, injuries and building damage caused by the earthquake scenario. The RiskScape team provided the following infrastructure and non-infrastructure impacts as inputs for the Cordon Analysis, Tourism Analysis, Population Relocation Module (PRM), Business Behaviour Module (BBM), and Transport Analysis (Table 4.1).

Table 4.1 Infrastructure and non-infrastructure impacts provided by the RiskScape modelling.

	Impact	**Units**	**Model/Module used[1]**
Infrastructure	Electricity outages	by meshblock, by day	BBM, PRM
	Fuel outages	by meshblock, by day	BBM, IA, SUT
	Gas outages	by meshblock, by day	BBM
	Telecommunications outages	by meshblock, by day	BBM, PRM
	Wastewater outages	by meshblock, by day	BBM
	Water outages	by meshblock, by day	BBM, PRM
	Port damages	qualitative	FA, Tour
	Rail outages	qualitative	FA, SUT
	Road connectivity	by 'road islands', by day, by 2 service types (Response, Recovery)	FA, IA, SUT, Tour, BBM, PRM
Non-Infrastructure	Landslide susceptibility	by building by Use Code by meshblock	PRM
	Ground Shaking Intensity	by meshblock	BBM
	Building damage state	By building by meshblock by Use Code[2] by RiskScape Run	BBM
	Cordon (Area)	by meshblock	BBM
	Cordon (Building)	by meshblock by Use Code by building by RiskScape run	BBM, PRM
	Occupancy – Day Occupancy - Night	by building by meshblock by Use Code[2]	BBM
	Number of deaths	by building number by Use Code by meshblock by RiskScape run	PRM
	Number injured – severe Number injured – critical	by building by meshblock by Use Code by RiskScape run	PRM

1. BBM= Business Behaviours Model, PRM = Population Relocation Model, FA = Freight Analysis, Tour = Tourism Analysis, IA = Inaccessibility Adjustments, SUT= Simple Urban Transport Model. 2. Use Codes were provided by RiskScape and represent the use of the building e.g. residential dwelling, commercial business, education etc.

4.2 Cordon Analysis

Two types of cordons were created to identify buildings excluded from occupation. This information was used as an input into the Population Relocation Module and Business Behaviours Module.

The first cordon represented the initial cordon put in place while clean-up of debris, assessment of buildings and such activities occur. It was assumed to be a relatively large area at first, given the nature of the event and the need to first establish appropriate information on damage. The first cordon occupied the whole Wellington CBD, and a map of the CBD area was used to identify the meshblocks within the cordon, and hence employment impacted. This meshblock-level data was also aligned with RiskScape building damage data to identify the buildings affected by the cordon. This cordon area was used in the Business Behaviours Model as an input to the 'neighbourhood disruption' assessment (see Brown *et al*., 2015). Essentially, all businesses within the cordon received the highest-level rating of neighbourhood disruption.

For the second cordon, we concentrated on identifying individual buildings that could not be occupied for a relatively long basis. Direct information on buildings that were significantly damaged was provided via the RiskScape modelling ('damage state' class for each type) and used in the Population Relocation and Business Behaviours Model (Sections 4.4 and 4.5). We supplemented this information on direct building damage by identifying buildings that were likely to be classed as unable to be occupied due to being located near to another badly damaged building. For each of the 10 RiskScape runs, buildings greater than or equal to 3 storeys and with a damage state of 5 were identified. These were assumed to be at risk of collapse and thus it was assumed that a cordon would be implemented. Buffer areas in proportion to 2.5 times the number of storeys were created to represent the cordons around each of the buildings identified. If any other buildings intersected these cordons then that building was also cordoned off, but without a cordon buffer.

Ideally, we would also extend the analysis of buildings unable to be occupied to make sure that we also capture buildings located within inundation zones, however no information on these areas was provided. This could be a topic for future extension.

4.3 Tourism Analysis

Major earthquake events do not happen frequently. This means that it can be very difficult to obtain appropriate data sources upon which to infer likely behavioural changes in response to a major disruption event. Fortunately, in the case of tourism, two studies were recently undertaken that examined changes in tourism demands following significant earthquake events, i.e. the November 2016 Kaikōura quake and the February 2011 Canterbury quake (see Smith *et al*. (2017) and Orchiston *et al*. (2014)).

Although each disruption event will have its own unique circumstances, we believe that the findings from the Christchurch and Kaikōura quake experience were a good starting point for estimating the likely shifts in tourism demands following a Wellington fault event.

After the February 2011 quake, with the issue of travel notices, negative media publicity, and fear and anxiety caused by the quakes, most potential visitors chose not to travel to Christchurch, and instead travelled to other parts of the country or avoided travel to New Zealand altogether. In the case of a Wellington fault event, we assumed that regardless of the level of infrastructure resilience, there would be a similar type of outcome for Wellington. As documented by Smith *et al.* (2017), international guest nights in Christchurch plummeted after the Kaikōura quake, and remained below forecast levels even out to 2017. Domestic guest nights were also significantly reduced for the city and remained below forecast expectations out to 2017. Nevertheless, the net outcome for tourism activity across New Zealand appeared to be relatively small-to-inconclusive, indicating likely transfers in tourism demands to other parts of the country. Certainly, the analysis of Marketview[4] data on international spending indicated that in the short term following the event, spending in the North Island by people who were in New Zealand at the time of the Christchurch event was higher than expected.

Obviously the greater the length of time that has passed since the Christchurch event, the more difficult it is to determine the impacts of the quake on tourism demands. This is because while we can gather data on actual tourism expenditure, visitor nights, etc since the event, there is significant uncertainty as to how tourism demands would have changed over time had the event not occurred.

Table 4.2 provides a summary of our best estimates of the likely changes in tourism demands following a major earthquake event, from one week to five years after the event. This is generated from a synthesis of the various datasets analysed in the Smith *et al*. (2017) study. We term this the 'background' change in tourism demands, because it does not account for any of the special circumstances of the Wellington tourism market and disruption event, as discussed in the next few paragraphs.

Key assumptions in generating the background projections were: (1) half of the domestic spend lost from the Wellington region was recaptured as additional spend in the rest of New Zealand; and (2) initially only around 40% of international lost expenditure was recaptured by the rest of New Zealand, but this quickly increased to around 80% after around one month, and 100% by two years.

Table 4.2 Background Change in Tourism Demands after Major Quake.

		1 week	2 week	1 month	3 months	6 months	1 year	2 years	3 years	4 years	5 years
Wellington Region	Domestic	-20%	-20%	-20%	-18%	-17%	-16%	-9%	-8%	-6%	-5%
Rest of New Zealand	Domestic	0.5%	0.5%	0.5%	0.4%	0.4%	0.4%	0.2%	0.2%	0.1%	0.1%
Wellington Region	International	-66%	-66%	-53%	-52%	-51%	-51%	-46%	-45%	-42%	-34%
Rest of New Zealand	International	2%	2%	3%	3%	3%	3%	4%	4%	3%	3%

Role of ferries between Wellington and South Island

A relatively unique feature of Wellington is that it is the origin of, and destination for, passenger and vehicle ferries linking the North and South Islands. A portion of the Wellington tourism market is thus directly dependent on its role as the 'gateway to and from the South Island'. Informed by information from Sanderson *et al*. (2016) and the Statistics New Zealand International Visitor Survey, it is estimated that approximately one quarter of all international tourism demands in Wellington, and just less than 20% of domestic tourism demands, are directly dependent on this gateway role of Wellington. It is therefore

[4] The Marketview BNZ-derived data identifies credit and debit card transactions from BNZ customers, and establishes the geographic link between the residential address of the cardholders and the location and type of merchant involved in the transaction. It is estimated that the BNZ data accounts for approximately 15% of all retail spending in the NZ economy. Marketview also has available data from Paymark, operator of New Zealand's largest electronic transaction payment network, processing around 70% of the nation's electronic transactions. http://www.marketview.co.nz/

assumed that these shares of tourism demand (including demand that returns after the event), can only be realised with operation of the ferries, as well as provision of access to the ferry terminal from out of the Wellington region.

Impact of inaccessibility of Wellington

We recognise that another significant feature of the Wellington fault scenario, which was not experienced in the previous Christchurch event, is the level of inaccessibility that will be generated for the city due to the damage to key road and rail links. For the period over which Wellington is effectively isolated due to transport disruptions, the better analogy is probably the Kaikōura quake, as the Kaikōura township suffered similar isolation due to transport network disruptions.

To reflect the inaccessibility of Wellington city for visitors, we decreased our projections of domestic and international tourism demands further. Effectively, demands by tourists for goods and services produced within Wellington city was set to zero, up until access to central Wellington was restored.

Note that because accessibility was restored sooner under the investment packages, the loss of demands in Wellington region returned to the background level sooner in Table 4.4 compared to Table 4.3. For the proportion of the tourism market located outside of Wellington city, the projected disruption was left the same as the background assumption (incorporating adjustments for the ferry disruption). As there has been some evidence of increased international travel by New Zealanders in the months following the Kaikōura event, it was assumed that only half of the additional loss in domestic travel for the Wellington region was transferred as additional demands in other parts of New Zealand. For international tourists it was conservatively assumed that 90% of the additional losses from the Wellington region were transferred as additional demands in the rest of New Zealand.

Table 4.3 Change in Tourism Demands Incorporating Ferry and Road Disruptions – No Investment Package.

		1 week	2 week	1 month	3 months	6 months	1 year	2 years	3 years	4 years	5 years
Wellington Region	Domestic	-92%	-92%	-92%	-92%	-23%	-16%	-10%	-8%	-6%	-5%
Rest of New Zealand	Domestic	2.2%	2.2%	2.2%	2.2%	0.6%	0.4%	0.2%	0.2%	0.1%	0.1%
Wellington Region	International	-97%	-96%	-96%	-96%	-56%	-53%	-47%	-45%	-42%	-34%
Rest of New Zealand	International	4%	6%	6%	7%	4%	4%	4%	4%	3%	3%

Table 4.4 Change in Tourism Demands Incorporating Ferry and Road Disruptions – Investment Packages included.

		1 week	2 week	1 month	3 months	6 months	1 year	2 years	3 years	4 years	5 years
Wellington Region	Domestic	-92.45%	-92.45%	-92.45%	-25.01%	-21.73%	-13.08%	-8.75%	-7.50%	-6.25%	-5.00%
Rest of New Zealand	Domestic	2.21%	2.21%	2.21%	0.60%	0.52%	0.31%	0.21%	0.18%	0.15%	0.12%
Wellington Region	International	-97.04%	-96.35%	-95.90%	-57.48%	-55.24%	-50.60%	-45.66%	-44.83%	-41.73%	-33.68%
Rest of New Zealand	International	4.40%	6.22%	6.41%	3.79%	3.81%	3.81%	3.63%	3.56%	3.31%	2.67%

4.4 Population Relocation Module

For a Wellington Fault earthquake scenario, a key driver of economic impacts and recovery was assumed to be the potential movement of people away from the Wellington region, i.e. population relocation. The analysis of population relocation was undertaken by first identifying four separate phases of population movement: emergency evacuation, strategic evacuation, shelter relocation, and voluntary flight. These reflect the complex drivers that might 'push' people to move away from the Wellington region, and then to attract them back into the region as key milestones in the recovery are achieved (Figure 4.2). Each phase is discussed separately below.

Figure 4.2 Components within the Population Relocation Module.

4.4.1 Emergency Evacuation

The purpose of the Emergency Evacuation component was to calculate the number of people (injured, support, vulnerable) moving out of the region and the number returning by age group and day.

First, the average number of deaths by age group and by meshblock was calculated based on RiskScape estimates and the assumed proportion of people usually resident in each building type. The average numbers of critically and severely injured people were also calculated based on RiskScape estimates, and the assumption that 50% of severely injured were evacuated and 100% of critically injured were evacuated. To calculate the number of support persons it was assumed that one support person aged 15-65-years-old would move with each injured person relocated. The number of vulnerable persons to be relocated were calculated based on several assumptions, as outlined in Table 4.5.

To calculate the number and timing of people moving back into the region it was assumed that people (injured, vulnerable, support) returned once water, electricity and road access to the region was restored.

Evidence to support vulnerable person evacuation assumptions

The Ministry of Civil Defence and Emergency Management (MCDEM) Mass Evacuation Guidelines (MCDEM, 2008) identify these groups as vulnerable during a mass evacuation event.

- *Māori communities;*
- *ethnic communities (non-English speakers/English as a second language);*
- *remote/isolated communities;*
- *aged and/or infirm;*
- *people with disabilities;*
- *tourists;*
- *people in prisons or residential institutions; and*
- *schools.*

For the purposes of this modelling we assumed that only the aged, infirm, people with disabilities, people in prisons and tourists needed to be evacuated due to disruption to critical infrastructure and other essential services (e.g. food, shelter etc).

Table 4.5 Specific assumptions used to calculate vulnerable people moving out of the Wellington region.

Group	Number of evacuees				Assumptions	Sources
		Under 15	15-65	Over 65		
Aged	Vulnerable persons			3500	5.5% of over 65 are in hospital or in residential or community care in 2013. 13% of Wellington population are over 65. Therefore assume 0.7% of total population are in this group. Total Wellington region pop in 2013 - 471,315 *Assume one support person relocate with these aged 15-65*	Stats NZ, 2013 census data (Statistics New Zealand, 2015)
	Support persons		3500			
Infirm	Vulnerable persons		250	250	Wellington Hospital total beds 484 Wellington Hospital total beds 29 Hutt Valley 322 Kenepuru Hospital 131 Porirua (Mental health) 118 *Assume half would need to be relocated and that half are over 65 and half are 15-65* *Assume 1 person aged 15-65 accompanies these people*	Health.govt.nz
	Support persons		500			
People with disabilities	Vulnerable persons	2000	9500	3000	114,000 (22% of population in Wellington) have at least one disability. 16% of disabled population (or 3% of total population) have high support needs (approx. 18,000), 59% of total population of over 65s have a disability, 11% of total population of under 15s have a disability, 13.2% of Wellington population are over 65, 19.5% of Wellington population under 15. There are 6,500 over 65 in this group – assume that 3500 of these are included in the 'aged' population estimate above. *Assume 1-person age 15-65 accompanies these people*	2013 Disability report (Statistics New Zealand, 2014) 2006 Disability report (Statistics New Zealand, 2007) Stats NZ 2013 census
	Support persons		14,000			
People in prisons	Vulnerable persons		1200		Maximum capacity Rimutaka Prison – 1078 Arohata Prison – 159	Corrections.govt.nz
Tourists	Vulnerable persons	7000			2.5 million commercial guest nights per year in Wellington. Average of 6849 guests/night. *Assume that age is not relevant as they are not part of the 'working' population*	WREDA Annual Report (WREDA, 2015)
TOTAL	Vulnerable (excluding tourists)	2000	10,950	6750		
	Support		18,000			
	TOTAL (excl. tourists)	2000	28,950	6750		

4.4.2 Strategic Evacuation

The purpose of the Strategic Evacuation component was to calculate the number of people strategically relocated by large organisations due to their key employment role, by age group and meshblock.

To begin, it was assumed that two key personnel from every business with over 200 employees would evacuate to help their business continue operations at an alternative location.

The proportion of government staff relocated by meshblock was calculated based on the damage state of each meshblock and the relationship between damage state and proportion of government staff relocated. This relationship was based on the proportion of unusable commercial property, length of water, electricity, or telecommunications disruption, and length of time access to the local CBD, Wellington CBD and out of region was cut (see Table 4.6).

Table 4.6 Assumptions used to determine the percentage of government staff who would need to leave the region.

	Damage State					
Factor	**0**	**1**	**2**	**3**	**4**	**5**
Unusable commercial property across region	<5%	5-10%	10-20%	20-30%	30-80%	80-100%
Disruption of one or more of water, electricity, or communications (including data) at business premises level	<7 days	7-28 days	28-84 days	84-183 days	183-365 days	365 days +
Access to 'local CBD' – Wellington, Porirua, Upper Hutt and Lower Hutt (include fuel limitations) (N/A for Kapiti Coast district, Masterton, Carterton, South Wairarapa)	Full	<7 days	7-28 days	28-56 days	56-84 days	84 days +
Access to Wellington CBD (include fuel limitations)	Full	<14 days	14-42 days	42-84 days	84-183 days	183 days +
Access by road out of the region (include fuel limitations)	Full	<28 days	28-84 days	84-183 days	183-365 days	365 days +
% government staff leave region	0%	2.5%	5%	10%	20%	40%

It was assumed that persons strategically relocated would relocate with their families and therefore the total number of people strategically relocated was calculated using household composition estimates i.e. number of people by age group, based on Statistics NZ data. This was calculated based on the assumption that 80% of households with a household member relocated would also relocate with the strategically evacuated person.

4.4.3 Shelter relocation

The purpose of the Shelter Relocation component was to calculate (1) the number of people who might need to leave the region because they could not be housed within the region, and (2) the re-distribution of people within the region for the purposes of the transport modelling.

First, to calculate the damaged building capacity, the buildings unable to be occupied were identified. These were identified based on landslide susceptibility, cordon maps and RiskScape damage state. The number of residents impacted by lack of shelter and who therefore needed rehousing were then calculated based on the buildings unable to be occupied, RiskScape occupancy estimates, and population estimates based on Statistics NZ data. Note that in this analysis a conservative approach to residential capacity was adopted. We received advice that even relatively significantly damaged residential dwellings tended to be used for shelter while waiting for repairs/rebuild, provided the underlying structure of the building is timber (GNS, *pers. comm.*).

To calculate the number of residents able to be housed within the region, the capacity of meshblocks within the region for taking up re-housing was determined. This was calculated based on a factor increase in building capacity following major events, assuming that the ability to take up extra capacity varied with the social deprivation index of each building.

For each meshblock, the ΔNet Population was calculated as:

$$\Delta Net\ Population\ (zone) = TBC^{*}\ x - DBC + EA - Pop$$

Where *TBC* = total building capacity (by population), *DBC* = damaged building capacity (by population), *EA* = emergency accommodation (by population), *Pop* = pre-earthquake population, *x* is the fraction of increased building capacity (i.e. to allow for temporary co-location of families) and is correlated with the Social Deprivation Index (SDI) below.

SDI	1-4	5-7	8-10
x	1.1	1.1	1.3

Then overall displaced population for Wellington was calculated by

$$\Delta Net\ Population\ (Wellington) = \Sigma \Delta Net\ Population\ (all\ zones)$$

People were rehoused within the region where possible (pro-rated around zones with capacity). Any proportion of the population that could not be rehoused within the region was assumed to relocate out of the region.

Evidence for SDI-based additional housing capacity assumptions

Based on 2013 data, 10% of New Zealanders live in crowded situations (Ministry of Health, 2014). Overcrowding is one of the contributing variables to the NZ Social Deprivation Index (SDI, NZDep2013) (Atkinson, Salmond, & Crampton, 2014). While not a direct correlation, it could be assumed for the purposes of our modelling that those in an area of SDI 10 (equivalent to the most deprived 10%), are on average, living in a crowded situation already. Data from the Canterbury earthquakes showed that there was a 29% increase in overcrowding following the earthquakes. And overcrowding was more likely amongst those in a low socio-economic situation (families in renting situations paying less than $300/week) (MBIE, 2013).

The SDI includes a factor of whether homes are rented or owned but there is no easy link to make between SDI and typical rental rates. For the purposes of this modelling we will assume that those with decile 7-10 are the most likely to share their premises. We have also allowed spare capacity within high socio-economic groups to be taken up by some shared housing situations (in the interim).

4.4.4 Voluntary flight

The purpose of the Voluntary Flight component was to calculate the number of people voluntarily leaving and returning to the Wellington region. In these regards it was assumed:

- People could start leaving the region voluntarily at day 14 (after emergency evacuation has finished).
- A maximum of 10,000 people could leave the region per day.

The key driver of voluntary population movements was deemed to be 'liveability' within the region. A liveability category was assigned to each meshblock, where the category applied was where 2 or more of the factor conditions were met (see Table 4.7)

Importantly, it was assumed that all people who left Wellington moved to the Rest of New Zealand, and not overseas. This assumption was made for several reasons: 1) GDP is a per population metric, and so it would unduly complicate the reporting and explanation of modelling results for the Wellington region and New Zealand economy as a whole; and 2) while there was likely to be some movement of people overseas, evidence from the Christchurch earthquakes and other disasters indicates that people are far more likely to relocate close to home, and to then return if/when conditions improve (see box below for more details).

The number of people returning to the region by meshblock, age group and day was calculated assuming a maximum of 1000 people per day could return, and a relationship between the percentage of population movement that returned once services were restored, damage state and social deprivation index.

Table 4.7 Assumptions used to determine the percentage of population which would leave the region and return once services were restored.

	Liveability					
Factor	A	B	C	D	E	F
Disruption duration of one or more of water, electricity, or communications (including data) at household level*	<7 days	7-28 days	28-84 days	84-183 days	183-365 days	365 days +
% houses uninhabitable in meshblock (i.e. forced evacuation leading to community disaggregation)	<1%	1-2%	3-5%	6-9%	10-14%	>15%
Access to 'local CBD' – Wellington, Porirua, Upper Hutt and Lower Hutt (include fuel limitations) (N/A for Kapiti Coast district, Masterton, Carterton, South Wairarapa)	Full access to zone	Zone isolated for up to 1 week	Zone isolated 1-4 weeks	Zone isolated for 4-8 weeks	Zone isolated for 8-12 weeks	Zone isolated for more than 12 weeks
Access to Wellington CBD (include fuel limitations)	Full	Access restored within 2 weeks	Access restored 2- 6 weeks	Access restored 3-12 weeks	Access restored 3-6 months	Access restricted over 6 months
Access by road out of the region (include fuel limitations)	Full	Access restored within 4 weeks	Access restored 4- 12 weeks	Access restored 3-6 months	Access restored 6-12 months	Access restricted over 12 months
% population movement (on top of initial evacuations)						
SDI 1-4	0%	5%	10%	20%	30%	50%
SDI 5-7	0%	3%	5%	10%	15%	25%
If SDI 8-10	0%	5%	10%	20%	30%	50%
% of relocated population that returns once services were restored **						
SDI 1-4	0%	90%	80%	70%	60%	50%
SDI 5-7	0%	95%	90%	90%	85%	85%
If SDI 8-10	0%	90%	80%	60%	40%	20%

*Note it is assumed that sufficient emergency water and food supplies are available for those that choose to stay. Their provision is likely to be inconvenient (walk to water, food rations etc) and this factors into the estimated relocation proportions.
** % of relocated population return when full services are restored (all of water, electricity, telecommunications, road access and fuel). Return at rate of 1000 people/day.

Aspects that were not included in the Voluntary Flight component

The availability or quality of schooling in the region was not included as a factor (even though this came through strongly in the workshops as a key factor likely to drive people's decision making). This was because there was significant uncertainty around the triggers for school closures – dependent on damage and Ministry for Education decisions. Also, to some extent, school closures would be correlated with community disaggregation.

Food availability, while essential, was not modelled. It was assumed that sufficient emergency rations would be made available through Civil Defence arrangements. Although it may be costly to provide emergency rations under some scenarios compared to others (i.e. because lack of vehicle access), the financial costs of emergency provision were not modelled. 'Full' food supplies were assumed to be available to a meshblock once access out of the region was restored.

Fear, while likely to be a considerable driver in the decision for individuals and families to leave the region, was not incorporated as it is challenging to define at a spatial level and will be highly correlated to other disruptions.

Evidence for relocation assumptions

In San Francisco, the city has set several resilience targets for post-earthquake performance. That is, they have set minimum levels of service for some infrastructure. One indicator they have set is level of housing damage. San Francisco have set a 95% habitability rate of housing stock post-disaster to prevent tip-out/out-migration of residents (and therefore associated economic losses). They have gathered evidence from several different disaster events and looked at the correlation between housing damage and out-migration. Below is data from the case studies used to support their case (SPUR, 2012).

An equivalent set of recovery targets has been created for lifeline services. However, the evidence and process for establishing these targets is not supported with the evidence provided for the housing stock (SPUR, 2009)

The Social Deprivation index has been included in the criteria for voluntary flight as several previous studies have indicated that socio-economic status of community, and in particular, poverty has been associated with the slow pace at which people are able to return and rebuild (Xiao & Van Zandt, 2011; Le Sage et al., 2011). Post-Hurricane Katrina, Xiao and Van Zandt (2011) found that income negatively correlated with population return; households with higher incomes were less dependent of low waged service industry jobs, and are therefore more likely to be professionally and financially mobile. In contrast, low wage householders were more likely to remain in damaged housing, with fewer alternative options available to them. Longer term, if low wage households do not own property, they are more likely to relocate if living expenses increase or job opportunities reduce (SPUR, 2012).

Based on this evidence, we have stratified population movements in our model into three SDI levels to represent low, middle and high socio-economic groups. High socio-economic groups (SDI1-4) are assumed to have high rates of immediate temporary relocation due to their capacity to find alternative accommodation in the short term – rentals, holiday homes or relocation out of the region. Longer term we have assumed a moderate rate of return as many in this group will likely to be able to afford to leave a *region, even if there is capital loss on their property. They are also likely to be highly employable. Low socio-economic groups (SDI 8-10) are assumed to be more heavily dependent on emergency shelters and are more likely to leave the region. Long term, it is assumed they are less likely to return, particularly if there are housing and job shortages. For middle socio-economic groups (SDI5-7) we have assumed they are the least mobile group. Those in this group that own property may not be able to leave their, likely, primary asset, and may be reluctant to relocate without guaranteed employment.*

It is important to note that research indicates that there are other under-lying factors that impact populations' capacity and desire to relocate including social capital (Aldrich, 2012) and existing population growth/decline trajectories (Aldrich, 2011; Matanle, 2011). These factors are not currently included in our model but are an area for future exploration

Where did Christchurch City residents move to after the 2011 earthquake?

The February 2011 earthquake was a catalyst for a surge in population movement out of Christchurch City. Where did people go? In the long run, it appears that most did not go too far away from home.

An experimental analysis of cellphone usage shows that people mainly relocated to nearby districts in the Canterbury region during the first week after the quake, and to other regions (mainly Otago and Auckland) during the second week. Most people returned to Christchurch by about five weeks following the quake.

Forty per cent of Christchurch school students who were enrolled in the Christchurch city, Selwyn and Waimakariri districts before the earthquake on 22 February 2011, re-enrolled within the Canterbury region by September. Of these, 63% returned to Christchurch city and the Selwyn and Waimakariri districts themselves.

The school re-enrollment data aligns with the Household Labour Force Survey on individuals' movement in June 2011. Of the 16,600 people who had moved to a new residence due to the earthquake, 64 percent still lived in the Canterbury region. Of those who left the region due to the February earthquake, 38 percent intended to move back to their previous address in the future.

Further, the number of permanent and long-term departures overseas from Christchurch, mostly to Australia, peaked only in the first four months immediately after the earthquake. By November 2011, the move aboard stabilized to the same level as that pre-earthquake. The 8% of Christchurch residents who moved overseas between the 2008 and 2013 censuses is comparable to the New Zealand average, and slightly below that for Auckland (11%) and Wellington (12%).

Finally, the 2013 internal migration data, coupled with the 2013 Census Greater Christchurch Quick Stats data (see Figure 4.3 *below), confirm that most Christchurch residents stayed in the city. Overall, the steady return and temporary relocation of Christchurch residents suggest that the February earthquake was perceived as a short-term shock rather than long-term adversity requiring a more drastic decision to move further afield.*

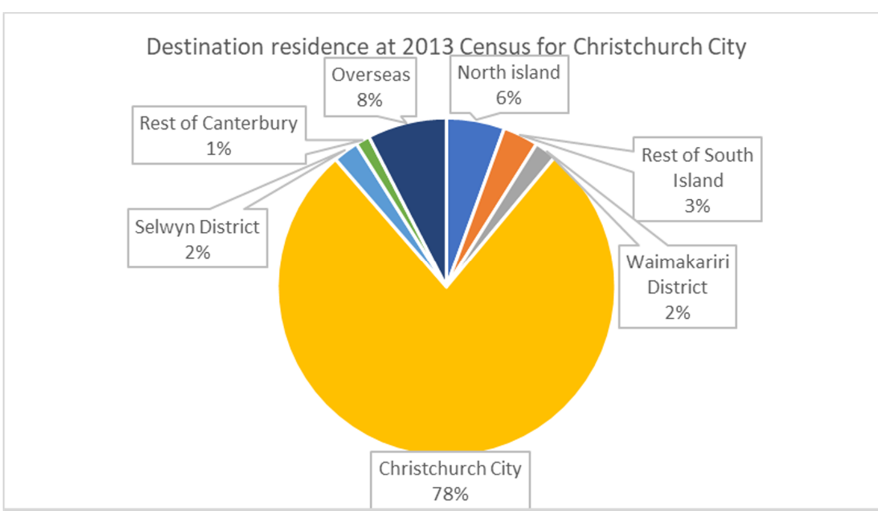

Figure 4.3 Area of usual residence in 2013 for Christchurch City as the source area of residence in 2008.

4.4.5 Incorporating Population Relocation in the Economic Model

For the economic modelling, the primary outcome of changes in population was changes in the location of labour resources and changes in the distribution of demands for goods and services.

In terms of labour force changes, note that the Dynamic Economic Model incorporated two economic regions: Wellington and Rest of New Zealand. To incorporate the change in labour force between these regions the following further assumptions were made:

- After relocating from Wellington to the rest of New Zealand, many people were not able to enter the workforce immediately due to the need to organise transportation, housing, set up networks, and so on. The entry of a new person to the workforce was therefore staggered over time, starting at least one week after the person left Wellington, and up to two months.
- For those persons who returned to Wellington once liveability improved, there was also a lag before re-entry to the labour force. Given the likely existence of more established networks, this was assumed to be shorter, ranging from one week to one months.

To ensure that the movement of people between regions immediately resulted in a change in the distribution of demands for goods and services, a portion of the household income account for Wellington region was relocated to the rest of New Zealand household income account. This was undertaken simply on a per-capita basis assuming that all residents in Wellington had an equal share in the household income account at the time of relocation. Once residents moved to a new region, they took on the demand behaviours of resident's in their new location.

4.5 Business Behaviours Model

Resilient Organisation's original Business Behaviours model is described in the report:

> Brown, C., Giovinazzi, S., Seville, E., Vargo, J., Stevenson, J.R. (2015) *Developing the Business Behaviours Module within MERIT*. Economics of Resilient Infrastructure Research Report 2015/02. 71p.- addendum added January 2016.

As already explained, the original modelling was based largely on data arising out of the 2011 Canterbury Earthquake event. At the commencement of the project a review was undertaken to determine the types of modifications that would be necessary to the original model, to allow for the differences in the nature and extent of impacts faced under the Wellington Fault earthquake event. One set of changes was to incorporate a new Population Relocation Model, as already explained above. In terms of the Business Behaviour's Model, two principal additions were made: (1) modification of the original 'operability' curves, and (2) inclusion of business relocations (for reasoning and assumptions behind each of these two topics of see sections 4.5.1, 4.5.2 and 4.5.3). As a start point, however, the modelling and assumptions for the extensions both relied on classifying business/industries into a set of subcategories, to reflect the different infrastructure needs and capacities for adaption of different industry groups. The following industry groups were identified:

1. Place-based people services

   Businesses in this group were predominantly 'non-moveable' because of an in-region customer base. Sectors considered to fall into this category included Health care and Social assistance, Education and Training, and Local Government Administration.

2. Moveable discretionary spend services

   This group was predominantly place-based, serving customers who choose to visit or reside at a locality. Demands for services that these activities provided would potentially relocate should customers choose to relocate. Sectors considered to fall into this category included Retail, Accommodation and Food Services, and Art and Recreational Services.

3. Office-based services

   This group was generally moveable, with working from home often a viable option. The customer base could be either in or out of region. Sectors considered to fall into this category included Professional, Scientific and Technical services, Information Media and Telecommunications, and Financial and Insurance Services.

4. Manufacturing

   Sectors considered to fall into this category included Food Manufacturing, Transport, Equipment and Machinery Manufacturing, and Wood and Chemical Product Manufacturing.

5. Place-based activities

   Sectors considered to fall into this category included Construction, Electricity Generation and Supply, Water, Sewerage, Drainage and Waste services, and Rental and Real Estate Services.

6. Central Government

7. Primary

   Included agricultural and mining sectors.

4.5.1 Business Operability

The Business Behaviours Model took information on infrastructure and non-infrastructure disruptions, and calculated the level of 'operability' achieved by each business/industry compared to as-usual operability. To reflect that businesses are adaptive to situations, full operability generally returns over time, however the more severe the level of disruption, and the longer the duration, the greater the initial fall in operability and the longer the recovery period. The generated operability curves described the rate at which normal levels of productivity in an industry fell, and then returned to normal.

The business behaviours model was originally developed using data on business recovery following the 2010-2011 Canterbury earthquakes (Table 4.8). Following the Canterbury earthquakes infrastructure systems were not sufficiently disrupted to tip businesses into different behaviour (e.g. closure, relocation out of region etc). Perhaps one of the most significant differences between the Canterbury experience and the Wellington fault scenario in this study was the level of inaccessibility faced by disruptions to the Wellington transport network, which was never faced in Canterbury. Not only would this severely limit the delivery of goods, abilities of staff to get to work, and customers to access services, it would severely limit the options available to organisations to adapt and cope to the disruption. Another key aspect of the Wellington scenario was that some infrastructure types have much longer outage times over much of the city. For example, electricity and communications were generally restored relatively quickly in Christchurch, but in the case of Wellington, the very long outage times would restrict organisations from taking up some of the more common adaptation options (e.g. working at home, remotely).

Table 4.8 *Percentage of surveyed organisations experience infrastructure disruption following the 2010-2011 Canterbury earthquakes.*

	Length of disruption				
	N/A	*Hours*	*Days*	*Weeks*	*Months*
Electricity	*28%*	*31%*	*27%*	*10%*	*4%*
Phone networks	*22%*	*43%*	*25%*	*7%*	*3%*
Data networks	*32%*	*36%*	*23%*	*7%*	*2%*
*Road**	*35%*	*14%*	*15%*	*10%*	*26%*
Fuel	*66%*	*12%*	*18%*	*3%*	*1%*
** Many respondents considered travel delays and detours a disruption. Nowhere in Christchurch was completely inaccessible.*					

The following specific assumptions were applied to the seven industry categories to adapt the operability curves for the Wellington scenario:

- Place-based people services
  - Standard Business Behaviour Model (BBM) operability curves were applied, however, t=0 operability levels applied until:
    - Electricity restored (at local meshblock)
    - Telecoms / data restored (at local meshblock)
    - Domestic fuel availability and access to 'local CBD' restored (to enable supplies and staff transportation)
- Moveable discretionary spend services
  - Standard BBM operability curves were applied, however, t=0 operability levels applied until:
    - Electricity restored (at local meshblock)
    - Telecoms / data restored (at local meshblock)
    - Domestic fuel availability and access to 'local CBD' restored (to enable supplies and staff transportation)
- Office based services
  - Standard BBM operability curves were applied, however, t=0 operability levels applied until:
    - Electricity restored to at least 70% of population
    - Data restored to at least 70% of population

    - Note that many within this grouping could work from home. These conditions enable working from home. Road disruptions were not included as this is less important for those that can work from home.
- Manufacturing
    - Standard BBM operability curves were applied, however, t=0 operability levels applied until:
        - Electricity restored (at local meshblock)
        - Telecoms / data restored (at local meshblock)
        - Access in and out of region restored (to allow movements of supplies)
- Place-based activities
    - Standard BBM operability curves were applied
- Government
    - Standard BBM operability curves were applied, however, t=0 operability levels applied until:
        - Electricity restored (at local meshblock)
        - Telecoms / data restored (at local meshblock)
        - Domestic fuel availability and access to 'local CBD' restored (to enable supplies and staff transportation)
- Primary industries
    - Standard BBM operability curves were applied, however, t=0 operability levels applied until:
        - Access to central Wellington restored

Note: each criterion only applied where the infrastructure was disrupted for 3 or more days. If the disruption was less than 3 days, then standard operability applied.

4.5.2 Business Relocation

The Business Relocation component models the relocation of businesses from the region (over and above adjustments made due to reduced demand due to the population movements described above). This reflects the assumption that some businesses chose to relocate some, or all, of their operations to outside of the Wellington Region. This relocation of businesses triggered a shift of capital to outside the region.

First, for each industry category, a set of business viability factors were listed, reflecting decision drivers for:

- could they move,
- would they move,
- why would they move.

The factors were primarily based on a series of expert workshops held in March 2017 with key industry representatives. Based on these factors an estimated percent of the industry was assumed to leave the region, taking their capital with them.

Business relocations were only considered for the groups 'office-based services', 'manufacturing', and 'central government'. These were the industry groups considered most able to move their capital base (perhaps only in part) to an alternative location. Nevertheless, we should recognise that movements of people and goods will cause relative regional contraction and expansion for other types of industry groups, and to a large extent these effects were covered in the economic model. For example, when people moved out of the Wellington region, demand for retail services would increase in the rest of New Zealand, and fall in Wellington.

To estimate the proportion of businesses relocating within each of the studied industry groups, we essentially assigned a 'business viability' score at each location (Table 4.9, Table 4.10). Note that the overall score assigned was the highest score for which at least two categories were fulfilled. Note also that within these tables we considered accessibility issues for businesses at several different levels – the time taken to restore access from their location to the rest of New Zealand, time to restore access to their 'local CBD', and time taken to restore access from their location to the Wellington CBD.

Table 4.9 Business viability assumptions for businesses in the office-based services category.

	Business Viability					
Factor	A	B	C	D	E	F
Unusable commercial property across region	<5%	5-10%	10-20%	20-30%	30-80%	80-100%
Disruption of one or more of water, electricity, or communications (including data) at business premises level*	Disruption <1 week	Disruption 1-4 weeks	Disruption 4-12 weeks	3-6 months lack of adequate services	6-12 months lack of adequate services	>12 months lack of adequate services
Access to 'local CBD' – Wellington, Porirua, Upper Hutt and Lower Hutt (include fuel limitations) (N/A for **Kapiti Coast district, Masterton, Carterton, South Wairarapa)**	Full access to zone	Zone isolated for up to 1 week	Zone isolated 1-4 weeks	Zone isolated for 4-8 weeks	Zone isolated for 8-12 weeks	Zone isolated for more than 12 weeks
Access to Wellington CBD (include fuel limitations)	Full	Access restored within 2 weeks	Access restored 2-6 weeks	Access restored 3-12 weeks	Access restored 3-6 months	Access restricted over 6 months
Access by road out of the region (include fuel limitations)	Full	Access restored within 4 weeks	Access restored 4-12 weeks	Access restored 3-6 months	Access restored 6-12 months	Access restricted over 12 months
% business leave region	0%	2.5%	5%	10%	20%	40%
*Note: it is assumed that sufficient emergency water and food supplies are available for those that choose to stay. Their provision is likely to be inconvenient (walk to water, food rations etc) and this factors into the estimated relocation proportions.						

Table 4.10 Business viability assumptions for businesses in the place-based production and central government categories.

	Business viability					
Factor	**A**	**B**	**C**	**D**	**E**	**F**
Unusable industrial property across region	<5%	5-10%	10-20%	20-30%	30-80%	80-100%
Disruption of one or more of water, electricity, or communications (including data) at business premises level*	Disruption <1 week	Disruption 1-4 weeks	Disruption 4-12 weeks	3-6 months lack of adequate services	3-6 months lack of adequate services	>6 months lack of adequate services
Access to 'local CBD' – Wellington, Porirua, Upper Hutt and Lower Hutt (include fuel limitations) (N/A for **Kapiti Coast district, Masterton, Carterton, South Wairarapa)**	Full access to zone	Zone isolated for up to 1 week	Zone isolated 1-4 weeks	Zone isolated for 4-8 weeks	Zone isolated for 8-12 weeks	Zone isolated for more than 12 weeks
Access to Wellington CBD (include fuel limitations)	Full	Access restored within 2 weeks	Access restored 2-6 weeks	Access restored 3-12 weeks	Access restored 3-6 months	Access restricted over 6 months
Access by road out of the region (include fuel limitations)	Full	Access restored within 4 weeks	Access restored 4-12 weeks	Access restored 3-6 months	Access restored 6-12 months	Access restricted over 12 months
% business leave region	0%	1%	2%	5%	10%	20%
*Note: it is assumed that sufficient emergency water and food supplies are available for those that choose to stay. Their provision is likely to be inconvenient (walk to water, food rations etc) and this factors into the estimated relocation proportions.						

Rationale for road zone tipping points (both in liveability and business viability)

Road zone connection times were based on 'recovery' level access – allowing full travel (rather than only access for response vehicles).

Access is restored to the rest of New Zealand. This level of access means that each meshblock had access to bulk food and fuel supplies and businesses in these zones can transport their goods. Restoring access to the rest of New Zealand is also an enabler for people and businesses to move outside of the region.

Access to a local 'CBD'. Access to a central service base was assumed to be an important hub to access local services, for community connections and for local employment. Based on average commuting distances in Wellington, (5km[5]) it is reasonable to assume most people live close to their place of employment. Kapiti Coast district, Masterton, Carterton, South Wairarapa, were not included in this category as they don't get cut off from their 'community/commerce hub' in this scenario.

[5] *http://wellington.govt.nz/~/media/about-wellington/profile/files/wellington-city-profile.pdf - although no date on this source*

Access to Wellington CBD. *Wellington CBD is the source of roll-on/roll-off services and employment[6]. Even if there was no central city and businesses relocated within the region – it would be a reasonable assumption that businesses would only relocate to a location that was connected to the CBD (i.e. they wouldn't move to somewhere more isolated).*

Aspects that were not included in the Business Relocation component

Business confidence was assumed to be a significant factor in whether businesses remained in the region or relocated. However, we have not included this here as it was challenging to define and was likely to be highly correlated with other disruptions.

Health and Safety legislation may have played a part in how able and willing businesses were to operate in a disrupted environment. Our approach assumed that a pragmatic approach to health and sanitation and other safety issues was taken by regulatory authorities and would not be a significant driver for businesses.

Evidence for business relocation

There is limited literature on both business closure and relocation following disaster events. Sydnor et al.'s (2017) study is one of a limited number that measures permanent business closure because of a natural disaster. They found that 10% of the small businesses (0-74 employees) that were in operation prior to Hurricane Katrina, had closed immediately and permanently after the event; this figure had grown to 25% some 8 years on. Sydnor et al. (2016) found that age and health of the business played an important and substantial role in the recovery. Business sector was also relevant, with service sector businesses less likely to close when compared to other sectors. Older businesses bring more experience to problem solving, while larger firms are likely to have greater human and financial capital required to ride the wave of recovery. None the less, the extent of damage cannot be overlooked, since catastrophic damage to assets was also a significant predictor of failure to resume business, irrespective of size of the organisation.

Wasileski et al. (2010) compared the impact of natural disaster on the continuity (and survival) of businesses following the Loma Prieta earthquake in Santa Cruz US in 1989, with Hurricane Andrew which occurred in 1992 in South Dade County in Florida. Wasileski et al. (2010) found that in the case of the Loma Prieta earthquake 6.7% of businesses either closed or relocated permanently following the event. Loss of lifeline services (i.e. electricity, phone, water) and non-ownership of the business building contributed to a greater likelihood of closure. In the case of Hurricane Andrew, an estimated 12.5% of businesses relocated, though no data was available from businesses that entirely ceased to operate. Business closure in both cases disproportionally impacted the retail and wholesale sector (Wasileski et al., 2010).

In Table 4.11, we have compiled statistics on business change (closure and relocation) and compared that with statistics on population movement following the same event to determine a) whether there is likely to

[6] *http://www.stats.govt.nz/Census/2013-census/profile-and-summary-reports/commuting-patterns-wtn/working-in-wellington.aspx*

be additional business changes aside from those drive by population changes, b) the identified triggers for closure or relocation and c) the scale of closures/relocations.

Note that we have included data on both business closure and relocation because the current literature does not give definitive descriptions as to what happens to businesses when they 'close'. Some studies assume businesses are closed when they are not in their original location; however, businesses often adapt and work from alternative locations, so these studies will over-estimate closure. Similarly, data on where businesses relocate too is often not provided. With these limitations in mind, this data is primarily useful for identifying patterns in behaviour and magnitude changes in business operation.

The data indicates that business closure and/or relocation rates vary significantly between events, location and across time. With the limited data available, and a complex range of geographical, socio-economic, political and other variables to consider, it is difficult to draw robust conclusions around the drivers, and extent, of business relocation following a different earthquake event.

Table 4.11 Business change (closure and relocation), population change and triggers for business change.

Disaster event	Location	Study timeline	Business change	Population change	Triggers for business change	References
Hurricane Andrew	South Dade County	A few months after	• 89.9% of businesses closed immediately after the Hurricane. • 29.2% temporarily relocated; • 12.5% have been permanently relocated (no data on whether relocated within or outside the region)	17% loss within first year 7% loss over first 2 years (Smith & McCarty, 1996)	• Transport issues for customers and suppliers • Sector: wholesale/retail most likely to close • More likely to relocate if business premises were rented rather than owned.	(Wasileski, Rodríguez, & Diaz, 2011)
Hurricane Katrina	Southern Mississippi	5 years after	A total of 6.9% of businesses verified as closed, and a further 10.3% were likely closed but were unverifiable.	9% loss a year after 2% loss six years later (Cutter *et al.*, 2014)	None given	(Schrank, Marshall, Hall-Phillips, Wiatt, & Jones, 2012)
Hurricane Katrina	Village L'Est	2 years after	10% loss	10% loss	None given	(Aldrich, 2012)
Hurricane Katrina	Mississippi area	8 years later	• Around 10% immediately closed. • 25% business closure after 8 years	9% loss a year after 2% loss six years later (Cutter *et al.*, 2014)	• Overall age and health • Loss of lifelines, inventory loss and loss of customers/sales • Service sector less likely to be closed. • Specific geographical location relevant. • Endogenous effects - vulnerability to endogenous shock.	(Sydnor, Niehm, Lee, Marshall, & Schrank, 2017)
Hurricane Katrina	New Orleans	0-12 months after	None given	None given	• Loss of utilities • Low socio-economic status of customers • Neighbouring business failure • Level of impact from event	(LeSage, Kelley Pace, Lam, Campanella, & Liu, 2011)

Loma Prieta earthquake	Santa Cruz	A few months after	• 75% of businesses closed immediately after the earthquake. Closure was from a few hours to several months. • 6.7% relocated permanently - no data on whether relocated within or outside the region.	<<1% loss	• Leased business space • Lifeline interruptions	(Wasileski *et al.*, 2011)
Hurricane Ike	Galveston Texas	3 months after for population estimates 7 months after for business estimates	41.4% businesses not operating from pre-disaster location	36% of households unoccupied	• Business return had a positive impact on household return	(Xiao & Nilawar, 2013)

4.5.3 Incorporating Business Behaviours in the Economic Model

Operability

The method for calculating operability for industries was highly spatial, generating unique results for each meshblock and 41 industry types. The economic model, however, utilised only two geographic regions, Wellington and rest of New Zealand. It was therefore necessary to create overall operability curves for each industry and economic region. To do this, we utilised the operability curves at each location as calculated in Section 4.5.1, and weighted these by the relative number of employees at each location. The process was undertaken twice, once for businesses that remained in the Wellington region, and once for those that relocated outside of the region.

Importantly, for businesses that relocated to the rest of New Zealand, it was assumed that the original operability curves, as would be generated following the method specified in Brown *et al*. (2015), were more relevant, as the specific extensions for significant infrastructure disruption discussed in Section 4.5.1 were not relevant in the non-disrupted rest of New Zealand region. However, a lag in recovery of approximately 1.5 months compared to the Brown *et al*. (2015) curves was considered an appropriate new adjustment to reflect the extra disruptions likely to be faced by businesses setting up in an entirely new region.

For infrastructure services industries, ad-hoc adjustments to the operability curves were made. In short, it was assumed that operability for these activities at any point in time would be directly proportional to the share of normal infrastructure services in operation (i.e. as determined directly from the infrastructure outage information provided by GNS Science).

Business Relocation

The principal method for implementing business relocations in the economic model was through adjusting the capital stocks held by industries, the multifactor productivity of industries, and the functions that determine the rates of investment in new capital. Key assumptions were as follows:

- The value of capital held by a business relocating was equivalent to that businesses' share of total employment in its industry group, multiplied by the value of capital held by that industry group at the time of the quake.
- Not all capital held by businesses could be relocated. For example, stocks of buildings were generally fixed at the original location. To estimate the proportion of total capital held by a business relocating, we examined the Net Capital Stock data series from the national accounts and assigned a proportion to each built capital type that is relocatable. This generated a range of relocatable capital shares for different industry groups (e.g. 68% relocatable for Professional, Scientific, Technical, Administrative and Support Services compared to 20% for Agriculture, Forestry and Fishing)
- Capital that was left behind must be re-acquired by businesses. This was implemented in the economic model by taking funds from the general investment pool to support the compulsory investment in business relocation (i.e. for some months there was less funds available in the national economy for normal investment activities).
- Businesses furthermore incur a one-off relocation set of costs which was implemented by increasing the value of compulsory investment for relocation (point above) by 5%.

- Businesses would also likely face some reduction in productivity compared to productivity prior to the quake, associated with loss of networks, goodwill and so on. This supports the inference that decisions to relocate would not be taken lightly. This was implemented in the model through a one-off drop in multifactor productivity of 5% for organisations relocating.

4.6 Transport Analysis

The transportation modelling covered three separate themes: freight, inaccessibility, and urban transportation (Figure 4.1). These are discussed separately in the sub-sections below.

4.6.1 Freight Analysis

The freight analysis was undertaken in three separate components:

1. **Inter-island freight disruption – transport margins –** the purpose of this part of the analysis was to estimate the way in which changes in the operation of the inter-island ferries impacted on the costs of transporting commodities around New Zealand. We concentrated only on domestic commodity trade (i.e. where sources of supply and demand are both within New Zealand). In part this was due to time and cost constraints in the modelling work. Additionally, we received advice in an expert interview that, given the many ports in both the North and South Islands, and the very agile nature of the logistics industry, export and import trade would be relatively quickly adapted to avoid inter-island crossings in the transportation to/from ports (Mainfreight, pers. comm.).

   A likely outcome of the loss of the roll-on-roll-off ferry service between the two islands was a shift away from road and rail modes to coastal shipping while the ferry terminal was out of operation. Furthermore, the costs incurred for transportation, per unit of commodity transferred, may have changed because of the mode shifts and consequential increased competition for transportation services (e.g. competition for space on ships).[7] The analysis therefore provided estimates of the net change in transport margins, by commodity type, and mode of transportation (road, rail, coastal shipping).

   First, estimates of the total expenditure on transportation of different types of commodities, by transport mode utilised were developed. The estimates were derived by simply allocating the total value of output of each of the freight transport service sectors to commodity types, according to the total tonne km of transportation across New Zealand associated with each commodity and transport model (see Ministry of Transport (2014)). Next, given time and information constraints, we narrowed down the analysis to consider changes in transportation costs only for those commodities where interisland trade is likely to be significant, i.e. horticulture and grain products, limestone, cement, fertiliser and concrete, and general retail and manufactured goods (Ministry of Transport, 2014).

[7] Price changes resulting from increased demands compared to supply are addressed within the economic model itself. In this part of the analysis we therefore use only current or constant prices.

For commodities with significant levels of trade between islands, it was necessary to estimate for each dollar currently spent on road/rail transport between regions located in different islands, the value that would need to be spent on coastal shipping instead.[8] Fortunately as part of the development of the MERIT model, M.E Research created a detailed set of economic accounts known as Social Accounting Matrices (SAMs) for 16 New Zealand regions (Smith *et al*., 2014).[9] These SAMs provided detailed information on the production and use of economic commodities in New Zealand, and commodity trade between regions and other nations. The SAMS were a source of information for estimating the proportion of domestic commodity trade by region impacted by the interisland ferry and/or rail disruption.

An examination of the current value of transport service industries compared to the mass of commodities transported indicated that generally coastal shipping and rail were relatively less expensive than road for transportation on a per kg basis. This likely reflected the types of goods currently transported by rail and coastal shipping, often bulk homogenous goods requiring relatively little sorting and handling. It was assumed that costs (in constant dollar terms prior to the quake) remained the same for transporting goods between islands by coastal shipping as by rail, and thus the major impact was a shifting in demands for the type of transport service demanded. When shifting from road transport to coastal shipping, however, it was assumed that the costs of coastal shipping were only around half that of the original road transport costs, per kg of commodity transported. Conservatively it was also assumed that 20% of the road service demands per kg of commodity transported remained due to the need to transport goods to local ports.

2. Inter-island Freight Disruption – Time Delay Costs

An interesting observation from the commodity transport margins analysis described above was that while road freight was typically the most expensive choice of freight transportation, it was often still the selected mode for freight transport. The likely explanation is that road transportation was also the fastest mode, and thus an important consideration for consumers in addition to actual financial costs. By implication, when the transport system was disrupted such that the transportation of commodities between islands took longer, there was likely to be a range of economic consequences associated with the time delays.

It was quite challenging to ascertain a suitable method for incorporating these delay costs in an economy-wide model such as MERIT, given that the economic outcomes were likely to be quite nuanced. For example, the impacts would vary according to the time of year, commodities impacted, levels of inventories held, and so on. For the purposes of this study we adopted a method common to CGE modelling where an 'ad valorem'[10] delay cost was added to the price of commodities traded between islands. These per day delay costs for each commodity were sourced

[8] Note that the method also seeks to calculate the changes in transport margins from rail to road over the period in which the ferries are operating but the rail network is not.

[9] For each region the accounts are broken down by 205 different commodity types, 106 different industry types and 5 additional categories of final consumption for commodities (exports, household consumption, local government consumption, central government consumption, and investment consumption). To derive the commodity flow accounts in the SAMS, estimates are made of the total supply and demand for commodities by each region, and a gravity model is used to estimate the distribution of trade, or in other words, how origin and destination of commodities are paired.

[10] 'Ad valorem' are costs specified as a percentage of the value of the good.

from (Hertel *et al*., 2008) and enter the economic model essentially as 'pseudo' costs. That is, while the costs were considered in the behaviour functions of economic agents, for example the functions that determine whether domestic consumers chose to source goods from the domestic market or from overseas, no actual money transfers were associated with the incurrence of these costs.

Based on the study by Cenek *et al*. (2012), the magnitude of the additional delay associated with shifting from road to coastal shipping for inter-island trade was assumed to be around one third of a day. This was probably a conservative estimate for the Wellington Fault scenario given the Cenek *et al.* study did not involve a situation where the transportation system was significantly impacted causing increased competition for coastal shipping infrastructure. Significant further work would, however, be required to develop time delay estimates more specific to this case study.

3. **Port disruption –** In addition to the disruptions to ferry and inter -island freight movements, port infrastructure disruption was assumed to alter the costs of transportation for import and export trade. We used a method developed previously for analysis of the Kaikōura 2016 quake (Smith *et al*., 2017) to estimate the net increase in export and import transport margins, by economic commodity, associated with disruption to CentrePort. An important assumption was that all commodities were re-routed through other New Zealand ports; particularly Napier Port and Port of Tauranga. This generated additional demands for road transport services, per unit of export/import commodity, and added to the effective price of the exports/imports.

4.6.2 Inaccessibility Adjustments

The analysis of road impacts indicated that immediately following the earthquake event, damages to the road network were likely to be severe, with the Wellington region separated into around twenty different areas or 'road islands', with each generally isolated from others. Over time, with repairs and restoration to the network, the isolated road islands were progressively linked back together, until eventually full access was provided across the region. Not surprisingly, accessibility between road islands and accessibility in and out of the region were generally restored faster under the investment package scenarios compared to the baseline scenario without investments.

The level of inaccessibility experienced by road network damages was one of the most important aspects of the Wellington fault scenario. Sections 4.4 and 4.5 have explained that accessibility has already been taken into consideration in the estimation of the level of people and business movements out of the region. Furthermore, accessibility impacted industry productivity, by potentially delaying the recovery of operability following the event. In addition to this supply-side adjustment to the economic system, it was also important to incorporate within the economic model demand-side adjustments in response to inaccessibility. This prevented unrealistic price change responses in the model, and enabled demand-side adaptations to inaccessibility to be better captured. [11] In particular, when faced with an inability to source goods from Wellington suppliers, there was more chance that consumers looked to source goods from alternative suppliers within New Zealand and elsewhere.

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[11] When only impacts on supply are modelled, prices in the economic model will adjust upwards, to reflect a shortage in supply relative to demand. Disruptions to accessibility, however, create a unique situation where neither demand or supply can be realised in the market.

Similar to the estimation of freight impacts, our analysis of inaccessibility first required an estimation of the distribution of trade between Wellington and elsewhere. This time, however, we were interested in not only physical commodities that were freighted between locations of supply and demand, but also service commodities where inaccessibility acted as a barrier to consumption.

To estimate the origin and destination of commodities at detailed spatial units across New Zealand we essentially disaggregated the commodity components of the regional SAMs (see section 4.6.1 above) into individual accounts for each Census Area Unit (AU). This was undertaken in two steps. First, the regional commodity accounts were disaggregated to account for each territorial authority (TA) and a gravity model was used to estimate the level of trade within and between each TA (see Smith *et al*. (2014) for further information on this approach). The TA accounts were then further disaggregated into AU accounts. At this level it was assumed that commodity movements were distributed in direct proportion to the level of population/employment within each AU. The principal data used for disaggregation were Statistics New Zealand's population and employment data by AU. Information on commodity imports and exports through each New Zealand port (from the Harmonised System), also enabled the commodity accounts to be extended to show the origin and destination of commodities to and from ports as a result of import/export trade.

The census area accounts were then re-aggregated to match with the 'road island' spatial units used in the road impact analysis. With this newly derived information on the levels of trade between road islands and between road islands, the rest of New Zealand and abroad, and given the times at which accessibility was regained between road islands[12], it was possible to estimate the proportion of 'as normal' demand that could not be satisfied at each day of our analysis.

Within the economic model, an extra 'inaccessibility price' was applied to the proportion of commodity trade that was deemed inaccessible over and above normal costs including transportation.[13] The inaccessibility price was set at a very large $5 per kg. The exact magnitude of the price was not particularly important; what was important was that the price was sufficiently large to induce the envisaged demand-related behavioural responses. In these regards the economic model used tiered constant elasticity of substitution (CES) demand functions, as is standard practice within computable general equilibrium models (see Smith *et al*. (2016)). This means, for example, that when consumers located outside of the Wellington region were faced with a very high price for goods produced within the Wellington region, they chose to purchase instead more goods produced in parts of New Zealand outside of Wellington instead. These

[12] Note that the road impact analysis provided two sets (i.e. matrices) of restoration times under each investment scenario: (1) Response matrix and (2) Recovery matrix. It was assumed that day-to-day movements of people and goods and services would only occur in the recovery phase, and thus for this modelling we have relied only on the restoration times provided by the Recovery matrices.

[13] Three categories of trade were considered: exports from Wellington region to rest of New Zealand, exports from rest of New Zealand to Wellington, and exports from Wellington region to the rest of world. Although trade solely within the Wellington region would also be impacted on accessibility, it was not considered that this method of accessibility pricing would be suitable for within-Wellington trade. First, the method is based on calculations of 'as normal' proportions of trade impacted by inaccessibility and in the case of Wellington the disruptions will be so significant, and the level of adaptations necessary also significant such that 'as normal' shares will not relevant. Second, because many businesses will be highly isolated, the choices to purchase from an alternative region (i.e. rest of NZ or rest of world) will also not be available and hence the CES substation options irrelevant. Third, because many consumers in Wellington will also be impacted directly, the model already incorporates much of the necessary demand-side adjustments.

effects also translated up the 'CES' demand tree, so that imported goods also became relatively more desirable than domestic goods.

4.6.3 Simplified Urban Transportation Model

The final component of transport-related modelling was aimed at incorporating changes in transportation costs faced by households, and the types of transport demanded by households, because of damages to transportation infrastructure and household/business relocations.[14] A typical method for calculating changes in transportation costs, and mode choices, is by an urban four-stage transport model such as the Wellington Transport Strategy Model (Opus, 2012a). This was, however, not a viable option for this project. For one, transportation models are calibrated against 'typical' circumstances but in this project, we are dealing with severe disruptions and changes to the whole system. Second, running a four-stage transport model involves significant calculation times, additional consultant costs, and contracting of a third-party organisation, all of which was beyond the scope of the current project. Overall, we recommend that this is a suitable topic for further research and refinement.

In this project we adopted an intermediate approach whereby we attempted to take key components of an urban transport model, and implemented these in a simplified manner. Probably the most important limitation of the simplified transport model was that it concentrates principally on whether connections between locations were available, and not the number and standard of connections. It thus provided limited ability to quantify the costs of increased congestion and travel times, which were likely to be relatively significant after the event. By implication our analysis did not fully capture the economic consequences of the network outages and by implication the economic benefits of investments that increased redundancies in the transport network (e.g. provision of a second resilient road link between Porirua/Johnsonville and Lower Hutt). In short, the simplified transportation analysis was undertaken in four key steps:

Step 1: Generate baseline household transport costs (i.e. without disruption)

First, the baseline transport costs incurred by Wellington region households were calculated on an annual basis. Most of the necessary information/data was obtained directly from the 2013 release of the Wellington Transport Strategy Model (Opus, 2012a), including input parameters specifically provided to us on request. Inputs included:

- 2013 trip demand matrices for Wellington region transport zones (zone by three survey periods (am peak, interpeak, pm peak), and by three modes (cars, public transport, heavy commercial vehicles);
- 2013 time and distance matrices per trip (same matrix definitions as per (1));
- Distribution of regional trips by transport purpose (see Opus, 2012b, Table 2.2);

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[14] Although we recognise that changes in transportation costs and demand types will also be incurred by businesses (e.g. in day-to-day movements of people who are required to travel for work, and moving goods around the Wellington region), it was considered outside the scope of this project to develop a model to estimate such costs. Note also that freight cost changes resulting from port, ferry and rail disruption are addressed separately.

- The regional mode shares (car, public transport, commercial vehicle) for each type of trip purpose (see Opus, 2012b, Table 2.2).
- Scaling factors to translate the number of am, pm, and interpeak trips into the number of annual trips (supplied by Greater Wellington)

To split the public transport mode trips among bus and train trips, annual bus and rail trips (origin-destination) from the Wellington Transport Strategy Model (Opus, 2012a) were used. Bus and rail fares from the Wellington Transport Strategy Model were used to assign costs to rail and bus trips.

It was also assumed that 100% of trips for 'home-based work' was incurred by households, 100% of 'home-based education', and 70% of 'other' purpose trips. Furthermore, a cost of $\$_{2007}0.27$ was assigned per km of household travel by a private vehicle based on a Ministry of Transport estimate to run a medium-sized car with an average travel distance of 14,000km per year and a petrol cost of $2.10 per litre.

Step 2: Generate trip generation functions from baseline

The next step was to generate functions that would allow us to estimate new trip generation matrices, given revised information on employment (aggregated into four categories: manufacturing, retail/other services, education, other) and population within transport zones. These functions were calibrated from the baseline trip generation matrices received from the Wellington Transport Model, and the data we had on population and employment, by transport zone.

Trip generation functions for each non-heavy commercial and heavy commercial transport modes between transport zones was generated by running a non-negative coefficient linear regression using population estimates, and four industry-employment types.

The time taken to get from zone to zone was calculated by running a non-negative least-squares regression using the number of vehicle trips between transport zones and total number of regional vehicle trips.

Step 3: Estimate new trip generation statistics

Some information necessary to estimate changes in the distribution of people and business activities after the quake was also relevant to the Business Behaviours and Population Relocation models, either as an input to those models or as an output. For example, estimates of the number of people moving in and out of the region were made in the Population Relocation Model. It can be noted, however, that the economic model only operated at the total regional level, and thus did not require inputs that were defined spatially across the Wellington region. To generate information suitable for the transport modelling, it was therefore necessary to provide some ad-on features to both the Business Behaviours and Population Relocation models, so that information on population and business activities became always defined spatially for the Wellington region, i.e. by meshblock. It should also be noted that relatively little information was available on how adaptations to infrastructure and building damage might occur in a heterogenous way across space, for example through targeted business parks and emergency housing at specific locations. Therefore, the approach taken for the transport modelling involved the application of relatively broad assumptions, applied homogenously across the district. Further work could look more closely at likely locations for permanent and temporary rehousing and capacities at these locations.

Key assumptions for the current modelling were:

Population

- The meshblock location of buildings where injuries and fatalities occurred was the same meshblock location as the residency of persons injured/killed (note that the earthquake scenario occurred at night and an adjustment was already made for the proportion of deaths and injuries of non-residents).
- The number of vulnerable and support persons evacuated within a meshblock for a given age group, out of the total regional number of vulnerable and support persons evacuated within that age group was proportional to the meshblock's share of regional population for that age group. If these people returned, it was to the same meshblock from which they were evacuated.
- The residence location of employees (and their families) strategically evacuated was distributed across meshblocks on a pro-rata basis according to each meshblock's share of working age population (note that only meshblocks within commuting distance from Wellington CBD were considered).
- For buildings classified as 'residential' or 'commercial' use, the number of people displaced by building damage or cordoning (i.e. 'shelter' displacement) was equal to the night occupancy of those buildings.
- The capacity of remaining buildings to take up residents who were displaced was determined by applying an 'extra capacity factor' to the current occupancy of those buildings. The factor was assumed to be 10% for SDI categories 1-7 and 30% for SDI categories 8+. Displaced persons were then distributed across meshblocks on a pro-rata basis according to the extra capacity available in each meshblock, out of the total extra capacity available.
- As the voluntary flight components of the Population Relocation model were calculated at a meshblock level, no further assumptions were required to determine how people leaving the region under voluntary flight were distributed spatially. The people who were deemed to return to the region were simply assumed to return to the same meshblock of origin (note more severely degraded locations had a smaller share of people returning).

Employment

- In addition to population statistics, the trip generation functions relied on estimates of people working in different industry groups, by meshblock, as a means of estimating likely trips originating and destined for each meshblock. It was recognised, however, that while people may still be employed, normal day-to-day trips may nevertheless be reduced due to the types of disruptions experienced across the region. We therefore adjusted the employment statistics to generate 'effective' employment at each location. It was also considered reasonable to scale down employment to an 'effective level' by taking around one third of the reduction in operability calculated for each industry group within each meshblock.[15]
- The calculations of business/employee movements out of the region (based on levels of business viability) were undertaken at a meshblock level.
- Employees who needed to evacuate due to building damage or cordoning but who remained in the region were redistributed to meshblocks on a pro-rata basis according to each meshblocks'

[15] It would overestimate impacts if we used the full reduction in operability to scale down employment levels. Operability changes cover a range of circumstances including, for example, situations when an industry continues to use the same level of inputs and by implication still requires the same number of staff to travel to work, but productivity losses mean the outputs generated reduce.

share of remaining occupancy. The redistribution was also undertaken separately for industrial versus commercial activities, so that industrial activities were more likely to redistribute to areas that are already high industrial, and vice versa.

Step 4: Estimate new household transport costs after quake

Under the final step of the analysis, revised annual household transportation costs were generated, iteratively for each day following the earthquake event. The revised transportation costs were then compared to the baseline annual costs, to obtain a net change in annual transportation costs over time. Note also that the costs were broken down according to commodities purchased by households (fuel, vehicle repairs, rail transportation services, etc) so that the costs could be incorporated into the economic model from both a demand and supply perspective.

First, armed with the functions derived under step 2, and the new population and employment statistics generated under step 3, this step began with the calculation of revised annual trip generation matrices for Wellington's transport zones for each day of the analysis. Next, further revisions to the trip generation matrices were made to incorporate damages to the road and rail network infrastructure, and the way in which the networks were restored over time. Relevant assumptions were:

- Trips assigned to the rail network over the period in which the commuter rail was not operational were assigned half to buses and half to private vehicles.
- Trips that could not be made simply because there was no connectivity between the relevant road islands were redistributed from the origin road transport zone to new destination zones on a pro-rata basis according to the remaining distribution of trips from that zone. The same process was then undertaken but this time redistributing trips to new origin zones for a given destination zones. The final matrices used were the average of the origin-based and destination-based matrices.
- Not all trips that could not be made because of lack of connectivity between road islands were assumed to be redistributed for the first six months after the event. Initially, because the disruptions were significant, and people and businesses were still developing adaptation strategies, it was assumed that 0% of trips were redistributed. The proportion redistributed was however assumed to reach 50% by day 100 and 100% by six months.

5 References

Aldrich, D. P. (2011). The power of people: social capital's role in recovery from the 1995 Kobe earthquake. *Natural Hazards*, *56*(3), 595–611.

Aldrich, D. P. (2012). *Building resilience: Social capital in post-disaster recovery*. Chicago: University of Chicago Press.

Atkinson, J., Salmond, C., & Crampton, P. (2014). *NZDep2013 Index of Deprivation*. Wellington, New Zealand.

Brown, C., Giovinazzi, S., Seville, E., Vargo, J., Stevenson, J.R. (2015) *Developing the Business Behaviours Module within MERIT*. Economics of Resilient Infrastructure Research Report 2015/02. 71p.- addendum added January 2016.

Cenek P.D., Kean, R.J., Kvatch, I.A., Jamieson, N.J. 2012. Freight transport efficiency: a comparative study of coastal shipping, rail and road modes. NZTA research report 497.

CERA. (2011). *Canterbury Economic Indicators June 2011*. Retrieved from http://cera.govt.nz/sites/default/files/common/canterbury-economic-indicators-june-2011.pdf

Corey, C., & Deitch, E. (2011). Factors Affecting Business Recovery Immediately after Hurricane Katrina. *Journal of Contingencies and Crisis Management*, *19*(3), 169–181.

Cutter, S. L., Emrich, C. T., Mitchell, J. T., Piegorsch, W. W., Smith, M. M., & Weber, L. (2014). Uneven Recovery. In *Hurricane Katrina and the Forgotten Coast of Mississippi* (p. 68). New York: Cambridge University Press.

Hertel, T. W., McDougall, R. A., Narayanan, B., Aguiar, A. H., Narayanan, G. B., Aguiar, A., & McDougall, R. (2008). Global Trade, Assistance, and Production: The GTAP 7 Data Base. *Center for Global Trade Analysis, Purdue University*, 18.

LeSage, J. P., Kelley Pace, R., Lam, N., Campanella, R., & Liu, X. (2011). New Orleans business recovery in the aftermath of Hurricane Katrina. *Journal of the Royal Statistical Society: Series A (Statistics in Society)*, *174*(4), 1007–1027.

Matanle, P. (2011). The Great East Japan Earthquake, tsunami, and nuclear meltdown: towards the (re)construction of a safe, sustainable, and compassionate society in Japan's shrinking regions. *Local Environment*, *16*(9), 823–847.

MBIE. (2013). *Housing pressures in Christchurch. A summary of the Evidence / 2013*. Wellington, New Zealand.

MCDEM. (2008). *Mass Evacuation Planning. Director's Guideline for Civil Defence Emergency Management Groups DG 07/08*. Wellington, New Zealand.

Ministry of Health. (2014). *Analysis of Household Crowding. Based on Census 2013 data*. Wellington, New Zealand.

Ministry of Transport. (2014). *National Freight Demand Study*. Wellington, New Zealand

Newell, J., Beaven, S., & Johnston, D. M. (2012). *Population movements following the 2010-2011 Canterbury Earthquakes. Summary of research workshops November 2011 and current evidence*.

Orchiston, C., Seville, E. and Vargo, J., 2014. Regional and sub-sector impacts of the Canterbury earthquake sequence for tourism businesses. *Australian Journal of Emergency Management, The*, *29*(4), p.32.

Opus, 2012a. *Wellington Transport Models. Model Development Report*. Technical Report 00, Wellington, New Zealand.

Opus, 2012b. *Wellington Transport Models. Input Parameters*. Technical Report 15, Wellington, New Zealand.

Sanderson, K., Nana, G. and Dixon, H. 2016. *Economic Impact of CentrePort on Central New Zealand 2016*. Berl, Wellington.

Schrank, H., Marshall, M. I., Hall-Phillips, A., Wiatt, R., & Jones, N. (2012). Small-business demise and recovery after Katrina: rate of survival and demise. *Natural Hazards Review*, *65*(3), 2353–2374.

Smith, N.J., Harvey, E., and McDonald, G.W. (2016). *Dynamic Economic Model. A technical report*. Economics of Resilient Infrastructure Research Report 2017/02. 109p.

Smith, N, McDonald, G, Ayers, M, Kim, J, Harvey, E. (2017). Economic impact of the 2016 Kaikōura earthquake. A report prepared for the Ministry of Transport, New Zealand.

Smith, S. K., & McCarty, C. (1996). Demographic Effects Of Natural Disasters: A Case Study Of Hurricane Andrew. *Demography*, *33*(2), 265–275.

SPUR. (2009). *Lifelines: Upgrading infrastructure to enhance San Francisco's Earthquake Resilience*. San Francisco. Retrieved from https://www.spur.org/sites/default/files/publications_pdfs/SPUR_Lifelines.pdf

SPUR. (2012). *Safe Enough to Stay*. San Francisco. Retrieved from http://www.spur.org/publications/spur-report/2012-02-01/safe-enough-stay

Statistics New Zealand. (2007). *2006 Disability Survey*. Wellington, New Zealand.

Statistics New Zealand. (2014). *Disability Survey 2013*. Wellington, New Zealand.

Statistics New Zealand. (2015). *2013 QuickStats About people aged 65 and over*. Wellington, New Zealand.

Sydnor, S., Niehm, L., Lee, Y., Marshall, M., & Schrank, H. (2017). Analysis of post-disaster damage and disruptive impacts on the operating status of small businesses after Hurricane Katrina. *Natural Hazards*, *85*(3), 1637–1663.

Wasileski, G., Rodríguez, H., & Diaz, W. (2011). Business closure and relocation: a comparative analysis of the Loma Prieta earthquake and Hurricane Andrew. *Disasters*, *35*(1), 102–129. Retrieved from

Webb, G. R., Tierney, K. J., & Dahlhamer, J. M. (2002). Predicting long-term business recovery from disaster: A comparison of the Loma Prieta earthquake and Hurricane Andrew. *Environmental Hazards*, *4*(2–3), 45–58.

WREDA. (2015). *Annual Report 2015*. Wellington, New Zealand.

Xiao, Y., & Nilawar, U. (2013). Winners and losers: analysing post-disaster spatial economic demand shift. *Disasters*, *37*(4), 646–668.

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Appendix M

Preferred Programme Map

Preferred Investment Programme

Appendix N

Wellington Lifelines Project Financial Case, EY, September 2019

Wellington Lifelines Project - Financial Case

24 September 2019

Building a better working world

Table of contents

1. Introduction

1.1 Background & Context

The probability of a major earthquake hitting New Zealand's capital city of Wellington is widely accepted, and the disastrous effects of major earthquakes have been demonstrated in the 2010/11 Christchurch Earthquakes as well as the 2016 Kaikoura Earthquake. In recent years, local councils have worked on increasing household resilience and have tightened building codes to protect lives in such an occurrence, but this focus on readiness has not been reflected across the board. Saving lives is paramount, but the survivors of a major disaster also need to be able to function in a working economy after the event. In the case of Wellington, the need for economic resilience is critical not only for the half a million people who live in the region, but also for the nation.

Wellington's economy contributes 13.5% of New Zealand's GDP, but this figure does not tell the entire story of why Wellington's economy is important. Not only is it the seat of Government and the transport hub between the North and South Islands, but its large knowledge sector also has New Zealand's fastest growth in digital businesses[1]. This concentration of services, financial and technology sectors makes it vulnerable to loss of firms who rely on intellectual capital and have the ability to move quickly to another place – not necessarily in New Zealand – should their current location become unsustainable.

To ensure the fastest possible economic recovery following a major earthquake, it is imperative that core infrastructure is as resilient as possible. In order to move towards this level of resilience, the Wellington Lifelines Group began the first stage of the Wellington Lifelines Programme Business Case (the 'Business Case'). The Business Case has two major components:

- Analysing the economic cost of not being prepared and the consequent savings to the nation if we had infrastructure that was ready for a major earthquake and sufficiently resilient to be able to maintain services or recover rapidly. This stage of the Business Case is comprised of the Strategic and Economic Cases.
  - The Strategic Case makes the argument for change
  - The Economic Case determines value for money
- The development of the financial case (this report).

1.2 The Business Case

This business case is the first of this size and complexity ever undertaken in New Zealand[2]. It considers the interdependencies of 16 infrastructure providers in order to identify a step-change improvement to the Wellington Region's resilience to a large earthquake.

The Strategic and Economic Cases are comprised of six key components:

1. Identification of significant benefits from improving Wellington and NZ's infrastructure resilience to earthquake events

The strategic and economic cases detail how investing in infrastructure resilience will reduce the national economic impact of a large Wellington earthquake by more than $6 billion. In addition to the avoided economic losses, there will be significant social benefits achieved through Wellington's communities surviving and thriving after a major seismic event.

Many of the resilience projects are already on long term asset plans and have funding earmarked. The business case identifies that if the interdependent resilience projects are delivered in a priority

[1] Wellington Lifelines Project. Protecting Wellington's Economy Through Accelerated Infrastructure Investment Programme Business Case. Stage 1 – Demonstration of Benefits.2018.p.iii

[2] Wellington Lifelines Project. Protecting Wellington's Economy Through Accelerated Infrastructure Investment Programme Business Case. Stage 1 – Demonstration of Benefits.2018. p.iv

order and accelerated, there will be significant benefits to Wellington and New Zealand's economy when a major earthquake occurs.

2. Wellington is vital to New Zealand's economy but is currently very vulnerable to large seismic events

Wellington is a vibrant and growing capital city and a key contributor to the New Zealand economy. It is the seat of Government, has high concentrations of professional and value-added services, is a centre for arts and innovation, a key tourist destination and also fulfils a role as a vital transport link between North and South Island. Wellington contributes 13.5% to New Zealand's gross domestic product (GDP), which is second only to Auckland and is the highest GDP per capita in the country. Wellington also has a significant place in the national identity, and is home to more than 400,000 people.

Wellington's vulnerability to a major earthquake is well-known, and it is not a question of if, but when the 'big one' will occur. The imminent questions are:

- How big will the economic and social impact be when the earthquake happens?
- What can be proactively done to reduce this impact?

To give confidence to Wellington residents and the people of New Zealand, as well as international investors, insurers and visitors, a credible plan must be in place to minimise the potentially devastating impact of a disaster in Wellington.

The recent Kaikoura and Canterbury earthquakes demonstrated the need to build resilient infrastructure in our cities. Evidence from our domestic experience and recent international disasters has shown that communal infrastructure is critical to habitability and, when it fails, cities can quickly become unliveable. When key infrastructure is out or operating at degraded levels of service, people leave, productivity drops and communities, and the economy suffer as a result.

Lifeline infrastructure organisations (Lifelines) are entities that provide essential infrastructure services to the community such as water, transport, energy and telecommunications and include ports, roads and power stations. Lifelines are key service providers to our cities and regions, and have a major role to play in minimising the impacts of hazard events.

Lifeline organisations have historically planned their resilience investments independently and over long periods of time. The drawback of this approach is that planning can become disaggregated and projects delayed due to a lack of centrally driven urgency, and/or internal competition from other priority projects. Even more compellingly, a city's overall resilience is inherently interdependent across lifelines. For example, there is limited benefit in building a resilient water network, if the electricity network is not equally resilient such that pumping stations can function after an earthquake. Lack of co-ordination in planning resilience projects will result in suboptimal investment outcomes.

3. Integrated infrastructure approach to understand and model Wellington's economic resilience

The Business Case draws on the expert knowledge held by Wellington Lifeline Infrastructure providers. Each Lifeline organisation helped identify infrastructure projects that would increase resilience and support faster economic recovery in the Wellington Region in the aftermath of a 7.5 magnitude earthquake.

A preferred programme of infrastructure projects was identified and modelled to understand potential economic benefits flowing from pre-earthquake investment, and to provide insights into the nationwide economic impacts of any large natural disaster.

4. Demonstration of benefits of improving the resilience of the Wellington Region

The first key finding from the economic modelling was that if a magnitude 7.5 earthquake occurs on the Wellington Fault with no investment (the do-nothing scenario), the expected loss to New Zealand's GDP over a 5-year period will exceed $16 billion (this is in 2016 dollars and excludes recovery costs or building damage; it is just the immediate impact).

The second key finding was that if the preferred investment programme is implemented before such earthquake occurs, the expected economic loss is reduced to $10 billion over a 5-year period, and a $6 billion impact to New Zealand's economy is avoided. The reason for this reduction in economic loss is due to shorter outage durations on key lifeline infrastructure with the preferred programme implemented. The people of Wellington will be less impacted and economic activity in New Zealand will return to normal sooner.

5. Preferred programme of infrastructure investment to deliver maximum resilience benefits

The preferred programme of investment comprises 30 resilience projects or initiatives at an estimated total whole-of-life cost (including both capital and operating expenditure) of **$5.3b.** This programme includes projects across the fuel, transport, electricity, telecommunications, water and gas sectors. Projects have been scheduled across a 20-year time horizon and have been arranged so that interdependencies between projects and other lifeline services are considered. Fuel, road, and electricity projects were found to provide the greatest resilience benefit to other projects.

The estimated **$5.3b** cost of the preferred programme is not all extra or new expenditure, as many of the projects identified already feature in the long-term capital plans of Wellington's infrastructure providers. Additionally, many of the projects are justified on primary (non-resilience) benefits they provide to the people of Wellington. By undertaking smart prioritisation and acceleration of infrastructure resilience improvements, these 'business as usual' benefits are also further amplified.

This Business Case schedules projects so that resilience benefits can be optimised. This Business Case is the first study to place an economic value on what these projects collectively provide in terms of resilience when a major earthquake (or another natural hazard event) occurs.

The Business Case analyses the benefits of improving resilience to a high-impact but infrequent major earthquake. The proposed infrastructure improvements will also make the Wellington Region more resilient to smaller and higher frequency seismic events (for example earthquakes like the Cook Strait and Kaikoura events). Taking these smaller and more frequent types of shock events into account will mean the real economic benefits will exceed $6 billion of avoided impacts for the single magnitude 7.5 earthquake modelled in this study.

6. Wellington and New Zealand must make improving resilience a priority

It has been over 160 years since a truly large earthquake impacted the Wellington Region; the magnitude 8.2 Wairarapa earthquake. Every day that passes without the 'big one' means we are one day closer to when it will occur. On average, earthquake statistics suggest there is a ~30% chance of a damaging earthquake every decade, so we need to keep pressing forward at pace to realise the benefits of this study and improve resilience before the inevitable earthquake strikes. The people of Wellington and New Zealand are relying on the key decision makers to ensure their welfare and economic future is secure.

The Business Case and its results is intended to be shared with infrastructure providers and local/central Government. The target is to confirm the Wellington Region's integrated infrastructure resilience plan by the end of 2019 and commit to determine a way forward.

1.3 The Financial Case

The Financial Case presents a high-level assessment of the costs and funding requirements for the Accelerated Integrated Programme Option and the Unaccelerated, "Do-Minimum" Programme Option, as identified in the Economic Case of the Wellington Lifelines Programme Business Case. In doing so, this case:

- Sets out the financial impact of the options and the expected costs to the lifeline utilities
- Outlines potential funding sources
- Discusses overall affordability of the options and the additional funding required to deliver the programme

The purpose of the financial case is to determine the funding requirements of the project and to demonstrate that the recommended pathway forward is affordable. This case sets out the indicative Programme costs and related funding requirements. The initial capital expenditure, revenue and funding are summarised in Table 1 below.

Table 1: Initial Capital Expenditure and related Revenue & Funding Summary ($m)

Item	Nominal Value	Present Value
Revenue	25.3	12.3
Funding	1,938.1	1,106.9
Initial Capital Expenditure*	3,865.7	2,353.4
Surplus/(Shortfall) with respect to initial capex costs	**(1,902.2)**	**(1,234.3)**

Note that the initial capex cost in the table is not the same as the total programme cost, which comprises the initial capex as well as all other capital and operating costs. In nominal terms, the total programme cost is **$5,326.6m, while the total programme shortfall is **$3,363.2m**, as reported in Table 20 in section7 below.*

1.4 The Initiatives

The Wellington Lifelines programme consists of 30 initiatives designed to make Wellington resilient to future earthquakes and potential other natural disasters. Given the interdependencies between projects and the long lead-times for potential property acquisition, design and consenting, sequencing of the programme was undertaken in such a way that maximises resilience benefits through co-ordinated investments. The initiatives were prioritised and bundled into three phases over a 20-year programme:

- Phase 1 runs for years 1-7 and is composed of the highest priority initiatives
- Phase 2 runs for years 8-14
- Phase 3 runs for years 15-20

Prioritisation was based on the following principles:

1. Projects were scheduled using expected durations and cost estimates obtained from lifeline organisations

2. Projects supporting an alternative (redundant) lifeline route were scheduled as a priority. Where no alternative route exists, strengthening works on the primary lifeline route were scheduled as a priority

3. Higher feasibility, lower cost projects were scheduled as a priority

4. Fuel, road and electricity projects were scheduled as a priority since other initiatives were heavily dependent on them

5. Projects with a high complexity and cost were scheduled later in the programme to allow for appropriate planning

6. General strengthening works on the electricity and water distribution networks were phased evenly across the 20-year programme.

Each phase is further split into groups based on the lifeline (e.g. road, electricity etc.) they fall under. The phases and groups are summarised in Table 2 below.

Table 2: Initiative Phasing Summary

Phase	Lifeline	Initiatives	Outcome achieved
Phase 1 Years 0 - 7	1. Road/Fuel	► A: Seaview Wharf Strengthening ► B: SH58 ► C: Taita Gorge access ► D: Wadestown to Johnsonville	A viable alternative route for fuel and people to get into the CBD
	2. Road	► Airport connectivity to Newton	A viable alternative route for vehicles to get into the CBD from the airport
	3. Electricity	► A: Central Park Substation ► B: Central Park to Frederick St Cables ► C: Seismic upgrade of 33kV Cables - I	Single point of failure risk at Central Park substation lowered, and 33% of identified 33kV network strengthened
	4. Water	► A: Cross Harbour Pipeline ► B: Omaroro and Moe-te-ra Reservoirs ► C: Silverstream Bridge Pipe Replacement project ► D: General toughening of pipes - I	A viable alternative water supply to Carmichael reservoir achieved via the cross-harbour link, water risk to the central park substation is removed and 33% of identified pipe network is toughened
	5. Communications	► Dedicated backup power for cell towers	Alternative power for mobile telecommunication networks achieved
	6. Port/Road	► A: Port Seismic Strengthening ► B: Better engineered links to the existing RORO terminal and port area	Strengthened port and port access (existing facilities)
	7. Rail	► Rail Seismic upgrade of slopes - I	50% strengthened NIMT, Hutt Valley, Upper Hutt and Wairarapa lines
Phase 2 Years 8 – 14	8. Electricity	► Seismic upgrade of 33kV cables - II	66% of identified 33kV network strengthened
	9. Water	► A: Carmichael to Johnsonville ► B: Porirua Branch replacement ► C: Porirua Low level zone reservoirs ► D: Waterloo Treatment plant ► E: General toughening of identified pipes - II	A second viable alternative water supply to CBD achieved, Porirua secured and 66% of identified pipes are toughened
	10. Road	► A: Petone to Grenada ► B: Cross Valley Link	A second viable alternative route for fuel and people to get into the CBD
	11. Port	► New RORO Terminal	A viable alternative sea access if strengthening undertaken at the port in Phase 1 fails. Location TBD.
	12. Rail	► Rail Seismic upgrade of slopes - II	100% strengthened NIMT, Hutt Valley, Upper Hutt and Wairarapa lines
Phase 3 Years 15 - 20	13. Road/Gas	► Middleton Road retaining walls upgrade	Additional road resilience and aids with gas main recovery
	14. Electricity	► Seismic upgrade of 33kV buried cables - III	100% of identified 33kV network strengthened
	15. Water	► A: Waterloo Pump Station Extension and new Pipeline from Waterloo to Haywards ► B: General toughening of identified pipes - III	100% of identified pipes are toughened. Ability to meet most of Wellington’s initial water needs through restarting a single plant

Each initiative is summarised in Table 3 below. Each initiative is classified with a number representing the lifeline group each initiative belongs to. Additionally, each initiative is classified as belonging to either the transport or utilities sector.

Table 3: Initiative Summary

Phase	Initiative no.	Initiative Name	Provider/ Owner	Sector	Description
1	1A	Seaview Wharf strengthening	CentrePort	Transport	Involves seismically strengthening the Seaview Wharf and the associated 3km of fuel pipelines that extend from the end of the wharf to Point Howard. This initiative will provide a more resilient fuel supply to greater Wellington. There will likely be significant road closures preventing fuel tankers getting into the region, therefore a robust refuelling and storage facility for fuel is critical.
	1B	SH58	New Zealand Transport Agency (NZTA)	Transport	Involves the stabilisation of slopes above SH58 at Haywards Hill from SH2 to summit (just east of Mt. Cecil Road). It is in addition to the 2.5km of safety improvements currently committed on SH58 between Transmission Gully and SH2. Silverstream bridge may also require seismic strengthening. This initiative will provide alternate access through to Porirua from the Hutt Valley, allowing residents of the Hutt Valley to travel through to Wellington via Porirua in the likely event that access along the SH2 coastal road is cut off. Additionally, this initiative will provide access for fuel trucks to transport fuel from Petone through the region.
	1C	Taita Gorge Access	Hutt City Council (HCC)	Transport	Includes slope stabilisation and upgrading of walls supporting the Eastern Hutt Road just north of Stokes Valley Road roundabout. This initiative will help prevent collapse of the Eastern Hutt Road into the Hutt River, maintaining access up the eastern side of Taita Gorge following an event and helps maintain access to Hutt Hospital.
	1D	Wadestown to Johnsonville	Wellington City Council (WCC)	Transport	Involves strengthening the retaining walls and engineering of some major uphill slopes on Churchill Drive, Blackbridge Road and Wadestown Road. This route is likely to be one of the first access routes open for ambulances to get through to Bowen hospital. It also provides access through to WE's critical Wilton Substation for inspection and repair following an event as well as a potentially important secondary route towards Wellington's CBD.
	2	Airport connectivity to Newton	WCC	Transport	Involves emergency response planning for the roads alongside the hospital and Constable Street and Crawford Street areas. It would involve potential interventions around the Mt. Victoria Tunnel portals to protect from landslides either side and reduce the tunnel outage time. This initiative provides access from Wellington Airport through to the CBD that will be required for recovery and response personnel if the Evans Bay route is blocked due to landslides.
	3A	Central Park Substation	Wellington Electricity	Utilities	This initiative will improve the resilience of the assets contained within Central Park Substation by spreading them over a larger geographic footprint. Specifically, this option involves construction of a second Central Wellington grid exit point substation at an unspecified location near the Central Park Substation and the associated 33kV cable connections into the WE network. One cable from each zone substation would be extended to the new switchboard. This initiative will improve the resilience of the electricity network, in particular the supply of electricity to Wellington CBD including parliament and the stock exchange, which are crucial for the return to BAU. Improved resilience in the provision of electricity to Wellington Hospital will have direct health benefits. This option will support recovery of other lifelines including pump stations and the telecommunications network, and will also mitigate against other risks such as fire or sabotage
	3B	Central park to Frederick Street cables	Wellington Electricity	Utilities	Replacement of the cables between Central Park Substation and Frederick Street Zone Substation with cross-linked polyethylene. This initiative has been scheduled for implementation under WE's ongoing cable replacement programme and has therefore been included to accelerate funding.
	3C	Seismic strengthening 33KV Cables - I	Wellington Electricity	Utilities	Seismic upgrade of 33kV buried cables replacing the oil and gas fuelled cables to 25 substations with modern solid insulated cables that would perform much better in a fault event. Those areas in significant liquefaction zones will be priorities including: Wellington CBD and the Port area (Frederick, Hataitai, Evans Bay, Kilbirnie, Ira Street) and Lower Hutt (Petone, Seaview) 33kV rings. This initiative is a key enabler of other infrastructure types to operate. It will benefit the entire region and have direct public health benefits through improved resilience of supply to hospitals and medical facilities. It has been included in the programme to potentially accelerate its implementation rather than waiting for cables to reach the end of their life before requiring replacement. This is the first stage of the seismic strengthening of the 33kV cables.
	4A	Cross Harbour pipeline	Wellington Water	Utilities	Involves the installation of a 12.7km underwater pipeline from Seaview to Evans Bay with a connection to the Carmichael Reservoir. The pipeline will be trenched into the seafloor as well as on land. Provision of an alternate major bulk water main provides resilience to the network, should the existing watermain be ruptured by a Wellington Fault event.

Table 3: Initiative Summary

Phase	Initiative no.	Initiative Name	Provider/ Owner	Sector	Description
					Without this alternative pipeline Wellington City would be without water for an extended period.
	4B	Omaroro and Moe-te-ra Reservoirs	Wellington Water	Utilities	Involves replacing the existing Bell Road Reservoir with a new 10ML reservoir and construction of a new 35ML reservoir at the Omaroro (Prince of Wales) site. These will be constructed to withstand an ultimate limit state of a 1-in-2,500-year event and a serviceability limit state to withstand a 1-in-1,000-year event. The existing Bell Road Reservoir is over 100 years old and does not meet current seismic standards. If it were to fail it could potentially take out the Central Park Substation in its path, causing a cascade of lifeline asset failures and loss of life. A larger reservoir at Omaroro is required to support flows from the cross-harbour pipeline. This initiative is also referred to as the 'Prince of Wales and Bell Road Reservoir Upgrade' in other documents.
	4C	Silverstream Bridge pipeline replacement project	Wellington Water	Utilities	Replacement of the Te Marua to Ngauranga pipeline where it crosses the Silverstream Road bridge and the Wellington Fault. The proposed pipeline replacement will be from the eastern end of the Silverstream Bridge, following the Eastern Hutt Road south approximately 1km. It then crosses the Hutt River elevated on piers with large ball joints on each side preventing horizontal movement. After the Wellington Fault the pipeline will be buried, crossing the Manor Park golf course, the railway line and reconnecting to the existing pipeline on the western side of SH2. The initiative also involves replacement of the existing pipe that branches off supplying the Kingsley Pumping Station and the steel rising main from Kingsley Valley. This initiative will provide a more robust Wellington Fault crossing than the existing watermain crossing at Fergusson Drive, connecting the Te Marua River supplied system with the Waterloo Aquifer supplied system.
	4D	General toughening of pipes-I	Wellington Water	Utilities	Upgrading a critical network of pipes to ductile pipes, approximately 152km total length and predominantly watermains and mains-to-reservoirs. This initiative ensures critical customers can quickly access network water services. This is the first of three initiatives involving upgrades to the network of pipes.
	5	Dedicated backup power for cell towers	Telcos	Utilities	Involves the procurement and installation of permanent back-up generators (10-12kV) and fuel supply storage of 400-500L. Also included in this initiative (but not included in the geological or economic modelling) was the installation of generators at Vodafone and Spark sites. Approximately 40 sites across the region would be suitable for generator installation for each provider. This initiative will provide approximately two weeks of power before requiring re-fuelling by helicopter or road, if the electricity network has not been restored by this time. It will ensure voice coverage is provided in most areas throughout the Wellington region.
	6A	Port seismic strengthening	CentrePort	Utilities	Lateral spread prevention measures across the standing area along Aotea Quays 1 to 3 and strengthening of the associated wharf facilities to provide protection against seaward slumping and interference with the berthing pockets. Also includes removal of buried underground structures and treatment of the main hard-standing area (Thorndon Reclamation) is also proposed to reduce the extent of non-uniform settlement/liquefaction induced surface undulation to the hard stand area. These works will help ensure the shipping link is retained and that ships can use the quays following an earthquake event. The realignment and upgrade of the crane electricity supply will enable full crane operation within 3-4 weeks of an event. These works are also expected to enable the Thorndon hard standing area to remain functional for the relevant port operational vehicles and reduce the outage times for the container wharf and cranes.
	6B	Better engineered road links to RORO terminal	NZTA/WCC	Transport	Involves mitigation measures to potential liquefaction on Aotea Quay following a seismic event, seismic upgrading of the Skew Rail Bridge and an emergency ramp from SH1 to the RORO area that can withstand a Wellington Fault event. The initiative would increase the likelihood of access both to the core port and to a RORO facility.
	7	Rail Seismic upgrade of slopes-I	KiwiRail	Transport	Seismic upgrading of structures and slopes along the NIMT, Hutt Valley Line, Upper Hutt Line and Wairarapa Line. This initiative would allow freight and commuter trains to be back running earlier and with greater reliability. It is the first of the two rail seismic upgrades.
2	8	Seismic strengthening 33kV-II	Wellington Electricity	Utilities	This is the second stage of the seismic strengthening of the 33kV cables.
	9A	Carmichael to Johnsonville	Wellington Water	Utilities	The only remaining viable pipeline following an earthquake is installed below the Johnsonville-Karori road and has non-resilient joints every few metres (over 1,000 joints prone to failure in an event) which would require closure and excavation of a key transport route to repair. There is no resilient fault line crossing as the alternative pipeline and associated pump station will be largely destroyed at the current location on Hutt Road/Thorndon Quay. This initiative involves:

Table 3: Initiative Summary

Phase	Initiative no.	Initiative Name	Provider/ Owner	Sector	Description
					► Construction of a new CLS welded watermain between Carmichael reservoir and a new pump station located near Omaroro Reservoir ► A new pumping station to pump water from the cross harbour pipeline to Johnsonville ► Construction of a CLS welded watermain between Omaroro Reservoir and Churchill Drive ► Upgrade to batter slopes along Grant, Lennel and Wadestown Road to prevent dropouts ► Construction of 700mm CLS branch at the top of Churchill Drive, Wadestown. This initiative forms part of an existing project designed to establish a new bulk main from Porirua to Carmichael over the longer term, and get the existing bulk main off Moonshine Valley/fault line
	9B	Porirua branch replacement	Wellington Water	Utilities	Involves construction of a Concrete Lined Steel (CLS) fully-welded watermain from Moonshine Valley Tee to Cleat Street, and a welded steel pipe through from Cleat Street to State Highway 1. Construction also includes a butt-welded steel pipeline along Mana. The initiative also includes provision of a containerised emergency water treatment facility. Water will be drawn from a tributary near the Tee in the Moonshine Valley and pumped into the Porirua Branch Main once treated. This initiative is important since an emergency water treatment station is required to extract and treat water from an identified river source. The branch replacement is required as the existing pipeline will suffer severe damage due to age, materials and joint type.
	9C	Porirua low level zone reservoirs	Wellington Water	Utilities	This initiative provides an additional 9ML reservoir, near the existing Porirua Low Level 1 and 2 reservoirs and providing an additional 3ML of storage at Takapuwahia. Reservoirs will be fed by the upgraded Porirua Branch main and constructed to an ultimate limit state of a 1-in-2,500-year event and a serviceability limit state to withstand a 1-in-1,000-year event.
	9D	Waterloo Treatment Plant	Wellington Water	Utilities	Involves measures to mitigate liquefaction risk and improve the ground at the southern end of the site or providing additional structural support. This initiative would enable the Waterloo Water Treatment Plant to remain operational and bulk water to be supplied to the network following a major quake.
	9E	General toughening of pipes-II	Wellington Water	Utilities	This is the second of three initiatives involving upgrades to the network of pipes.
	10A	Petone to Grenada	WCC	Transport	Includes a new road link from Hutt Valley to SH1. It will include slope stabilisation measures and basic resilience enhancements to increase the chance of a link between the two corridors following a 7.5 Wellington Fault earthquake event. This link would provide significant benefits to communities in terms of access into and out of the Hutt Valley. It also improves the lifeline restoration times of other lifelines that require road access to refuel and repair.
	10B	Cross Valley link	HCC	Transpo rt	Currently has provision of a new grade separated two-lane road with cycle lanes between Hutt Road in the West and White Lines road in the east, approximately following the alignment of the Hutt Valley Rail Line. The link would be constructed to withstand probable liquefaction and bridges or raised piers would be constructed to ensure the route Is usable following an earthquake event. The link would provide a stronger connection between the fuel terminals at Seaview with the transport network and the rest of the region.
	11	New RORO terminal with links to SH1	CentrePort, NZTA & KiwiRail*	Transport	Construction of a new ferry terminal and associated roll on/roll off docking facilities. Options for new terminal(s) are currently being considered, and may be at current locations or other sites. It is intended that SH1 and other parts of the transport system will be improved as part of these works. This initiative is critical to retaining the connection between the North and South Island which is an essential link in NZ's freight distribution network.
	12	Rail Seismic upgrade of slopes-II	KiwiRail	Transport	This is the second of the two rail seismic upgrades.
3	13	Middleton Road retaining walls upgrade	WCC	Transport	Involves the strengthening of retaining walls for gas main protection or alternatively the re-laying of the gas main on the uphill side of the slope. Minor improvements to batter slopes may also be included to reduce the amount of material likely to slide during an event, and therefore reduce the recovery time. By strengthening the existing retaining walls there will be fewer and smaller landslides along Middleton Road from an earthquake event, therefore improving the recovery time for the gas main which is currently located beneath Middleton road. This initiative also provides an alternate route through Johnsonville should there be damage closing SH1
	14	Seismic strengthening 33KV-III	Wellington Electricity	Utilities	This is the third and final stage of the seismic strengthening of the 33kV cables.
	15A	Waterloo Pump station extension and new pipeline to Haywards	Wellington Water	Utilities	Installation of a new pump station adjacent to Waterloo Water Treatment Plant, and provision of a CLS fully welded watermain from Waterloo Pump Station to the Haywards Valve, including a new flexible Wellington Faultline crossing.

Table 3: Initiative Summary

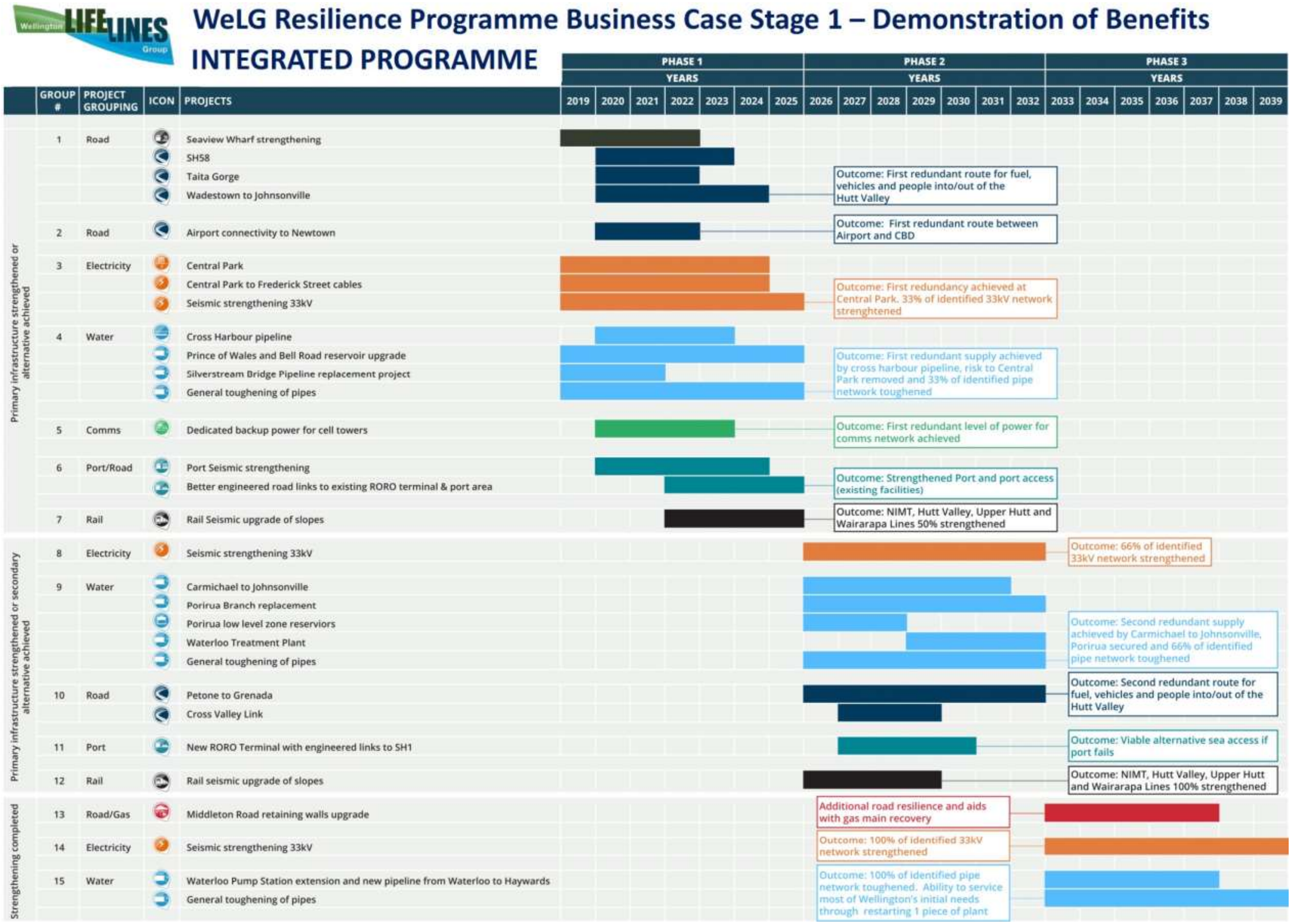
Phase	Initiative no.	Initiative Name	Provider/ Owner	Sector	Description
					Currently, there is no connection between the Te Marua river supplied system and the Waterloo aquifer-supplied system. This connection allows Wellington Water to focus energy on restarting a single plant that can effectively meet all initial regional water demands.
	15B	General toughening of pipes-III	Wellington Water, Greater Wellington Regional Council (GWRC), other city councils**	Utilities	This is the third and final initiative involving upgrades to the network of pipes.

*The 'New RORO terminal with links to SH1' has three owners: Centreport for the terminal itself, NZTA for the road links and KiwiRail for the rail construction.

**The owners of the 'General toughening of pipes – III' initiative are Wellington Water, Greater Wellington Regional Council and each of the city councils in the greater Wellington area: Wellington City Council, Hutt City Council, Upper Hutt City Council and Porirua City Council

The programme timeline, including the timing of each initiative, is illustrated in Figure 1 on the following page.

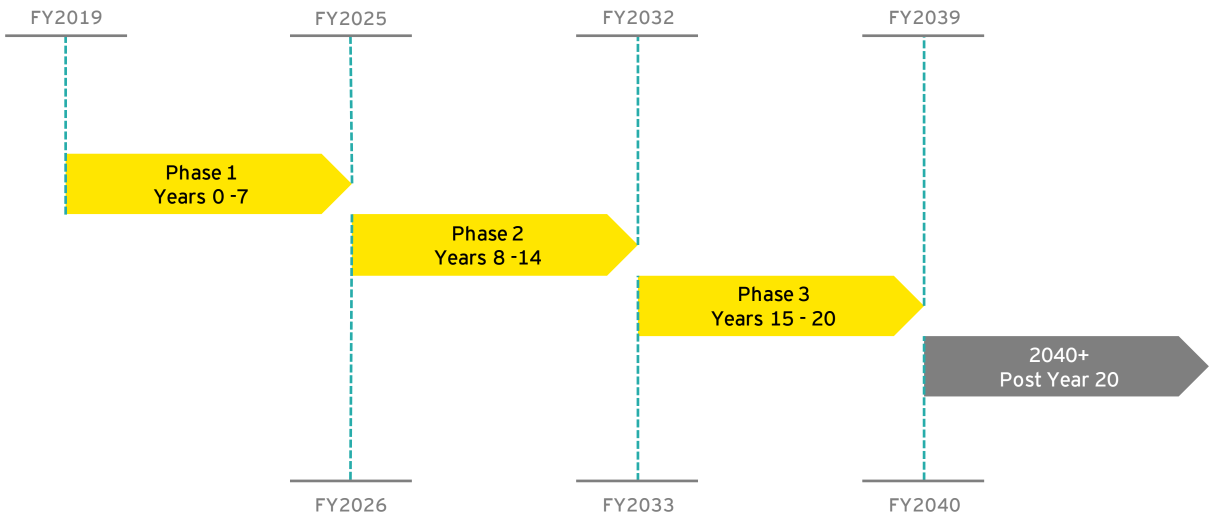
Figure 1: Wellington Lifelines Programme Timeline



1.5 The Financial Model

In order to forecast, collate and compare costs, revenue and funding, a financial model was developed. The financial model has a 20-year assessment period from FY2019 to FY2039. The 20-year time horizon aligns with the programme business case forecast period, and breaks down the costs, revenue and funding estimates for the programme into the three seven-year phases, as illustrated in Figure 2.

Figure 2: Project Phasing



The financial model also considers two scenarios:

- The Accelerated Integrated Programme Scenario
- The Unaccelerated "Do Minimum" Scenario, in which some initiatives are delayed and therefore incur costs (and revenue. funding etc.) at a later date

The key difference between the scenarios is that many initiatives are delayed under the unaccelerated scenario, so they may be scheduled to proceed after the assessment period of the financial model. Therefore, despite the effect of inflation, costs are lower under the unaccelerated scenario, however it delivers fewer initiatives and therefore fewer resiliency benefits during the assessment period. All the tables in the main body of the financial case present estimates for the accelerated scenario. Estimates for the unaccelerated scenario are presented in Appendix A.

These scenarios were designed and specified by the Lifelines Group. EY conducted this financial analysis based on the inputs and scenarios provided by the Lifelines Group.

Additionally, some of the initiatives incur costs that occur outside of the model period (i.e. from FY 2040 onward). These costs are not included in the financial case, so the costs presented in this document should not be interpreted as total programme costs, they should be interpreted as total programme costs over the key phases of the programme within the forecast time horizon.

Table 4 below presents the specifications of the financial model:

Table 4: Model Specifications	
Model Period	20 years
Model Start Date	1-July-2018

Table 4: Model Specifications	
Model End Date	30-June-2039
Inflation Index	Dependent on type of cost. Indices used include: ► Consumer Price index (CPI) ► Construction cost index ► Operation & Maintenance cost (O&M) index ► Revenue index
Depreciation	Based on asset life
Discount rate (for NPV calculations)	6%

Inputs to the financial model such as cost estimates were provided by the owner of each initiative. These owners are:

- CentrePort Ltd
- New Zealand Transport Agency
- Hutt City Council
- Wellington City Council
- Wellington Electricity
- Wellington Water
- Telcos
- KiwiRail

Due to potential commercial sensitivities, there are constraints on presenting individual projects owner's figures in the Financial Case. All figures are presented on an aggregated basis, or split by the transport or utilities sectors. Appendix B documents the initiatives considered to be part of the transport sector and those considered to be part of the utilities sector.

2. Phase 1 Summary

Phase 1 of the programme runs for the first seven years of the programme, from FY2019 to FY2025. It comprises the highest priority initiatives that support alternative (redundant) lifeline routes. These initiatives are generally higher feasibility, lower cost initiatives from the fuel, road and electricity sectors. The initiatives included in Phase 1 are:

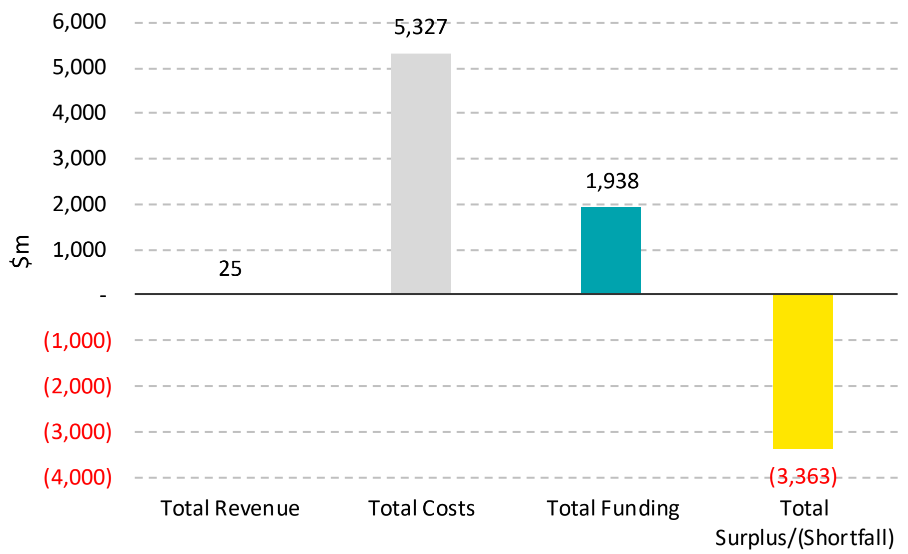
- 1A Seaview Wharf Strengthening
- 1B SH58
- 1C Taita Gorge Access
- 1D Wadestown to Johnsonville
- 2 Airport connectivity to Newton
- 3A Central Park Substation
- 3B Central park to Frederick Street cables
- 3C Seismic strengthening 33KV-I
- 4A Cross Harbour pipeline
- 4B Omaroro and Moe-te-ra Reservoirs
- 4C Silverstream Bridge pipeline replacement project
- 4D General toughening of pipes-I
- 5 Dedicated backup power for cell towers
- 6A Port seismic strengthening
- 6B Better engineered road links to RORO terminal
- 7 Rail Seismic upgrade of slopes-I

The summary results of Phase 1 of the programme are displayed in Table 5 below.

Table 5: Phase 1 Summary ($m nominal)	
Item	Phase 1 Years 0 - 7
Transport	
Total Revenue	-
Total Costs	242.4
Total Funding	115.7
Transport Surplus/(Shortfall)	(126.7)
Utilities	
Total Revenue	1.7
Total Costs	891.8
Total Funding	434.8
Utilities Surplus (Shortfall)	(455.3)
Overall	
Total Revenue	1.7
Total Costs	1,134.3
Total Funding	550.5
Total Surplus/(Shortfall)	(582.0)

The total programme revenue in Phase 1 comes to **$1.7m**, while funding is **$550.5m** and costs are **$1.1b**, leaving a shortfall of **$582.0m.** These results are illustrated in Figure 3 below.

Figure 3: Phase 1 Summary



In Phase 1, the funding shortfall is largest in the utilities sector, with **$455.3m (78.2%)** of the **$582.0m** total shortfall coming from utilities initiatives and **$126.7m** from transport initiatives.

3. Revenue

3.1 Revenue Summary

Revenue makes up a very small portion of the overall programme costs **(0.5%)**, since most of the initiatives deliver public benefits to the Wellington Region, they are not revenue generating. Table 6 below presents the estimated revenue across all three phases of the programme. Revenue estimates were provided by the owners of each initiative in real terms.

Table 6: Revenue summary by Phase and Sector ($m nominal)

Sector	Phase 1 Years 0 - 7	Phase 2 Years 8 - 14	Phase 3 Years 15 - 20	Total
Transport	-	-	-	**-**
Utilities	1.7	11.9	11.8	**25.3**
Total Programme Revenue	1.7	11.9	11.8	25.3

None of the transport initiatives generate any revenue, however the utilities sector is expected to generate **$25.3m** in revenue, which can offset a small proportion of the funding requirement.

4. Costs

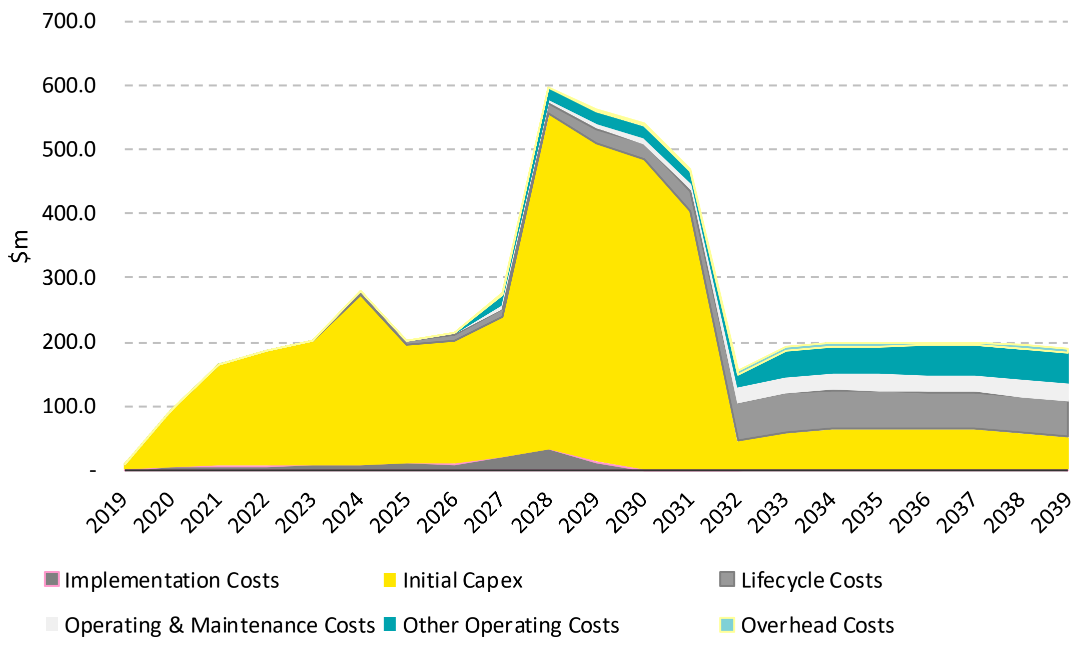
4.1 Cost Summary

The total costs for the programme by cost category and phase are presented in Table 7 below:

Table 7: Cost Summary by Cost Type ($m nominal)				
Cost	Phase 1 Years 0 - 7	Phase 2 Years 8 - 14	Phase 3 Years 15 - 20	Total
Implementation Costs	44.5	72.7	5.4	**122.6**
Initial Capex	1,077.9	2,369.7	418.1	**3,865.7**
Lifecycle Costs	8.7	177.9	407.3	**593.9**
Operating & Maintenance Costs	1.6	56.1	185.8	**243.5**
Other Operating Costs	-	119.5	317.1	**436.5**
Overhead Costs	1.5	21.9	41.0	**64.4**
Total Costs	**1,134.3**	**2,817.8**	**1,374.6**	**5,326.6**

The total cost of the programme is estimated to **be $5.3b. 21.3%** of the **$5.3b** is incurred in Phase 1 of the programme, while **52.9%** and **25.8%** are incurred in Phases 2 and 3 respectively. Each cost over the course of the three phases is illustrated in Figure 4 below.

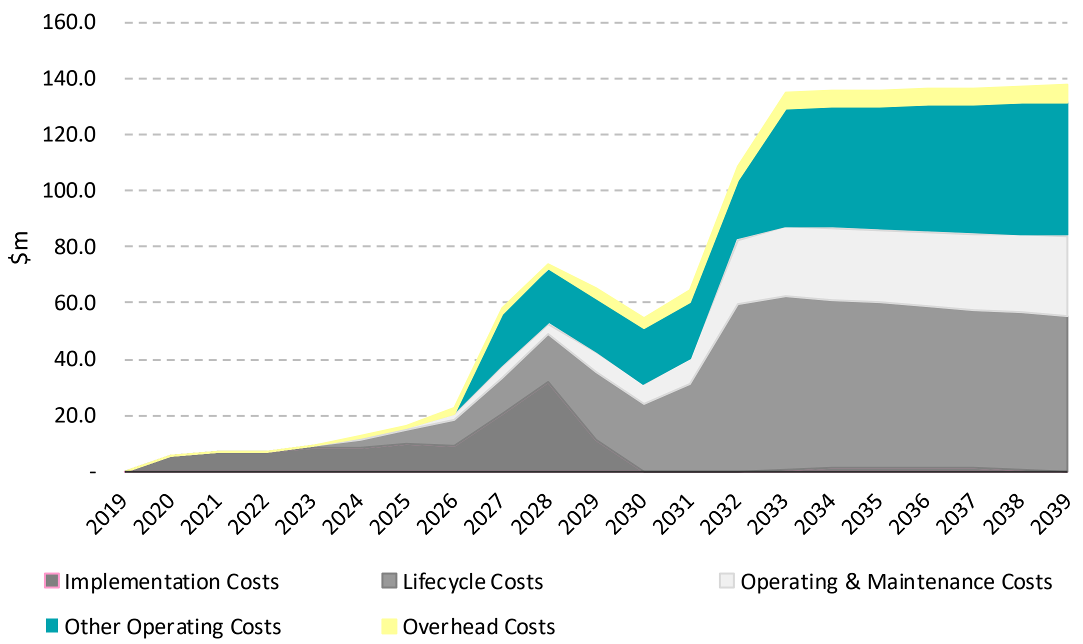
Figure 4: Cost Summary



The initial capex costs make up by far the largest component of the total programme costs, and peak in Phase 2 at **$2.4b.**

The other costs, with the exception of the implementation costs (which are an up-front cost) are incurred once the initiatives are in operation. In the later phases, more initiatives are in operation so these costs are higher. For the purposes of seeing the other costs more clearly, all costs except initial capex are presented in Figure 5 below.

Figure 5: Cost Summary excluding initial capex

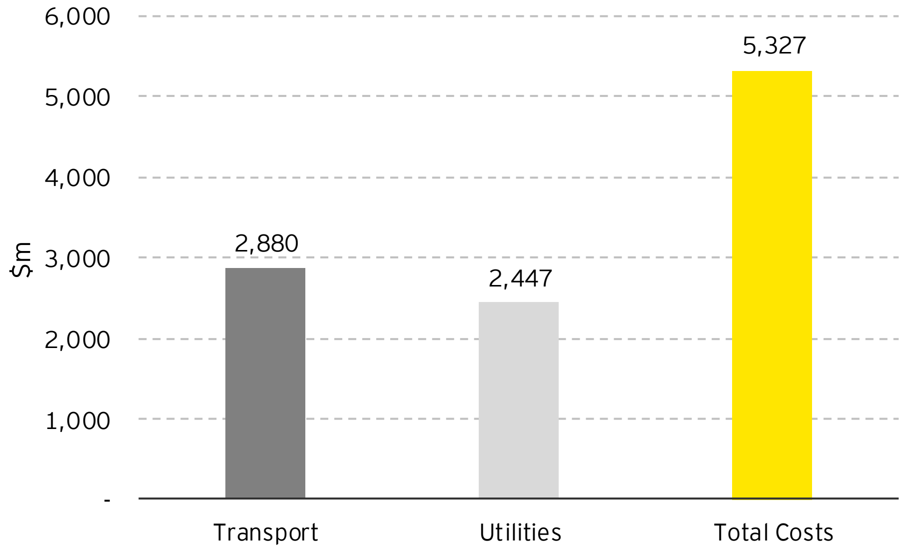


The total costs by sector are summarised in Table 8 below:

Table 8: Cost Summary by Sector ($m nominal)				
Sector	Phase 1 Years 0 - 7	Phase 2 Years 8 - 14	Phase 3 Years 15 - 20	Total
Transport Costs	242.4	2,105.5	532.0	**2,879.9**
Utilities Costs	891.8	712.3	842.6	**2,446.7**
Total Programme Costs	**1,134.3**	**2,817.8**	**1,374.6**	**5,326.6**

The total programme cost of **$5.3b** is comprised of **$2.9b** for initiatives in the transport sector and **$2.4b** for those in the utilities sector. This breakdown by sector is illustrated in Figure 6.

Figure 6: Cost Summary by Sector



4.2 Implementation Costs

Many initiatives have costs associated with the implementation of the project. These can be internal project set up and management, business cases, consulting fees or any other cost incurred in the early stages of the project not considered part of the initial capex. The implementation costs by sector are summarised in Table 9 below. Implementation cost estimates were provided in real terms by the owner of each initiative and include a 10%-30% contingency depending on the initiative.

Table 9: Implementation Costs by Phase ($m nominal)

Sector	Phase 1 Years 0 - 7	Phase 2 Years 8 - 14	Phase 3 Years 15 - 20	Total
Transport	30.4	72.7	5.4	**108.5**
Utilities	14.2	-	-	**14.2**
Total Implementation Costs	44.5	72.7	5.4	**122.6**

The total programme implementation costs are **$122.6m**. These costs mainly apply in the transport sector, with **$108.5m (88.5%)** coming from transport initiatives compared to **$14.2m** from utilities initiatives. The implementation costs are also concentrated in the early stages of the programme (Phases 1-2) since they are incurred at the start of each project. Once each initiative is in operation (i.e. in the later stages of the programme), implementation costs are no longer incurred.

4.3 Initial Capital Expenditure

The largest single component of the total programme costs **(72.6%)** is the initial capital expenditure. The initial capex is comprised of construction and design costs. Estimates were provided by the owner of each initiative in nominal terms. The initial capex broken down by sector is presented in Table 10. All initial capex estimates include a 10%-30% contingency.

Table 10: Initial Capex by Phase ($m nominal)				
Sector	Phase 1 Years 0 - 7	Phase 2 Years 8 - 14	Phase 3 Years 15 - 20	Total
Transport	208.6	1,884.1	60.0	**2,152.7**
Utilities	869.3	485.6	358.1	**1,713.0**
Total Initial Capex	1,077.9	2,369.7	418.1	**3,865.7**

The total programme initial capex is **$3.9b**, which is comprised of **$2.2b** from initiatives in the transport sector and **$1.7b** from initiatives in the utilities sector.

4.4 Lifecycle Costs

Lifecycle costs represent the cost of renewal capex or 'wear and tear' on an asset over its lifetime. They can be analogous to depreciation allowance, which represents the cost of an asset over its useful life.

In this analysis, the owner of each initiative provided an estimation of lifecycle costs typically via a percentage of an asset's initial value that is expected to be incurred annually post construction or an estimate of the expected asset life.

The Lifecycle costs by phase and sector are presented in Table 11 below.

Table 11: Lifecycle Costs by Phase ($m nominal)				
Sector	Phase 1 Years 0 - 7	Phase 2 Years 8 - 14	Phase 3 Years 15 - 20	Total
Transport	2.0	95.6	289.6	**387.2**
Utilities	6.8	82.3	117.7	**206.7**
Total Lifecycle Costs	8.7	177.9	407.3	**593.9**

The total estimated lifecycle costs for the programme are **$593.9m**. This figure is comprised of **$387.2m** from initiatives in the transport sector and **$206.7m** from initiatives in the utilities sector. These costs are expected to be predominantly incurred later in the programme, with **68.6%** being incurred in Phase 3, compared to **30.0%** in Phase 2 and just **1.5%%** in Phase 1. A relatively small amount of costs is incurred in the earlier phases because fewer initiatives are in operation and are therefore not incurring any lifecycle costs.

4.5 Operating & Maintenance Costs

The operating & maintenance cost estimates were provided in real terms by the owners of each initiatives and include a 10%-30% contingency. The estimated operating & maintenance costs are presented by sector and phase in Table 12 below.

Table 12: Operating & Maintenance Costs by Phase ($m nominal)				
Sector	Phase 1 Years 0 - 7	Phase 2 Years 8 - 14	Phase 3 Years 15 - 20	Total
Transport	0.8	35.7	143.3	**179.7**
Utilities	0.8	20.4	42.5	**63.7**
Total Operating & Maintenance Costs	1.6	56.1	185.8	**243.5**

The total estimated operating & maintenance cost for the programme is **$243.5m**. This figure is comprised of **$179.7m** from initiatives in the transport sector and **$63.7m** from initiatives in the utilities sector. This equates to **73.8%** of the programme operating & maintenance costs coming from transport initiatives compared to **26.2%** from utilities initiatives.

The operating & maintenance costs are skewed towards the later stages of the programme, since more initiatives will be in operation the more time passes and more initiatives are completed. **76.3%** of these costs are incurred in Phase 3, compared to **23.0%** in Phase 2 and only **0.7%** in Phase 1.

4.6 Other Operating Costs

The other operating costs are broken down by phase and sector in Table 13 below.

Table 13: Other Operating Costs by Phase ($m nominal)				
Sector	Phase 1 Years 0 - 7	Phase 2 Years 8 - 14	Phase 3 Years 15 - 20	Total
Transport	-	-	-	**-**
Utilities	-	119.5	317.1	**436.5**
Total Other Operating Costs	-	119.5	317.1	**436.5**

The total other operating cost is **$436.5m**, and is entirely comprised of costs from initiatives in the utilities sector. These costs are incurred later in the programme, with **72.6%** being incurred in Phase 3 and the remaining **27.4%** being incurred in Phase 2.

4.7 Overhead Costs

The annual overhead cost estimates were provided in real terms by each initiative owner and include a 10%-30% contingency. These estimates represent the administration and management costs for each initiative. The estimated overhead costs are presented by sector and phase in Table 14 below.

Table 14: Overhead Costs by Phase ($m nominal)				
Sector	Phase 1 Years 0 - 7	Phase 2 Years 8 - 14	Phase 3 Years 15 - 20	Total
Transport	0.8	17.3	33.7	**51.9**
Utilities	0.7	4.6	7.3	**12.6**
Total Programme Overhead Costs	1.5	21.9	41.0	**64.4**

Overheads are estimated to cost **$64.4m** over the course of the project. Like the operating & maintenance costs, the overhead costs are skewed towards the later stages of the programme and the majority of the costs come from initiatives in the transport sector:

- **63.6%** of overhead costs are incurred in Phase 3 of the programme, compared to **34.0%** in Phase 2 and just **2.4%** in Phase 1.
- **$51.9m** of the total **$64.4m** in overhead costs comes from initiatives in the transport sector, while the other **$12.6m** comes from initiatives in the utilities sector. In percentage terms, **80.5%** of overhead costs come from transport initiatives and the remaining **19.5%** come from utilities initiatives.

5. Financial Impact

The total programme costs and revenue as well as the funding requirement (revenue less costs) are presented in Table 15 below.

Table 15: Funding Requirement ($m nominal)				
Item	Phase 1 Years 0 - 7	Phase 2 Years 8 - 14	Phase 3 Years 15 - 20	Total
Total Revenue	1.7	11.9	11.8	**25.3**
Total Cost	1,134.3	2,817.8	1,374.6	**5,326.6**
Funding Requirement	**1,132.6**	**2,805.9**	**1,362.9**	**5,301.3**

Since revenue only makes up 0.5% of the total programme costs, the funding requirement is only slightly less than the total programme cost.

5.1 Present Values

The estimates in previous sections are nominal values that consider inflation and do not account for the time value of money (the value of money available in the present moment is worth more than the identical sum in the future due to its earning potential). For instance, they consider $100 paid in 10 years' time to have the same value as $100 paid today. To account for the time value of money we have calculated Present Values for the total revenue, funding, costs and shortfall.

Present Values discount values that occur in the future using the following formula:

$$PV = \frac{Value}{(1 + discount\ rate)^t}$$

The discount rate is the rate at which the value declines over time. A higher discount rate implies more value placed on the present. t refers to the time period, so future values are discounted by increasing amounts the further in the future they occur.

Our analysis has used the standard 6% p.a. Treasury discount rate. The revenue, costs and the funding requirement are presented in present value terms in Table 16 below, along with their corresponding nominal values.

Table 16: Funding Requirement ($m)		
Item	Nominal Value	Present Value
Revenue	25.3	12.3
Cost	5,326.6	2,998.8
Funding Requirement	**5,301.3**	**2,986.5**

6. Funding

A range of funding sources will be employed to cover the costs of the initiatives. Some funding has already been committed to the programme, whereas some is contingent on certain requirements being met.

The sources of funding include:

- The Crown
- Private funding and insurance
- Rates

6.1 Committed Funding

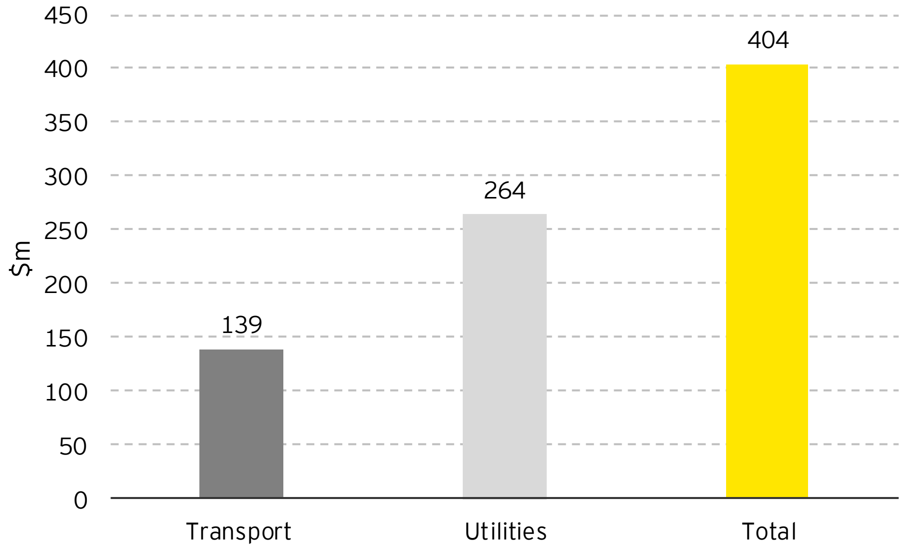
The funding already committed to the programme is detailed in Table 17 below:

Table 17: Committed Funding ($m nominal)

Funding Type	Phase 1 Years 0 - 7	Phase 2 Years 8 - 14	Phase 3 Years 15 - 20	Total
Transport				
Crown	56.7	43.3	-	**100.0**
Private and Insurance	6.0	-	-	**6.0**
Rates	1.9	31.4	-	**33.3**
Total Transport Committed Funding	64.6	74.7	-	139.3
Utilities				
Crown	-	-	-	**-**
Private and Insurance	60.5	-	-	**60.5**
Rates	198.8	5.0	-	**203.8**
Total Utilities Committed Funding	259.3	5.0	-	264.3
Total Committed Funding	323.9	79.7	-	403.6

The total amount of funding already committed to the programme is **$403.6m**. This figure is comprised of **$139.3m** for initiatives in the transport sector and **$264.3m** for initiatives in the utilities sector. This sector breakdown is illustrated in Figure 7 below.

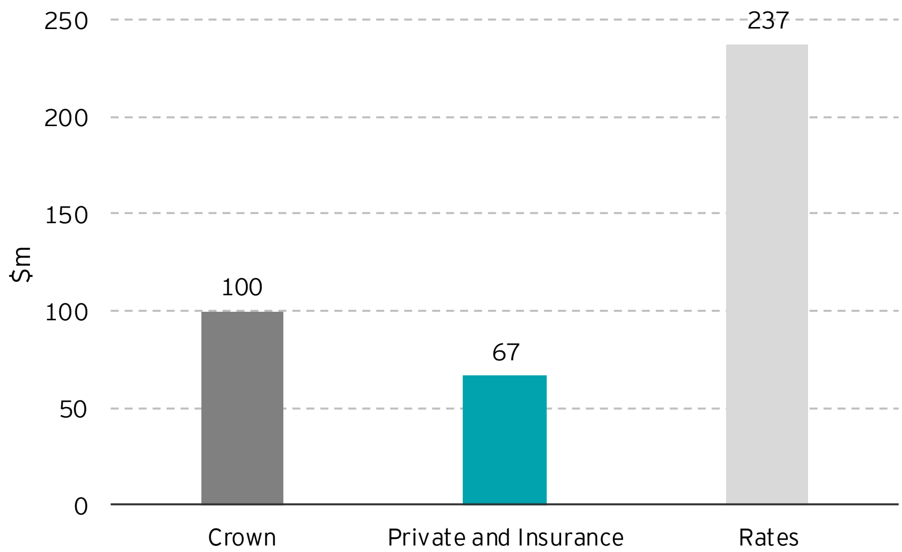
Figure 7: Committed Funding by Sector



All the committed funding is committed in Phases 1 and 2. **$323.9m** (**80.3%** of the total allocation) is committed to Phase 1 of the project, while **$79.7m (19.8%)** is committed to Phase 2.

The largest proportion of committed funding comes from rates **(59%)**, followed by Crown funding **(25%)**, and finally private & insurance **(16%)**. The breakdown of committed funding by funding type is presented in Figure 8 below.

Figure 8: Committed Funding by Type of Funding



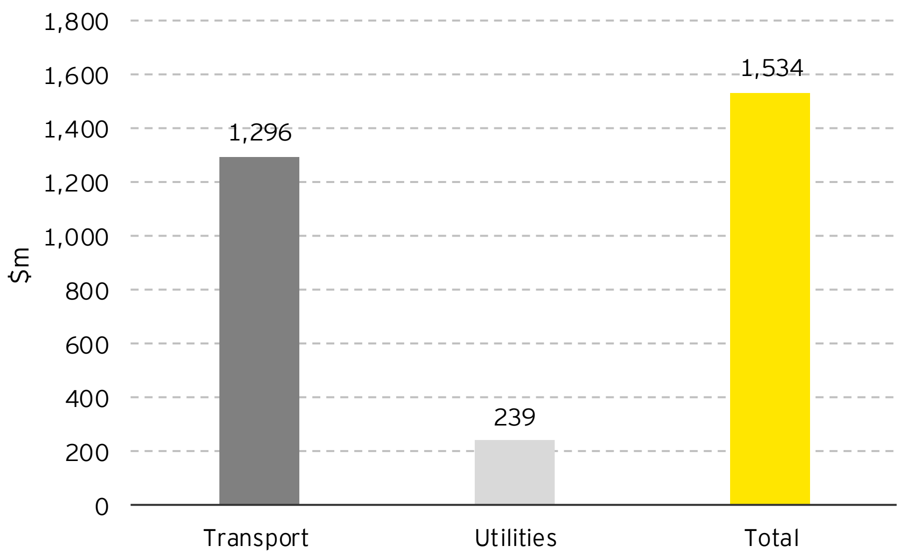
6.2 Contingent Funding

The programme's contingent funding is detailed in Table 18 below.

Table 18: Contingent Funding ($m nominal)				
Phase	Phase 1 Years 0 - 7	Phase 2 Years 8 - 14	Phase 3 Years 15 - 20	Total
Transport				
Crown	19.9	201.4	550.5	**771.8**
Private and Insurance	17.0	-	16.5	**33.5**
Rates	14.2	460.0	16.5	**490.7**
Total Transport Contingent Funding	**51.1**	**661.4**	**583.5**	**1,296.0**
Utilities				
Crown	-	-	-	**-**
Private and Insurance	175.5	63.0	-	**238.5**
Rates	-	-	-	**-**
Total Utilities Contingent Funding	**175.5**	**63.0**	`	**238.5**
Total Contingent Funding	**226.6**	**724.4**	**583.5**	**1,534.5**

The total amount of contingent funding currently available to the programme is **$1.5b.** This figure is comprised of **$1.3b** for initiatives in the transport sector and **$238.5m** for initiatives in the utilities sector. This sector breakdown is illustrated in Figure 9 below.

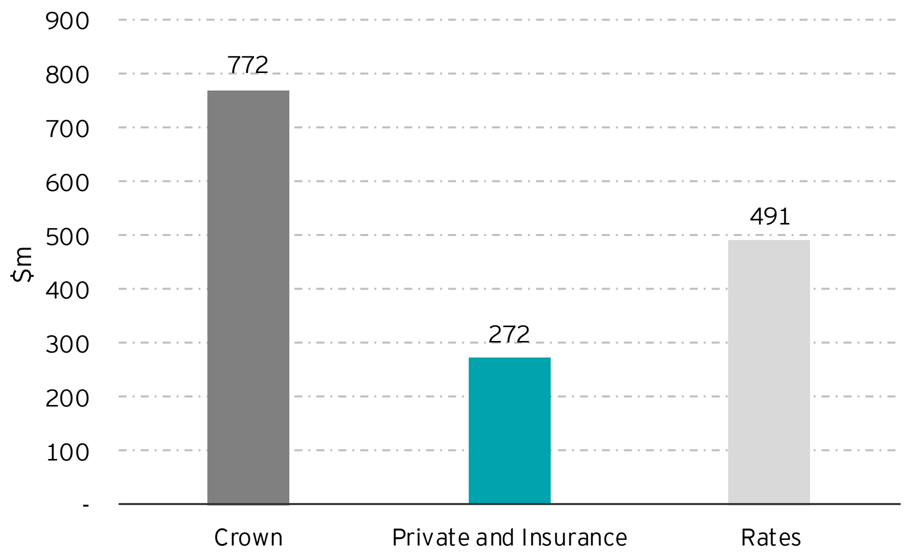
Figure 9: Contingent Funding by Sector



The contingent funding is comprised of **$226.6m** (**14.8%** of the programme's contingent funding) in Phase 1, **$724.4m** (**47.2%**) in Phase 2 and **$583.5m** (**38.0%**) in Phase 3.

The largest component of the contingent funding comes from crown funding (**50.3%**), followed by rates (**32.0%**), and finally private & insurance (**17.7%**). The contingent funding allocation broken down by funding type is illustrated in Figure 10 below.

Figure 10: Contingent Funding by Type of Funding



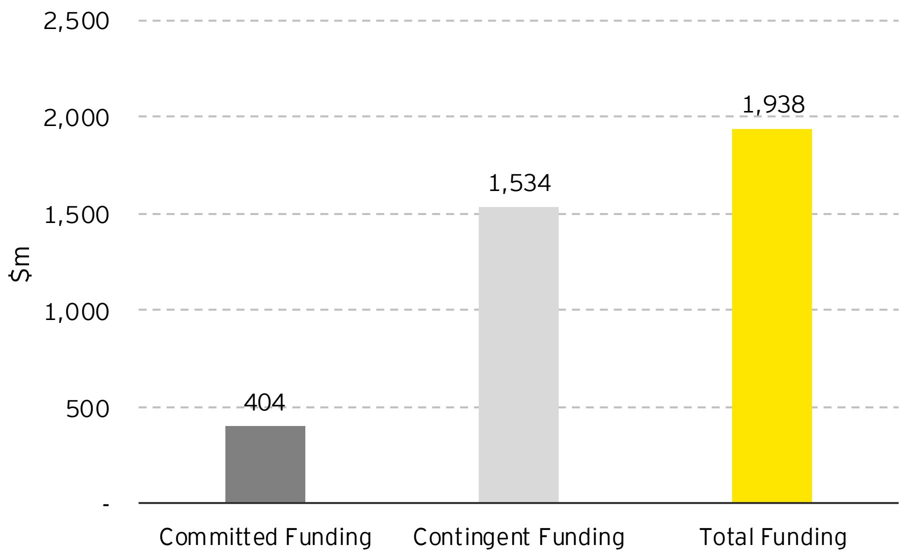
6.3 Funding Summary

The overall funding split between committed and contingent funding is presented in Table 19 below.

Table 19: Funding Summary by Phase ($m nominal)				
Funding	Phase 1 Years 0 - 7	Phase 2 Years 8 - 14	Phase 3 Years 15 - 20	Total
Committed Funding	323.9	79.7	-	403.6
Contingent Funding	226.6	724.4	583.5	1,534.5
Total Funding	550.5	804.1	583.5	1,938.1

The total funding for the programme is **$1.9b**, which is comprised of **$403.6m** in committed funding and **$1.5b** in contingent funding. In percentage terms, committed funding makes up **20.8%** of the total funding, while contingent funding makes up **79.2%**. This funding split is illustrated in Figure 11 below.

Figure 11: Funding Summary



7. Overall affordability

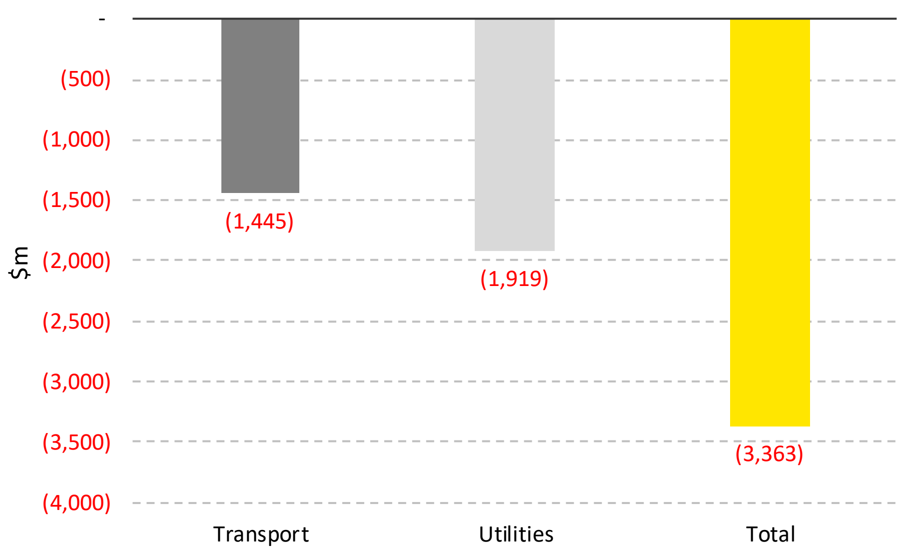
Table 20 below presents the total programme costs, revenue and funding as well as the total surplus/(shortfall) for the transport and utilities sectors and overall.

Table 20: Overall Affordability ($m nominal)

Item	Phase 1 Years 0 - 7	Phase 2 Years 8 - 14	Phase 3 Years 15 - 20	Total
Transport				
Total Revenue	-	-	-	**-**
Total Costs	242.4	2,105.5	532.0	**2,879.9**
Total Funding	115.7	736.1	583.5	**1,435.3**
Transport Surplus/(Shortfall)	**(126.7)**	**(1,369.4)**	**51.5**	**(1,444.6)**
Utilities				
Total Revenue	1.7	11.9	11.8	**25.3**
Total Costs	891.8	712.3	842.6	**2,446.7**
Total Funding	434.8	68.0	-	**502.8**
Utilities Surplus (Shortfall)	**(455.3)**	**(632.4)**	**(830.8)**	**(1,918.6)**
Overall				
Total Revenue	1.7	11.9	11.8	**25.3**
Total Costs	1,134.3	2,817.8	1,374.6	**5,326.6**
Total Funding	550.5	804.1	583.5	**1,938.1**
Total Surplus/(Shortfall)	**(582.0)**	**(2,001.8)**	**(779.4)**	**(3,363.2)**

The initiatives in both sectors both incur large shortfalls. The transport sector incurs a shortfall of **$1.4b**, while the utilities sector incurs a shortfall of **$1.9b**, resulting in a total funding shortfall for the programme of **$3.4b.** The shortfall across sectors as well as overall is illustrated in Figure 12 below.

Figure 12: Shortfall by Sector



The largest shortfall occurs in Phase 2, in which the total costs exceed funding and revenue by **$2.0b.** This figure makes up **59.5%** of the total shortfall, compared to **17.3%** in Phase 1 and **23.2%** in Phase 3.

7.1 Present Values

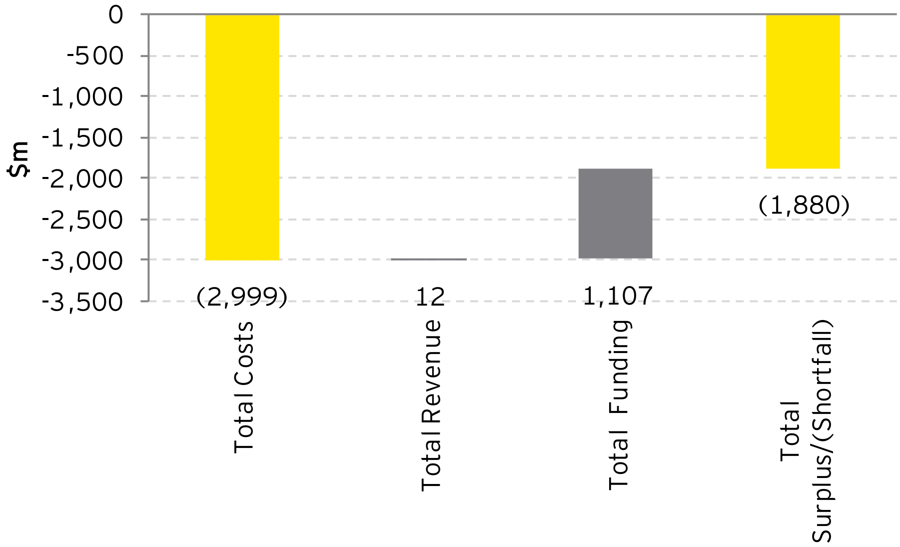
The Present Values for the total surplus/ shortfall are presented in Table 21 below along with the nominal values for comparison.

Table 21: Total Surplus/(Shortfall) Present Values ($m nominal)

Item	Nominal Value	Present Value
Revenue	25.3	12.3
Funding	1,938.1	1,106.9
Cost	5,326.6	2,998.8
Total Surplus/(Shortfall)	**(3,363.2)**	**(1,879.6)**

The total funding in present value terms is **$1.1b**, compared to **$1.9b** in nominal terms. The total shortfall is **$1.9b** in present value terms, compared to **$3.4b** in nominal terms. The PVs for total programme revenue, funding, costs and the overall shortfall is presented in Figure 13 below.

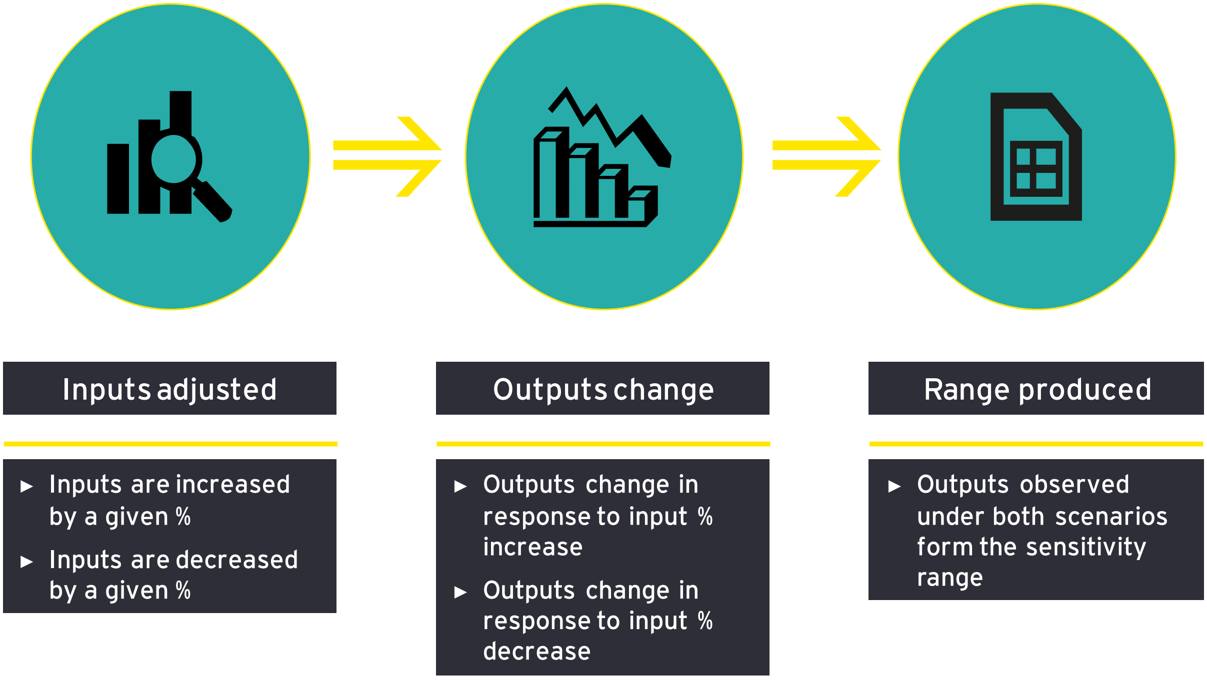
Figure 13: Present Value Summary



8. Sensitivity Analysis

In order to test the robustness of the estimates throughout the financial case and to provide a range in which the true results are likely to fall within, a sensitivity analysis has been undertaken. The process of our sensitivity analysis is illustrated in Figure 14 below:

Figure 14: Sensitivity Analysis



More specifically:

- The CPI and O&M indices were changed by +/- 1% to see the effect this had on the shortfall from Phase 1
- The contingencies on initial capex and implementation costs were changed by +/- 10% to test the effect this had on the shortfall from Phase 1

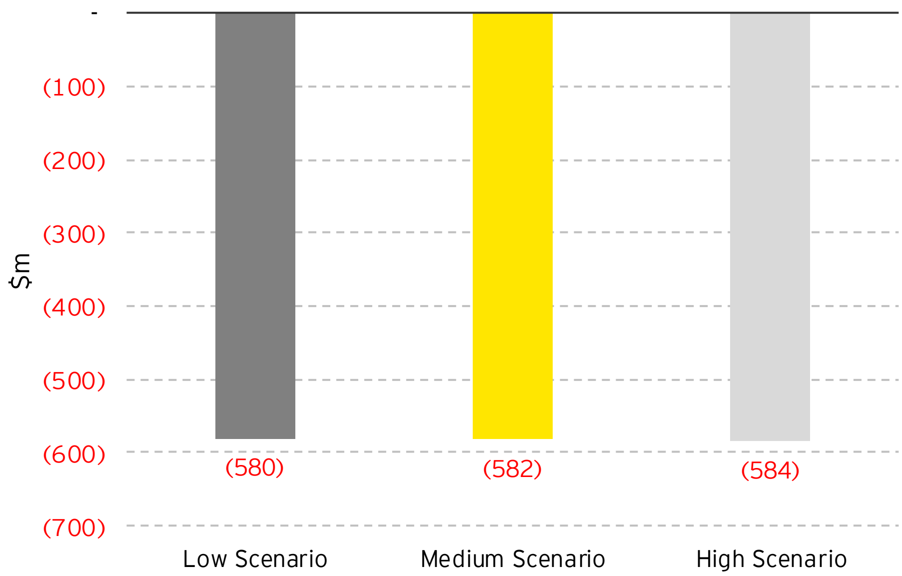
The results from the sensitivity analysis on the CPI and O&M indices are presented in Table 22 below.

Table 22: Sensitivity Analysis – Indices ($m nominal)	
Surplus/(Shortfall)	**Phase 1** **Years 0 - 7**
High Scenario (+1%)	(583.9)
Medium Scenario (as in rest of financial case)	**(582.0)**
Low Scenario (-1%)	(580.2)

The total shortfall in Phase under the high scenario is **$583.9m** compared to **$582.0m** in the medium scenario and **$580.2m** in the low scenario. In percentage terms, these changes are +**0.3%** and **-0.3%**, respectively. each. In terms of absolute value, these differences are **$1.8m** and **1.9m**.

The changes to the overall shortage in response to changing the indices are summarised in Figure 15 below.

Figure 15: Sensitivity analysis - Indices

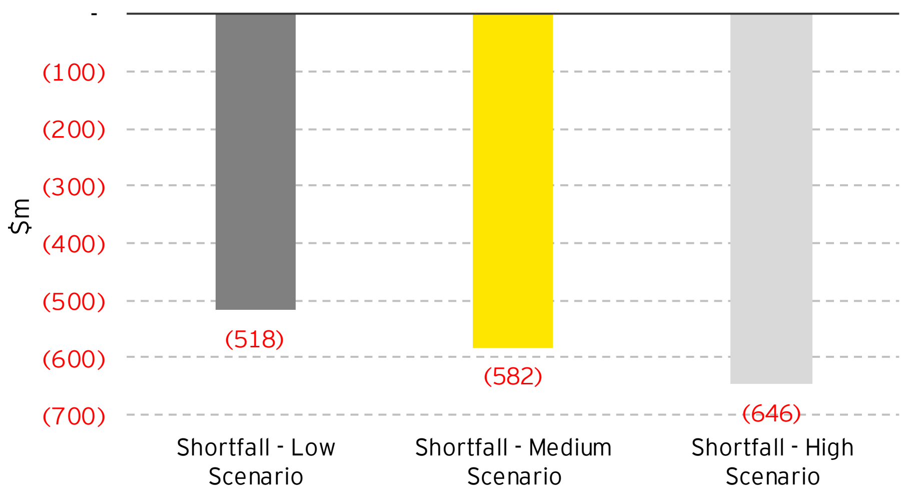


The results from the sensitivity analysis on the initial capex and implementation costs contingency are summarised in Table 23 below:

Table 23: Sensitivity Analysis – Contingencies ($m nominal)	
Surplus/(Shortfall)	Phase 1 Years 0 - 7
High Scenario (+10%)	(646.4)
Medium Scenario (as in rest of financial case)	(582.0)
Low Scenario (-10%)	(517.7)

The total shortfall under the high scenario is **$646.4m** compared to **$582.0m** in the medium scenario and **$517.7m** in the low scenario. In percentage terms, these changes are **+11%** and -11% respectively. In terms of absolute value, this difference is **+/- $64.4m**. The changes to the overall shortage in response to changing the indices are summarised in Figure 16 below.

Figure 16: Sensitivity Analysis - Contingencies



9. Conclusions and Recommendations

This Financial Case has demonstrated that a large amount of additional funding is required in order to implement the Lifelines Programme and realise the very large resiliency benefits. The key findings of the Financial Case are:

- The programme costs are estimated to be **$5.3b**. While this is a very large figure, it should be acknowledged that these are not all new costs, many of these initiatives already feature in the long-term capital plans of Wellington's infrastructure providers
- Comfortably the largest single component of the programme cost is the initial capital expenditure of **$3.9b**, which represents **72.6%** of the total cost
- The estimated revenue generated from the initiatives is small (**$25.3m**), and represents only **0.5%** of the programme cost
- The estimated funding for the programme comes to **$1.9b**, which is **36.4%** of the programme cost. However, only **$403.6m** of this amount is committed to the programme, while **$1.5b** is contingent on certain requirements being met. The committed funding makes up only **7.6%** of the programme costs
- There is currently a significant funding shortfall of **$3.4b**, which represents **63.4%** of the funding requirement. Therefore, only **36.6%** of the funding required is allocated to the programme. If only committed funding is considered, this figure falls to only **7.6%**
- In Phase 1 of the programme (the Phase containing the highest priority initiatives that deliver the greatest benefit and upon which other initiatives depend on), the funding shortfall is estimated to be **$582.0m**
- While the funding shortfall is large, many of the as yet unfunded projects are likely be funded through the crown, rates or user payment & insurance in the future
- The sensitivity analysis estimates the range within which the true shortfall amount for Phase 1 of the programme can be expected to fall, assuming that the cost estimates provided by the initiative owners are accurate. This range is **$517.7m** to **$646.4m**.

Appendix A Unaccelerated Scenario

Table 24: Revenue summary by Phase and Sector ($m nominal)				
Sector	Phase 1 Years 0 - 7	Phase 2 Years 8 - 14	Phase 3 Years 15 - 20	Total
Transport	-	-	-	**-**
Utilities	1.7	11.9	11.8	**25.3**
Total Programme Revenue	**1.7**	**11.9**	**11.8**	**25.3**

Table 25: Cost Summary by Cost Type ($m nominal)				
Cost	Phase 1 Years 0 - 7	Phase 2 Years 8 - 14	Phase 3 Years 15 - 20	Total
Implementation Costs	15.7	27.3	32.3	**75.3**
Initial Capex	508.6	383.7	1,312.0	**2,204.3**
Lifecycle Costs	7.1	69.2	136.1	**212.5**
Operating & Maintenance Costs	1.1	14.5	54.0	**69.6**
Other Operating Costs	-	20.9	206.1	**227.0**
Overhead Costs	0.9	9.5	24.8	**35.1**
Total Costs	**533.4**	**525.1**	**1,765.3**	**2,823.8**

Table 26: Cost Summary by Sector ($m nominal)				
Sector	Phase 1 Years 0 - 7	Phase 2 Years 8 - 14	Phase 3 Years 15 - 20	Total
Transport Costs	33.6	262.0	1,317.2	**1,612.8**
Utilities Costs	499.8	263.1	448.1	**1,211.0**
Total Programme Costs	**533.4**	**525.1**	**1,765.3**	**2,823.8**

Table 27: Implementation Costs by Phase ($m nominal)				
Sector	Phase 1 Years 0 - 7	Phase 2 Years 8 - 14	Phase 3 Years 15 - 20	Total
Transport	3.9	24.6	32.3	**60.8**
Utilities	11.8	2.8	-	**14.6**
Total Implementation Costs	15.7	27.3	32.3	**75.3**

Table 28: Initial Capex by Phase ($m nominal)				
Sector	Phase 1 Years 0 - 7	Phase 2 Years 8 - 14	Phase 3 Years 15 - 20	Total
Transport	28.8	202.1	1,171.8	**1,402.7**
Utilities	479.9	181.5	140.2	**801.6**
Total Initial Capex	508.6	383.7	1,312.0	**2,204.3**

Table 29: Lifecycle Costs by Phase ($m nominal)				
Sector	Phase 1 Years 0 - 7	Phase 2 Years 8 - 14	Phase 3 Years 15 - 20	Total
Transport	0.5	23.5	63.6	**87.6**
Utilities	6.7	45.7	72.6	**124.9**
Total Lifecycle Costs	7.1	69.2	136.1	**212.5**

Table 30: Operating & Maintenance Costs by Phase ($m nominal)				
Sector	Phase 1 Years 0 - 7	Phase 2 Years 8 - 14	Phase 3 Years 15 - 20	Total
Transport	0.3	5.9	32.0	**38.1**
Utilities	0.8	8.6	22.0	**31.4**
Total Operating & Maintenance Costs	1.1	14.5	54.0	**69.6**

Table 31: Other Operating Costs by Phase ($m nominal)				
Sector	Phase 1 Years 0 - 7	Phase 2 Years 8 - 14	Phase 3 Years 15 - 20	Total
Transport	-	-	-	**-**
Utilities	-	20.9	206.1	**227.0**
Total Other Operating Costs	**-**	**20.9**	**206.1**	**227.0**

Table 32: Overhead Costs by Phase ($m nominal)				
Sector	Phase 1 Years 0 - 7	Phase 2 Years 8 - 14	Phase 3 Years 15 - 20	Total
Transport	0.2	5.9	17.5	**23.6**
Utilities	0.6	3.6	7.3	**11.5**
Total Programme Overhead Costs	0.9	9.5	24.8	35.1

Table 33: Funding Requirement ($m nominal)				
Item	Phase 1 Years 0 - 7	Phase 2 Years 8 - 14	Phase 3 Years 15 - 20	Total
Total Revenue	1.7	11.9	11.8	25.3
Total Cost	533.4	525.1	1,765.3	2,823.8
Funding Requirement	**531.7**	**513.2**	**1,753.6**	**2,798.5**

Table 34: Committed Funding ($m nominal)				
Funding Type	Phase 1 Years 0 - 7	Phase 2 Years 8 - 14	Phase 3 Years 15 - 20	Total
Transport				
Crown	-	-	-	**-**
Private and Insurance	6.0	-	-	**6.0**
Rates	1.9	31.4	-	**33.3**
User Payment	-	-	-	**-**
Total Transport Committed Funding	7.9	31.4	-	39.3
Utilities				
Crown	-	-	-	**-**
Private and Insurance	51.7	8.8	-	**60.5**
Rates	184.7	1.3	12.8	**198.8**
User Payment	-	-	-	**-**
Total Utilities Committed Funding	236.4	10.1	12.8	259.3
Total Committed Funding	244.3	41.5	12.8	298.6

Table 35: Contingent Funding ($m nominal)				
Phase	Phase 1 Years 0 - 7	Phase 2 Years 8 - 14	Phase 3 Years 15 - 20	Total
Transport				
Crown	2.7	36.1	8.2	**47.0**
Private and Insurance	17.0	-	-	**17.0**
Rates	-	-	-	**-**
User Payment	-	-	-	**-**
Total Transport Contingent Funding	19.7	36.1	8.2	64.0
Utilities				
Crown	-	-	-	**-**
Private and Insurance	155.3	83.7	-	**239.0**
Rates	-	-	-	**-**
User Payment	-	-	-	**-**
Total Utilities Contingent Funding	155.3	83.7		239.0
Total Contingent Funding	175.0	119.8	8.2	303.0

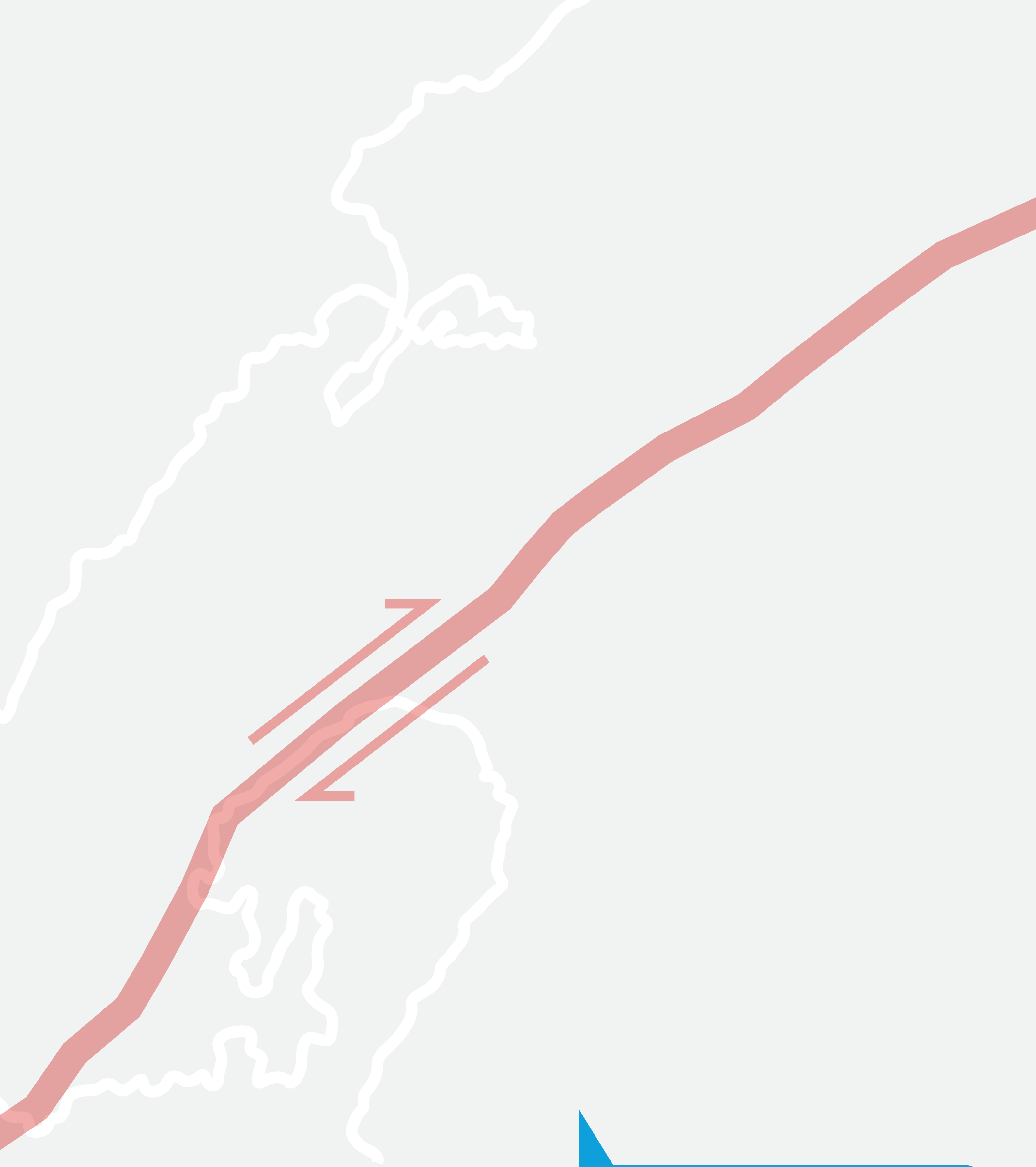
Table 36: Overall Affordability ($m nominal)				
Item	Phase 1 Years 0 - 7	Phase 2 Years 8 - 14	Phase 3 Years 15 - 20	Total
Transport				
Total Revenue	-	-	-	**-**
Total Costs	33.6	262.0	1,317.2	**1,612.8**
Total Funding	27.6	67.5	8.2	**103.3**
Transport Surplus/(Shortfall)	**(6.0)**	**(194.5)**	**(1,309.0)**	**(1,509.5)**
Utilities				
Total Revenue	1.7	11.9	11.8	**25.3**
Total Costs	499.8	263.1	448.1	**1,211.0**
Total Funding	391.7	93.8	12.8	**498.3**
Utilities Surplus (Shortfall)	**(106.4)**	**(157.4)**	**(423.6)**	**(687.4)**
Overall				
Total Revenue	1.7	11.9	11.8	**25.3**
Total Costs	533.4	525.1	1,765.3	**2,823.8**
Total Funding	419.3	161.3	21.0	**601.6**
Total Surplus/(Shortfall)	**(112.4)**	**(351.9)**	**(1,732.6)**	**(2,196.9)**

Table 37: Funding Requirement ($m)		
Item	Nominal Value	Present Value
Revenue	25.3	12.3
Funding	601.6	445.6
Cost	2,823.8	1,358.5
Total Surplus/(Shortfall)	**(2,196.9)**	**(900.6)**

Appendix B Sources

Wellington Lifelines Project. Protecting Wellington's Economy Through Accelerated Infrastructure Investment Programme Business Case. Stage 1 – Demonstration of Benefits.2018.

Reserve Bank Bulletin, Vol 79, No.3. February 2016.



WELLINGTON LIFELINES

REGIONAL RESILIENCE PROJECT