WELLINGTON LIFELINES
REGIONAL RESILIENCE PROJECT

WELLINGTON LIFELINES PROJECT

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

Revision 3 - **Date** 04 October 2019

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*

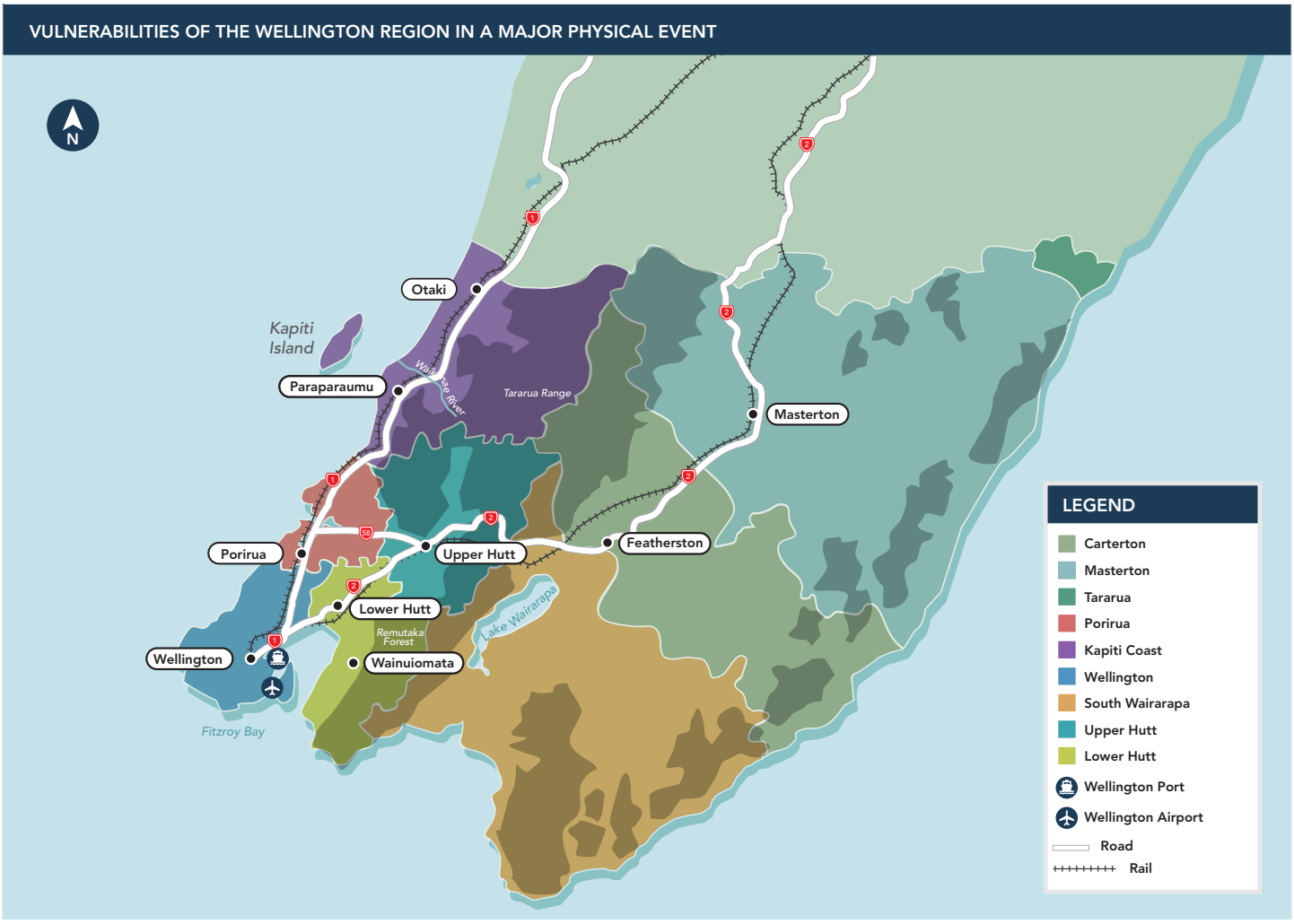

Figure 2: Overview of the Wellington Region (dark shading indicating the location of major ranges between Wellington and the rest of the North Island)

earthquake will cause isolation of the communities between mountain ranges and the sea. The Tararua and Rimutaka 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 Rimutaka 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)

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[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.

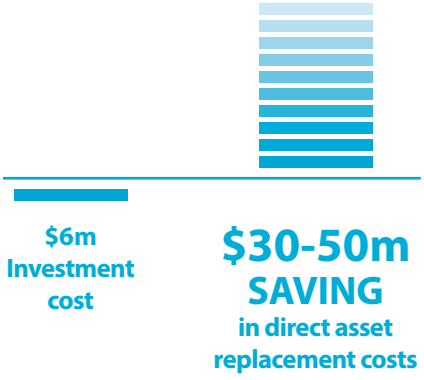
Wellington has many major assets that are themselves of significant value – they include universities, schools, hospitals, arts and cultural venues, eateries, international sports venues, Wellington Airport and the sea port. Together they support the special elements of Wellington's higher order economy.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

"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]

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.

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.

[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.

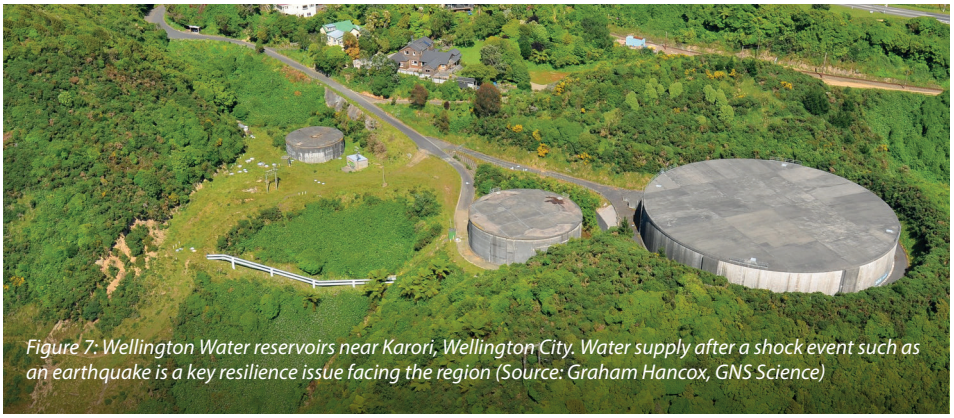


Figure 7: Wellington Water reservoirs near Karori, Wellington City. Water supply after a shock event such as an earthquake is a key resilience issue facing the region (Source: Graham Hancox, GNS Science)

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%)
  - Reduced Predicted NZ Economic Loss
  - Reduced Predicted Recovery Period
- Benefit 2: Safer People and More Resilient Community (20%)
  - Reduced Recovery Period
  - Reduced Population Loss
  - Reduced Community Isolation
  - Reduced Disease Risk
- Benefit 3: Optimised Strategic Lifelines Investment (20%)
  - Finalised Investment Plan
  - Aligned Central/Local Government
  - 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%).

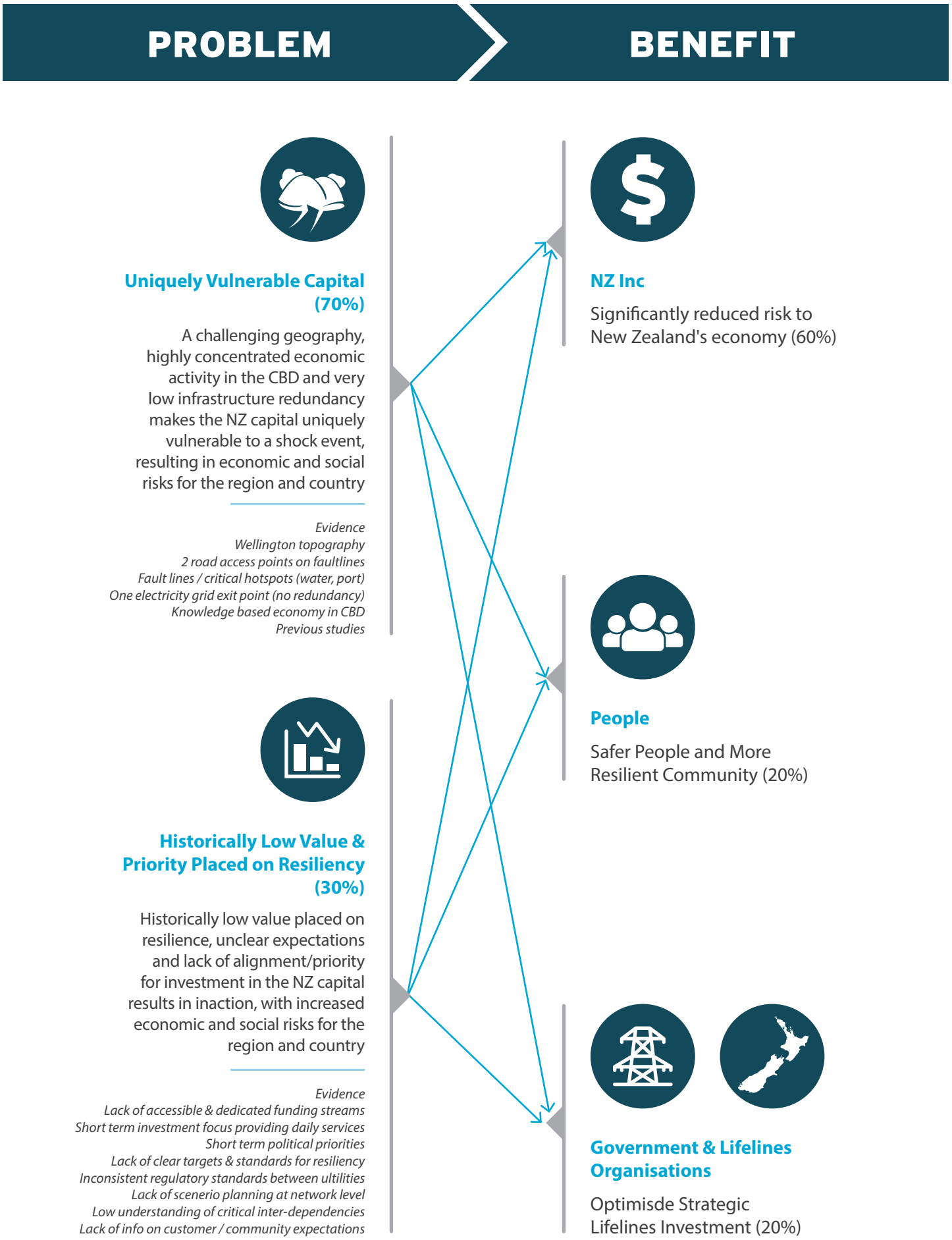


Figure 8: Summary of Investment Logic Mapping Outputs

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.

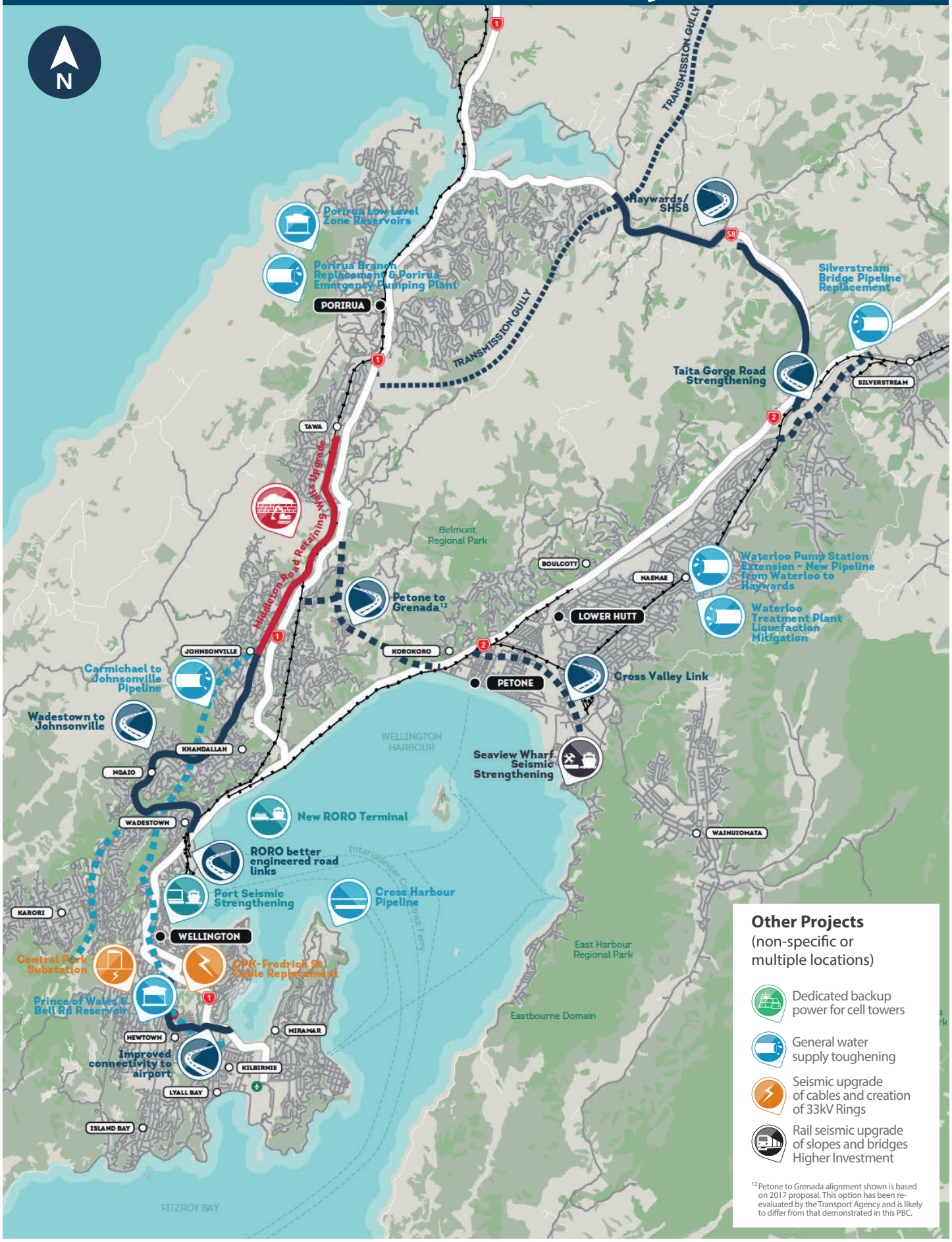
7.1 – Base Case

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.

Preferred Investment 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.

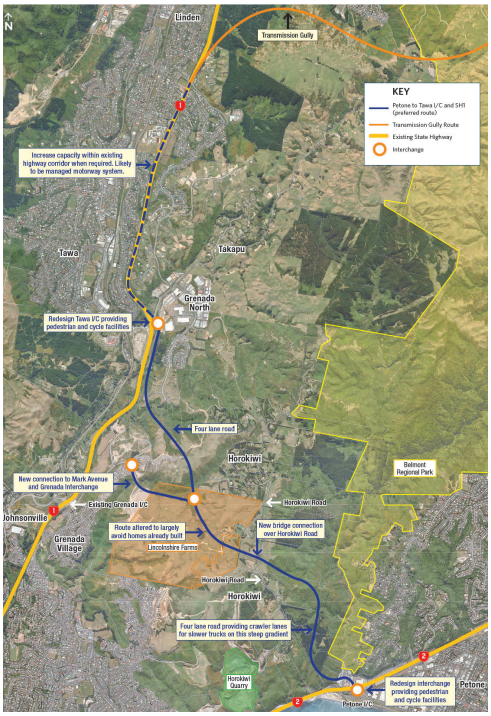
Special Note Regarding the Cross Valley Link – as mentioned above, this project is a key element to ensure fuel supply. The project has been included as a proxy for improving fuel links to ensure the resilience necessity is captured. As part of future detailed work, there could be alternative preferable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

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

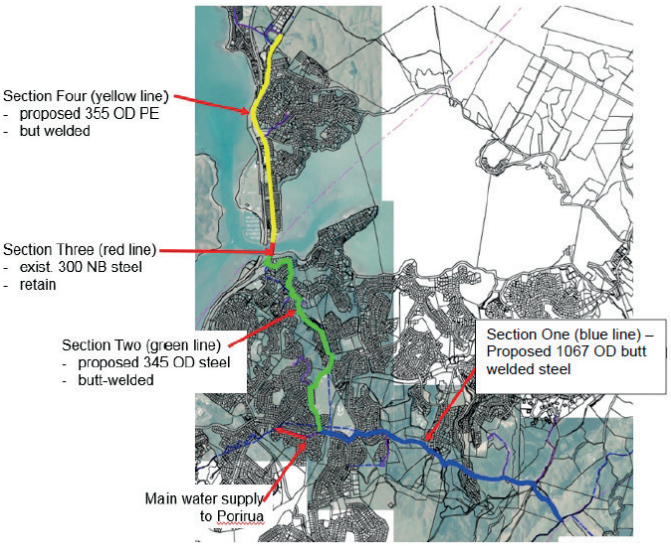
Project description:	This project involves the installation of a 12.7km underwater pipeline from Seaview to Evans Bay and with a connection to the Carmichael Reservoir. The pipeline will be trenched into the seafloor as well as on land. It will likely be constructed of electrofused 500mm (ID) HDPE.
Estimated 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

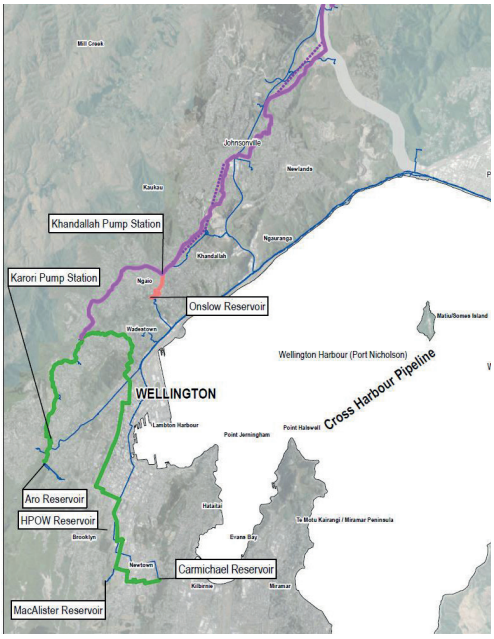
Project description:	This project involves replacing the existing Bell Road Reservoir with a new 10ML reservoir and construction of a new 35ML reservoir at the Prince of Wales (Omaroro) site. These will be constructed to withstand an ultimate limit state of a 1-in-2500 year event and a serviceability 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

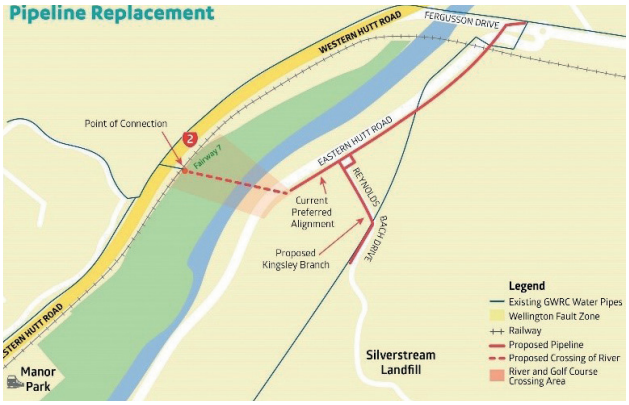
Rationale for potential inclusion:

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.

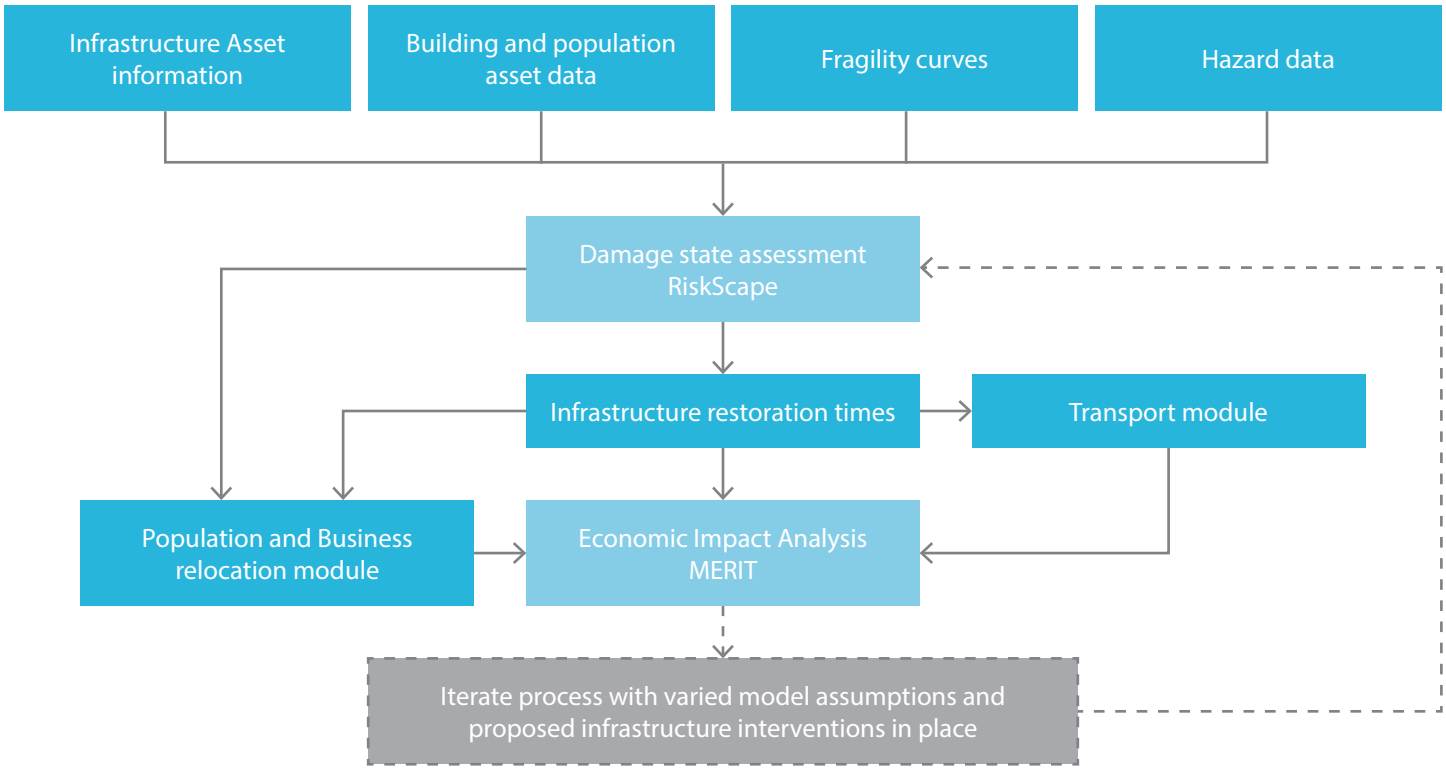


Figure 9: Linkages between the various stages of damage loss assessment and economic impact analysis

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.

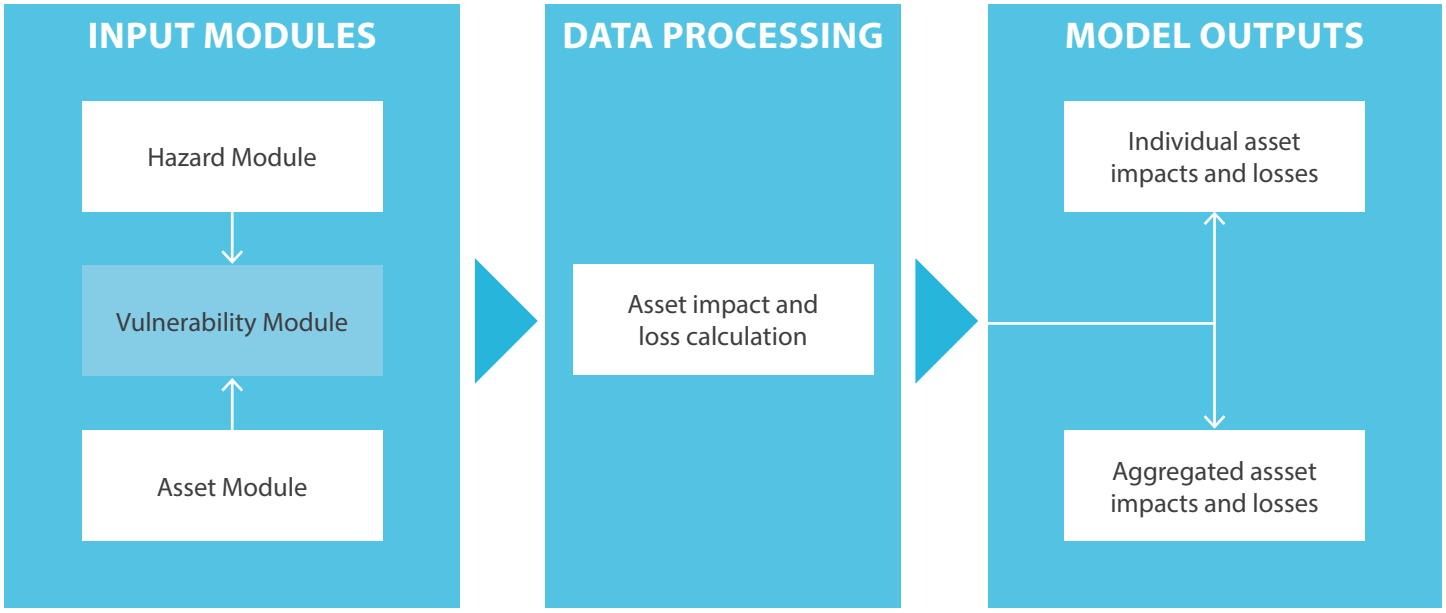


Figure 10: RiskScape Framework

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.

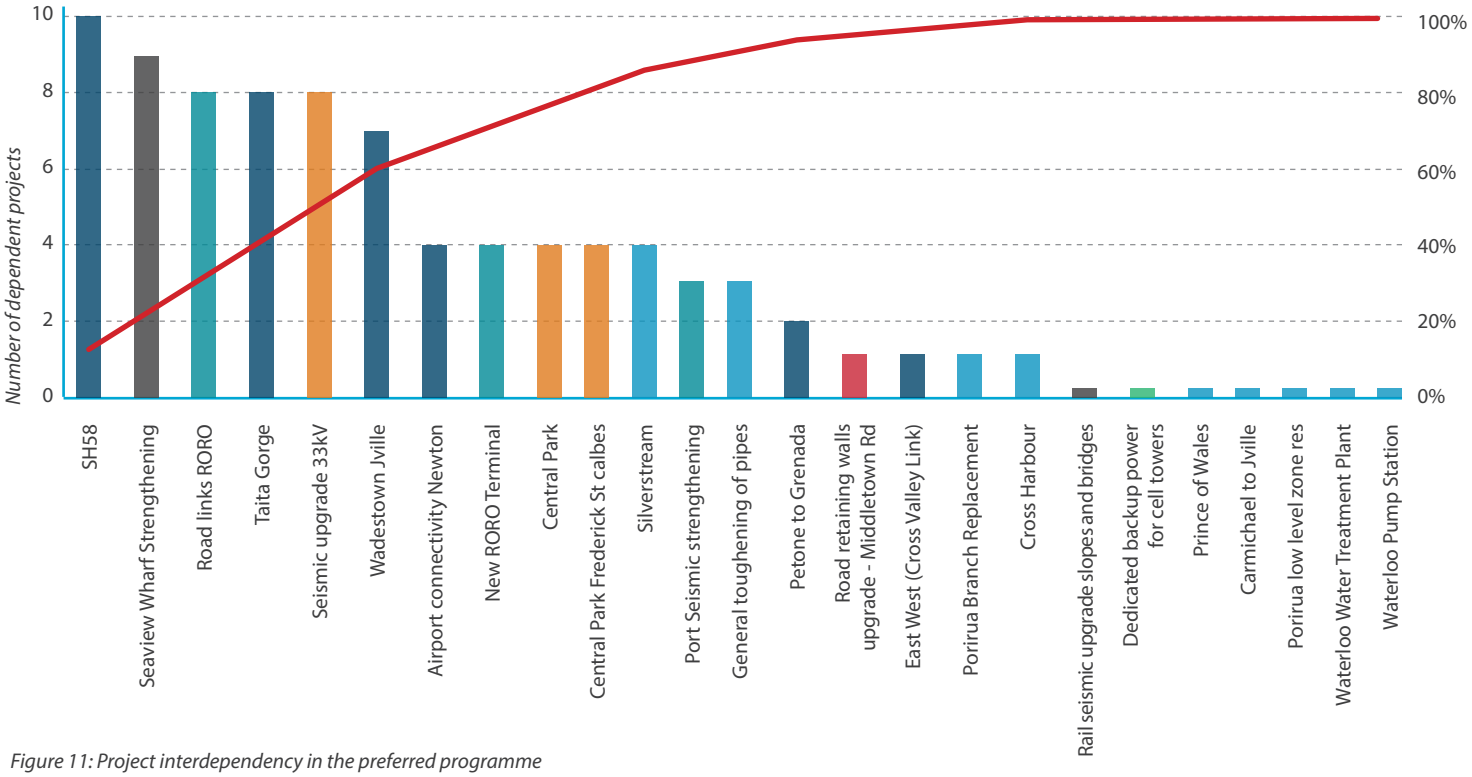


Figure 11: Project interdependency in the preferred programme

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].

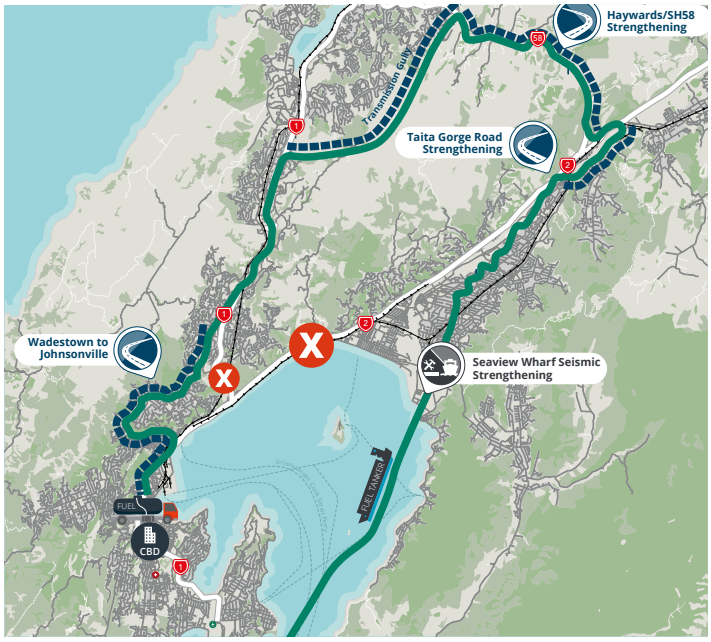


Figure 12: Access to fuel with Taita Gorge and SH58 Strengthening in place

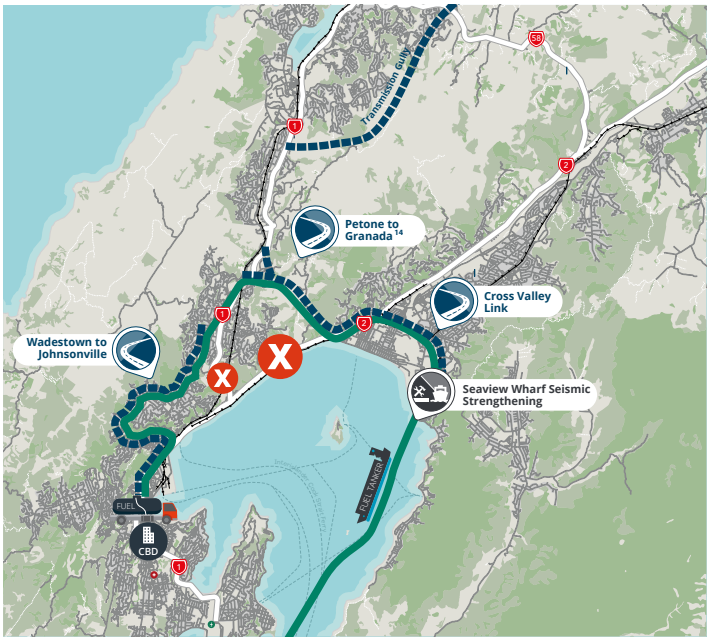


Figure 13: Access to fuel with Petone to Grenada and Cross Valley Link in place

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.

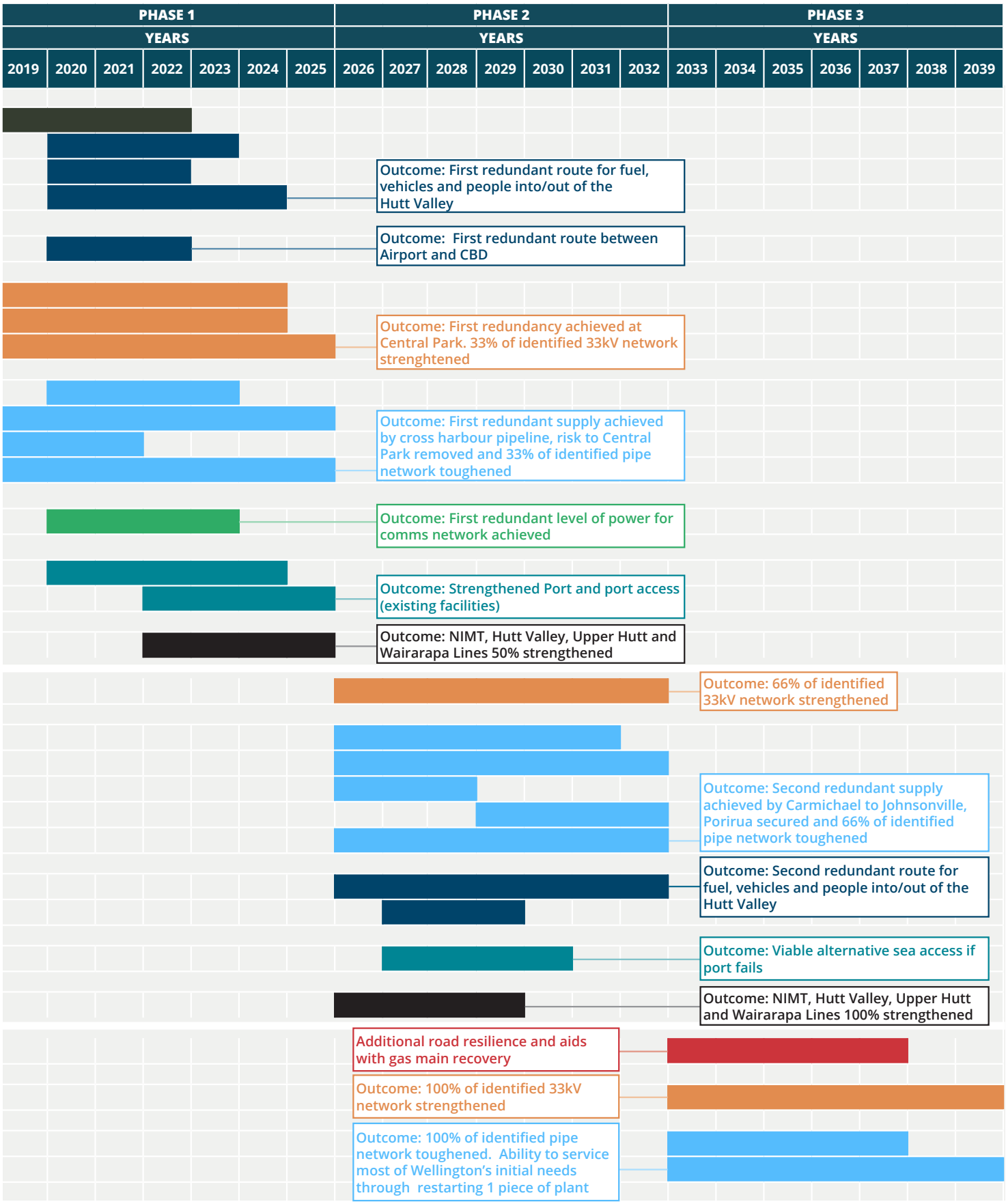
[14] *Petone to Grenada alignment shown is based on 2017 proposal. This option has been re-evaluated by the Transport Agency and is likely to differ from that demonstrated in this PBC*

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
2019
2020
2021
2022
2023
2024
2025
PHASE 2
YEARS
2026
2027
2028
2029
2030
2031
2032
PHASE 3
YEARS
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.

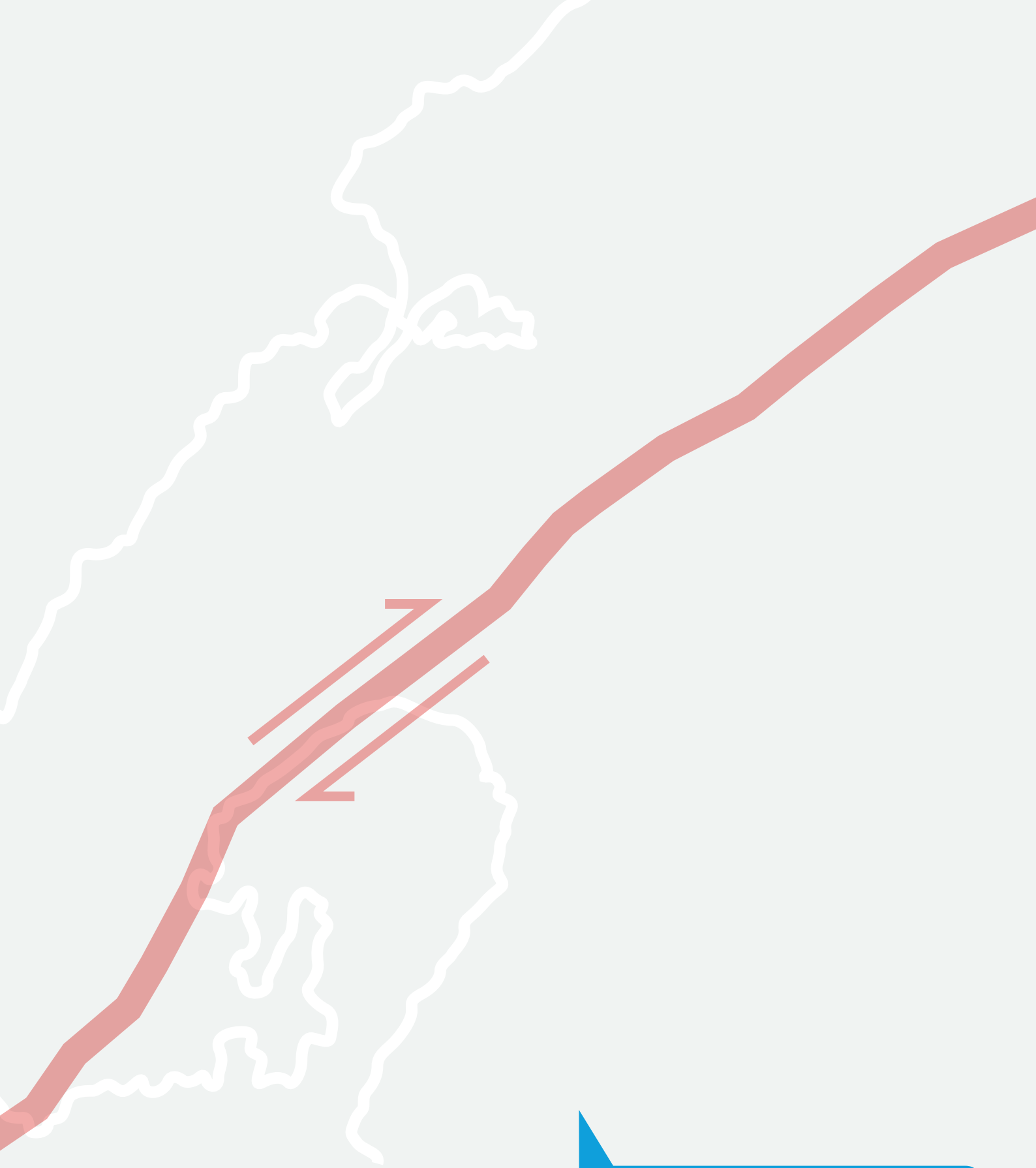
It is clear that a coalition across local and central government and the private sector will be required to progress this step and address the funding shortfall.

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