Earthquake Readiness

Reducing risk and improving earthquake readiness

Business Case

5 December 2017

Executive Summary

Wellington Electricity delivers electricity to over 400,000 people (via 167,000 connections) in the Wellington region through our owned and operated electricity distribution network.

Background

In late 2016, following the Kaikoura earthquake, Government asked key infrastructure providers what could be done to improve the region's readiness to respond to a second significant earthquake.

At that time, correspondence from the Ministry of Business, Innovation and Employment (MBIE)[1] included the following commentary:

> *"Wellington faces an elevated risk of an aftershock that may damage energy and transport infrastructure, leaving the region cut off from other regions and with fragmented internal road links. MBIE and other agencies, is looking for assurance that Wellington is prepared for a significant aftershock (e.g. 7.5 on the Richter scale)."*

Since the 2010-11 Canterbury earthquake sequence, we have been proactively assessing the potential damage to our network from a major earthquake (7.5 on the Richter scale). We have undertaken seismic strengthening of earthquake prone buildings and investigated what else we could do to reduce the economic and societal impacts of extended electricity outages across the region. Our investigation and analysis should be viewed within the context of the wide-ranging impacts of such a significant event as summarised below.

- Electricity is an essential service for our community; it is the lifeblood for society's welfare and essential to a thriving economy. Losing it for a prolonged period of time has a devastating impact on people's quality of life, particularly if they are unable to seek alternatives. At a most basic level, access to fresh water, lighting, cooking, refrigeration, heating and communication would be seriously compromised without electricity, often with no viable substitute for most families.
- Wellington's electricity network, although strong in the face of the region's challenging weather due to its underground cabling, is especially vulnerable to damage from a major earthquake. The many fault lines that run across the region mean that the high proportion of assets which are located underground become difficult to manage following strong ground shaking events.
- In the event of a major earthquake, there is a very real risk that the region will be cut off from the rest of the country if transport links are severed. The limited access in, out and within the region will prevent the provision of outside assistance, including people and equipment to repair damage to our network, for many weeks. This would also lead to Wellingtonians being unable to move out of the Wellington area. In this situation, recovery at home will be required, making prompt return of electricity and other services very important for our residents and businesses. Because the impact of such an event happening could be devastating for the region's economic and societal welfare, we have identified a number of areas where we could be better prepared.

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[1] Email from MBIE to Wellington Electricity and Transpower dated 22 November 2016.

- Our network supplies electricity to the city's critical infrastructure services including Wellington airport, the Beehive disaster response bunker, several hospitals, telecommunication exchanges, water pumping stations, fuel storage and supply hubs, and emergency services headquarters. Whilst many of these have emergency back up generation, there could be a limit to fuel availability so we need to be sufficiently prepared to return these services to operation with a safe and reliable supply of electricity as soon as practical.
- The potential outages have been estimated to last as long as 100 days[2] and could incur social and economic costs in the order of billions of dollars.

This business case proposes a number of initiatives to be deployed within the next three years to reduce risk and improve our readiness to respond to a major earthquake.

Longer term resiliency planning continues in parallel as part of the Wellington Lifelines programme[3], Investments that arise out of that planning will be the subject of future funding applications which are outside the scope of this business casa.

Our Proposed Initiatives

We are proposing to invest $31.24 million (Opex and Capex) over the next three years to improve our readiness to respond to a major earthquake for the benefit of our communities and businesses. The proposed investments relate to quick wins we can achieve in the short term and include increasing our stores of emergency spares and other key equipment across the region and extending our seismic strengthening programme for all our key substation buildings. These are prudent, cost effective and sensible first steps which will go a long way to enabling us to restore power a lot quicker than we are currently able to do following a major earthquake.

A summary of our proposal is shown in the table below.

Risk being addressed	Proposed initiatives	Capex ($m)	Opex ($m)	Total
33 kV Cable faults	Emergency hardware	4.74	0.67	5.41
Loss of transformers and switchgear	Mobile substations and switchboard	4.73	-	4.73
11 kV Cable and equipment faults	Critical emergency spares	4.94	-	4.94
Preventing damage to equipment in buildings	Seismic reinforcement of significant buildings	10.40	-	10.40
Maintaining data and communication links	Communication Systems	5.26	0.50	5.76
	TOTAL	**30.07**	**1.17**	**31.24**

Table 1 – Summary of business case

The first three initiatives shown above were chosen based on the $26 million net benefit (benefit minus cost) they provided relative to other options. The benefit relates to the improvement in restoration times that each option offers against the current state. These improvements are a combination of reduced repair time and the time it would take to transport equipment into the region compared with our current state – i.e. if we don't have adequate spare equipment in the right location.

2 Refer Wellington Lifelines Group Restoration Times report date November 2012, p 24, table 5.

3 This group includes Transpower, NZTA, Wellington Water, Kiwirail, city and region al councils amongst others.

The proposal to seismically strengthen our buildings is being primarily driven by an impending change to our seismic building standard to bring all zone substation and important buildings up to 67% of NBS. This standard is consistent with peer utilities.

The proposal to add three data centres and improve our communications systems is driven by the recognition that restoration efforts can only begin if we have adequate communication links and access to critical systems and tools. A delay in the restoration of the initial loss of supply (estimated at 60% of total supply) is estimated to cost around $110 million a day. Add to this the compounding impact on our communities and businesses being without power for days on end, and one can see there is significant value that could be lost from not addressing this relatively simple problem.

Proposed Readiness Initiatives in Detail

These readiness initiatives are the preferred options, derived from an assessment of several potential options.

Emergency hardware includes:

- equipment required to construct around 19 km of emergency overhead power lines in the event of 33kV fluid filled cable damage. Our 33kV cable network is critical for electricity supply; hence it is essential that the 33kV backbone can be quickly re-established with overhead power lines. The spare poles and wires will be stored across the region so that they will be accessible if transport links are damaged. It could improve transport restoration times by between 2 and 12 weeks; and
- 33 kV XLPE (plastic) cable spares which will be stored in Wellington CBD and used to reconnect power lines to equipment or interconnecting within the 33kV system. It has the potential to save two weeks in equipment transport time compared to our current state.

Mobile Substations and Switchboard includes:

- two mobile 10 MVA substations which will be held ready for deployment with one in Wellington CBD and the other in the Hutt Valley region; and
- one 11kV mobile switchboard which will enable the restoration of the electrical load at substations damaged by liquefaction and/or ground shaking.

When deployed with the emergency overhead lines, these options have the potential to improve the restoration time (repair and transport) by up to 12 weeks in the Hutt Valley from the current state of 16 weeks and 6 weeks from the current state of 14 weeks in Wellington CBD.

Critical emergency spares include:

- three sets of cable fault location equipment, 1,018 cable joint repair kits and 4,090 m of 11kV cable; and
- critical distribution switchgear and transformers including 12 transformers and 30 units of switchgear.

By storing the above equipment in various locations across the region, we are confident that we could reduce the significant outage impacts from 11kV cable failure. We would do this by ensuring that there are enough cable spares to keep our available cable jointers occupied whilst we wait for transport links to open up sufficiently to provide further equipment and human resource to assist with repair work. Under a worst-case scenario under which the Hutt Valley is isolated for 12 weeks, this investment would allow us to improve restoration times for 36% of the impacted customers, compared to current capability. This investment is especially important for our ability to quickly restore critical loads across the region.

Seismic reinforcement of significant[4] buildings includes:

- Strengthening 91 substation buildings to 67% of the New Building Standard (NBS).

Lessons from past events, not least Orion's experience in the 2010/2011 earthquakes, has led us to further increase strengthening standards for earthquake risk buildings to ensure that all of our key buildings (including zone substations and other major switching stations) in our network are raised to 67% of the NBS.

The strengthening of our substation buildings to this standard will help ensure equipment contained within them can withstand a major earthquake, protect the public as well as being safe for our workers who need to visit to operate and maintain the equipment within. Our people will need to access substation equipment to return supply so our buildings must remain undamaged for safe entry and safe return to service of the equipment. Major substation equipment (transformers and switchgear) is difficult to move within the region and has long (6-12 month) replacement lead times. Stronger buildings will make access easier which will expedite the restoration of power.

Assuming a similar ratio of avoided asset replacement costs as Orion (between 5 to 8 times cost of building reinforcement)[5], this work would also avoid a rebuild cost between $50-$80 million on our network after a major earthquake. The reinforcement investment has the benefit of allowing us to restore supply more quickly and avoid very high equipment repair costs .

Communications systems include:

- installing three data hubs to ensure that four critical network systems we need are accessible should telecommunications links fail between islanded regions after an earthquake; and
- improving voice communications systems for maintaining operational control. Communicating immediately after an event with contracted field service providers will enhance our ability to respond to damage and prioritise assessment and recovery efforts.

Communicating with field workers and restoration crews is vital for building a picture of damage and network availability ahead of restoration. This has a strong link to personnel and public safety management. An independent radio network allows us to respond without reliance on public communications systems, which may be compromised. Communication is critical in a time of crisis to manage the high volume of information required for situational reporting and response planning.

Information is required for planning and establishing diversified data hubs and to improve response and recovery management. To ensure we have access to plans, specifications, and manufacturer's records, data needs to be available independently of potentially vulnerable buildings and records diversified so they can be accessed from more than one location. Having data hubs as a simple shipping container that can be located at three separate sites provides the redundancy and data required to operate the network recovery from three alternative sites. This allows for a reduction in risk of a key site being unavailable, jeopardising efficient response and recovery planning. This is

4 Significance is based on criteria including public and worker safety, network criticality and the type of connected load.

5 Resilience Lessons: Orion's 2010 and 2011 Earthquake Experience report by the Kestrel Group, September 2011.

also necessary to reduce personnel and public safety risks for building entry and to ensure system control of emergency conditions.

The ability of our field staff to report damage and be directed through effective communication following a disaster is imperative if we are to be able to safely respond to the event and restore supply as quickly as possible. We also require staff to be able to travel to and access a control centre.

This initiative is seen as an enabler of the other initiatives in that it allows us to effectively assess earthquake damage, prioritise options for recovery, plan our response, and execute these plans.

Conclusion

Our society depends on continuity of power supply and it is quite hard to imagine life without it. While large disruptions can occur, and some interruption is expected, our customers also reasonably expect to have supply returned without undue delay, as their welfare and the region's economy will quickly suffer if the power stays off.

This business case proposes a range of options that will deliver a benefit of improving our readiness to restore supply to our community following a major earthquake event. It builds on work undertaken earlier in 2012 and knowledge gained post the Kaikoura earthquake in 2016 and clearly demonstrates that the economic benefits are higher than the cost of the proposed investments. Our estimate of benefit is based on a fairly narrow value of unserved energy which does not capture all the social and wider economic benefits that these investments will provide.

In a 2015 report by BERL[6], the economic loss resulting from a major earthquake in Wellington was estimated at about $30-$40 billion. Quickly restoring electricity supply would significantly reduce such a loss. For this reason, we believe that our estimate of benefits is very conservative.

The Civil Defence Emergency Management Act 2002 (CDEMA) requires lifelines utilities to follow a systematic approach of reduction, readiness, response, and recovery (4 Rs) planning to discharge their responsibility of continuing to operate (albeit at a reduced level) following a major disruption. This readiness business case has been developed using the CDEMA principles and supports our ability to respond and recover following a major disruption, by:

- investing in additional critical spares to mitigate the risks of damaged transport links limiting access to spares;
- reinforcing buildings to avoid damage to critical equipment so continuity of service can be maintained; and
- mitigating potential failure of communications (radio) and data (information) systems which would severely limit response and recovery efforts leading to health and safety risks.

Bringing critical spares into the region to assist earthquake response readiness in the expectation that transport links will be cut off for some time (up to 12 weeks) is a prudent step in being able to further meet our lifelines responsibilities to respond and recover following a major disruption.

This business case clearly demonstrates that it is in the best interests of consumers to make further investment in the readiness capability of network now, to ensure we can safely restore supply to

[6] "Wellington – essential to NZ's Top Tier", BERL, December 2015.

essential services in the shortest possible timeframe. This will support our communities following an earthquake and have wider economic benefits by enabling business continuity.

Contents

1 Business Case Development

To ensure we are investing for the long-term benefit of our consumers, we have assessed our asset vulnerabilities in detail and developed appropriate readiness solutions to reduce these. We have ensured these are prudent and sensible investments. These are economically robust using conservative assumptions about the quantum of potential benefit.

Our approach to the development of this business case has been to:

- define the need by identifying vulnerable network areas susceptible to failure, including building vulnerabilities, and risks to our communications and data access;
- identifying the readiness options that can bring back supply to enable us to promptly start restoration efforts following an event;
- estimating the costs and benefits of each option; and
- selecting preferred options based on their effectiveness, technical feasibility, and their expected benefits.

Our quantitative assessment of consumer benefit in this business case is based on the "value of unserved energy" which is a well-used proxy for valuing the direct impact of supply interruptions. It has been used extensively in proposals for capital expenditure related to electricity infrastructure in New Zealand.

Whilst using this figure supports the economic case for investment, we believe it significantly understates the wider economic and societal impacts of an event such as a 7.5 magnitude earthquake. For this reason, we believe the merits of the proposed investments should be viewed within this broader context.

2 The Needs Case

This section details the context for this business case. It discusses various impacts that we are looking to reduce through the proposed investment. It also includes a summary of our responsibilities under the CDEMA.

2.1 Potential for a Major Earthquake

Wellington Electricity owns and operates one of the most reliable electricity networks in the country. However, our network is located in one of the most seismically active regions so is vulnerable to a major earthquake. There are several fault lines across the region including the Wellington fault line which cuts across the Wellington region and along the western edge of Wellington Harbour and the Hutt Valley.

There are a large number of known fault lines in the Wellington region, as shown in Figure 1 below.

Figure 1 - Map of fault lines in the Wellington Region (GNS Science)[7]

The scenario we have used to assess potential damage to our network is a 7.5 magnitude earthquake[8] on the Wellington fault line. While there are numerous potential scenarios that could occur, we have focussed our efforts on this scenario due to the higher probability of occurrence as well as the potential to cause the most damage to the network. To account for the numerous other scenarios, we have assumed a forecast return period of 1 in 300 years in our modelling.

7 https://www.gns.cri.nz/Home/Learning/Science-Topics/Earthquakes/Major-Faults-in-New-Zealand/Wellington-Fault/How-often-do-earthquakes-occur-along-the-fault

8 The scenario is consistent with that used in the Wellington Lifelines Group Restoration Times report dated November 2012.

We have not assessed the impact of a near position significant tsunami as it is widely accepted that in the event of such a tsunami (6,000 year return period); there would be widespread devastation similar to the Tohoku event in 2011. As such, there would be very little we could do to restore power to the impacted areas quickly after such an event, given there would be little if any viable infrastructure remaining. This is also consistent with the scenario modelled by the Wellington Lifelines Group.

Following a severe earthquake event there would be significant disruption to the distribution network. Given that Transpower expects that in most scenarios, its transmission network will remain largely intact, or at least be able to be restored quicker than our distribution network, we have assumed supply from their GXPs continues to be available under the earthquake scenario.

2.2 Impact on Transport Links

Whilst there is much we have learned from the Christchurch earthquake, a major difference between Orion's ability to restore power and our current ability after a major earthquake is the potential impact of the event on transport links.

There are multiple routes into Christchurch that facilitated movement of repair staff and transport of equipment. In contrast, there are very few roads in and out of the Wellington region and even fewer between different areas of the network. In March 2013, Wellington Lifelines published results of this impact as modelled by Opus.[9] It concluded that the region could be split into seven 'Islands' that will have no road access between them for an extended period (months rather than weeks), with some roads into the region being closed for up to four months.

Five of these 'islands' are within our area of supply as shown in Figure 2 below where the grey straight lines show the island boundaries

It is expected that there will be no transport between the 'islands' for at least two weeks after the event with roads gradually becoming partially passable and opening gradually over the following months. The Hutt region could be most badly impacted with current estimates of road outage times in and out of the area of 12 weeks.

[9] Restoring Wellington's transport links after a major earthquake, Wellington Lifelines Group, March 2013

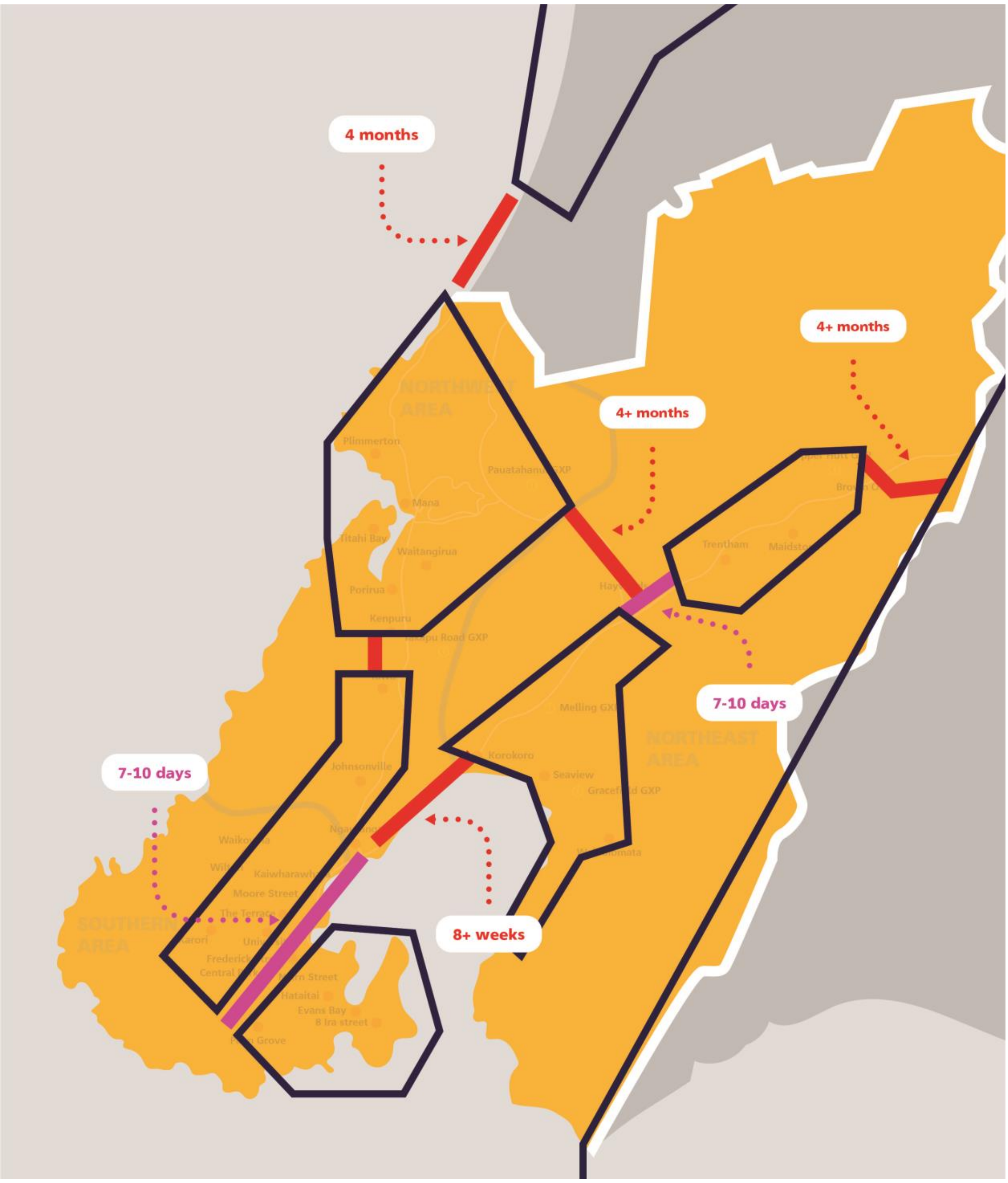

Figure 2 – Impacted Transport Links

Wellington Electricity and its contractors have staff based throughout the region so it is likely that there would be people in an area with the necessary skills to begin repair work if the required equipment is available.

2.3 Impact on Critical Services

We have estimated that a major earthquake would result in an immediate loss of up to 60% of the region's electricity supply which is similar to Christchurch in the 22 February 2011 earthquake. Some of this can be restored relatively quickly if we can communicate effectively with patrolling field crews, safely access our buildings and our data systems to control our equipment. However, we expect that up to 35% of power could be lost from a few days up to three months and over 100,000 customers (via 48,000 customer connections) could be severely impacted.

While much of this loss can be attributed to asset damage, the duration of outage is also negatively affected by Wellington being cut off from the rest of the country by severed transport links. This would make restoration efforts very difficult and exacerbate what would already be a desperate situation for many of the most vulnerable members of our society.

Our network supplies electricity to the city's critical infrastructure including Wellington airport, the Beehive disaster response bunker, several hospitals, telecommunication exchanges, water pumping stations, fuel storage and supply hubs and emergency services headquarters. All of these are likely to be overwhelmed in the immediate aftermath of a major earthquake and ensuring power supply continuity is a key priority. While many of these sites have their own backup generation, access to fuel could impact their functionality and the lack of critical network spares will severely hamper our ability to ensure continuity of supply.

2.4 Impact on our Communities

Electricity is an essential service, the lifeblood of society and fuel for our economic prosperity. Losing it for an extended period of time has a devastating impact on people's ability to function and lead normal lives. At a most basic level, access to what we deem as essentials such as fresh water, lighting, cooking refrigeration, heating and communication is compromised often with no viable alternatives.

This is further compounded if the outage extends into weeks and possibly months. Businesses that cannot function productively may relocate, taking the people that work there with them. However, in many areas, people will be unable to move due to severed transport links and this makes it imperative that we are well equipped to return electricity services as quickly as possible so they can recover in their own homes.

In Wellington's case, government personnel may be required to move away, even temporarily, and there is a possibility that parliament would relocate to another city to ensure continuity of government.

Add this to the general trauma and distress that a major earthquake would cause and it is not hard to imagine the vast social and wider economic impacts that a business case of this nature does not capture. Without a prompt return of utility services, the social fabric may unravel as people's ability to relocate, or to receive alternative help will be limited. Those without financial resources will find it even more difficult to meet daily needs. Those with mobility or financial constraints may find it difficult to find temporary assistance as organisational and social support may be absent for an extended period after an earthquake.

As noted by Fran Wilde in the November 2012 Lifelines report:

> *"There is so much at stake. Not only does the region comprise 11 per cent of the country's population, but it also generates 15 per cent of its GDP. Wellington is the seat of government and the transport hub between the North and South islands. Many organisations have their national headquarters in the capital's CBD so that a severe earthquake would affect operations far beyond the city."*

2.5 Wider Economic Impacts

The impact of a major earthquake on the city's infrastructure and the wider economic and societal impacts have been well documented and discussed over the past few years, with heightened awareness following the Christchurch and Kaikoura earthquakes.

In 2015, Wellington Lifelines commissioned a report by BERL[10] which concluded that there is:

> *"A potential permanent economic loss to New Zealand with a present value of $30-$40 billion of New Zealand's GDP from emigration of highest level business services firm. The investment in buildings and infrastructure needed to increase Wellington's resilience to mitigate this loss is of the order of $3-$4 billion"*

The duration of electricity outages following an earthquake is directly relevant to the potential emigration of businesses and this cost is on top of the direct impact that can be represented by a value of unserved energy.

We are firmly of the view that while these investments are justified using a value representing the direct impact of supply interruptions, the wider impact of long duration interruptions cannot be easily captured by a single figure and therefore our estimates of benefits are conservative.

Our proposal to invest around $31 million will significantly improve our readiness to respond to a major earthquake. This investment equates to around 1% of BERL's cost estimate to improve resilience. As such, this proposed investment is a relatively small cost for what is a significant reduction in risk.

2.6 Civil Defence Obligations

Local authorities and Lifeline Utilities' responsibilities in an emergency situation are outlined by the CDEMA. The Act sets out requirements for utilities around planning requirements so that a coordinated effort can be made to improve the resilience of these networks.

As part of our asset planning process, we identify vulnerabilities and engage with other utility operators over shared learnings.

The CDEMA outlines a process for emergency management and improving resilience known as the '4Rs' describing different areas of planning and response.

10 "Wellington – essential to NZ's Top Tier. Its resilience is a national issue." -BERL, December 2015.

- **Reduction:** Identifying and analysing long-term risks to human life and property from natural or man-made hazards; taking steps to eliminate these risks where practicable and, where not, reducing the likelihood and the magnitude of their impact.
- **Readiness:** Developing operational systems and capabilities before an emergency happens. These include self-help and response programmes for the general public, as well as specific programmes for emergency services, utilities, and other agencies.
- **Response:** Actions taken immediately before, during or directly after an emergency, to save lives and property, as well as help communities to recover.
- **Recovery:** Activities beginning after initial impact has been stabilised and extending until the community's capacity for self-help has been restored.

This business case has been developed with these principles in mind. The proposed initiatives will reduce risk through readiness investments that will reduce the impact of a major earthquake on our electricity network. This is evidenced by our estimates of reduced outages under each investment option. Our longer term resiliency plans will build on this work and future investment proposals will seek to reduce this risk further.

The majority of the options themselves are very much 'readiness' focussed as we seek to develop our operational system and capabilities ahead of significant event, such as a major earthquake. The seismic strengthening programme has aspects of both readiness and resiliency.

2.7 Network Overview

Wellington Electricity's network system length is 4,710 km, with approximately 63% being made up of buried cables. It is supplied from Transpower's National Grid via nine Grid Exit Points (GXPs) which feed into the network at 33kV and 11kV. The 33kV GXPs supply 27 zone substations, two critical switching stations and four Transpower owned sites that feed directly into our network. The 11kV GXPs supply directly to the distribution network. The map below shows the location of these assets.

Figure 3 – Wellington Electricity Network Area

Our network comprises three areas, described below. Further detail can be found in our 2017 Asset Management Plan which is attached to our Main Proposal.

Southern Area

The Southern area of the Wellington Electricity network is defined as the area supplied from the Central Park (CPK), Kaiwharawhara (KWA) and Wilton (WIL) GXPs. There is also grid connected generation at West Wind and Mill Creek. It supplies approximately 58,000 customer connections.

Northeast Area

The Northeast area is supplied from Transpower's Gracefield (GFD), Haywards (HAY), Melling (MLG) and Upper Hutt (UHT) GXPs. It contains two significant population centres in Upper Hutt and Lower Hutt cities containing approximately 66,000 customer connections.

Northwest Area

The Northwest area is supplied from Pauatahanui (PNI) and Takapu Road (TKR) GXPs. This covers the northern suburbs of Wellington City from Johnsonville up to Pukerua Bay, serving approximately 43,000 customer connections.

2.8 Earthquake Impact on our Network

Our analysis focusses on the following potential impacts resulting from the 7.5 magnitude earthquake scenario:

- slope failure;
- ground shaking and liquefaction; and
- fault line movement.

2.8.1 Slope failure - the 'seven islands' problem

Slope failure has the potential to impact some of our assets directly, but the most significant impact will be on access in and out of the region. In March 2013, an Opus report[11]. noted:

- the region may become isolated by normal road access for up to 120 days. This is due to likely landslips on State Highway 1 from Paekakariki to Pukerua Bay; the Paekakariki Hill Road; the Akatarawa Road, and State Highway 2 over the Rimutaka Hill.
- in addition to isolation, the region may become fragmented due to landslips on the Haywards Hill section of State Highway 58 and the Horokiwi area of State Highway 2, in addition to other regional fragmentation.

The report indicated that the region could possibly be split into seven 'islands' as a rupture of magnitude 7.5 or greater along the Wellington fault could damage road links so badly that the northern and western suburbs would be cut off from the central, eastern and southern suburbs. Essentially, seven islands would be formed comprising, Upper Hutt, Lower Hutt, Wairarapa, Porirua, Kapiti, Wellington CBD and Western Wellington. Five of these 'islands' are within our network.

Safe access to key zone substations would be limited for extended periods resulting in the inability to restore supply to consumers if major infrastructure such as power transformers or switchboards is damaged.

2.8.2 Ground shaking and liquefaction

The Christchurch earthquake confirmed that underground assets are the most vulnerable to damage, especially in areas of high liquefaction. The majority of the damage to Orion's sub-transmission cables was due to liquefaction as well as the pressure wave caused by the earthquakes.

Our distribution network is especially vulnerable to damage from a major earthquake due to the high proportion of the network that is underground including the poor performance of fluid filled (oil and gas)sub-transmission cables in a seismic event. We do have a replacement programme underway to replace all fluid filled cables with more resilient XLPE cables based on their replacement criteria, however this is a long-term plan which will take many years to complete.

Under the Wellington earthquake scenarios, significant damage is expected to all types of cable in the Petone/Seaview areas as well as in the northern areas of the Wellington CBD, which lies on reclaimed land, and parts of Kilbirnie and Miramar.

A combination of liquefaction and ground shaking poses the greatest risk of structural damage to substations. Therefore, those areas prone to liquefaction will also likely incur substation damage.

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11 WeLG / WREMO 'Transport Access' initial project report – March 2013

2.8.3 Fault line movement

The movement of ground along the Wellington fault line would be significant during a major earthquake. Given many of our assets traverse the fault line from Karori through to Upper Hutt, there is likely to be extensive damage to cabling and substations.

2.9 Asset Damage

Our analysis of potential asset damage is primarily based on a single earthquake scenario to enable us to be specific about the types of risk mitigations that would provide most benefit in terms of improving restoration time. It allows us an anchor on which to base all ensuing technical and economic analysis which has been used as a tool to select the preferred option. However, in the options analysis stage, consideration and preference was given to options which would provide benefit under a range of earthquake or other natural disaster damage scenarios.

To assess the potential damage to our network assets, we overlaid our network with the Regional Council and the Institute of Geological and Nuclear Science seismic hazard maps that show impacts by region. These were rated high, medium and low depending on their proximity to assets on our network as follows:

- high impact: total loss of supply;
- medium impact: equipment is damaged but the power remains on; and
- low impact: service continues as normal and provides support to other damaged areas.

Damage was considered for the following asset categories by zone:

- zone substations;
- 33 kV cables; and
- 11 kV cables.

This gave us a 'heat map' or matrix of potential damage (for the following risks) by zone substation area and asset class.

- slope failure;
- ground shaking and liquefaction; and
- fault line movement.

		33kV Lines			Zone subs			11kV		
Area	llington Electricity Zo	Slope Failure	Ground shaking/ Liquefaction	Fault Line Movement	Slope Failure	Ground shaking/ Liquefaction	Fault Line Movement	Slope Failure	Ground shaking/ Liquefaction	Fault Line Movement
North Eastern	Brown Owl	L	L	H	L	L	L	L	L	M
	Maidstone	L	L	H	L	L	L	L	L	M
	Trentham	H	L	M	L	L	L	L	L	L
	Haywards	N/A	N/A	N/A	N/A	N/A	N/A	H	L	H
	Naenae	L	L	L	L	M	L	L	L	L
	Melling	N/A	N/A	N/A	N/A	N/A	N/A	L	L	M
	Waterloo	L	L	L	L	L	L	L	L	L
	Petone	L	H	L	L	H	L	L	H	L
	Seaview	L	M	L	L	H	L	L	H	L
	Gracefield	L	L	L	L	H	L	L	H	L
	Korokoro	L	H	H	L	H	H	L	H	H
	Wainuiomata	H	L	L	L	M	L	L	L	L
North Western	Plimmerton	L	L	L	L	H	L	M	H	L
	Mana	H	L	L	L	H	L	H	H	L
	Waitangirua	L	L	L	L	L	L	L	L	L
	Titahi Bay	L	H	L	L	L	L	L	M	L
	Porirua	L	L	L	L	M	L	L	L	L
	Kenepuru	L	L	L	L	L	L	L	L	L
	Tawa	L	L	L	L	L	L	M	L	L
	Johnsonville	L	L	M	L	L	L	M	L	L
	Ngauranga	M	L	L	L	L	L	M	L	L
Southern	Waikowhai St	M	L	L	L	L	L	M	L	L
	Kaiwharawhara	N/A	N/A	N/A	N/A	N/A	N/A	M	H	H
	Karori	M	L	L	L	L	L	L	L	L
	Moore St	M	M	H	L	H	L	L	H	M
	The Terrace	L	L	L	L	M	L	L	M	L
	University	L	L	L	L	L	L	M	L	M
	Frederick St	L	L	L	L	M	L	L	M	L
	Nairn St	L	L	L	M	L	L	M	L	L
	Palm Grove	M	L	L	L	L	L	L	L	L
	Hataitai	L	L	L	L	L	L	L	M	L
	Evans Bay	L	H	L	L	H	L	L	H	L
	8 Ira St	L	H	L	L	M	L	L	H	L

Table 2 – Asset Impact by Zone Heat Map

It is worth noting that this is a heat map for a specific earthquake event, namely a 7.5 earthquake caused by the Wellington Fault Line. A rupture of the Ohariu fault line would result in high risks for much of the Northwest area which includes Tawa and Johnsonville. For this reason, we have carefully considered where we would store critical spares so they could provide restoration assistance under a range of other earthquake scenarios.

This table is a high level view of the seismic risk and is not used when assessing site specific hazards which require more in depth analysis and assessment. Such hazard assessment is undertaken by qualified geotechnical engineers when the work is initiated. In the absence of detailed seismic assessments at each site, we have estimated the damage based on the data that is available.

For buildings, we have used different criteria for prioritising the criticality of seismic strengthening and this is discussed further is Section 3.5.

Similarly, we didn't use specific risk areas for the communications systems aspects of the business case, since this was treated as an essential enabler of the restoration effort. In other words, it wouldn't matter what we did to reduce the outage duration if we didn't have well-functioning communications and access to essential systems and data.

2.10 Time to Repair

To effectively assess and differentiate between different options, we need a measure of the improvement that each option offers. The measure we have used is the improvement in restoration time (i.e. reduction in outage time). We did this for our current state which is expressed as a "do nothing" option and then for each of the options that were assessed.

The restoration estimate is made up of two elements.

1. **Repair time:** the time it would take to conduct the repairs if we had access to equipment. For instance, we have assumed that it would take eight weeks to decommission a power-transformer, move to another zone substation and commission it there. Similarly, we have estimated the number of weeks it would take to erect an emergency overhead line.
2. **Transport time:** the time it would take to transport equipment, and even people into the area where they are required to start the restoration efforts. It assumes that our network region is split into five islands (Kapiti and Wairarapa are excluded). Transport between these islands would be compromised and transport into the region is severely restricted. The Hutt Valley is the worst impacted with transport links into this area expected to be out of service for up to 12 weeks. These estimates were sourced from the most recent Lifelines draft study into the impact on transport routes.[12]

There is significant uncertainty about other forms of access into the Hutt Valley region. Civil Defence would have control of all air space and sea transport which will be prioritised on the basis of need with medical and emergency response being prioritised above everything else. As a lifeline utility requiring air access to bring equipment into the region, we are likely to rank as priority 4 behind:

1. airborne firefighting;
2. urban search and rescue;
3. casualty evacuations; and
4. emergency supplies out of, and into the region.

This would leave sea barges as an alternative means of access. However, we do not know for certain if we would be able to land a barge with equipment and/or people into the Hutt Valley. The Seaview marina is the only likely spot, but discussions with the Wellington Lifeline project team indicate that there could be potential issues with that, and work continues to scope out suitable landing areas.

Note that there is overlap of restoration time between damage caused by 33kV cable damage and zone substation damage. In our analysis, this happens at Korokoro, Mana, Evans Bay and Ira Street. The restoration time is based on the fact that in order to supply electricity, both the cable and substation damage needs to be resolved. In these instances, we show the outage impact for both sources of damage, but the outage associated with zone substation damage is the longest duration and provides an indication of the total risk exposure at these sites.

The number of potentially impacted customers is based on a percentage of electrical demand that will be unserved by the outage. As a result, it should be treated as a high-level approximation of how many customer connections would be impacted, rather than an accurate number.

12 The latest study is yet to be published, though WELL has had access to draft findings.

2.10.1 33 kV cable faults

In the event of a major earthquake, we expect that there would be extensive damage to our fluid filled (oil and gas) 33kV sub-transmission cables resulting in a loss of the network's electricity supply to over 29,000 customer connections.

Given that it is time consuming to identify and repair faults of this nature (we have assumed 3 weeks to locate and repair each fault), we would generally opt to construct emergency overhead lines in the event of a major earthquake that caused widespread damage.

After the 2011 Christchurch earthquake, Orion built two emergency overhead sub-transmission circuits to supply the most seriously impacted areas of its network. These overhead circuits were crucial to the restoration of the network after the earthquake.

The repair times shown in this table relate to the time it would take to construct an emergency overhead line to supply 33 kV load. The time is dependent on the length of line and complexity of construction which is influenced by the terrain.

Asset Class	Zone	Weeks Repair	Weeks Transport	Weeks Total	Impacted Customer Connections	% Zone Lost Load
33 kV cables	Brown Owl	3	12	15	5,320	76%
	Maidstone	3	12	15	1,672	38%
	Trentham[13]	3	1	4	5,605	95%
	Korokoro	4	12	16	974	24%
	Wainuiomata	2	0	2	5,776	76%
	Mana	4	1	5	3,610	48%
	Titahi Bay	4	1	5	2,120	61%
	Evans Bay	8	2	10	1,140	24%
	8 Ira St	12	2	14	2,660	48%
	Moore St	2	2	4	190	48%
	Total				**29,067**	

Table 3 - 33 kV Cable Damage Restoration Estimates

Our estimates for erecting an emergency overhead line are generally between 2 and 4 weeks. However, a solution for the Evans Bay – Ira Street cable would likely take substantially longer (around 12 weeks) because it is expected that the sub-transmission cable feeding Evans Bay would be damaged as well as the cable feeding Ira Street. In this scenario, a line would need to be built from Central Park GXP to Ira Street with a tee-off to Evans Bay. The total length of line required, along with the complexities of building an overhead line in Mount Victoria and the Basin Reserve increases the expected duration of this outage.

The transport time relates to the time it would take to transport the required equipment into the area. The 33 kV cables in the Hutt area are severely impacted by the lack of heavy transport routes into the area for up to 12 weeks. For other zones, we would expect transport routes to be open within 1 to 2 weeks.

13 Note: Trentham is an overhead line and we have sufficient spares currently to repair, hence transport time is the time it would take to transport spare equipment from within the Hutt area.

We currently hold sufficient overhead line spares to repair any damage to the overhead sub-transmission lines that supply Wainuiomata and Trentham.

2.10.2 Loss of transformers and switchgear

A number of zone substations across the region are at a high risk of damage from ground shaking and liquefaction. It is anticipated that the damage will result in a loss of transformer and/or switchgear.

The table below shows our estimates of time to restore power to the damaged zone substations.

Asset Class	Zone	Weeks Repair	Weeks Transport	Weeks Total	Impacted ICPs	% Lost Load
Zone Substation Damage	Seaview	8	0	8	855	32%
	Korokoro/ Petone	4	12	16	974	24%
	Mana	8	1	9	2,423	48%
	Evans Bay	12	2	14	1,140	24%
	8 Ira St	12	2	14	2,660	48%
	Total				**8,051**	

Table 4 – Loss of Transformers and Switchgear Restoration Estimates

Note there is no load supplied directly by Petone as it is a switching station. However, the station does serve to supply customers that are fed by the transformers at Korokoro and any damage to Petone will impact our ability to supply these customers, hence combining these locations.

It should also be noted that supply lost by zone substation damage overlaps with that lost by 33kV cable damage. This happens at Korokoro, Mana, Evans Bay and Ira Street. Care has been taken in the options analysis to ensure we do not double count this in our justification of investments.

Our current emergency plans for dealing with damage at these zone substations are summarised below.

Area	Zone Substation	Equipment Damage	Solution under current state / spares holdings
North Eastern	Seaview	Transformer Loss x 2	8 weeks duration is based on the expected time to decommission, transport and re-commission a transformer from Waterloo to Seaview.
	Petone	Switchboard Loss	New switchboard would take 12 weeks to get to site given transport links are cut and a further 4 weeks to install. We currently have no spare for zone sub switchboards and so a spare would have to be sought from outside the region.
	Gracefield	None	Building has been strengthened under current seismic programme and switchboard is to be replaced in 2018 so no expected loss of switchboard. Possibility of a single transformer loss but load can then be supplied from the second transformer.
	Korokoro	Transformer Loss x 2 Switchboard loss	It would take 8 weeks to decommission, remove, transport and re-commission a transformer from Naenae to Korokoro. A new switchboard would take 12 weeks to get to site given transport links are cut. A spare would have to be sought from outside the region. It would then take 4 weeks to install. The transformer move would happen whilst awaiting the arrival of a new switchboard.
North Western	Plimmerton	None	Building is in good condition as are transformers, therefore no loss of supply anticipated despite high risk location.
	Mana	Transformer Loss	The current state at Mana would involve the building of an overhead line should the transformer at the substation be damaged. This will enable the Mana switchboard to be energised from Plimmerton.
Southern	Evans Bay	Transformer Loss x 2 Switchboard loss	Some supply from Hataitai and Palm Grove would be possible. In the mean time we would need to find another site and move transformer from Hataitai and get a new switchboard from outside the region.
	Ira Street	Loss due to supply loss from Evans Bay	The current solution to a loss at Ira Street due to Evans Bay substation damage would be to construct the emergency overhead line from Central Park to Ira Street.
	Moore Street	None	Building is in good condition as are transformers, therefore no loss of supply anticipated despite high risk location.

Table 5 - Zone Substation Damage Current State Solutions

2.10.3 11 kV cable and equipment faults

The November 2016 Kaikoura earthquake taught us first hand that buried cables are susceptible to ground shaking damage in areas of liquefaction (or reclaimed land areas).

Our 11 kV network that supplies Centerport is on reclaimed land and the shaking of the 2016 earthquake resulted in cables pulling apart then coming back together. Some of these cables were able to be energised but then subsequently failed after a period of time, whereas others failed immediately.

 

Figure 4 – Examples of 11 kV cables at Centerport that pulled apart and then came back together.

We estimate that 11kV cable damage would be extensive and our estimates of load that could be lost are based on a number of assumptions:

- the ability to supply electricity from other zones given back feed capability;
- three cable faults per km (as per Orion's experience) each requiring two cable joints to fix and a 5m length of cable per fault; and
- two cable joints per cable jointer can be installed each day.

Using these assumptions, we would require 2,385 joint kits, almost 6 km of cable and require 30 jointers working for 40 days to fix all 11 kV cable damage. This is equivalent to around eight weeks assuming they work for five days out of every seven. Under the current state, the repair work would be delayed as we would have to wait between 2 and 12 weeks to get spare equipment into the region.

It is difficult to estimate the exact impact of an outage as we would endeavour to restore critical loads as soon as we could and then progressively more load would reconnect as time went on.

The following table shows the likely impact in terms of impacted customers and our expectations of the percentage of lost electricity load.

Asset Class	Zone	Impacted ICPs	% Lost Load
11 kV cable and distribution equipment damage	Frederick St	567	23%
	University	532	10%
	Hataitai	1,406	19%
	The Terrace	371	41%
	Evans Bay	1,140	24%
	8 Ira St	2,660	48%
	Korokoro	974	24%
	Gracefield	887	32%
	Wainuiomata	1,444	19%
	Seaview	855	32%
	Naenae	437	6%
	Mana	1,211	24%
	Porirua	241	6%
	Maidstone	418	10%
	Brown owl	1,330	19%
	Moore St	190	48%
	Waikowhai St	1,254	19%
	Kaiwharawhara	1,108	32%
	Melling	694	10%
	Haywards	1,219	16%
TOTAL		**18,937**	

Table 6 - 11 kV Cable Damage Estimates

2.10.4 Preventing damage to equipment in buildings

One of the most useful learnings from the Orion experience has been the importance of seismic strengthening of substation buildings and the important role it plays in terms of preventing equipment damage during a major earthquake.

We require the equipment housed within our critical sites to remain undamaged by building failure after an earthquake. People safety requires buildings to be strengthened between 34-66% of the New Building Standard. However our buildings must also protect equipment needed to return supply and provide quick and easy access following an earthquake.

The impact of equipment damage to weakened buildings is significant. We anticipate up to 60% of electricity could be lost immediately following an earthquake. Much of this may be a result of equipment turning off. It is likely that this electricity supply could safely be switched on soon after an event, but that is dependent on satisfying ourselves that the equipment housed in our buildings is in a state that it can be switched back on.

Orion's critical buildings performed well in the 2010-2011 earthquakes having been strengthened to 67% of the New Building Standard. A subsequent study reported that the $6 million Orion spent on strengthening work avoided a direct asset replacement cost of $30 to $50 million.[14]

[14] Resilience Lessons: Orion's 2010 and 2011 Earthquake Experience - Kestrel Group September 2011

The photo below shows the result of strengthening work completed on one half of a building.

Figure 5 - Redcliffs waterworks substation in Christchurch - Orion had strengthened the right-hand side of the Building[15]

61 Molesworth Street Case Study

We currently have around 300 substations that reside in basements of third party owned buildings within Wellington CBD. The November 2016 earthquake showed that not all buildings within Wellington CBD are of adequate strength to resist large seismic events. We were impacted at our substation at 61 Molesworth Street where significant building damage meant that we were unable to attend to our 2 MVA substation that had tripped during the earthquake until the building had been seismically assessed. This meant that we had to bypass the substation by cutting and jointing new cables around the substation (effectively removing it from the system) until we were allowed to access the building to assess the damage to our equipment.

Figure 6 - Jointing of cables to remove 61 Molesworth Street from the 11kV network

The building was later condemned which meant that we had to remove our substation permanently. This led to us establishing new temporary road side substations along Hawkestone Street to assist in

[15] Resilience Lessons: Orion's 2010 and 2011 Earthquake Experience - Kestrel Group September 2011.

managing the load in the area. 61 Molesworth Street was an important node in the 11kV network which served as an inter-tie between zone substations.

Figure 7 - Temporary Substation at Hawkestone Street

Given we have little control over these third party owned buildings, we have ensured that our plans include sufficient spare cabling equipment and transformers to allow us to bypass these substations should an earthquake result in unsafe access. This would be similar to the approach at Molesworth Street.

2.10.5 Maintaining Data and Communication Links

Currently our data centre is located in Melbourne and we access all our core systems via communication links. This works well for day to day operations, however, in the event of a major earthquake, our ability to access essential data and systems will be severely compromised as local telecommunication services are likely to be disrupted.

There is an immediate need to increase the resilience of our Information Systems by improving our communication links which provide us access to essential systems and data.

In 2012, the Wellington Lifelines report suggested it would take up to 10 days to restore telecommunication services to operational level and this would likely increase if the power supply was unreliable.[16]

Operational control lies at the heart of our ability to respond effectively. This relies heavily on a telecommunication network which, in turn, relies on continuity of power supply presenting interdependency risks that could greatly reduce our ability to respond to a major earthquake. It also means that telecommunication links which will be, for many of us, the only means of communication with the outside world, are likely to be out of service for far longer than would be the case if we improve our readiness in this area.

Current State

In the event of a major earthquake causing extensive damage, we would expect around 60% of our network's load to trip off. We currently rely on our SCADA systems to provide information about

16 More recent discussions with the Lifeline project manager have indicated that the situation is likely to be worse than initially thought in 2012.

what equipment has tripped off and what is likely to be damaged. Our SCADA hardware is currently located at Petone and Haywards. Whilst SCADA is also vulnerable to fibre damage impacting the flow of information from our substations, the lack of access to four key engineering information systems (described below) following a widespread failure of the telecommunications network would severely hamper restoration efforts.

1. **GIS:** our Geospatial Information System stores all our information about the location of our assets. Without access to this information, we may know there is a cable fault, for example, but there is no way to easily locate it as we won't have any way of knowing the exact route that the cable traverses. In the absence of this we would send someone out to physically plot the cable route by using cable tracing equipment and once that was done, we would attempt to locate the cable fault with fault locating equipment. Access to GIS would save valuable and significant amounts of time in physically identifying the buried cable routes.

   Without GIS, we would not know what make and type of equipment is housed in our distribution and zone substations and would have to rely on staff knowledge and memory. This creates an additional safety issue should emergency services need to access any of our substations where there is a fire or other secondary risk that emerges.

2. **PowerFactory:** is a network modelling and protection calculation tool. It is essential for establishing what load can be shifted between zones and substations as well as what changes to protection may be required in order to make those changes. Without ready access to this tool, we would not know what load could be potentially back fed from another zone substation. Such modelling would need to be done manually – a time consuming effort which only a handful of people could do effectively. This would cause load that could potentially be restored fairly easily, to stay off unnecessarily.

3. **Stationware:** is a database that stores all our protection settings. This information is critical to support the restoration of power supply whilst keeping our personnel and public safe. In our current state, the modelling that is carried out to confirm load can be backfed from another zone substation would confirm that the network can be reconfigured, but without knowing what protection settings need to be changed, the protected devices may just trip off again. Without access to Stationware, we would need to physically go to our relays, record the protection settings and then calculate new settings based on the reconfigured network.

4. **Projectwise:** this software stores all our engineering drawings and records. Without access to it, we are unable to assess where equipment is physically located at each site and thus start planning for repair of the damage. We would have to rely on visits to each site to establish the exact configuration of the site and where each piece of equipment is physically located.

Without access to these systems and tools, there is a possibility that the initial expected 60% loss of supply would be extended for a significant length of time under our current state. This would in turn, impact on the restoration of power associated with the more serious damage to our assets as discussed above. The value of 60% of our network load is estimated to be $110 million a day. Add to this the compounding effect of our communities and businesses being without power for days on end, and one can see there is significant value that could be lost from not addressing this relatively simple problem.

The loss of transport links and the potential damage to our own communications fibre network (Central Park to Haywards and Haywards to Pauatahanui) leaves us vulnerable to losing operational control of the Porirua/Tawa, Western Wellington and the Wellington CBD networks. This presents a risk not only to our ability to restore supply, but more importantly creates a significant safety risk. For example, should we receive notification from a member of the public or emergency services of a live line on the ground, we would have no ability to remotely switch off the supply to that line and would need to send someone out to physically switch the line off. This loss of operational control would severely hamper any restoration efforts and it could take days before restoration of supply could be initiated effectively and presents an unacceptable risk.

2.10.6 Restoration Summary

We anticipate that we could lose up to 60% of electricity supply immediately following a significant earthquake event. Whilst much of this could be restored quickly, if we can safely access our buildings and have full operational control, up to 35% of the electrical load could be disconnected for between 2 and 16 weeks.

The total direct cost of this outage is conservatively estimated at around $2.9 billion assuming average load conditions. The social welfare and direct measured cost could be much higher if a major earthquake happened in mid-winter. Also, this estimate does not take account of additional electricity that could potentially be unserved through critical building damage which would further delay restoration as access to buildings would be compromised. This additional unserved energy has not been included in this analysis as the proposal to strengthen our buildings is being primarily driven by an impending change to our seismic building standard. This change will bring all zone substation and critical Important Level 4 (IL4) buildings up to 67% of NBS. This standard is consistent with peer utilities.

3 Options Analysis

A range of options to increase our earthquake readiness was considered. These options were assessed based on their potential to improve restoration times following a major earthquake. Preference was given to those options that could be implemented within a three year window and provide benefit over a range of earthquake scenarios.

3.1 Approach

Having specified the need case in terms of potential damage to our network assets, we investigated potential options that could reduce the time it would take to restore power supply following a major earthquake.

The following criteria were applied to the options:

- options should be short term initiatives that can reduce restoration times;
- options should be flexible under a number of earthquake scenario outcomes;
- options must be technically feasible;
- options must be able to be fully deployed within a three-year timeframe; and
- options which require significant network augmentation would not be considered as part of this proposal, but rather included in longer-term resiliency plans.

To address a need, the option had to reduce the restoration time of an outage and the option which resulted in the greatest reduction in restoration time became the preferred option.

We have developed and chosen preferred options for the following asset types:

- 33 kV cable failure;
- zone substations; and
- 11 kV cables.

3.1.1 Economic analysis

We use economic analysis to help differentiate between the options, having applied the criteria above. This involved using a discounted cash flow method which estimates the total cost and benefit of investment options over a given period of analysis (20 years). It is a common technique that is used to value projects by converting the total costs and benefits into today's dollars (net present value) by use of a discount rate (usually equivalent to the cost of capital). If the benefits are greater than the costs, options are deemed to have a positive net benefit and the option with the highest net benefit is usually the preferred option.

While costs are relatively easy to estimate, benefits are often more difficult to accurately quantify.

For the purposes of this analysis, we have used an estimate of the avoided unserved energy (outage duration multiplied by lost load) and valued that at a pre-determined "value of unserved energy."

Unserved energy is essentially the total amount of electricity supply that our customers have been deprived of due to an outage.

The Electricity Authority has defined the value of any expected unserved energy to be $20,000/ MWh[17]. This figure was originally set in 2004, so for the purposes of this business case it has been inflated to $28,278/ MWh assuming the average inflation rate of 2.7% pa.[18]

We consider this value to be a fairly narrow proxy for the total cost of supply interruptions. For instance, it does not capture the variability between types of loads, or the changes in value attributed to electricity supply interruptions for extended durations. Nor can it capture the wider societal and economic impacts that an event such as a major earthquake could have on the Wellington region. However, it provides us with a useful tool to measure the relativity of options and provides assurance that we are investing in the right solutions to improve our ability to respond.

For the purposes of this economic analysis, the restoration improvement is expressed as a net present value of avoided unserved energy over 20 years taking into account the return period (probability) of an earthquake.

Key assumptions are as follows:

- value of lost load of $28,278/ MWh [19];
- discount rate of 7.19%[20];
- 20-year analysis period; and
- return period of a major earthquake of 1 in 300 years or 0.33% probability.

Return Period

Selecting an appropriate return period is challenging given the range of return periods in the public domain and the number of faults that could rupture resulting in a damage causing major earthquake.

It was not practical to model the specific damage that could arise from all fault lines and resulting earthquake scenarios, so we used a Wellington fault line earthquake as it has a higher probability of occurrence as well as the potential to cause the most damage to the network. However, assessing damage associated with this fault alone underestimates the quantum of risk posed by all faults.

To compensate for this underestimation, we have used the cumulative probability of each of the five fault line return periods as follows: Wellington, 920 years; Wairarapa, 1,040 years; Ohariu, 2,200 years; Wairau, 1,650 years and Shepherds Gully, 3,750 years. The cumulative probability equates to a 296 year return period.

We are of the view that this is a reasonable and conservative approach as supported by the following which appears on GNS' website:

> *'The last time the Wellington Fault ruptured through the Wellington region, causing a major earthquake, was around 300 - 500 years ago. Geoscientists estimate the Wellington Fault will cause a major earthquake every 500-1000 years. However other faults around the Wellington region are also active and capable of generating major earthquakes, for example the Ohariu*

17 Schedule 12.2, 4.1a of the Electricity Industry Participation Code 2010

18 https://www.rbnz.govt.nz/monetary-policy/inflation

19 This is derived from the VoLL specified in the Electricity Governance Rules 2004 and adjusted for inflation.

20 This is equivalent to our cost of capital.

Fault and the Wairarapa Fault which last ruptured in 1855 causing a great earthquake that severely impacted Wellington. The frequency of large earthquakes affecting the Wellington Region is therefore much higher, with an average return time of about 150 years for a very strong or extreme ground shaking quake.'[21]

Given the return period is one of the more uncertain input assumptions, we have sensitised our cost benefit analysis to test whether it is robust to differences, refer sections 3.2.7, 3.3.9 and 3.4.4.

3.2 33 kV Cable Faults – Response Options

The damaged zones and associated outages under this option are detailed in section 2.10.1.

After the Christchurch earthquake, Orion built two emergency overhead sub transmission circuits to supply the most seriously impacted areas of their network in the Eastern suburbs. These overhead circuits were crucial to the restoration of the network after the earthquake. A similar approach is expected to be required in the event of a major earthquake in the Wellington region.

The following options were considered to address the risk of damage to the network's 33 kV sub transmission cables.

Option	Description	Restoration Improvement (Weeks)
1	Current State - Do Nothing	
2	Carry O/H line spares for vulnerable routes	1-12
2a	Carry 33 kV fluid filled cable spares including jointing kits	7
3	Replace all fluid filled cables with XLPE	2-14
4	Carry 33 kV XLPE cable spares including jointing kits	2

Table 7 – 33 kV cable readiness options

3.2.1 Option 1 current state – do nothing

The damaged zones and associated outages under this option are detailed in section 2.10.1. We estimate damage to 33 kV cables and lines would occur in 10 zones would result in over 29,000 customer connections being without power for between 2 and 16 weeks. The direct impact of this has a net present value of $36.06 million but this estimate is considered very conservative given the high societal cost that an outage of this duration would have on our customers.

3.2.2 Option 2 - carry overhead line spares for vulnerable routes

This option allows for sufficient spare line hardware and cabling equipment to construct 19km of 33kV overhead lines to connect into our zone substations.

[21] https://www.gns.cri.nz/Home/Learning/Science-Topics/Earthquakes/Major-Faults-in-New-Zealand/Wellington-Fault/How-often-do-earthquakes-occur-along-the-fault

Line Route	Capex ($m)	3 Year Opex ($m)	Km	Current State Outage weeks (a)	New State outage weeks (b)	Restoration Improvement weeks (a - b)	Storage Location
Central Park - Evans Bay	1.09	0.09	4.35	10	8	2	Palm Grove, Duncan Terrace
Evans Bay - Ira St	0.63	0.09	2.54	14	12	2	Palm Grove, Duncan Terrace
Gracefield - Korokoro	1.16	0.32	5.23	16	4	12	Naenae, Taita
Plimmerton - Mana[22]	0.46	0.09	1.55	9	4	5	Plimmerton
Upper Hutt - Brown Owl[23]	0.26	0.00	0.88	15	3	12	Maidstone
Brown Owl - Maidstone	1.06	0.09	4.76	15	3	12	Maidstone
Total	**4.66**	**0.67**	**19.31**				

Table 8 – Emergency Overhead Line Routes

The improvement in restoration time is due to a reduction in the time it would take to transport equipment to where it is required. Under this option, we will have readily available spare equipment in the right location.

Note that we carry enough spares to address the potential cable damage at Trentham. The damage at Moore Street would be addressed by acquiring XLPE cable spares – see option 4 in section 3.2.5.

There are potentially 23 emergency overhead line routes that could be built to cover all eventualities, spanning 58 km. We already have detailed designs for eight of these and high level route layouts and designs for 15. The total cost of carrying spares to cover all eventualities is in the region of $12 million. Our proposed option is to carry around 30% of what would be required under all eventualities which is a prudent approach.

3.2.3 Option 2a - 33 kV fluid filled cable spares and jointing kits

This option is a sub option and alternative to carrying emergency overhead line spares for the Upper Hutt-Brown Owl and the Brown Owl- Maidstone lines. It includes carrying sufficient jointing kits and cable lengths to repair cables damaged by fault line movement in Upper Hutt.

Fluid filled cables that are damaged in a liquefaction zones are likely to suffer irreparable damage. However, those that are damaged by fault line movement can be repaired, although it takes considerable time at around 3 weeks per joint repair.

Jointing of fluid filled cables is a specialised task that requires a skill set that we don't have ready access to in the Wellington region. Under normal business as usual operations, we would expect it would take around a week to mobilise this resource using our service provider, Northpower, which has resource in Auckland. However, after an earthquake and assuming transport links are damaged, bringing resource into the region within the first few weeks will be challenging as the expectation is that civil defence will prioritise more critical services that deal with casualties and evacuations ahead of us. The lifelines utilities (e.g. water, transport, electricity) will then be prioritised amongst themselves to see which gets access to helicopters first.

22 Note the outages for the Plimmerton Mana line include the reduction in outage time for the zone substation because the construction of the overhead line and operating it at 11 kV addresses the zone substation damage at no extra cost.

23 There are no Opex costs for this option the storage of this equipment is covered in the storage costs for the Brown-Owl Maidstone equipment.

The current state assumes a 12-week transport delay and three week repair time, giving total outage duration of 15 weeks. The benefit of this option is a 12-week reduction in transport time, however the repair time increases to seven weeks as it takes far longer to repair fluid filled cables than to erect emergency overhead line.

Whilst this is a relatively low cost option requiring spend of around $400,000, the restoration improvement is around half that of option 2, making option 2 the preferred option.

3.2.4 Option 3 – replace all fluid filled cable with XLPE cable

Our long-term asset management plan is to replace all our fluid filled cables with the more resilient XLPE cables as they come up for replacement. The total cost of bringing this work forward would be over of $300 million and provide roughly the same benefit (post-earthquake) as we would get using the overhead line emergency spares (option 2). Given it is clearly not economic to accelerate this replacement it is not a preferred option as a short term readiness option.

3.2.5 Option 4 - carry 33 kV XLPE cable spares including jointing kits

The 33kV XLPE cables that run across the fault line from Wilton GXP to Moore Street are at the highest risk of failure due to fault line movement. Other XLPE cables that could be at risk of earthquake damage under various scenarios are cables in Mana-Plimmerton, Ngauranga, The Terrace and Palm Grove. Cables in Mana will be covered by the overhead spares there, the Ngauranga cable is very short and the Terrace and Palm Grove cables are in the same island as the Moore Street cables so the spares could be used there if required.

To improve the restoration time, this option sees us stocking 12 cable joint kits and 500m of 33 kV cable lengths in Wellington CBD to repair the faults.

Cable Route	Capex ($m)	Opex ($m)	Restoration Improvement
Wilton – Moore St	0.08	0.00	2 weeks

Table 9 – Option 3 XLPE Cable Spares

There is no Opex as storage is in the same facility that includes our overhead line spares. This is a preferred option.

3.2.6 33 kV cable fault option benefits

Care needs to be taken when assessing the costs and benefits of these options and the zone substation options in the next section. This is because in the zone substation options, the full restoration benefit cannot be realised unless the emergency overhead line is also built in parallel.

To ensure we aren't double counting benefits, or understating costs, we have separated out the costs and benefits of three of the overhead lines and included them in the zone substation analysis, detailed in section 3.3.8. For this reason, the net present value costs will look low compared to the total cost of equipment in this category.

The three overhead lines that are not included in the 33 kV cable failure economic analyses are:

- Gracefield – Korokoro (sub option LGK);
- Central Park-Evans Bay (sub option LCE); and

– Evans Bay – Ira Street (sub option LEI).

Additionally, the Plimmerton-Mana line provides a five week improvement in restoration time in total because if we operate it at 11 kV, we can energise the Mana switchboard from Plimmerton negating the need to install a transformer at Mana which is an obvious solution to address substation damage. So in essence, the construction of the overhead line addresses the 33kV cable damage and the zone substation damage – the full benefit of which has been included here.

Option	Description	NPV Cost 2017 $m	NPV Benefit 2017 $m	NPV net Benefit 2017 $m
2	Carry O/H line spares for vulnerable routes	2.21	20.68	18.47
2a	Carry 33 kV fluid filled cable spares including jointing kits	1.07	13.83	12.76
3	Replace all oil filled cables with XLPE	296.67	38.28	- 258.39
4	Carry 33 kV XLPE cable spares including jointing kits	0.08	1.64	1.56

Table 10 – Comparison of 33 kV cable readiness options

Options 2 and 4 provide the highest net benefit and are our preferred options to improve the restoration time resulting from damage to 33 kV cable and lines.

We have the potential to significantly reduce the duration of outages on our 33 kV network through being in a position to start constructing emergency overhead lines as soon as possible following an earthquake. We have estimated up to 12 weeks of 33 kV load outages could be avoided in some areas, returning a net present value benefit of avoided unserved energy of around $20.68 million and a net benefit of $18.47 million.

We can save two weeks in Wellington CBD by holding sufficient spares to repair the XLPE cable between Wilton and Moore Street. This provides a net present value net benefit of around $1.56 million.

3.2.7 33 kV cable fault options – sensitivity analysis

The sensitivity of our analysis was tested against two of the more uncertain assumptions: the return period and the value of unserved energy. The results are shown in Table 11 below.

Net Benefit 2017 $m			Return Period		Value of Unserved Energy	
Option	Description	Base Analysis	150 years	400 years	$15,000/ MWh	$45,000/ MWh
2	Carry O/H line spares for vulnerable routes	18.47	39.15	13.30	8.76	30.70
2a	Carry 33 kV fluid filled cable spares including jointing kits	12.76	26.59	9.30	6.26	20.94
3	Replace all oil filled cables with XLPE	-258.39	-220.10	-267.96	-276.36	-235.75
4	Carry 33 kV XLPE cable spares including jointing kits	1.56	3.20	1.15	0.79	2.53

Table 11 – 33 kV cable readiness options sensitivity analysis

The preferred option remains the same in all sensitivities so we concluded that the analysis is robust to changes in these key input assumptions.

3.2.8 Emergency Hard ware – summary

The preferred options to address the risk of 33 kV cable damage are:

- Option 2 - carry sufficient spares to construct around 19 km of emergency overhead line and
- Option 4 - carry sufficient XLPE cable spares to repair damaged cable in Wellington CBD.

Whilst the quantum of spares has been determined using a specific earthquake scenario, we believe the storage locations provide sufficient diversity to make use of them should other scenarios eventuate.

	Options	Description	Capex ($m)	3 years Opex ($m)	Total ($m)
Emergency Hardware	2	Emergency overhead line spares	4.66	0.67	5.33
	4	XLPE cable spares	0.08	-	0.08
Total			**4.74**	**0.67**	**5.41**

Table 12 – Emergency overhead line routes and XLPE spares costs

3.3 Loss of Transformers and Switchgear – Response Options

The damaged zone substations and associated outages are detailed in section2.10.2.

In the event of a major earthquake in the region it is likely that there will be liquefaction and/or ground shaking damage at Korokoro, Seaview, Petone, Mana and Evans Bay (which in turn supplies Ira Street). It is anticipated that the damage will result in a possible loss of transformers and switchgear. We expect this will result in a loss of supply to over 8,000 customer connections for between 4 and 16 weeks.

Note that operating the Plimmerton-Mana emergency overhead line at 11 kV reduces the restoration times caused by potential damage to the Mana substation. This benefit is achieved at no additional cost and has been included in the 33 kV cable damage cost benefit analysis – refer section 3.2.6.

The cost benefit analysis for zone substation damage is complicated by the fact that several investments, or sub options are required to gain the full restoration benefit. For example, option 2 (shown below) requires a new spare zone transformer, 2 portable switchboards and an emergency overhead line to realise the full benefit of a 10 week improvement in restoration time. The options that have been compared are a combination of the sub options and emergency overhead lines.

Whilst the economic analysis includes all the sub option costs, the costs detailed in this section apply only to the substation assets. This is to ensure that we do not double count the overhead line costs which are shown in section 3.2 above.

Region	Option	Sub option	Description	Capex $m	Total Capex $m	Restoration Improvement (Weeks)
Hutt	1		Current State - Do Nothing			
	2	a	1 new Spare zone transformer in Lower Hutt	0.93	2.73	10
		b x 2	2 Portable Switchboards in Lower Hutt	1.80		
		LGK	O/H line Gracefield-Korokoro	Included in 33 kV cable option 2 Costs		
	3	c	Mobile Substation in Lower Hutt	1.86	2.76	12
		b	1 Portable Switchboard in Lower Hutt	0.90		
		LGK	O/H line Gracefield-Korokoro	Included in 33 kV cable option 2 Costs		
	4	d	Refurbish and relocate spare zone transformer from Petone	0.42	2.22	10
		b x 2	2 Portable Switchboards in Lower Hutt	1.80		
		LGK	O/H line Gracefield-Korokoro	Included in 33 kV cable option 2 Costs		
CBD	5	e	1 new Spare zone transformer in CBD	0.93	1.83	6
		f	Portable Switchboard at CBD	0.90		
		LCE	O/H line Central Park-Evans Bay	Included in 33 kV cable option 2 Costs		
		LEI	O/H line Evans Bay – Ira Street			
	6	g	Mobile Substation located at Palm Grove to connect at Evans Bay	1.97	1.97	6
		LCE	O/H line Central Park-Evans Bay	Included in 33 kV cable option 2 Costs		
		LEI	O/H line Evans Bay – Ira Street			

Table 13 – Comparison of Loss of Transformers and Switchgear Options

LGK – Emergency overhead line between Gracefield and Korokoro

LCE – Emergency overhead line between Central Park and Evans Bay

LEI - Emergency overhead line between Evans Bay and Ira Street

3.3.1 Sub options

This section describes the sub options required in the Hutt Valley and Wellington CBD. None of these would provide any restoration benefit on their own, but combinations of them along with emergency overhead lines would.

Sub option a – one new spare zone transformer in Lower Hutt

This sub option is a new spare 20 MVA 33/11kV transformer to be stored at a storage facility in Clendon Street, Lower Hutt. We have assumed a 20 MVA spare zone transformer as we anticipate it would become the permanent replacement for the damaged transformer. The $0.93 million capex cost includes the transformer, site civil work and installation.

Sub option b – one portable switchboard in Lower Hutt

This option is a portable 11 kV switchboard to be stored at a storage facility in Clendon Street, Lower Hutt. In the event of a major earthquake, we are assuming that both Petone and Korokoro suffer significant damage. Depending on the option, either one or two switchboards are required. The $0.90 million capex cost per switchboard includes the switchboard, cabling and container.

Sub option c – one mobile substation at Lower Hutt

This option is a 10 MVA 33/11 kV mobile substation to be stored at a storage facility in Clendon Street, Lower Hutt. It is anticipated that it will be moved to Korokoro to restore load there. Under different damage scenarios, it could be deployed at other zone substations in the Hutt Valley area. We have assumed a 10 MVA mobile substation as we require a compromise between function and mobility, and would use it as a temporary option to support the restoration of power for as long as it takes to replace permanent equipment. The $1.86 million capex cost includes the design, construction and all equipment.

Sub option d – refurbish and relocate spare transformer from Petone

This option involves the refurbishment and relocation of our existing spare 20 MVA 33/11 kV transformer from Petone to a lower risk site in Lower Hutt. It is anticipated that this would be used at Korokoro after a major earthquake to restore load there. Under different damage scenarios, it could be deployed at other zone substations in the Hutt valley area. The $0.42 million cost includes the refurbishment work and installation at a new site.

Sub option e – one new spare zone transformer in the CBD

This sub option is a new spare 20 MVA 33/11 kV transformer to be stored at a low risk site, such as Palm Grove, in Wellington CBD. It is anticipated that this could be moved to Evans Bay after an earthquake to restore load there. Under different damage scenarios, it could be deployed at other zone substations in Wellington CBD. As in the Hutt option, we anticipate requiring a 20MVA transformer as it would remain on site as the permanent replacement for the damaged transformer. The $0.93 million capex cost includes the transformer, site civil work and installation.

Sub option f – one portable switchboard in the CBD

This option is a portable 11 kV switchboard to be stored in Wellington CBD. The $0.90 million capex cost includes the switchboard, cabling and container.

Sub option g – one mobile substation in the CBD

This option is a 10 MVA 33/11 kV mobile substation to be stored at a low risk site, such as Palm Grove, in Wellington CBD. It is anticipated that this could be moved to Evans Bay after an earthquake to restore load there. Under different damage scenarios, it could be deployed at other zone substations in Wellington CBD. As is the case with the Hutt mobile substation, we have sized it at 10 MVA to support restoration efforts for as long as it takes to replace the damaged equipment on a more permanent basis. The $1.97 million capex cost includes the design, construction and all equipment. This is more expensive that the mobile substation in Lower Hutt (sub option c) primarily due to the requirement for a new pad in Palm Grove required to store the equipment.

3.3.2 Option 1 current state – do nothing

The damaged zones and associated outages under this option are detailed in section **Error! eference source not found.**. In total 5 zone substation are damaged under our scenario and it takes between 8 and 16 weeks to fully restore power to around 8,000 customer connections. The net present value cost of the unserved energy is estimated at $34.86 million.

3.3.3 Option 2 – 1 new spare zone transformer and 2 spare switchboards in Lower Hutt

This option includes purchasing another 20 MVA 33/11 kV spare zone transformer (sub option a) to be stored at a low risk site in the Hutt region. Under our earthquake scenario, the assumption is that the transformer would be moved to assist with the restoration of load at Korokoro after the event.

The current strategy for switchgear spares does not account for the possibility of a complete switchboard failure so any failure of this nature would require replacement equipment to be brought into the region.

A spare 11 kV switchboard (sub option b) will enable quicker restoration in the event of the loss of a zone substation or major switching station switchboard. This switchboard would consist of a single bus section with one incoming connection and five or six feeders and would be similar to portable switchboards constructed for other networks. This switchboard will be kept in the Hutt Valley.

Under this option, we would require two new switchboards, one at Petone switching station and the other at Korokoro zone substation.

This option saves the transport time for new line equipment but still requires two weeks to transport a transformer to where it is required. There is then an additional four weeks required to install the transformer at its new site resulting in six weeks outage in total, a restoration improvement of 10 weeks.

To realise the full improvement of a 10 week restoration benefit against the current state would also require the emergency overhead line from Gracefield to Korokoro, sub option LGK. This cost is included in the cost benefit analysis but excluded from the cost summary here to avoid double counting it. It has been accounted for in the overhead line costs in section 3.2.2 above.

Option	Sub option	Description	Capex ($m)	Opex ($m)
2 – Spare Zone Transformer and 2 switchboards in the Hutt	a	one new Spare zone transformer in Lower Hutt	0.93	0.002
	b x 2	two Portable Switchboards	1.80	0.00
	LGK	O/H line Gracefield-Korokoro	**N/A**	**N/A**
	TOTAL		**2.73**	**0.002**

Table 14 – Option 2 New Spare Zone Transformer Lower Hutt

The Opex will start once the equipment is purchased, so in this case, we only anticipate around $2,000 per year in testing costs for a spare zone transformer from 2020 on. The opex associated with the portable switchboard would start from 2021.

3.3.4 Option 3– mobile substation plus 1 spare switchboard located in Lower Hutt

This is another option that looks to improve the restoration time in the Hutt Valley. It involves the purchase of a 10 MVA mobile substation (sub option c) which can be stored in a low risk site in the Hutt Valley for deployment anywhere in that area to support restoration efforts. Under our major earthquake scenario, it would be deployed at Korokoro. A mobile substation enables a fast and effective response to multiple scenarios which result in a full zone substation outage.

Design and construction of a mobile substation would mitigate the risk of a total loss of a zone substation as was experienced in Christchurch where the New Brighton substation was unusable after it was damaged by liquefaction. The proposed mobile substation will be similar to the one shown below.

Figure 8 – Mobile Substation

Costs for this substation have been based on the costs of a similar, recently constructed mobile substation.

Option	Sub option	Description	Capex ($m)	Opex ($m)
3 – Mobile Substation in Lower Hutt	c	Mobile Substation at Lower Hutt	1.86	0.00
	b	Portable Switchboard at Lower Hutt	0.90	0.00
	LGK	O/H line Gracefield-Korokoro	**N/A**	**N/A**
	TOTAL		**2.76**	**0.00**

Table 15 – Option 3 Mobile Substation Lower Hutt

Opex costs for both the mobile substation and portable switchboards would begin in 2021.

This option negates the transport time for new line equipment as well as transport time for substation equipment. It is assumed it will take four weeks to install the mobile substation at its new site resulting in 4 weeks outage in total, a restoration improvement of 12 weeks.

To enable the full benefit of a reduction in restoration times requires a new 11 kV switchboard at Petone switching station as well as the construction of the emergency overhead line between Gracefield and Korokoro, sub option LGK. The line cost is included in the cost benefit analysis but excluded from the cost summary here to avoid double counting it. It has been accounted for in the overhead line costs in section 3.2.2 above.

3.3.5 Option 4–refurbish & relocate the Petone spare transformer plus 2 spare switchboards

This option involves moving the 20 MVA 33/11 kV spare zone transformer from Petone now, as it is likely to incur serious damage in the event of a major earthquake – sub option d. This would reduce the outage at Korokoro by 10 weeks but would also require the purchase of two spare switchboards, sub option b x 2, to support the re-energising of the Petone switching station and Korokoro zone substation.

Option	Sub option	Description	Capex ($m)	3 years Opex ($m)
4- Refurbish and relocate spare transformer - Hutt	d	Refurbish and relocate spare zone transformer from Petone	0.42	0.002
	b x 2	2 Portable Switchboards	1.8	0.00
	LGK	O/H line Gracefield-Korokoro	**N/A**	**N/A**
	TOTAL		**2.22**	**0.002**

Table 16 – Option 4 Refurbish and relocate the Spare Zone Transformer Lower Hutt

Opex for sub option d is only $2,000 a year from 2020, while Opex for a new switchboard starts from 2021.

The improvement in restoration time for this option is the same as option 2, i.e. 10 weeks.

To enable the full benefit of a reduction in restoration times of 10 weeks requires the construction of the emergency overhead line between Gracefield and Korokoro, sub option LGK. This cost is included in the cost benefit analysis but excluded from the cost summary here to avoid double counting it. It has been accounted for in the overhead line costs in section 3.2.2 above.

3.3.6 Option 5 - new spare zone transformer in CBD plus 1 spare switchboard

This option involves purchasing another 20 MVA 33/11 kV spare zone transformer (sub option e) to locate in Wellington CBD.

A spare 11 kV switchboard (sub option f) will enable quicker restoration in the event of the loss of a zone substation or major switching station switchboard. This switchboard would consist of a single bus section with one incoming connection and five or six feeders and would be similar to portable switchboards constructed for other lines businesses. This switchboard will be kept in Wellington CBD.

Understanding the restoration improvement for this option and option 6 is complicated by the fact that there are two lines to be built as well as the substation damage to address. Figure 9 below shows the time it would take to transport equipment and complete overhead line builds and substation repairs under the current state and the equivalent times for options 5 and 6.

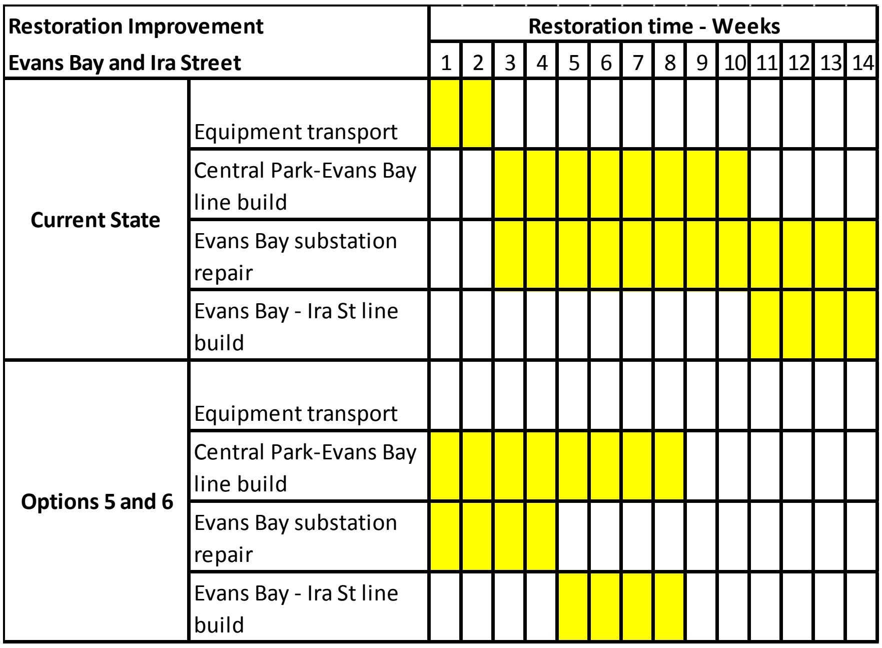

Figure 9 – Restoration improvements for Evans Bay and Ira Street

Both options 5 and 6 result in a six week restoration benefit against the current state and this requires the emergency overhead lines from Central Park to Evans Bay, sub option LCE, and Evans Bay to Ira Street, sub option LEI. These costs are not included in the costs shown here as they have already been accounted for in section 3.2.2 above.

Option	Sub option	Description	Capex ($m)	Opex ($m)
5 – Spare Zone Transformer in CBD	e	1 new Spare zone transformer in CBD	0.93	0.002
	f	1 Portable Switchboard in CBD	0.90	0.000
	LCE	O/H line Central Park- Evans Bay	**N/A**	**N/A**
	LEI	O/H line Evans Bay – Ira Street	**N/A**	**N/A**
	TOTAL		**1.83**	**0.002**

Table 17 – Option 5 New Spare Zone Transformer CBD

The opex costs will begin once the equipment is purchased, so in this case, we only anticipate around $2,000 per year in testing costs for a spare zone transformer from 2020 on. The opex associated with the portable switchboard would start from 2021.

3.3.7 Option 6 – mobile substation in CBD

This option is another option which looks to improve the restoration time in Wellington CBD. It involves the purchase of a mobile substation (sub option g) which can be stored in Wellington CBD for deployment anywhere in that area to support restoration efforts. A mobile substation enables a fast and effective response to multiple scenarios which result in a full zone substation outage.

To realise the full six week restoration benefit would also require the emergency overhead lines from Central Park to Evans Bay, sub option LCE, and Evans Bay to Ira Street, sub option LEI.

Option	Sub option	Description	Capex ($m)	3 years Opex ($m)
6 – Mobile Substation in CBD	g	Mobile Substation in CBD	1.97	0.00
	LCE	O/H line Central Park- Evans Bay	**N/A**	**N/A**
	LEI	O/H line Evans Bay – Ira Street	**N/A**	**N/A**
	TOTAL		**1.97**	**0.00**

Table 18 – Option 6 Mobile Substation CBD

Opex costs for the mobile substation would start in 2021.

3.3.8 Loss of transformers and switchgear - option benefits

To evaluate the full costs and benefits of these options requires costs of all combinations to be considered. This is because the full benefit of any restoration improvement requires the overhead lines to be built in parallel with any repair option at the zone substation.

Option 3, a 10 MVA mobile substation in the Hutt returns the highest net benefit of all options to address the zone substation damage in the Hutt Valley region. The CBD options are much closer with only $0.08 million difference in net benefit between a 20 MVA spare transformer and a 10 MVA mobile substation. This difference is only 4% of the total cost of each option (excluding the overhead lines) and given the range of uncertainties in input assumptions, the two options can be deemed to be on a par with each other.

When two very similar options emerge from an economic analysis, it is usual practice to look at unquantified benefits to enable a final decision. In this case, the mobile substation is a more flexible option that provides a range of BAU operational benefits that a spare zone transformer does not. For instance, a mobile substation is better suited to supporting the continuity of supply of electricity when substation equipment is taken out of service for maintenance. Additionally, should there be any unexpected failure of substation equipment which impacts on security of supply, a mobile substation can be deployed to support continuity of supply to our customers whilst replacements equipment is sourced, acquired and installed.

Given the unquantified benefits support a 10 MVA mobile substation, it is our preferred option to address the zone substation risk in the Wellington CBD.

Region	Option	Description	Sub option Combinations	Current State Outage weeks (a)	New State Outage weeks (b)	Restoration Improvement weeks (a-b)	NPV Costs 2017 $m	NPV Benefits 2017 $m	NPV net Benefit 2017 $m
Hutt	2	Spare zone transformer and 2 switchboards Hutt	a + b + b + LGK	16	8	10	4.64	4.16	-0.48
	3	1 Mobile substation and 1 switchboard Hutt	c + b + LGK	16	4	12	4.62	4.99	0.37
	4	Relocate Petone spare zone transformer plus 2 switchboards Hutt	d + b + b + LGK	16	6	10	4.20	4.16	-0.03
CBD	5	Spare zone transformer and 1 switchboard CBD	e + f + LCE + LEI	14	8	6	4.03	6.42	2.39
	6	Mobile substation CBD	g + LCE + LEI	14	8	6	4.10	6.42	2.31

Table 19 – Loss of Transformers and Switchgear Option Costs and Benefits

3.3.9 Loss of transformers and switchgear - sensitivity analysis

The sensitivity of our options analysis was tested against two of the most uncertain assumptions: the return period and the value of unserved energy. The results are shown below.

Net Benefit 2017 $m				Return Period		Value of Unserved Energy	
Region	Option	Description	Base analysis	150 years	400 years	$15,000/ MWh	$45,000/ MWh
Hutt	2	Spare zone transformer and 2 switchboards Hutt	-0.48	3.68	- 1.52	- 2.44	1.98
	3	1 Mobile substation and 1 switchboard Hutt	0.37	5.37	- 0.88	- 1.97	3.33
	4	Relocate Petone spare zone transformer plus 2 switchboards Hutt	-0.03	4.16	- 1.04	- 1.95	2.46
CBD	5	Spare zone transformer and 1 switchboard CBD	2.39	8.80	0.78	- 0.63	6.18
	6	Mobile substation CBD	2.31	8.73	0.71	- 0.70	6.11

Table 20 – Loss of Transformers and Switchgear - Sensitivity Analysis

While none of the options are economic under the lower unserved energy value, the relativity remains the same and we are of the view that it is highly unlikely that the value of unserved energy would fall as low as $15,000/ MWh in the Wellington region.

The differential of $0.08 million net benefit between options 5 and 6 remains the same under all sensitivities so option 6 is still justified on the basis of the additional unquantified benefits.

The higher return period results in a negative net benefit for the mobile substation in the Hutt valley, option 3. However, the same unquantified benefits would apply to this option as apply to option 6 and this would increase its net benefit overall. Additionally, it is still the option that returns the highest net benefit of all options for the Hutt Valley region.

The sensitivity analysis does not change our preferred option conclusions.

3.3.10 Loss of transformers and switchgear preferred options summary

The preferred options to address the zone substation damage risk are options 3 and 6. These are the options that return the highest net benefit. They also have the advantage of portability which means they can be deployed where they are needed most in the event of any earthquake or other disaster scenario that may eventuate.

We propose buying or building two mobile 33kV/11kV substations similar to ones recently built by a South Island EDB. This will enable a fast and effective response to multiple scenarios and especially where there is a full sustained zone substation outage. This would also add value in other less severe events such as localised fire. The portable switchboard is also a flexible option that could be used at a different location under different damage scenarios.

	Preferred Options	Description	Sub Options	Capex ($m)	3 year Opex ($m)	Total ($m)
Mobile Substations and Switchboard	3	One 10 MVA mobile substation and 1 portable 11 kV switchboard in Lower Hutt	c + b + LGK	2.76	0.00	2.76
	6	One 10 MVA mobile substation in the CBD	g+LCE+LEI	1.97	0.00	1.97
		TOTAL		**4.73**	**0.00**	**4.73**

Table 21 – Loss of Transformers and Switchgear Preferred Options

3.4 11 kV Cable and Equipment Faults – Options

The damaged zones and associated outages under this option are detailed in section 2.10.3.

Based on experience from the Christchurch earthquake, it is expected that a significant number of outages within the network after a major earthquake will be caused by cable faults in the 11kV distribution network.

According to the Kestrel Group that wrote an independent report around Orion's 2010 and 2011 experiences:

> *"Little can be done to mitigate risks to key buried assets such as cables arising from ground failure… Orion has also given particular consideration to spare parts management including seismic risks relating to spares storage."*[24]

There may also be a need to access and repair cables at substations that exist in third party buildings should significant damage to the buildings prevent access, as occurred at 61 Molesworth Street after

[24] Resilience Lessons: Orion's 2010 and 2011 Earthquake Experiences – Kestrel Group Ltd – September 2011

the 2016 Kaikoura earthquake, refer section 2.10.4. There may be the need to circumnavigate the substation within the damaged building, or to alternatively install a new substation outside the building on the roadside which will require us to hold spares for cables, joint kits, 11kV transformers and 11kV switchgear in various areas throughout the region.

The following options were considered.

Option	Description	Capex $m
1	Current State - Do Nothing	
2	Critical emergency spares	4.94

Table 22 – 11 kV Cable and Equipment Faults Options

3.4.1 Option 1 current state – do nothing

The damaged zones and associated outages under this option are detailed in section 2.10.3. We estimate extensive damage to the 11 kV cable network in 20 of our zone areas. Estimating the cost of this outage is difficult given the restoration efforts will progressively bring load back on but an outage of 1 week would cost around $8 million and this would rise to $96 million for a 12 week outage. The real impact of a do-nothing option will be somewhere within this range.

3.4.2 Option 2 – critical emergency spares

To determine the quantum of cable spares, we have assumed that transport links into the CBD are out for 2 weeks and that the Hutt Valley area is isolated for 12 weeks. This estimate was made following a meeting with the Wellington Lifelines Group Project Manager where we discussed the high level of uncertainty around barge access into the Hutt region. There are apparently few suitable landing areas into the Hutt with the most promising option being Seaview Marina, but even this has its challenges. The Wellington Lifelines Group is continuing to scope out potential landing areas and is in discussions with the defence force to assist with this.

This option includes the purchase of two sets of cable fault location equipment, 1,018 joint repair kits, critical distribution equipment and 4,090m of 11kV (300mm, 185mm and 95mm) cable. The quantity of spares has been determined by a reasonable estimate of the work that could be done by the available resource in the CBD and in the Hutt Valley. Assuming the Hutt Valley is cut off for 12 weeks and the CBD for 2 weeks, this should provide sufficient spares to make significant progress in our restoration efforts during that time.

We have 564 11kV ring main units located in areas identified as being at risk of high ground shaking or liquefaction. 28 spare units will be purchased on the assumption that 5% of these units will need replacement. Another 240 units in areas at risk of medium ground shaking or liquefaction, and two spare units will be purchased to cover a 1% failure rate for these.

There is no opex associated with this option as they will utilise the same storage space and be covered by the same storage management fee as the overhead spares.

	Option	Description	Annual Opex ($m)	Capex ($m)
Critical Emergency Spares	2	11 kV transformers	-	0.20
		11 kV switchgear	-	0.73
		Generation connection transformer	-	0.10
		Cable Joints		2.87

	Spare Cable		0.27
	Fault Location Equipment		0.58
	Project management	-	0.17
Total		**-**	**4.94**

Table 23 – 11 kV Cable and Equipment Faults Option Costs

3.4.3 11 kV cable and equipment faults - preferred option summary

Holding critical 11 kV emergency cable spares is the only viable option to address 11 kV cable damage. Access to skilled personnel who can joint cables is the biggest constraint and the quantity of spares has been estimated with that constraint in mind.

We have estimated that access to these 11kV critical emergency spares would avoid around 9,607 MWh based on an estimate of load restored per repair. The NPV benefit of this restoration improvement amounts to $9.45 million and the net benefit is $5.13 million.

3.4.4 11 kV cable and equipment faults – sensitivity analysis

The sensitivity of our analysis was tested against two of the most uncertain assumptions: the return period and the value of unserved energy. The results are shown below.

Net Benefit 2017 $m			Return Period		Value of Unserved Energy	
Option	**Description**	**Base analysis**	**150 years**	**400 years**	**$15,000/ MWh**	**$45,000/ MWh**
2	Critical Emergency Spares	5.13	14.58	2.77	0.69	10.72

Table 24 – 11 kV Cable and Equipment Faults Sensitivity Analysis

The preferred option has a net benefit under all sensitivities, so we can conclude that the analysis is robust to changes in these key input assumptions.

3.4.5 Storage of all equipment

The improvement in restoration time for many of these options is based on having the right spares in the right location. To avoid the transport issues caused by the seven islands issue, we are planning to store our spare equipment as follows, noting that only five of the seven islands are located within our network.

'Island'	Storage Facility	Stored Assets
Wellington CBD	Palm Grove	Mobile Substation OH Line spares – Blocks and foundations
	Duncan Terrace	OH Line spares – poles, conductor & hardware 11kV cable spares & joint kits 11kV transformers and switchgear
Western Wellington	Chaytor Street	11kV cable spares & joint kits 11kV transformers and switchgear
Upper Hutt	Maidstone zone sub	OH Line spares – poles, foundations & blocks
	Maidstone store	OH Line spares – conductor & hardware 11kV cable spares & joint kits 11kV transformers and switchgear
Lower Hutt	Naenae Storage park	Mobile Substation OH Line spares – foundations, blocks & poles
	Taita Store	OH Line spares – conductor & hardware 11kV cable spares & joint kits 11kV transformers and switchgear
Porirua	Plimmerton zone sub	OH Line spares – poles, foundations, blocks, conductor & hardware 11kV cable spares & joint kits 11kV transformers and switchgear

Table 25 – Equipment Storage Locations

3.4.6 Critical sites

Damage to our 11kV assets is the main source of damage resulting in loss of supply to critical sites. Of the 42 identified critical sites the following would be impacted under our modelled earthquake scenarios:

- Te Marua water treatment plant in Upper Hutt. Supply may be interrupted if the Brown Owl sub transmission circuit is damaged.
- there are four critical sites in Lower Hutt that could have their electricity supply interrupted due to cable faults. These include New Zealand Oil Services, the Caltex terminal, Vodafone's cable and internet services at Seaview and a water treatment plant at Wainuiomata. We estimate that we would need to repair 18 faults before all can be restored.
- Porirua Police College is supplied from Mana, however we can supply it from the Porirua zone substation which is expected to perform well
- Southern Wellington - There are 11 critical sites in these areas that supply is expected to be impacted to with approximately 61 cable repairs required to restore supply to all of these. Wellington airport and Centreport make up a large portion of these repairs with the majority of the available supplies to these sites being through liquefiable land.
- Western Wellington - The only critical site in this area expected to suffer damage to the supply is the Karori pumping station which is located very close to the fault. Supply for this site is from the Chaytor St substation next door. Four cable fault repairs are expected to be required to restore this site, the substation building is being strengthened so is expected to survive an earthquake.

Cable repair will be prioritised to ensure load is restored to critical sites as soon as possible following a major earthquake.

3.5 Preventing Damage to Equipment in Buildings

Learning lessons from past events, not least Orion's experience in the 2010/ 2011 earthquakes, has led us to an expansion of our current building strengthening programme to ensure that all significant buildings (including zone substations and other major switching stations) in our network are raised to 67% of the New Building Standard (NBS).

> *" Since the mid 1990s, Orion has invested $41 million increasing the resilience of its network…..All new structural assets and existing strategic structural assets, e.g. sub-transmission lines and zone substations, are designed to withstand a 500 year seismic event with little or no service disruption. The seismic strengthening component cost $6million, an investment estimated to have saved Orion $30 to $50 million in direct asset replacement costs in the earthquakes. The balance between cost and benefits is even more pronounced when societal benefits (i.e. gains to the community that don't appear in Orion's accounts) are taken into account"*[25]

Orion therefore avoided a direct asset replacement cost ratio of between 5 to 8 times what it spent strengthening its significant buildings ahead of the earthquakes.

An NBS level of <34% indicates that a building is "earthquake prone" and an NBS level of 34-66% indicates that a building is "earthquake risk". An earthquake risk building designates that in a moderate earthquake there is a risk of damage to the building but low chance of injury to any occupants.

The expansion of our current building strengthening programme would ensure that all significant buildings in our network are no longer classified as "earthquake risk" buildings under the Building Act 2004.

In the event of damage to a substation building, it is possible that it would be deemed unsafe to enter, making access for restoration and testing purposes difficult and potentially, impossible. Improving all significant buildings up to 67% of NBS reduces this risk.

Ninety one buildings have been prioritised as critical using a combination of:

- **network criticality**: tie point between zone substations, first substation out from a zone substation or forms critical node in the network;
- **connected load and critical consumers:** high load substation that would be difficult to back feed, feeds critical consumers e.g. pump station, hospital, phone exchange; and
- **public and worker safety:** substation is on a major or busy road/pedestrian access way, close to parks/schools, feeding a busy/congested public area.

These buildings, comprising zone substations, switching stations and critical distribution substations have the potential to fail in an earthquake thereby damaging equipment and making the site inaccessible. Our proposed spend of $10.40 million will be phased over the next three years, this will increase the seismic strength of these 91 high priority buildings and greatly improve the networks resilience to seismic events and our ability to support the community post disaster.

25 Resilience Lessons: Orion's 2010 and 2011 Earthquake Experience report by the Kestrel Group, September 2011.

The cost estimates are based on:

- Detailed Seismic Assessments (DSAs) which provide an understanding of the deficient elements within the building driving the NBS rating and therefore the work required to raise the NBS rating;
- experience from the several years of seismic strengthening programme; and
- each substation building's unique characteristics including age, size and construction type, and location (e.g. hillside, main road).

Full details of the cost can be found in Appendix 2.

3.5.1 Seismic reinforcement of significant buildings - benefit

We did not take the same approach for buildings as we did for the other asset classes because this investment is driven by an intention to move to a standard which requires that all significant buildings should be strengthened to 67% of the new building standard (NBS). This is a prudent and sensible step given what we have learned from Orion's experience.

Assuming a similar ratio of avoided asset replacement costs as that experienced by Orion of between 5 to 8 times, we would avoid a rebuild cost between $50 and $80 million.

3.6 Maintaining Data and Communication Links

We currently face an untenable 'chicken and egg' situation caused by our dependence on communication systems. If the telecommunication's links within Wellington fail after a major earthquake (as is expected for at least 10 days), we will have no access to data and engineering information systems which are essential to start the restoration of the power supply. This inability to restore power supply will likely extend the communication outage thus leaving us stuck in a vicious cycle.

The four information systems are described in detail in section 2.10.5 :

1. Geospatial Information System – asset location data;
2. Stationware – protection settings database;
3. Power factory – network modelling tool; and
4. Projectwise – drawings records.

We also have vulnerability on our physical communication links between our Disaster Recovery control centre at Haywards and our main offices in Petone. If this was lost, our ability to co-ordinate the disaster recovery effort would be severely hampered.

We currently rely on cell phones for the majority of voice communication from the control room to field workers. While this is an ubiquitous and reliable method of communication for business as usual operations, the cellular network following a major earthquake is not likely to be able to effectively support recovery operations, through a combination of congestion and the loss of power to cell towers. Cellular network coverage is likely to be unreliable until backup generators are able to be installed at cell towers, and after that will rely on the restoration of the electricity network. A more resilient method of communication post-disaster is a voice radio network dedicated to our operations. This would alleviate the effects of cellular network overloading, and allow us to specify the required period for repeater sites to be able to operate on backup power supplies.

3.6.1 Maintaining data and communication links preferred option and expenditure

Our preferred option is to build three containerised data centres which will locally host our critical systems. We also propose strengthening and diversifying our communications infrastructure.

Three portable data centres will provide the required diversity as there is a real risk that we could lose both transport and communication links between Haywards, Porirua/Tawa and the CBD/ Western Wellington regions. Should we lose communication links, it is essential that we can operate these three islands separately. This will also make it easier for staff to travel to and access a local control centre

Figure 10 – Orion's Data Centre

The data centres will be similar to Orion's which are "*on separate sites and linked by a fibre network ring, create a highly resilient environment for our information systems.*"[26].

For the data centres, it is proposed that:

- we locate a data centre at three sites – Haywards, Newtown and Porirua;
- we improve key communications infrastructure in the building space at Haywards to ensure information accessibility if responding to the event out of our disaster recovery control room there;
- the data centre at Newtown will be installed on the spare land adjacent to the substation. This data centre could be used to set up temporary control at that site if required allowing direct operational control of the CBD; and
- we locate a third data centre at Porirua, to provide redundancy and diversity for the communications system. It will be installed in the outdoor yard and this location also has the added benefit of being close to the Porirua Fire Department and Wellington Free Ambulance.

[26] Orion's 2017 Asset Management Plan

Figure 11 – Newtown Substation as well as the space adjacent to the substation

To strengthen our communication infrastructure and address the current lack of diversity in access to telecommunication systems we propose:

- building a communications connection between our primary control centre at our Petone Head Office to the Disaster Recovery control centre at Haywards as well as between the other two data centres;
- establishing phone exchanges at Petone and Haywards. This removes our reliance on mobile phone networks;
- upgrading the network controllers' phone system to provides additional capabilities and functionalities; and
- replacing the existing voice radio system with a better 'fit for purpose' radio system[27].

The preferred option is to build three containerised data centres to be located at Haywards, Newtown and Porirua. Each data centre will have back up generation (500 kVA) which has already been purchased so is not included in these costs. This option includes the strengthening of our communications infrastructure. The costs are shown below.

	Description	Capex ($m)	3 year Opex ($m)	Total ($m)
Communication Systems	Haywards Data Centre	0.88	0.04	0.92
	Newtown Data Centre	1.51		1.51
	Porirua Data Centre	1.51		1.51
	Phone exchange and system upgrades	0.86	0.26	1.12
	Voice radio system	0.51	0.21	0.71
Total		**5.26**	**0.50**	**5.76**

Table 26 – Data Centre and Communications Costs

27 We have engaged a supplier for three options; a complete system build including WE* owned sites and assets; a system build using existing commercial sites; and dedicated access to the existing Push-Wireless Digital Network

3.6.2 Maintaining data and communication links - benefit

The proposal to add three data centres and improve our communications systems is driven by the recognition that restoration efforts can only begin if we have adequate communication links and access to critical systems and tools. A delay in the restoration of the initial 60% of lost electricity supply has an economic cost of around $110 million a day. Add to this the compounding effect on our communities and businesses being without power for days on end, and there is significant benefit in addressing this relatively simple problem.

4 Summary of Preferred Options

The following table summarises the risks, impacts and recommended short term mitigation options. The capital expenditure for each option has been estimated based on a combination of historical spend and supplier quotes.

Risk being addressed	Proposed readiness initiatives	Capex ($m)	Opex ($m)	Total
33 kV Cable faults	Emergency hardware	4.74	0.67	5.41
Loss of transformers and switchgear	Mobile substations and switchboard	4.73	-	4.73
11 kV Cable faults	Critical emergency spares	4.94	-	4.94
Preventing damage to equipment in buildings	Seismic reinforcement of significant buildings	10.40	-	10.40
Maintaining data and communication links	Communication Systems	5.26	0.50	5.76
	TOTAL	**30.07**	**1.17**	**31.24**

Table 27 – Summary of Preferred Options

5 Conclusion

Our society depends on the reasonable expectation that electricity is available in our day to day lives. While large disruptions can occur, and some interruption is expected, our customers also expect to have supply returned without undue delay, as otherwise people's welfare and the region's economy will quickly suffer.

It is important that we evaluate what affordable steps can be taken to be well prepared and ready to respond to events so impacts are managed to a more tolerable level than doing nothing but waiting for the event to occur and pick up the pieces afterwards.

This business case demonstrates the proposed spend of $31.24 million (including opex spend of $1.86 million over next three years) will significantly improve our readiness to return supply to customers. The investments can be delivered over the next three years to benefit our customers.

As a lifelines utility, we follow a systematic approach to reduction, readiness, response, and recovery planning so we can look to ensure continuity of operation albeit at a reduced level, following a major disruption. The reduction plans are focused on reinforcement of buildings to avoid damage to critical equipment so continuity of service can be maintained; the "readiness" planning is for bringing additional critical spares into the region in acknowledgement of transport links to access spares being unavailable. The "reduction" also extends to single point failure of communications (radio) and data (engineering information) systems which would severely limit response and recovery efforts and hinder health and safety being maintained should the required backup systems not be available.

Bringing critical spares into the region to assist earthquake response readiness in the knowledge that transport links may be cut off for some time (up to 12 weeks) is a prudent step in being able to meet our lifelines obligations to respond and recover following a major disruption.

This business case clearly demonstrates that it is in the best interests of consumers to make further investment in the readiness capability of the electricity network now, to ensure we can safely restore supply to essential services in the shortest possible timeframe. This will benefit our communities and provide wider economic benefits by enabling business continuity.

Appendix 1 – Network Load Assumptions

The following table shows the peak and average load at each zone substation for the 2016/17 year. Given the historical load growth forecast has been relatively flat, for simplicity, we have conservatively assumed no load growth through the period of analysis.

		2016/17 Load (MW)	
Area	WE Zone	Peak	Average
Southern	Waikowhai St	14.73	5.82
	Kaiwharawhara	29.98	16.40
	Karori	15.49	6.68
	Moore St	19.00	9.92
	The Terrace	26.13	13.75
	University	18.05	9.79
	Frederick St	26.13	14.96
	Nairn St	25.01	10.98
	Palm Grove	24.86	12.41
	Hataitai	16.52	7.47
	Evans Bay	12.29	7.50
	8 Ira St	15.17	9.18

		2016/17 Load (MW)	
Area	WE Zone	Peak	Average
North Eastern	Brown Owl	14.35	6.59
	Maidstone	13.40	7.54
	Trentham	13.16	6.62
	Haywards	17.30	7.44
	Naenae	13.95	6.67
	Melling	24.66	12.37
	Waterloo	14.81	7.96
	Petone	Switching Station	
	Seaview	13.59	7.60
	Gracefield	10.91	5.12
	Korokoro	17.48	10.07
	Wainuiomata	16.15	7.11

		2016/17 Load (MW)	
Area	WE Zone	Peak	Average
North Western	Plimmerton	9.68	3.74
	Mana	9.68	3.74
	Waitangirua	13.30	5.79
	Titahi Bay	Switching Station	
	Porirua	19.80	10.98
	Kenepuru	10.55	5.31
	Tawa	14.34	6.91
	Johnsonville	20.06	9.04
	Ngauranga	9.50	4.58

Table 28 – Average and peak load per zone substation

Appendix 2 – Seismic Strengthening Costs

These 91 IL4 buildings, comprising zone substations, switching stations and critical distribution substations have the potential to fail in an earthquake thereby damaging equipment and making the site inaccessible.

Substation	Cost $000s	Substation	Cost $000s	Substation	Cost $000s
Customhouse Quay 40	$180	MacDonald Crescent	$160	415 Adelaide Road	$90
174 Victoria Street (TS847 & TS743)	$150	Makara Radio	$100	130 Rintoul Street	$90
Flagstaff hill (Flagstaff Line Street)	$240	Wainuiomata	$200	254 Willis Street	$100
Frederick Street	$220	Gracefield	$300	Kings Crescent	$80
Wallace Street	$200	Seaview	$160	Haywards Load Control	$150
Wha Street (TS703)	$80	Petone	$160	3 Wall Place	$80
209 Hutt Road	$60	Korokoro	$155	Broken Hill Road A	$80
69 Miramar Avenue	$140	Waterloo	$190	Housing Corporation	$120
Messines Road (TS718) 6	$120	Trentham	$160	Hutt Park Road B	$85
Upland Road 59	$100	Maidstone	$160	Dulux	$80
139 Thorndon Quay	$140	Brown Owl	$170	BP Terminal	$130
Chaytor Street	$120	Ngauranga	$200	Hutt Rec A	$70
22 Donald Street	$70	Johnsonville	$160	Knights Road	$90
92 Washington Avenue	$60	Tawa	$150	Waterloo Road A	$80
Palm Grove	$0	Kenepuru	$240	VIC	$90
Moore Street	$200	Porirua	$120	66 Mabey Road	$80
36 Dixon Street	$110	Waitangirua	$120	Eastern Hutt Road A	$80
Karori	$160	Titahi Bay	$160	Fergusson Drive A	$70
2 Awa Road	$60	Mana	$100	Bathurst Street	$70
Colway Street	$50	Plimmerton	$0	26 Gower Street (TS801)	$90
215 The Terrace	$100	Whitemans Road	$80	Islington Street	$80
Hataitai	$85	Queen Street	$60	Fire Station	$150
37 Mersey Street	$50	41 Barber Grove	$80	Keys Street	$90
Nairn Street	$160	Marsden Street	$50	Whakatiki Street A	$90
The Terrace	$0	Downer Street	$50	Whakatiki Street B	$80
Bowen Hospital	$85	Park Street B	$40	Bill Cutting Place	$90
Wayside West	$60	Johnsonville Town Centre	$60	32 Dragon Street	$130
Ira Street 8	$260	Main Road 24	$70	Awatea Street A	$120
Waikowhai	$215	9 Semple Street	$60	Lyttelton Avenue B	$100
University	$180	25 Mein Street	$80	St Andrews Road	$140
41 Bloomfield Terrace	$70				

Table 29 - Priority 1 Buildings Seismic Strengthening Costs