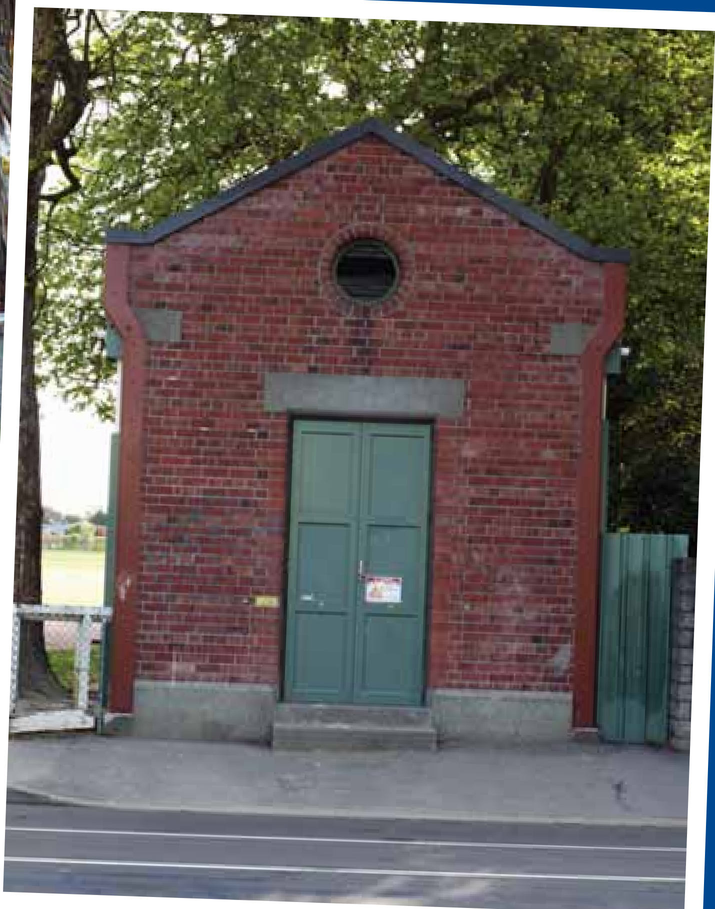
The Value of Lifeline Seismic Risk Mitigation in Christchurch

June 2012



^ This electricity substation had been decommissioned prior to the earthquakes and was unstrengthened

Nearby strengthened electricity substation >

See inside front cover for additional information

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This report was commissioned by the New Zealand Earthquake Commission under its 'Science-to-Practice' Programme.

The terms 'lifeline utility' and 'lifeline engineering' are used in this report.

Lifeline utilities are defined in the Civil Defence and Emergency Management Act 2002. Broadly, lifeline utilities are companies and publicly owned entities delivering infrastructure services in energy, telecommunications, transport and water / sewerage.

Lifeline engineering describes collaborations between lifeline utility representatives and scientists, emergency managers and other professionals aimed to reduce service outage risks and minimise restoration times when outages occur. Regionally based lifeline groups undertake collaborative projects to reduce vulnerabilities (regional group activity commenced in the early 1990s). The New Zealand Lifelines Committee was formed in 1999 to foster regional activity and provide a link to government.

Cover Photos:

The photos illustrate the value of seismic mitigation, in this case, strengthening unreinforced masonry structures, many of which serve as substations in Christchurch's electricity network. The substation on the left had been decommissioned prior to the earthquakes and was therefore excluded from Orion's mitigation programme (it is no longer owned by Orion). The building was severely damaged in the September 2010 earthquake. The substation on the right, approximately 500 metres away, had been seismically strengthened and was largely undamaged. Strengthening work of this nature greatly assisted electricity restoration in Christchurch following the earthquakes. (Photo source: Orion New Zealand Ltd.)

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Foreword

Christchurch has shown us that sometimes things go wrong and, unfortunately, we sometimes experience significant emergencies. This just serves to highlight that risk is a constant companion in all that we do.

Some risks are minor but others can be catastrophic. The purpose of this report is to show from Christchurch that steps can be taken to manage risk, but that these efforts need to focus on the things that really matter. The way we think about managing risk depends on the way we define it – we can't do anything about the likelihood of an earthquake, but we can do a lot about whether the consequences of an earthquake will be costly. This report helps us learn that many of these mitigation steps are not difficult to do, and that they are not always costly. But the time to act is now – before we experience an emergency.

The Ministry of Civil Defence & Emergency Management is working hard to do what it can to manage risks. Our contribution is in setting emergency management frameworks covering the 'four Rs'– risk reduction, readiness, response and recovery – and in promoting healthy arrangements to deliver good outcomes through the sector. While we can't ourselves ensure good outcomes, it is our responsibility to encourage local communities to adopt good mitigation practices.

This report is about the substantial range of risk reduction and readiness steps taken by lifeline utilities in Christchurch over recent years to reduce the impact of earthquakes. The work leading to the report of the Christchurch Engineering Lifelines Group in the 1990s, *Risks and Realities*, is the foundation for much of the measures adopted. As the report notes, seismic mitigation undertaken by Christchurch lifelines since *Risks and Realities* has served Christchurch well in reducing losses that would otherwise have been much greater. The mitigation work also helped facilitate improved emergency responses and recovery. The report shows that the costs of seismic risk mitigation in Christchurch will have been repaid many times over. It is therefore a most worthwhile investment.

Christchurch, and New Zealand, owes a debt of gratitude to the Christchurch lifeline community for its pre-earthquake preparation. It has set an example and it was most pleasing to see the lifelines across the many sectors step up to the plate, in challenging circumstances, and play their part in the immediate post-earthquake responses. I would like to acknowledge that very substantial contribution this made to the well-being of Christchurch citizens and businesses.

I also acknowledge EQC's historical and continuing support for these risk reduction activities and its sponsorship of this report. Lastly, thanks go too to the New Zealand Lifelines Committee for making arrangements for the report's preparation and release.

I commend this review to all agencies and individuals who have an interest in helping their communities prepare effectively for an emergency.

John Hamilton
Director Civil Defence

June 2012

Executive Summary

Christchurch and Canterbury suffered damaging earthquakes in September 2010 and February 2011. Underground infrastructure assets (pipes and cables) were severely impacted; unreinforced masonry structures and a number of reinforced concrete structures, including many owned by lifeline utilities, were also damaged.

Lifeline vulnerability to natural hazards including earthquakes had been given prominence in a comprehensive project undertaken by the Christchurch Engineering Lifelines Group in the first half of the 1990s. The project report *Risks and Realities* records the processes, findings and mitigation steps (risk reduction and readiness) identified at the time (Christchurch Engineering Lifelines Group, 1997).

The substantial programme of seismic mitigation undertaken by Christchurch lifeline utilities since *Risks and Realities* has served Christchurch well in reducing losses and facilitating emergency responses and recovery. The damage would have been greater and the response slower if the steps recommended in *Risks and Realities* and other preparatory work fostered by the Group had not been taken. For example, Orion's electricity distribution seismic strengthening programme, commenced in 1996 and progressed systematically each year, cost $6 million and is estimated to have saved $60 to $65 million in direct asset replacement costs and repairs.

The purpose of the present report is to crystallize the experience and learnings from the recent earthquakes to foster further, well-targeted, seismic mitigation in New Zealand. Accordingly, the report:

- comments on the value of pre-earthquake Christchurch lifeline engineering work to both the participating organisations and to the wider community
- suggests the elements that contributed most strongly to the benefits and that should therefore feature within the core activities of other lifeline utilities and groups in earthquake-prone areas.

The main elements that contributed most strongly to the benefits, and that should therefore feature in work programmes, are listed below:

- **Asset awareness and risk reduction: identifying points of particular vulnerability.** Issues likely to arise include:
  - surveying for site-specific risks, for example buildings that do not meet AS/NZS1170 loading standards (including where assets are placed on top of existing structures), and where liquefaction is possible
  - identifying likely fracture points (for example where cables and pipes enter structures such as buildings and bridges)
  - identifying cases where restraints to restrict movement of sensitive equipment are needed.
- **Readiness: taking steps to improve organisational performance in emergencies,** such as:
  - ensuring fit-for-purpose operating frameworks for business continuity
  - working collaboratively with other lifelines and relevant agencies on common issues such as looking for key interdependencies, examining generator sufficiency and planning for petroleum outages, and establishing lifeline utility coordination arrangements to facilitate emergency response
  - ensuring that engineers and contractors are available quickly to meet emergency needs
  - managing spare parts to promote availability when unexpected pressures arise.

- **Perseverance: maintaining the effort over time while communicating realistic expectations.**
  - Lifeline utilities that have retained a consistent focus on seismic mitigation have benefitted most significantly (asset management planning and similar annual-cycle processes provide an appropriate setting for much of the required work).
  - Improving end-user knowledge of infrastructure reliability and encouraging users (particularly organisations with emergency response roles such as hospitals) to plan for a level of infrastructure outage in the more extreme events are also essential.

Many of the elements that contributed to the benefits are not costly. For example, the inter-corporate and inter-personal relationships developed as *Risks and Realities* was prepared proved most valuable during earthquake responses.

The value of seismic mitigation by lifeline utilities (and by others) is in principle the reduction in the overall community loss resulting from the mitigation work. A range of New Zealand and overseas studies have found substantial benefits from seismic and other mitigation. For example, the United States-based Multihazard Mitigation Council (MMC), reporting on its landmark study on the value of hazard mitigation, concluded that "a dollar spent on mitigation saves society an average of $4" (Multihazard Mitigation Council, 2005).

Related issues have also been explored within New Zealand by lifeline groups and others. For example, modelling by Market Economics associated with Exercise Ruaumoko, a large civil defence exercise based on a volcanic eruption in Auckland, suggested the Auckland region would suffer a 47 per cent reduction in GDP, but that this could be reduced to 40 per cent if businesses had effective mitigation measures in place. A main theme of a 2010 infrastructure investment study by the Centre of Advanced Engineering is the importance of considering societal impacts when making infrastructure investment decisions: "An evaluation of [networks'] ability to withstand the effects of external events and recover from damage should be included in the [investment] analysis" (Centre for Advanced Engineering, 2010).

Taking into account the direct and indirect losses that arise from earthquakes (including downstream losses arising from infrastructure interdependencies), it is clear that the costs of seismic risk mitigation in Christchurch will have been repaid many times over.

Risks and Realities stands out as a very good example of collaborative work aimed at hazard risk reduction. It is often difficult to find individuals and organisations with the ability, incentive and standing to form effective collaborations on issues of public importance, not least high-impact low-probability ones. Canterbury and New Zealand are fortunate to have received the benefit of the efforts of a great many individuals and organisations who have contributed to collaborative lifelines engineering processes of which *Risks and Realities* is a prime example.

A CLARIFICATION OF THE RISK MANAGEMENT APPROACH IN THIS REPORT

This report describes many of the lifeline *risk reduction* and *readiness* seismic measures adopted in Christchurch, using the over-arching term *'risk mitigation'*. (*Risk reduction* may be thought of as asset-related work often with a large engineering content, while *readiness* refers to organisational preparedness issues including inter-organisational collaboration.)

Use of *'risk mitigation'* as an over-arching term reflects a view that the issue in question is the risk of an earthquake causing losses to the community as a whole.

The approach differs from an alternative often used in lifeline circles, in which mitigation is used more narrowly to refer to physical *risk reduction* alone, with *readiness* measures treated as additional steps within an overall risk treatment programme.

Introduction

The 2010 and 2011 Earthquakes

A shallow magnitude 7.1 earthquake occurred on 4 September 2010 on a previously unknown fault near Christchurch. Widespread damage resulted throughout the city and the surrounding area. A second shallow earthquake, magnitude 6.3, occurred closer to Christchurch on 22 February 2011. There were 181 deaths. Damage from this earthquake significantly exceeded the September event, including collapse of many buildings.

Two severe aftershocks occurred on 13 June 2011. Further damage occurred, including to infrastructure. However, the June events, together with significant shocks in December 2011 and January 2012, have generally been treated as setbacks. This report focusses on the September 2010 and February 2011 earthquakes.

Earthquake damage can arise from shaking and ground failure (for example, lateral spreading, liquefaction, landslide and / or rock-fall). Large ground motions were experienced in built areas in September and very large motions were recorded in the city in February.[1] These were beyond accepted design levels. Given shallow epicentres, shaking intensities dissipated over short distances. Liquefaction and lateral spreading were pervasive in both events; considerable rock-fall damage also occurred.

Total damage costs from the earthquakes have been estimated at $20 billion (New Zealand Treasury, 2011). This is about 10 per cent of GDP, a larger proportion than in other major disasters overseas (for example, Hurricane Katrina and the Fukushima earthquake).

Underground infrastructure assets (pipes and cables) particularly suffered extensive damage; unreinforced masonry structures and a number of reinforced concrete structures, including many owned by lifeline utilities, were also damaged. Damage to lifelines would have been greater had the earthquakes been longer in duration.

GOVERNMENT RESPONSE

A state of emergency was declared in the three territorial local authority (TLA) areas (Christchurch, Selwyn and Waimakariri) immediately after the September 2010 earthquake and the National Crisis Management Centre (Beehive basement) was activated in support. Legislation aimed to expedite recovery was passed within two weeks.

The February earthquake led to a declaration of a state of national emergency. The response was coordinated by central government working from Christchurch in an organisational structure known as the Christchurch Response Centre, based broadly on pre-established response models but with improvised features to integrate central, regional and TLA roles and perspectives.

Further wide-ranging legislation was passed and the response was soon transitioned to a new entity, the Canterbury Earthquake Recovery Authority (CERA, established in March 2011). An alliance known as Stronger Christchurch Infrastructure Rebuild Team (SCIRT) – involving CERA, the Christchurch City Council, the New Zealand Transport Agency (NZTA), and five contractors (City Care, Downer, McConnell Dowell, Fletcher Construction and Fulton Hogan), announced on 6 May 2011 – is expediting much ground-level and below-ground infrastructure recovery.

[1] Horizontal acceleration of 1.5g and vertical acceleration of 2.0g or more were recorded in February. Very high accelerations were focussed on a small area – central and eastern Christchurch.

Lifeline utilities worked actively within the local Civil Defence Emergency Management (CDEM) response frameworks and at the National Crisis Management Centre in the immediate post-earthquake environments, providing information, seeking advice and assistance, and offering help. The adequacy of these arrangements is currently under consideration as part of the Independent Review of the Response to the Christchurch Earthquake commissioned by the Ministry of Civil Defence & Emergency Management.

History

The first of a series of regional projects on infrastructure vulnerability to natural hazards addressed Wellington earthquake issues (Centre for Advanced Engineering, 1991). The Wellington project can be regarded as an evolution of pioneering New Zealand engineering work on performance of buildings in earthquakes. Damage to electricity and other infrastructure assets in the 1987 magnitude 6.3 Edgecumbe earthquake had added impetus to infrastructure vulnerability consideration.

Vulnerability to earthquake and other hazard damage to Christchurch lifelines was subsequently given prominence in a comprehensive project undertaken by the Christchurch Engineering Lifelines Group in the first half of the 1990s. The aptly named report, *Risks and Realities*, records the processes, findings and mitigation recommendations (covering risk reduction and readiness) identified as the project was undertaken (Christchurch Engineering Lifelines Group, 1997).

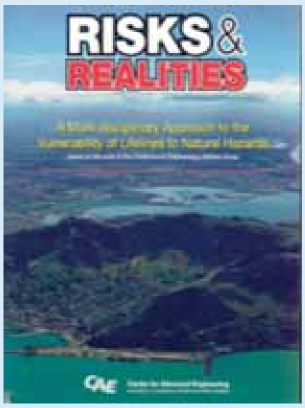
RISKS AND REALITIES

The report by the Christchurch Engineering Lifelines Group, *Risks and Realities – A Multi-Disciplinary Approach to the Vulnerability of Lifelines to Natural Hazards*, addressed Christchurch City's vulnerability to infrastructure damage from natural hazards. The report, prepared by the Christchurch Engineering Lifelines Project, took a broad approach to address hazards including earthquakes, flooding, tsunami and meteorological hazards. Lifeline sectors were covered (that is, energy, telecommunications, transport and water / sewerage), but the project also included emergency buildings (broadcasting, police and fire stations, ambulance bases, and so on).

The study scope was limited to what was then Christchurch City and did not include areas that are now part of the city or the wider Canterbury region.

The report was completed in 1994 (including an international peer review), updated in 1996 and published by the Centre for Advanced Engineering (CAE) in 1997.

Risks and Realities stands out for the careful and detailed work undertaken by task groups including lifeline utilities. Utility networks were described, broken down to component level, with each assessed for vulnerability to the various natural hazards. Assessments considered 'importance' to the network (recognising wider impact of damage of the component in question), and 'vulnerability' and 'damage impact' estimated in three timeframes: immediately after the event, period following, and time for return to normality. Assessments were presented on vulnerability charts similar to those used earlier in Wellington.[2] Mapping work included overlaying networks and hazards. Twenty-one of the resulting hazard maps, much reduced in size, are included in the *Risks and Realities* report.



Assessment was followed by consideration of mitigation, a main focus of the present report.

[2] *Risks and Realities* also includes a brief section on interdependencies. For this, matrices display interdependencies for two scenarios: both for normal operation (if A fails, B fails) and for response (restoration of B requires restoration of A first).

A great many individuals from lifeline utilities, local government (including civil defence emergency management personnel) and others contributed to *Risks and Realities*. That report, and the work on which the report is based, reflects their enthusiasm and commitment, in many cases ongoing over many years.

A perhaps unexpected outcome of these, and other regional projects that followed, was the recognition of a common cause and the high degree of socialisation that developed between the personnel involved. The ensuing benefits have included the formation of regional lifeline groups. The groups' activities have enhanced emergency response coordination *inter alia* through specific preparatory projects and strengthened relationships, supplementing more formal CDEM arrangements. The Christchurch Engineering Lifelines Group, now known as the Canterbury Lifeline Utilities Group, is a well-organised and well-functioning example.

New Zealand's CDEM arrangements were also under review in the late 1990s. A review outcome, the Civil Defence Emergency Management Act 2002 (the Act), calls for a risk-based approach to hazard management built around risk reduction, readiness, response and recovery (known as the '4 Rs'). Further, section 60 of the Act *inter alia* places obligations on lifeline utilities to ensure that they are able to function, if necessary at a reduced level, during and after an emergency. Section 60 also requires lifeline utilities to participate in CDEM planning. The CDEM framework further provides for lifeline utilities to be involved in CDEM hazard and risk management through regional CDEM groups.

Efforts to understand seismic risks to infrastructure continued after *Risks and Realities*. For example, Christchurch lifeline representatives visited Kobe following the 1995 earthquake, leading to further mitigation in Christchurch.

More recently, a set of CAE papers on infrastructure issues published in 2010 emphasises the case for recognition of societal benefits in infrastructure investment decisions, noting for example "an evaluation of [infrastructure networks'] ability to withstand the effects of external events and recover from damage should be included in [infrastructure investment] analysis" (Centre for Advanced Engineering, 2010).

EARTHQUAKE COMMISSION AND LIFELINES

For many years, the Earthquake Commission (EQC) has been prominent in fostering discussion and promoting understanding of a range of issues relating to earthquake costs and mitigation.

The EQC was one of the principal sponsors of the first regional project on infrastructure vulnerability to natural hazards, which addressed Wellington earthquake issues (Centre for Advanced Engineering, 1991). EQC was also a sponsor of the 1994 project undertaken by the Christchurch Engineering Lifelines Group that led to *Risks and Realities*.

EQC and the New Zealand Centre for Advanced Engineering (CAE) sponsored a landmark conference on Wellington earthquake issues in 1995. Following that conference, NZIER prepared a preliminary scoping study for EQC on the economic impact of a magnitude 7.5 Wellington earthquake, with a focus on implications for EQC (Savage, 1998). The framework outlined in that paper remains relevant today.

More recently, EQC was amongst the sponsors of a CAE conference on infrastructure resilience held in Rotorua in 2005.

In the immediate post-earthquake period, lifeline performance was the main theme at the National Lifeline Forum held in Christchurch in November 2011 (the Forum, held each year, is organised by the NZLC with EQC sponsorship). This report draws *inter alia* on views expressed at that Forum.

The Present Report

A number of reports have been prepared on the impact of the 2010 and 2011 earthquakes on lifelines, buildings generally and the community. A prominent example is the work of the United States-based Technical Council on Lifeline Earthquake Engineering (TCLEE).[3] Many of the infrastructure providers have prepared their own post-earthquake reviews. Further reports will no doubt appear in due course.

The lifeline material in these other reports generally includes attention to areas where performance might be improved and identifies learnings for wider use in New Zealand and overseas. The present report however focusses on successful Christchurch lifeline initiatives since the early 1990s. Specifically, this report:

- comments on the value of pre-earthquake Christchurch lifeline engineering work to both the participating organisations and to the wider community
- suggests the elements that contributed most strongly to the benefits, and that should therefore feature within the core activities of lifeline utilities and other lifeline groups in earthquake-prone areas.

The work leading to *Risks and Realities* was very resource-intensive. A main purpose of the present report is to crystallize the experience and learnings to foster further, well-targeted, seismic mitigation in New Zealand.

This report has been compiled from available documented information, responses to numerous enquiries to lifeline utilities, and ideas offered by the utilities at a meeting of the Canterbury Lifeline Utilities Group (August 2011) and at the National Lifeline Forum (November 2011). The numerous contributions from the many parties consulted are gratefully acknowledged.

The report is structured as follows:

- The next section, entitled '*Risks and Realities* – Main Mitigation Measures', summarises the main mitigation measures identified and recommended in *Risks and Realities* (sub-sections cover risk reduction and readiness).
- Seismic mitigation work immediately following *Risks and Realities* is then described.
- A major section, 'Mitigation Work Undertaken Following *Risks and Realities*', draws attention to many of the mitigation steps taken during ensuing years to the time of the earthquakes (again, sub-sections cover risk reduction and readiness).
- This is followed by a section assessing the benefits of mitigation. Overseas studies and relevant New Zealand work are briefly summarised.
- Concluding comments draw the report to a close.

[3] TCLEE's draft report was available at the time of writing on the editor's website http://web.me.com/eidinger/GE/Home.html (Technical Council on Lifeline Earthquake Engineering, 2011).

Risks and Realities – Main Mitigation Measures

This section summarises the main mitigation (risk reduction and readiness) measures identified and recommended in *Risks and Realities* (Christchurch Engineering Lifelines Group, 1997).

Risk Reduction

Risks and Realities draws attention to the importance of:

- retrofitting to improve the seismic performance of infrastructure assets
  - Seismic performance of buildings and other structures that are most at risk and pose significant threats should be reviewed and strengthening done where indicated.
  - A special case relates to buildings with Importance Levels 3 and 4.[4] These need to be brought up to standard.
  - Another special case relates to bridges, where strengthening connections between superstructures and substructures, increasing column strength and ductility, strengthening or renewing retaining and approach structures, strengthening lateral / longitudinal restraint mechanisms and other retrofitting were recommended.
- adopting best practice in design, choice of material and installation
  - Includes installing flexible connections where assets (for example, buried assets such as pipes and cables) enter buildings, especially in liquefaction zones. Special attention to underground assets (for example electricity and telecommunication cables, and pipes) is also necessary where they approach bridges.
- undertaking site-specific assessments of liquefaction risks, for example geotechnical and structural investigation of vulnerable bridges on primary or other significant routes where simple mitigation measures are not immediately apparent
- adding diversity and redundancy where cost-effective
- installing restraints to restrict movement of sensitive equipment. This includes large items such as generators and transformers (foundations should also be checked) and also smaller items such as computer equipment. It also includes building service plant such as diesel tanks and light fittings, and equipment installed on rooftops.

[4] Importance Levels are defined in Table 3.2 of the loadings standard AS/NZS1170 Part O. Structures with emergency and post-disaster functions are covered under Importance Levels 3 and 4 respectively. Many infrastructure buildings fall into Level 4, and accordingly need to be designed so that services may continue following severe earthquakes. Further information on this matter, together with thoughts on further work needed to complete the policy framework, have been published in a 2006 article in the Journal of the New Zealand Structural Engineering Society (Brunsdon, 2006). A particular area of ambiguity (noted in that article) relates to transmission assets installed on existing structures (building rooftops are a case in point).

Readiness

Risks and Realities notes that safety of the public and repair crews is generally the top priority in lifelines' emergency response planning.

Risks and Realities draws attention to the need for:

- recognition of interdependency needs with other lifeline providers so that appropriate mitigation and restoration priorities can be included in investment and planning
- response planning, including:
  - procedures for prioritising service continuity and repairs
  - operational / control procedures and training
  - ensuring that contractors with response roles are available, and that structural engineers are commissioned to undertake prompt building inspections
- developing a spare parts policy that takes into consideration emergency needs and likely delivery delays, especially for imported items. This includes ensuring that spare parts and other items are stored in locations likely to be accessible following earthquakes and on secure racks, and that larger items are seismically restrained
- establishment and management of mutual aid arrangements
- installation of stand-by generation where needed, ensuring that emergency generators are regularly tested under load and that a good supply of fuel is stored and regularly turned over, and that fuel lines are flexible.

Seismic Mitigation Work Immediately Following Risks and Realities

Risks and Realities contains a chapter (Chapter 11) noting mitigation developments immediately following development of the material above (Christchurch Engineering Lifelines Group, 1997). Some summarised points:

- Much equipment was bolted down, spare parts restrained and similar restraint actions taken.
- Seismic strengthening was improved at some reservoirs and pumping stations; isolating valves at bridges and flexible joints, at selected pump stations, were installed; and planning relating to valve shut offs was improved.
- Transpower reviewed assets in the Christchurch region to determine earthquake reliability, taking into account order and delivery lead times for key items (could be up to 12 months for transformers). Urgent action was taken to mitigate areas of concern. Transpower also strengthened major transformers and other essential equipment (a nationwide, ongoing initiative).
- Orion (or Southpower as it was then known) strengthened bridge approaches to protect cables at the transition between surrounding materials with sharply differing carrying characteristics, assessed substations[5] and designed generic systems for strengthening network substations. The control room was re-located, insecure buildings were removed, and spares were moved to more secure sites and restrained.
- Improvements were made at bridges including strengthening connections between superstructures and substructures, increasing column strength and ductility, strengthening or renewing retaining and approach structures, and strengthening lateral / longitudinal restraint mechanisms.

[5] *Risks and Realities* notes that of the 528 substation structures, 253 needed strengthening. The cost was expected to exceed $4 million, but *Risks and Realities* noted that "this is only a fraction of the cost of replacement".

- Planning was improved in relation to key roads, bridges and the Lyttelton Tunnel.
- Additional equipment, such as generators and portable pumps, was purchased.
- Improvements were made at the airport and port.

Much mitigation work was taken forward within annual maintenance plans. Orion noted, for example, that managing natural disaster risk had become part of their annual planning. Telecom said that recommendations in *Risks and Realities* were part of its ongoing risk management programme, adding that *Risks and Realities* had resulted in additional mitigation work in Christchurch (notably bracing and anchoring equipment). Christchurch City Council noted that bridge strengthening requirements were being taken into account in maintenance programmes and the NZTA (known at that time as Transit) said that a rolling programme for seismic strengthening of State Highway bridges had commenced.

Risks and Realities notes that "one of the continuing benefits of engineering lifelines projects is the inter-utility contact between persons who would be required to work together in … a major emergency". Cross-sector engagement between different lifelines increased and became more systematic as a result of the work leading to *Risks and Realities*. Christchurch City Council developed response plans, framed broadly to take into account emergencies wider than infrastructure-only events. Linkages were developed with CDEM planning.

Risks and Realities also notes that much potentially valuable mitigation work, including asset-related work, is not costly.[6] Restraining equipment, reviewing and improving spare parts practices, response planning and much seismic retrofitting, can be (and was) done without great expenditure.

Mitigation Work Undertaken Following *Risks and Realities*

This section describes mitigation work undertaken by lifeline utilities following publication of *Risks and Realities.*

The material is structured based on the measures identified in the earlier section entitled *Risks and Realities* – Main Mitigation Measures. The sub-headings on the left-hand side in the following pages repeat the main *Risks and Realities* measures.

The material on the right-hand side draws together many mitigation examples. The material on the right should not be regarded as exhaustive. Many good examples are unlisted due to space limitations or more simply because much good work has not come to attention, being done behind the scenes.

Notes are included on the value of specific mitigation steps where information is available.

The material in this section has been summarised from a variety of sources including reports and conference presentations made available by lifeline utilities describing their earthquake experience (much of this material is on the utilities' websites), reports prepared as part of more general reviews (the work of the TCLEE is a prominent example (Technical Council on Lifeline Earthquake Engineering, 2011)), notes from meetings and interviews, and personal correspondence.

[6] The approaches suggested in *Risks and Realities* – robust assets, coordinated responses and realistic end-user expectations – also form the basis of current work by the New Zealand Lifelines Committee on infrastructure resilience.

Risk Reduction Measures

Retrofitting to improve seismic performance of assets

Orion: Prompted by the work leading to *Risks and Realities*, Orion undertook a seismic strengthening programme commencing in 1996 and progressing systematically each year. By the time of the earthquakes, improved seismic standards had been achieved (or substantially achieved) in relation to district / zone, network and distribution substations, and to major cables including cables over bridges. The seismic strengthening cost $6 million, an investment estimated to have saved Orion $60 to $65 million in direct asset replacement costs and repairs.

Transpower also undertook much retrofitting since *Risks and Realities*. For example, soon after completing the work on which *Risks and Realities* was based, Transpower carried out a review of its Christchurch region assets to determine seismic reliability. Major transformers at Transpower's Islington and Bromley substations were significantly strengthened as a result of this review. [7]

Performance of Transpower Assets

Transpower notes that Transpower substations and primary plant suffered only minor damage in the two earthquakes. A small number of equipment failures in the 2010 earthquake revealed performance short of current performance requirements although the failures did not significantly impact supply. Greater damage suffered during the 2011 earthquake was to be expected given the much larger peak ground accelerations. The very timely transmission restoration following the two earthquakes substantially removed grid events as a source of outage for end-consumers. Total repair costs from the 2011 earthquake amounted to a modest $150,000.

Telecom also undertook earthquake strengthening on exchange buildings. The damage to these buildings was minimal considering the ground acceleration forces experienced (only two buildings suffered significant damage in February 2011). Unrestrained lighting systems were the main plant failures. *Chorus* also notes that the main points of failure were at the interface points between old and new structures where buildings had been extended.

Lyttelton Port: All port facilities performed to a level that has allowed resumption of operations within days of the largest earthquake events. The only trade unable to be supported has been cruise shipping.

Much strengthening of wharves was undertaken in the years prior to the earthquakes. This included additional beams installed under the container terminal. The terminal was damaged but the strengthening contributed to rapid resumption of serviceability.

7 Pre-earthquake seismic strengthening had also been undertaken at other substations in the Christchurch area following the 1987 Edgecumbe earthquake.

The berthing and mooring systems at the oil berth were also upgraded. Improvements were sufficient for post-earthquake serviceability, although some ground deformation and damage did occur.

Steps were taken to strengthen Wharf 7. Wharf 7 played an important emergency response role immediately after the February earthquake – it was cleared for use by HMNZS Canterbury to offload cargo within two hours of the main event.

Completion of a seismic study of the port and its structures, including soil / structure modelling, was undertaken some years before the earthquakes. This information, plus a completed new wharf design to a high level of seismic performance, provided a basis for rapid assessment and design of remedial measures. As a result, temporary works were able to be commenced shortly after earthquake damage. An important example of this was the coal export berth that has required a temporary support structure to be built to support the ship-loading equipment.

Christchurch City Council Water: The Christchurch City Council undertook a seismic upgrade programme for its water tanks during the decade prior to the earthquakes. While there was extensive damage and depressurisation in much of the water system, with one exception, no damage occurred to the tanks in September 2010. Much greater tank damage occurred in February 2011.

Special case: buildings with Importance Levels 3 and 4

Orion occupies a multi-building site in central Christchurch. Office buildings, acknowledged in *Risks and Realities* as not up to expected standards for lifelines, were unusable following the February earthquake. However, Orion had invested in a nearby hot site for immediate essential control functions, and was also soon able to occupy an older but robust on-site building for general office use. This level of preparedness (along with other preparedness and good post-earthquake performance) enabled Orion to commence repair work within a day or two of the earthquake.

Transpower follows the New Zealand Standard 1170.5:2004 Structural Design Actions – Earthquake for structures having post-disaster functions. Essential buildings and facilities are deemed Importance Level 4 structures in terms of AS/NZS 1170.0:2000. Although the majority of Transpower's buildings affected by the earthquakes were designed prior to Transpower's current policy and no major strengthening work had been carried out, they met or exceeded the current performance criteria.

Vodafone: Although its business activities commenced after *Risks and Realities*, all of Vodafone's national network components, including the Christchurch 'strong node', are built to withstand strong earthquakes and other hazards. Although the strong node does not fully comply with current Importance Level 4 standards (the code was updated soon after it was built in 2000), it suffered no damage in the earthquakes and was available for immediate reoccupation (it was used as Vodafone's response base – the building has its own generation and built-in water storage for cooling and human consumption).

Kordia's major transmission sites at Mt Grey, Sugarloaf, Mt Pearce and Hororata (along with numerous television translator sites) were designed and maintained to AS/NZS 1170 and AS 3995 Importance Level 4 standards. These structures were undamaged. All transmission buildings also survived without damage and services using these assets were uninterrupted.

Other lifeline utilities, including *Contact Energy* (Rockgas), took specific steps to evaluate buildings for earthquake performance before leases were signed.

Special case: bridges

NZTA had undertaken a (national) seismic-risk screening programme on its bridges. Seventeen Canterbury bridges, including many in or near Christchurch, were identified as at risk and had been retrofitted at a cost of $2 million. NZTA notes that this work prevented more critical damage.

The February earthquake caused much greater damage to State Highway bridges than the September earthquake (damage was $6 million in February). The February ground shaking was well in excess of design standards. However, while a small number of bridges were seriously damaged, only one was closed, this due to approach settlement (it was reopened after emergency repairs within a day; others remained open albeit restricted to a single lane in some cases). Damage was generally due to approach fill and foundation instability (that is, slope failure and liquefaction / lateral spreading). Six required monitoring.

State Highway 74 Horotane Valley Overpasses 1 and 2

Tunnel Road is the main freight route between the port and Christchurch. The alternative route, Evans Pass, was unusable. Pressure therefore arose for these bridges to be opened for recovery-related overweight vehicles such as mobile cranes and excavators (the bridges were already in use by fuel tankers and for other essential freight). Surveys indicated that settlement had continued following aftershocks. Single movements of overweight vehicles were permitted subject to case-by-case evaluation and survey confirmation that the bridge was stable.

Christchurch City Council also undertook much mitigation of seismic risk on its bridges following *Risks and Realities*. This featured tying components together. Ferrymead Bridge was included in this mitigation work.

Ferrymead Bridge

The Christchurch City Council's Ferrymead Bridge is an important transport link to Sumner, Redcliffs and Mt Pleasant. It serves as part of the route from the port to the city for overweight / oversize vehicles, and for vehicles carrying various classes of dangerous goods normally prohibited from the Lyttelton Tunnel. The bridge also carries water, sewerage, electricity and telecommunication lines.

The bridge was mentioned in *Risks and Realities* as being 'extremely vulnerable' to seismic events such as liquefaction-induced loss of lateral support to piles, approach embankment settlement and lateral spreading. The risks were first identified in the initial phases of the work leading to *Risks and Realities* (an October 1994 lifelines workshop). Work to widen and strengthen the bridge was underway at the time of the earthquakes.

Little ground failure occurred in the area in the September earthquake. However, the bridge sustained significant damage in February from lateral spreading – abutments rotated, piers were displaced and piles settled, although the superstructure was relatively unaffected.

Ferrymead Bridge was reopened to light traffic two days after the February earthquake following load testing and installation of monitoring systems. Speed and weight restrictions were lifted two months later, after completing securing work and re-levelling of the city pier.

Adopting best practice in design – choice of material and installation

Transpower is engaged in the development of, and draws from, international seismic design standards for high voltage equipment. Transpower notes that its ongoing resilience work includes plans to continue to use and support the development of standards in this area.

Orion: All new structural assets and existing strategic structural assets, for example sub-transmission lines and zone substations, are designed to withstand a 500-year seismic event with little or no service disruption.

Chorus prefers undergrounding for major links (a protection against weather-related events). Fibre coiling inside access pits, a step taken to facilitate maintenance, also mitigated the effects of land movement.

Mobil (owner and operator of the Woolston petroleum terminal) follows recognised standards in tank farms, and tank design and operation, and is applying lessons from Christchurch in its international operations. Mobil is also committed to fibreglass service station tanks and has noted that these retained integrity in the Christchurch earthquakes.

Contact Energy (Rockgas) notes that medium-density polyethylene (MDPE) pipework and installations in their network performed well (the network delivers LPG). The decision to use MDPE was based on international experience, primarily performance in the 1995 Kobe earthquake. No leaks were found on Rockgas's mains. More generally, Contact Energy (Rockgas) has systematic processes to ensure assets are built to (or beyond) suitable loadings.

Special case: installing flexible connections where buried assets, approach bridges, etc. carry infrastructure

Orion's steps to strengthen its network since *Risks and Realities* included attention to underground assets that would require long repair times. Approaches to the Armagh Street bridges and the Dallington footbridge were strengthened – these bridges carry main 66-kilovolt (kV) cables. While cables in these bridge approaches were damaged in September, they continued to function at down-rated capacity, notably maintaining supply to the Dallington area until February when they failed.

Ferrymead Bridge

As noted above, Ferrymead Bridge, identified as being vulnerable to liquefaction and lateral spreading, is an important transport link and carries many assets for other lifeline utilities.

Several mitigation steps for these lifelines were described in *Risks and Realities*. 'Service authorities' were further invited in *Risks and Realities* "to consider isolation of their services from the Ferrymead Bridge". However, when the earthquakes occurred, this work was still in progress and the bridge remained a significant link for many of them.

Little ground failure occurred in the area in the September earthquake, although there was considerable liquefaction in the area in February. Many fractures of sewer and water pipes occurred on bridges throughout the area, including the Ferrymead Bridge.

Undertaking site-specific liquefaction risk assessments [8]

Orion: Consulting engineers (Soils and Foundations) were engaged to evaluate liquefaction hazards at key substations in 1998. Two Grid Exit Points (GXPs) and six zone substations were identified as being on potentially liquefiable ground. Working with *Transpower,* Orion also commissioned a review of liquefaction risks at the four major Christchurch GXPs. Where liquefaction risk was identified, Orion gave attention to alternative supply routes (since liquefaction is difficult to mitigate). An example of this work is the investment in alternative central business district (CBD) supply from Bromley.[9]

[8] The soils beneath Christchurch are highly variable, laterally and in terms of depth. Assessments of liquefaction potential need to be site-specific.

[9] In a prescient comment, *Risks and Realities* notes (on page 135) that there may be a need for temporary overhead lines in emergencies to accelerate power restoration to some underground supply areas.

Waimakariri District Council had taken steps to build water infrastructure using flexible materials including allowing for the risk of liquefaction in areas known to be prone. Infrastructure using these materials generally stood up well, including in some of the worst affected areas.

Adding diversity and redundancy where cost-effective

Orion: Much of the earthquake damage to electricity (and other) assets was a result of liquefaction and lateral spreading. Little can be done to mitigate risks to buried assets such as cables arising from ground failure. Although much electricity supply was lost as a result of cable damage, the extensive interconnections in Orion's 11 kV and 400 volt network facilitated electricity restoration by providing routing options not available in radial (non-networked) distribution systems.

An example relates to the risk of lateral spread to the south bank of the Avon River that contained the two 66 kV cables feeding Dallington substation. Cost estimates of mitigation work exceeded the cable cost so Orion decided to plan a more secure supply from the north of Dallington (this was additional to the footbridge mitigation work mentioned above). Some of this new route work was completed prior to the earthquakes.

More generally, Orion's policy is that supply routes should be duplicated to areas serving 10,000 customers or more.

Kaiapoi Water and Electricity: Two water supply headworks exist in Kaiapoi, one on each side of the Kaiapoi River. In September 2010, this allowed supply to continue despite loss of the water main crossing the river.[10] Redundancy also helped *Mainpower* to continue electricity supply – three of the four cables under the Kaiapoi River failed, but one remained in service. Kaiapoi suffered little damage in February 2011.

Telecommunications: Redundancy (duplication of main links) is the norm in telecommunications, especially in backhaul. In access networks, much of *Vodafone's* 2G and 3G network components are separated (to quote one example).

10 More generally, Waimakariri District Council's infrastructure risk and vulnerability assessments proved valuable during and after the events. Waimakariri District Council's Disaster Resilience Assessment has since been revisited and updated to reflect new knowledge and revised seismic risk profiles, and is now guiding capital works decisions to improve infrastructure resilience.

111 Emergency Calling

Much of New Zealand's 111 emergency calling system is Christchurch-based. Redundancy / diversity arrangements facilitated ongoing national services immediately after the earthquakes. Six 111 call aggregation exchanges around New Zealand connect to two ICAP (Initial Call Answering Platform) exchanges (Christchurch and Palmerston North) via multiple connections, and then to one of two ICAP call centres (Christchurch and Wellington – there is also a warm back-up site in Palmerston North).

Contact Energy (Rockgas) has designed feed plant back-ups and redundancies, including for critical customers (for example, hospitals). Their looped system allows for supply from either of two directions.

Installing restraints to restrict movement of sensitive equipment, including large and small items, building service and rooftop plant

Chorus noted that all equipment in *Telecom's* buildings had been seismically supported and continued to operate. Most building services, for example, DC electricity supply equipment and generators, also continued to function normally (unrestrained lighting systems were the main plant failures). *Vodafone* has also taken strong steps to seismically restrain its equipment nationwide.

Racks and equipment at *Kordia's* network hub (located on the top of the Television New Zealand (TVNZ) Building in Gloucester Street) had been extensively seismically braced. The hub, including a 26-metre lattice tower on top of the building, continued to operate without incident following the earthquakes. The TVNZ building was however damaged and was deconstructed in March 2011 after re-routing Kordia and other services.

Transpower has noted that the seismic restraint programme undertaken in the 1990s following the 1987 Edgecumbe earthquake directly contributed to good earthquake performance.

Readiness Measures

Recognising lifeline interdependencies

Pre-event: Orion's risk management programme (aimed to mitigate seismic and other risks) included measures to strengthen supply to sites critical to other lifeline utilities. For example:

- *Orion* has replaced 'high risk' overhead supply lines with underground cables to two main communication sites serving Christchurch and the surrounding area – Sugarloaf and Marley's Hill. (Generators provided by *Kordia* and *Telecom* provide back-up.)
- Security of power supply to the airport has been improved by installing a cable to allow power supply from two alternative district substations. Back-up generation is also located on site.

- An 800-kilovolt ampere (kVA) generator has been located in Lyttelton to mitigate any loss of power to the port.

Post-event: Mobil needed, and received, support from *Orion* (electricity) and *Christchurch City Council* (water) following the September earthquake, to facilitate resumption of activity at their Woolston terminal. In turn, Mobil and other petroleum retailers made special arrangements to ensure supplies to vehicles needed for emergency response and repair work – for example, lifeline utilities (and their contractors) and the emergency services were able to use special lanes at some service stations.

Interdependencies in Practice – Telecommunications and Electricity

The ability to make phone calls immediately after the earthquakes was impacted by electricity outages, cable failures in liquefaction areas and congestion.[11] Battery life at telecommunication cabinets and cell towers quickly became a constraint on telecommunications performance. Over 200 small generators were deployed within telecommunication networks around the city to provide electricity as batteries ran down.[12] These required much refuelling, in turn requiring access to fuel sources, local road access for many trips to numerous sites where generators were located, and State Highways and ports for wholesale fuel supplies. In *Vodafone's* case, 2,200 hours of contract labour were required to keep generators refuelled around the clock for three weeks following the February earthquake with some CBD sites remaining on generator for several months.

Response planning, including the following:

- **Procedures for prioritising service continuity and repairs**

Orion and other lifelines drew on pre-established civil defence emergency management lists for prioritising their responses.

Mobil has adopted 'PEAR' principles: emergency priorities relate to people, environment, assets and reputation in that order.

Contact Energy's (Rockgas's) priority customer list had been regularly reviewed, facilitating its use immediately following the earthquakes.

- **Operational / control procedures and training**

NZTA's regional State Highway Emergency Procedures & Contingency Plan defines roles, including roles of consultants and contractors, and sets out communication lines. An Operational Emergency Response Plan contains further material, including arrangements for interfacing with other lifelines.

The pre-earthquake bridge screening programme assisted with development of inspection priorities. Key bridges were inspected within five hours, and 45 follow-up inspections were undertaken in the following six days.

11 Congestion largely resulted from the sudden substantial increase in call attempts rather than to telecommunication equipment failure.

12 Batteries at cell sites generally last up to eight hours depending on call traffic.

Similarly, ***Christchurch City Council*** inspected 360 bridges in the week following the February earthquake. Half of the bridges were damaged, primarily associated with liquefaction and lateral spreading (minor damage only in many cases). Twenty bridges were closed as a precautionary measure, with 16 reopening following structural inspection.

'Plan to Plan'

Orion's approach to emergency planning is based on promoting a corporate culture, developing facilities and putting other arrangements in place that are likely to help a range of emergency conditions, rather than detailed emergency planning. This 'plan to plan' approach allows for rapid re-setting of priorities and re-assignment of staff.

Similarly, ***Chorus*** advocates 'high-level pre-planning' in preference to detailed planning.

- **Ensuring contractors and structural engineers are available**

Many lifeline providers benefitted from firm pre-established arrangements with contractors.

- ***Chorus*** employs contractors to maintain its buildings and networks. These contractors formed part of Chorus's crisis management team, and had numerous operational roles in the response phase. Further, Chorus's national contractual relationship with its consultant engineers was most helpful in providing structural inspection and reporting following the earthquakes.
- ***NZTA's*** network consultants and contractors commenced drive-over inspections of the State Highway network immediately following the earthquakes.
- The ***Christchurch City Council*** employs three contracting companies and delegated much responsibility to Fulton Hogan.
- Following the February earthquake, ***Orion*** asked its contracting company, ***Connetics***, to take the lead in managing the additional out-of-town contractors brought in to repair its network.[13]
- ***Transpower*** draws on maintenance contractors for much day-to-day operational work and these arrangements continued to work smoothly in the emergency conditions.
- ***Contact Energy's*** (Rockgas's) long-term relationships with contractors and consultants proved valuable in obtaining expertise for assessments and remedial work (although no formal contracts are in place for large scale emergencies).

[13] Connetics is an engineering construction and maintenance company. It operates independently but is 100 per cent owned by Orion. All the 11 kV access work was controlled via the new Orion network management computer system.

Developing a spare parts policy that takes emergencies into consideration, including storage in accessible and secure racks and locations

Orion has given particular consideration to spare parts management including seismic risks relating to spares storage.

- A risk-based approach to anticipating failure rates has taken into account credible natural events that may impact Orion's ability to meet its security standard.
- Audits of stock levels and security are undertaken, with additional precautions in relation to transformers.
- Attention has been given to bracing storage racks and providing restraints to prevent items falling from shelves. Storage hold-downs have been improved – these are designed for ground accelerations of 1 to 2g, the equivalent of a 'maximum credible event'.

Contact Energy (Rockgas) has an inventory of pipes (various lengths) and fittings set aside for emergency response purposes, sufficient to fix three or four leaks.

Setting up and managing mutual aid

Particularly following the February earthquake, many lifeline providers sought or received offers of support from outside the affected area, either from within the same company (including overseas resources in some cases) or from other entities in the same sector (including suppliers able to offer advice). Some of these requests and offers were spontaneous; others derived from pre-established mutual aid arrangements.

Lifeline providers benefitting from intra-company arrangements included *Transpower, NZTA, Chorus, Vodafone* and *Mobil. Christchurch City Council* water and sewerage benefitted from support from counterparts in other areas including Australia.

Orion drew on the relatively well-established formal and informal mutual aid arrangements that exist within the electricity distribution sector. Around 40 companies came to help following the February earthquake, by far the largest mutual support exercise of its type seen in New Zealand. Altogether, 700 persons were involved.

Rockgas obtained support from other parts of New Zealand and from overseas – eight staff grew to 30.

Intra-sector cooperation amongst the four *petroleum* suppliers, based on long-standing industry supply coordination arrangements, is well-established in New Zealand. These arrangements were effective in ensuring continuity of supply to the Canterbury region during the emergency.

Mutual Aid in Telecommunications

A collaboration between telecommunication service providers and ministries, known as the Telecommunications Emergency Forum (TEF), was set up in 2008.

Vodafone initiated the response arrangements on 23 February 2011. Fifteen phone conferences were held between 23 February and 22 March, involving seven telecommunication service providers (TSPs), focussing on asset and equipment sharing, generator deployment and refuelling, cordon access,[14] and building demolition management. The calls were attended by *Vodafone, Telecom, Kordia, 2degrees, TelstraClear, Vector Communications, Enable Networks,* and *Team Talk*, together with lifelines utility coordinators at the National Crisis Management Centre (Beehive basement) and the Christchurch Response Centre (Art Gallery).

Meeting records note numerous intra-industry support examples (there may well have been others not mentioned at the meetings).

- Generators and spare parts were being requested, offered and shared where available.
- Offers to facilitate trunk migration by other companies to new sites were made and accepted.
- Information on access opportunities to the key TVNZ building was shared, so that equipment of different providers could be serviced in the limited intervals available.

Installing stand-by electricity generation, including testing and attention to fuel supply

Many lifeline providers have their own on-site generation to meet emergency needs. These include *Orion, Chorus, TelstraClear, Vodafone, Kordia* and *Contact Energy* (Rockgas). Further, telecommunication service providers generally have significant generator inventories for use at cell sites and cabinets, and additions to generator stocks are planned following the Canterbury earthquake experience.[15] *Waimakariri District Council's* generator strategy also proved helpful.

[14] Chorus notes that Telecom House (in the 'red' zone) has national networks operating in and through the building. These networks require regular reconfiguration to maintain national service standards. Many of the adjustments can be undertaken remotely, but often hardware reconfigurations have to be undertaken on site. Because these usually affect system operation for a short period, they are undertaken in the early hours of the morning when telecommunication traffic volumes are lowest. Chorus initially had some difficulties with technical teams gaining access to the red zone at these times. The delay in negotiating early-hour access did not seriously impact Chorus in this case, but is seen as a potential issue for consideration by CDEM authorities in the early stages of any event where cordons are being set up. Other lifeline utilities have made similar points.

[15] Many cabinets, especially in rural areas, now commonly have external generator sockets facilitating generator connections. This reflects a learning from Canterbury snowstorm experience over the last few years.

On-site Electricity Generation in Christchurch

Orion's line pricing for large consumers includes very high charges for peak winter periods and much lower off-peak prices. This is designed to reduce peak loads and allow consumers to manage their energy costs, while in turn improving capacity utilisation and reducing / deferring the need for expensive investment in the electricity distribution network.

Many major customers avoid these charges by installing in-house generation. Primarily designed to improve efficiency, these alternative supply sources also improve resilience to electricity outages (plants must run regularly to avoid the peak charge, offering regular testing under load).

On-site generation amounting to 20 megawatts (MW) was run following the September 2010 earthquake (Christchurch's capacity under these arrangements is around 50 MW – approximately 30 MW was unused for reasons including earthquake-related impediments to normal business).

Capturing the continuing benefits through ongoing inter-utility contact, including via training exercises

Most Christchurch lifeline utilities maintain links to CDEM through involvement in the Canterbury Lifeline Utilities Group. Many also participate in annual CDEM group exercises (known as 'Pandora'). Lessons gained are captured through post-exercise debriefs, leading to action programmes to improve future performance.

As noted earlier in this report, the Canterbury Lifeline Utilities Group is amongst those that have undertaken ongoing projects and other activities aimed to mitigate seismic risks. The following activities are examples of the Group's pre-earthquake actions that contributed to successful earthquake response:

- **Interdependency analysis:** A project to identify lifeline interdependencies and potential cascade impacts arising from infrastructure outages drew attention to vulnerabilities arising from interdependencies within the lifeline sector. The knowledge gained, although relatively recent, has helped sharpen focus on the value of reliability, vulnerabilities and (in some cases) the need for back-up arrangements (the interdependency work is described later in this report).

- **Petroleum hazard assessment:** A hazard assessment for petroleum storage, transport and supply drew attention to the nature of Canterbury supply arrangements and potential weaknesses in various hazard events. One example: constraints on use of the Lyttelton Tunnel for transport of high-volatility petroleum products were identified. These constraints became a real issue in the immediate post-earthquake environments and the relationships developed as the assessment was undertaken helped inform the special road transport arrangements that were put in place.

- **Priority routes and sites:** A project was undertaken to identify priority routes and community sites (such as hospitals and emergency service locations) that would need priority access and restoration, together with identification of priority routes for clearance. The knowledge gained provided a valuable information base, helping lifeline utility coordinators (in the Christchurch Response Centre) to understand the city roading network.

- **Risk management template:** A risk management template has been developed for inclusion in asset management plans. The template describes good practice in resilience planning, assisting inclusion of resilience considerations as a 'business as usual' activity. The Lifeline Group's continued support in this area lies behind much of the mitigation work undertaken prior to the earthquake.

- **Lifeline coordination protocols:** Lifeline coordination protocols (based on national arrangements) set out communication and reporting arrangements for emergency responses. Significant lifeline coordination difficulties arose in the response period, especially following the February earthquake, resulting mainly from organisational issues at the Christchurch Response Centre. Many elements of the coordination protocols nevertheless proved valuable, not least the contact lists (a key response resource).

These and other Canterbury Lifeline Utilities Group risk mitigation project documents are contained in a resources folder for ease of reference. The projects and documents assisted earthquake responses in many ways, both direct and indirect. More generally, the inter-corporate and inter-personal relationships developed as the projects were undertaken proved most valuable during earthquake responses. Organisations need to work together in emergencies and good communication is a key contributor to the overall response.

Assessing the Merits of Mitigation

The terms of reference for this report call for a qualitative assessment of the impacts on the community if the reduction in impact and consequences due to mitigation measures undertaken (risk reduction and readiness) had not been realised. In other words, what should be taken into account in assessing whether mitigation was worth the effort?

The Economic Costs of a Disaster

In a recent World Bank policy research paper, Hallegatte and Pryluski disentangle the range of issues arising in assessing the economic costs of disasters (Hallegatte and Pryluski, 2010).[16] There are two elements:

- **Direct costs:** that is, losses that are a direct result of the disaster. These may be measured as the cost of repair or replacement of buildings and other assets, including commercial plant and equipment, social assets (for example, schools, libraries and hospitals), homes, and infrastructure assets. Lost income by directly impacted businesses is included in direct costs.
- **Indirect costs:** that is, subsequent output losses that arise as a consequence of the disaster. Examples:
    - Losses arising from interruptions to supply chains serving businesses that are otherwise unaffected – the interrupted services are likely to include interrupted infrastructure services such as electricity and water supplies.
    - Reconstruction costs, included because the resources absorbed may be diverted from normal 'business as usual' productive and investment activity (rebuilding a damaged bridge may mean that a planned beneficial transport link is discontinued or deferred, for example).

Hallegatte and Pryluski also note that, following a disaster, the economy might not be running as productively as before. Losses might be greater if standard economic assumptions do not apply. On the other side of the ledger, Hallegatte and Pryluski note that positive impacts may also occur. For example, where increased incomes arising from reconstruction activity boost expenditures, where asset replacement provides opportunities for introduction of new technology, and / or where new, more productive businesses develop.

In summary, the overall economic impacts of disasters reflect the net outcome of a range of income, productivity and wealth effects, reflected in incomes (including national income aggregates such as GDP), balance sheets and economic welfare. These effects are not independent – weakened balance sheets (wealth reductions) can lead to reduced confidence and reduced expenditures (that is, reduced GDP).

The economic effects following a disaster can be favourably impacted by property and business interruption insurance payouts, especially if the payments boost reconstruction.

16 A key point in the World Bank paper is that parties such as insurers, banks and governments have different interests and will often use, and quote, different cost measures. A purpose of the paper is to define the cost elements and propose a common, comprehensive approach.

Price pressures, likely to arise initially in the construction sector, may provoke a monetary policy response, that is higher interest rates, especially if it appears that the pressures may spill over into more general inflation. The sudden increase in claims on financial markets as insurers liquidate assets and borrowers seek to finance uninsured restoration construction can also impact on financial markets.[17] New Zealand borrowers may face higher risk premiums when raising loans in domestic and international financial markets (these effects would likely arise from balance sheet deterioration and reduced investor confidence). And of course, insurance companies and re-insurers will be seeking additional fees to cover a perceived increase in seismic risks.[18]

Infrastructure occupies a central 'enabling' position in the economy, facilitating activity by businesses, households and other entities. Disaster-related infrastructure impacts, which play out within this wider economic and financial setting, are listed in Hallegatte and Pryluski's report as an area for further research.

Infrastructure outages impact households and businesses. In more detail:

- Households are vulnerable to outages over which they have very little control.
- Businesses are also vulnerable to infrastructure outages:
  - › Small to medium sized enterprises (SMEs) are particularly exposed to outages over which they also have very little control. Commercial activity, employment and livelihoods are at stake.
  - › Larger businesses are also vulnerable – they may be better placed to develop business cases for back-up arrangements but they are often unclear about the infrastructure risks they face.
  - › The businesses that may suffer infrastructure outage impacts include, for example, banking (which is particularly vulnerable to loss of electricity and telecommunications) and food distribution (which is particularly vulnerable to a range of energy, communications and transport failures).

WIDER PERSPECTIVES ON VALUE

The meaning of value (and, accordingly, value loss) differs depending on context. The discussion above has focussed on commercial and household impacts. These are economic and social issues. However, environmental and safety issues also enter the picture.

For example, following the earthquakes, Mobil's main concerns included ensuring the integrity of fuel containment systems at the Woolston terminal and service stations, recognising the environmental and safety hazards that can arise when containment systems fail. Mobil notes that the integrity of their pipelines and storage tanks was maintained at every location during the earthquakes.

17 If the insurers are New Zealand-based, the financial impacts are simply transfers within the economy. If the insurers are non-resident (either because the insurance companies are overseas-owned or because the New Zealand insurer has taken overseas reinsurance), the financial impacts may be more comprehensively reduced by insurance pay outs.

18 Further material on financial and economic issues is available in Savage, 1998 and White, 1997.

The Cascade Effect – Interdependencies between Lifeline Utilities

The businesses that rely on infrastructure include infrastructure businesses (lifeline utilities) themselves. The extensive interdependencies within this central group mean that infrastructure outages can cascade through the economy adding very substantially to overall cost.[19] The following schematic depicts the issue.

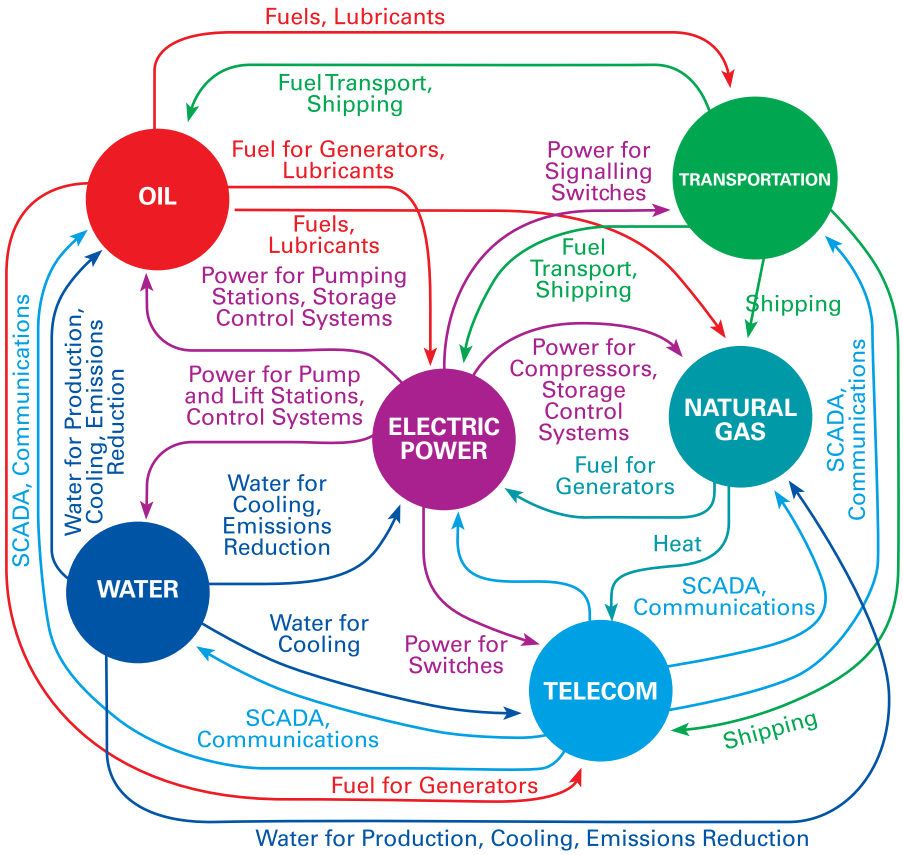


Figure 1: An Illustration of Infrastructure Interdependencies

Notes: The schematic draws attention to the extent of the interdependencies between different lifeline infrastructure types.

The schematic has been used by Prof Tom O'Rourke to illustrate interdependency issues during his visits to New Zealand.

The overall loss to the community from infrastructure outages is the aggregate of these direct and interdependency impacts.[20] All of these elements have impacted Christchurch in 2010 and 2011.

[19] The cascade impacts story cannot be generalised. Overall costs become greater (and are incurred more suddenly) when an event such as an earthquake leads to more than one contemporaneous infrastructure failure. On the other hand, demand for particular infrastructure services might actually reduce following an earthquake or similar event. For example, restoration of electricity and phones in the Christchurch CBD following the earthquakes was much less of a priority than restoration in other parts of the city because commercial activity had fallen there.

[20] For further thoughts on this matter, see Oakley Greenwood's February 2009 report to Transpower Assessing VoLL for High Impact Low Probability Events (Oakley Greenwood Pty Ltd, 2009) and LECG's Review of Grid Investment Approval Procedures: Report to Transpower NZ Ltd (LECG, 2008).

CHRISTCHURCH EARTHQUAKE – BUSINESS SURVEY RESULTS

Some information on business impacts is available from current research by the Resilient Organisations Research Group, University of Canterbury.[21] For example, surveys conducted with selected businesses in the greater Christchurch area (for an ongoing study) show the following:

- Over 50 per cent of Christchurch businesses closed temporarily, and over 10 per cent closed permanently, after the February event. Of infrastructure businesses, 50 per cent closed temporarily. However, no infrastructure businesses closed permanently, reflecting obligations for continued supply of the essential services they provide and (very likely) relatively effective seismic mitigation.
- Most businesses were impacted by infrastructure outages – only around 10 per cent were unaffected by interruptions to infrastructure services. Disruptions to road transport were most often quoted as impediments to business activity. Disruptions to communications, water and electricity were also mentioned as impediments by many businesses.

Issues in Measuring the Benefits of Seismic Mitigation

The value of seismic mitigation by lifeline utilities (and by others) is in principle the reduction in the overall community loss resulting from the mitigation work. Figure 2 illustrates the issues.

It is however difficult to measure the reduction gains, even the more immediate ones, after the event. The point is illustrated (and the value of mitigation qualitatively described) in the draft report on earthquake impacts on Christchurch / Canterbury infrastructure prepared by the Technical Council on Lifeline Earthquake Engineering (TCLEE). Addressing a key electricity earthquake mitigation measure, reinforcement of unreinforced masonry (URM) substations, the report notes that "had the URM buildings not been mitigated, results would have been much, much worse" (Technical Council on Lifeline Earthquake Engineering, 2011).

From a pre-earthquake perspective, the measurement challenge is even greater. The forecast loss reduction needs to be risk-weighted to take into account the likelihood that a serious earthquake will occur within the timeframe under consideration. Mitigation that may have benefits in more than one natural hazard situation would have an increased calculated value – locating underground assets away from riverbanks near estuaries might for example have benefits in an earthquake (given risks of lateral spreading), tsunamis and other coastal hazards. Mitigation at 'hotspots', that is locations where utilities are co-located and where there is particular exposure to natural hazards, would have an increased value. From a pre-earthquake perspective, the benefits would also need to be discounted to take into account the timing of cost and benefit value streams.

[21] The Resilient Organisations Research Group's website is at http://www.resorgs.org.nz/.

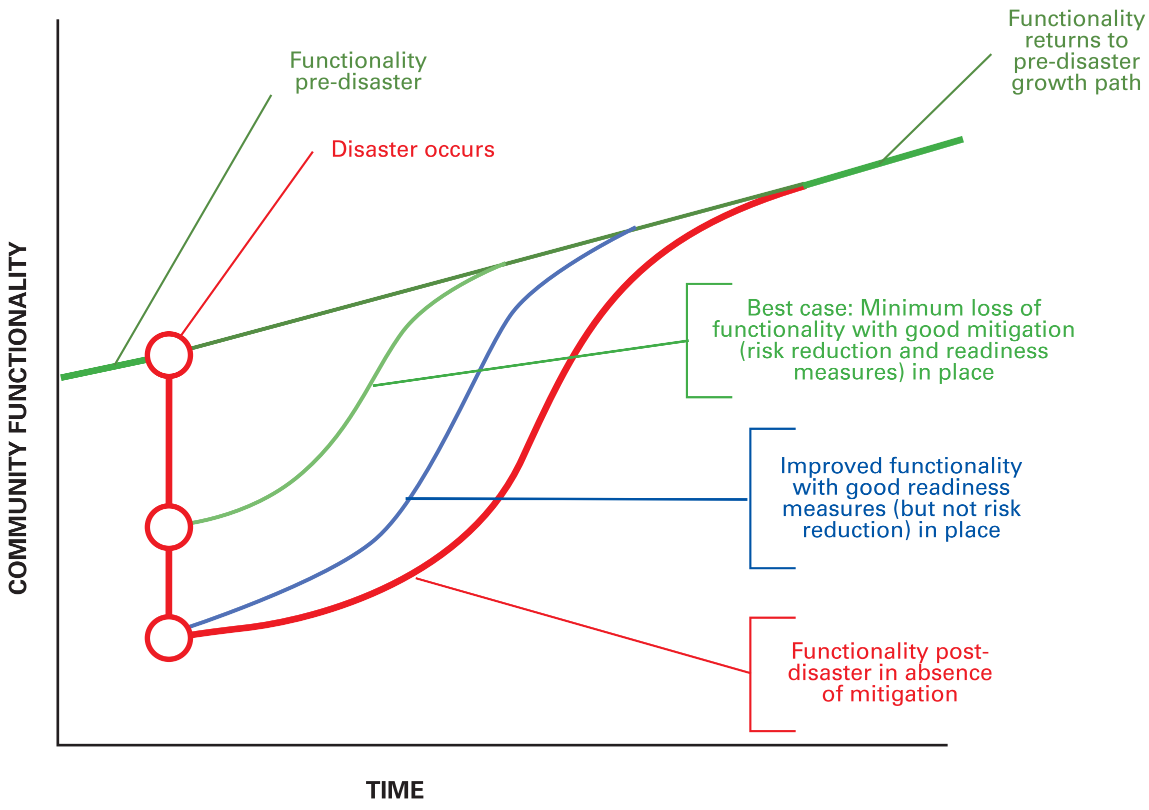


Figure 2: Community Losses With and Without Mitigation

Notes: Overall community losses are described by the shape under the functionality growth path (the size of the loss depends on the extent and duration of reduced functionality). The loss can be reduced by readiness steps by infrastructure owners (and others) – these steps facilitate an early return to the growth path. The best outcome will occur with good risk reduction and readiness in place (the shape is smallest in that case).

The figure was suggested by Prof Stephanie Chang, University of British Columbia, during her New Zealand visit in 2010.

Research on the Benefits of Seismic Risk Mitigation

Many researchers have addressed issues relating to the value of infrastructure reliability. Internationally:

- **Prof Stephanie Chang:** Dr Chang, a Canada-based interdisciplinary researcher with interests in disaster impacts and mitigation, has developed a lifecycle methodology for assessment of seismic risk mitigation for infrastructure assets taking societal costs and benefits into account. Drawing on examples from the Los Angeles Department of Water and Power, and from the Portland, Oregon water system, Chang and others demonstrate that seismic mitigation that is not cost-effective for the infrastructure provider can be very cost-effective from a social standpoint (Chang, 2003).[22]

[22] The introduction to Chang's paper offers a brief but useful survey of the literature in this area. A similar cost-benefit analysis framework is set out in Kunreuther et al (Kunreuther et al, 2000).

- **Multihazard Mitigation Council:** The United States-based Multihazard Mitigation Council (MMC), reporting on its landmark study for the United States Congress on the value of hazard mitigation (financed by the Federal Emergency Management Agency, FEMA), concluded that "a dollar spent on mitigation saves society an average of $4" (Multihazard Mitigation Council, 2005).[23] Looking just at the net fiscal position, the study concluded that "a dollar spent from the federal treasury on FEMA mitigation grants … leads to an average of $3.65 in avoided post-disaster relief costs, and increased federal tax revenues". The net benefits relating to seismic mitigation were estimated to be lower than those for wind and flood damage (seismic benefits were around $2), but a subsequent report to the Congressional Budget Office concluded that the seismic gains had been understated in the MMC study (Congressional Budget Office, 2007).
- Reporting on the MMC study, Godschalk et al note lessons for policy makers: "the need to consider a wide variety of losses, the importance of mixing qualitative with quantitative analysis, the value of averaging results over a large number of projects, and the need to more explicitly address social issues and data collection in order to reduce vulnerability and enhance resilience" (Godschalk et al, 2009).

Lifeline groups and others have also explored the issues within New Zealand.

- **Canterbury Lifeline Utilities Group:** Two documents on Canterbury lifeline interdependencies prepared by the Canterbury Lifeline Utilities Group describe workshop outcomes aimed to identify interdependencies and potential cascade impacts arising from infrastructure outages (Canterbury Lifeline Utilities Group, 2008; Canterbury Lifeline Utilities Group, 2010).

CANTERBURY LIFELINE UTILITIES GROUP – WORK ON INTERDEPENDENCIES

The main purpose of the Canterbury Lifeline Utilities Group's 2010 report was to test an approach to interdependency identification "thus enabling utilities to … improve their ability to function effectively during and after an emergency".

A score sheet was developed and used to categorise and rank interdependencies. The report records learnings "as a base level of information to introduce interdependency thinking into asset management planning".

The approach was developed in a workshop (May 2008) and tested in a further workshop (July 2009) using information from Waimakariri. A case study was also undertaken based on a week-long electricity outage. Significant value was gained from providing each utility with an opportunity to discuss their dependency on other providers using a 'speed dating' type of approach. Key users (beyond lifelines) were included in the exercise, notably banking and the fast-moving consumer goods sector (that is, supermarkets).

Practical material on managing interdependencies is included in the report. A concluding section notes that further development of the tool is envisaged.

Matrices in which the significance of interdependencies can be rated based on readily available information and judgements are described in the second report – analysis of this type was earlier undertaken in 1997 when *Risks and Realities* was prepared.

- Other lifeline groups: Most New Zealand lifeline groups have prepared studies that address infrastructure exposure to natural hazards.

[23] The MMC study was undertaken by Adam Rose and others (Rose et al, 2007). The benefit values make no allowance for the avoided costs arising from reduced deaths and injuries.

- › New Zealand's initial study, which related to Wellington, is described in *Lifelines in Earthquakes: Wellington Case Study* (Centre for Advanced Engineering, 1991). Vulnerability of lifelines was assessed and mitigation possibilities identified. Attention was confined to earthquake issues in the greater Wellington area.
- › The Christchurch *Risks and Realities* study followed soon after (Christchurch Engineering Lifelines Group, 1997).
- › Auckland followed soon after Christchurch. The Auckland report, *Auckland Engineering Lifelines Project (Stage 1)*, includes detailed hazard maps for the region (Auckland Engineering Lifelines Group, 1999).
- › Corresponding work was also undertaken in Dunedin (1998), Hawke's Bay (2001), Wairarapa (2003), Invercargill (2004) and Manawatu-Wanganui (2005).

Some of this work is currently being renewed. An updated Auckland project, *Infrastructure Vulnerability to Hazards*, aims to assess the impact of hazards on Auckland lifeline infrastructure taking into account community impacts and provides an information base on which to consider mitigation.[24]

Considerable work has also been done by lifeline groups on 'hotspots', that is locations where utilities are co-located, where there is exposure to geophysical and / or meteorological hazards, and where risk mitigation might call for collaboration.[25]

There have been some difficulties in maintaining commitment to these projects, which are often supported by lifeline provider staff and with varying amounts of time available. Issues relating to data confidentiality have arisen. Pragmatic approaches have often proved necessary to keep effort and elapsed time within bounds.

- ***NZIER scoping study on Wellington earthquake (1998):*** NZIER prepared a preliminary scoping study on the economic impact of a magnitude 7.5 Wellington earthquake soon after the 1995 landmark conference on Wellington earthquake issues (Savage, 1998).[26] The study estimated the mean probable maximum capital stock loss at $10 billion to $20 billion and a short-term production loss of over $1 billion. Taking into account capital write-offs and initial production losses, total accumulated production losses were estimated at around $2 billion to $3 billion under a mean loss scenario, and a much higher $9 billion to $11 billion under the '90 percentile loss scenario' (present value terms). The study assumed a high degree of insurance coverage and that the economy was in a 'healthy' state when the earthquake occurred.
- ***Economic modelling for Exercise Ruaumoko (2008):*** Market Economics (an Auckland-based economic and research consultancy) undertook economic modelling associated with Exercise Ruaumoko, New Zealand's largest civil defence exercise based on a volcanic eruption in Auckland. Although the modelling did not single out the impact of infrastructure outages, the final exercise report noted that "for a worst-case Mt Eden eruption, the modelling … anticipates that the Auckland region would suffer a 47% reduction in GDP, but this could be reduced to 40% if businesses had effective mitigation … measures in place… Overall, this would result in a 14% decline in GDP for New Zealand, which could be reduced to 12% with effective industry preparedness". The study was based on a maximum credible event rather than the actual exercise scenario, which would have had less impact.[27]

24 Information on this project is available at http://www.aelg.org.nz/reports/critical-infrastructure.cfm.

25 Auckland Harbour Bridge, which conveys electricity, gas, telecommunications and water; as well as State Highway 1; and Thorndon (Wellington) where road, rail, water, sewerage, electricity, petroleum, gas and telecommunication links converge, are prominent examples of hotspots. Information on specific Auckland areas where utilities converge was addressed later in a brief 2007 report (Auckland Engineering Lifelines Group, 2007). The Wellington Lifeline Group is currently pursuing projects aimed to promote collaboration in Thorndon and Seaview, another local hotspot.

26 The NZIER report was followed by a NZIER working paper *The Economic Effects of a 1998 Wellington Earthquake*, which assessed Wellington economic impacts assuming an event of the size of the 1931 Hawke's Bay earthquake (Clarke, 1998).

27 The Exercise Ruaumoko report is available at http://www.civildefence.govt.nz/memwebsite.nsf/Files/National%20Exercise%20Programme/$file/ExRuaumoko-FINAL-REPORT-Aug08.pdf.

LIFELINES ENGAGEMENT WITH THE SCIENCE COMMUNITY

Many examples exist of good engagement between lifeline groups and the science community. Often the relationships are supported by hazard analysts at regional councils. Hazard analysts from Environment Canterbury contribute actively to Canterbury Lifeline Utility Group proceedings, to quote one example.

The Wellington Lifelines Group, in a high seismic-risk area, is also engaged with the science community on earthquake issues. A collaboration entitled *Lifeline Disruption following a Wellington Earthquake* – involving the Wellington Lifelines Group (co-ordinating agency), Greater Wellington Water and GNS Science – aims to describe the situation following rupture of the Wellington fault and provides a basis for further development of frameworks for mitigation evaluation.

These exercises enrich understandings of earthquake hazard in Wellington including lifeline restoration. They also complement the ongoing *It's Our Fault* project and the GNS Science study on *Post-Earthquake Functioning of Cities*.[28]

GNS Science staff involved in *Riskscape* also participate in lifeline activities.[29]

- **Infrastructure investment study by Centre for Advanced Engineering (2010)**: A major study by the New Zealand Centre for Advanced Engineering (CAE) includes as a main theme the need for inclusion of the range of economic, social and environmental factors in infrastructure investment decisions, and describes progress in the methods available (Centre for Advanced Engineering, 2010). A summary report notes that "one important factor, especially to governments, is the resilience of infrastructure networks", adding that "an evaluation of [networks'] ability to withstand the effects of external events and recover from damage should be included in the [investment] analysis".

Figure 3 depicts, stylistically, intervention points at which community loss arising from infrastructure outages following earthquakes and other similar events may be reduced (the figure is in the same format as figure 2).

[28] *It's Our Fault* is a collaboration led by GNS Science (input also from NIWA (National Institute of Water and Atmospheric Research), University of Canterbury and Victoria University), and funded by EQC, ACC, Wellington City Council and the Wellington CDEM Group, to improve understanding of Wellington's earthquake risk (begun 2006, ongoing to 2012). *Post-Earthquake Functioning of Cities* was funded by the Foundation for Research, Science and Technology – components included assessment of implications of water disruption.

[29] *RiskScape*, under development by GNS Science and NIWA, is a purpose-made natural hazard loss estimation tool. Where the model is populated with hazard and asset datasets, it provides a desk-top environment for assessing the geographic distribution of losses of assets such as buildings and infrastructure in dollar terms due to natural hazards (it also estimates the number and type of injuries and fatalities).

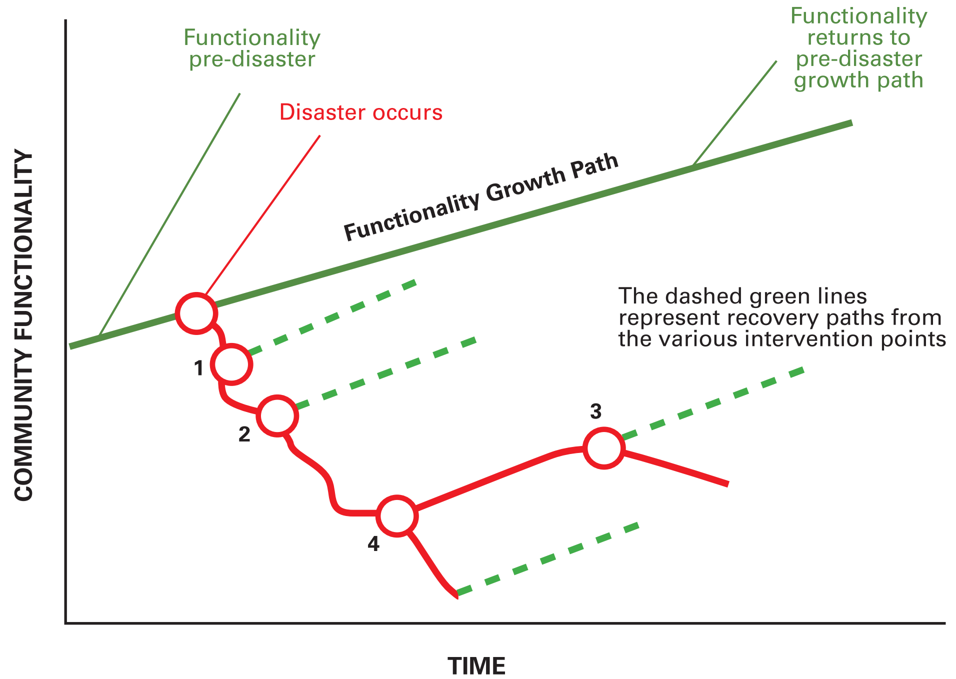


Figure 3: Intervention Points at which Community Loss May be Reduced

Notes: The size of the loss to the community is most effectively reduced by risk reduction action to prevent infrastructure outage (the loss may be stemmed early, at Point 1). Assuming ineffective risk reduction, actions to reduce the risk that infrastructure outages may spread to interdependent systems are depicted as a second line of defence (Point 2). Following commencement of a recovery, Point 3 illustrates gains from avoiding 'second-wave' outages (for example, subsequent outages in systems weakened by the earthquake, for example when aftershocks occur). Point 4 illustrates that major losses can occur if mitigation (risk reduction and readiness) are ineffective.

The figure was suggested by Prof Stephanie Chang, University of British Columbia, during her New Zealand visit in 2010.

The New Zealand and overseas studies mentioned above indicate that the significant costs from earthquakes can be reduced by well-directed mitigation work. Work of the type undertaken by lifeline utilities and lifeline groups, notably the steps taken in Christchurch, make valuable contributions to loss minimisation.

Conclusion

The substantial programme of seismic mitigation, fostered by the Canterbury Lifeline Utilities Group and undertaken by Christchurch lifeline utilities over many years, has served Christchurch well in reducing losses and facilitating emergency responses and recovery. The damage would have been greater and the response slower if the steps recommended in *Risks and Realities* and other preparatory work fostered by the Group had not been taken.

A range of studies indicate net economic benefits from mitigation, especially when wider societal benefits are taken into account. Taking into account the direct and indirect losses that arise from earthquakes (including downstream losses arising from infrastructure interdependencies) it is clear that the costs of seismic risk mitigation in Christchurch will have been repaid many times over.

The main elements that contributed most strongly to the benefits in Christchurch, and that should therefore feature within the core activities of lifeline utilities and lifeline groups, are listed below:

- **Asset awareness and risk reduction: identifying points of particular vulnerability.** Issues likely to arise include:
    - surveying for site-specific risks, for example buildings that do not meet AS/NZS1170 loading standards (including where assets are placed on top of existing structures) and where liquefaction is possible
    - identifying likely fracture points (for example, where cables and pipes enter structures such as buildings and bridges)
    - identifying cases where restraints to restrict movement of sensitive equipment are needed.
- **Readiness: taking steps to improve organisational performance in emergencies**, such as:
    - ensuring that lifeline utilities have fit-for-purpose operating frameworks for business continuity
    - working collaboratively with other lifelines and relevant agencies on common issues, such as looking for key interdependencies, examining rental generator sufficiency, planning for petroleum outages and establishing lifeline utility coordination arrangements to facilitate emergency response
    - ensuring that engineers and contractors are available quickly to meet emergency needs
    - managing spare parts to promote availability when unexpected pressures arise.
- **Perseverance: maintaining the effort over time while communicating realistic expectations**.
    - Lifeline utilities that have retained a consistent focus on seismic mitigation have benefitted most significantly (asset management planning and similar annual-cycle processes provide an appropriate setting for much of the required work).
    - Improving end-user knowledge of infrastructure reliability and encouraging users (particularly organisations with emergency response roles such as hospitals) to plan for a level of infrastructure outage in the more extreme events are also essential.

More generally, the relationships developed through participation in lifeline group activity have been most valuable in facilitating earthquake responses, as noted earlier in this report.

Lifeline performance in the Christchurch earthquakes was the main theme at the National Lifeline Forum held in Christchurch in November 2011. Attachment 1 summarises comments made in the closing session. The points made at the Forum are consistent with those in this report.

Risks and Realities concludes with the comment (Christchurch Engineering Lifelines Group, 1997):

> "It is gratifying to see [that] a large amount of work has been done or is proposed as a result of [this] engineering lifelines work. It shows that the considerable effort of so many people at surprisingly little cost has resulted in budget provision for mitigation and planning work that has and will continue to make Christchurch much better able to withstand the effects of natural hazardous events."

Risks and Realities stands out as a very good example of collaborative work aimed at hazard risk mitigation. It is often difficult to find individuals and organisations with the ability, incentive and standing to form effective collaborations on issues of public importance, not least high-impact low-probability ones. Canterbury and New Zealand are fortunate to have received the benefit of the efforts of a great many individuals and organisations who have contributed to collaborative lifelines engineering processes of which *Risks and Realities* is a prime example.

Attachment 1: National Lifelines Forum 2011: Key Learnings to Inform Earthquake Resilience Planning

Lifeline performance in the earthquakes was the main theme at the 2011 annual National Lifeline Forum, held in Christchurch in November of that year. The following summarises comments made by three commentators and other participants in the closing session.

Commentators and participants noted:

- the need to recognise and plan for a range of earthquake hazards (for example, shaking, ground failure such as liquefaction, landslides / rock falls)
- the need for continuing long-term systematic effort in mitigation and response (it's a marathon, not a sprint)
- the importance of collaboration including mutual aid (but aid needs to be well organised / integrated)
- the need for pre-arranged contracts with engineers to enable early post-earthquake building inspections
- the need for an increased pool of trained lifeline utility coordinators (the lifeline utilities themselves might be a source of personnel)
- the importance of simple tools (for example, posters) to communicate research and other messages
- the need to ensure that mitigation steps are both taken and function well (for example, water shut-off valves)
- the value in diversity (for example, ringed systems that offer alternative supply routes)
- the merits of 'planning to plan' as distinct from detailed response documents
- the importance of access to plans and maps in emergency conditions, and the value in GIS-based information systems
- the importance of customer education, emphasising that outages will occur from time to time despite efforts to increase supply resilience
- the pitfalls in assuming that response experience in one location is applicable in another (for example, Wellington's response challenges would be greater than Christchurch's in sectors such as transport, water, petroleum).

In concluding comments, others noted:

- the value of quick post-disaster reconnaissance
- the need for a focus on quick service restoration (for example, over-ground water pipes are likely to be acceptable as a temporary fix)
- the need for effective communication (for example, simple letter box drops were well received in Kaiapoi)
- the need to recognise the very large expenditure requirements building up in water asset renewals
- the importance of secure storage (for example, in food supply chains) and the differing seismic characteristics of alternative storage / racking products.

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