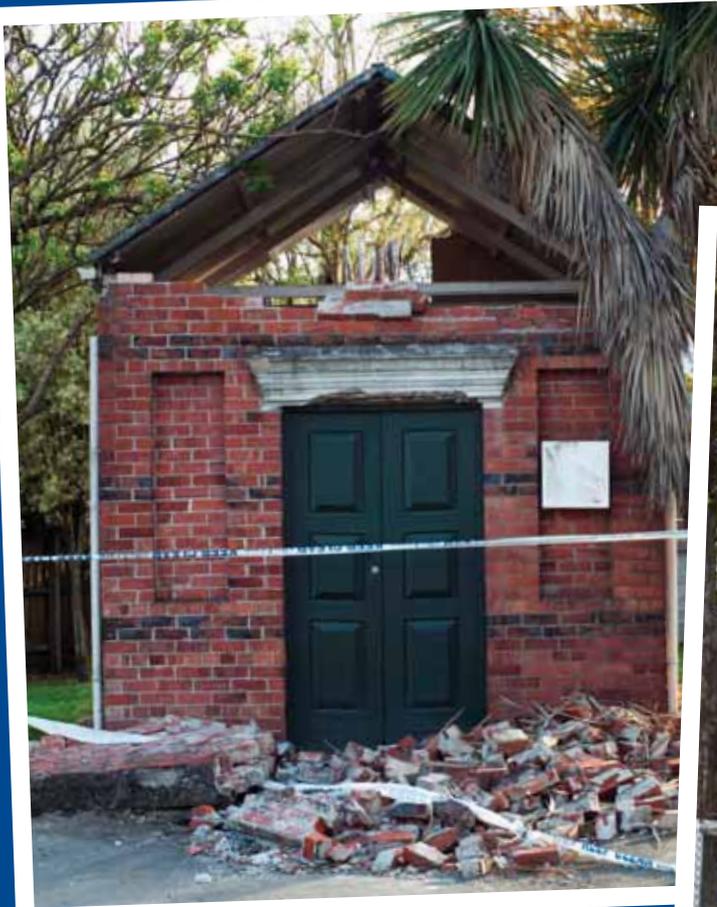


# The Value of Lifeline Seismic Risk Mitigation in Christchurch

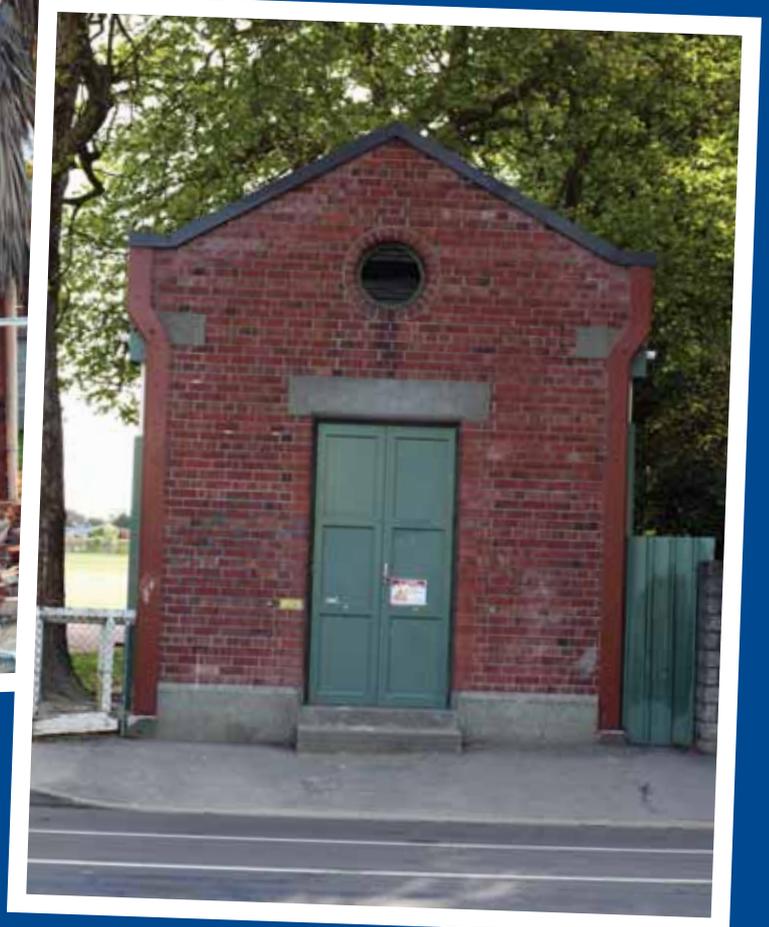
Summary Report – June 2012



^ 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 paper summarises the main points from the report *The Value of Lifeline Seismic Risk Mitigation in Christchurch*, prepared by Tony Fenwick for the New Zealand Lifelines Committee in June 2012.

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

- 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.

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



### **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.

### **DISCLAIMER**

This high-level overview has been compiled from available documented information, responses to numerous enquiries made to lifeline utilities, and ideas offered by representatives of the utilities at a meeting of the Canterbury Lifeline Utilities Group (August 2011) and at the National Lifelines Forum (November 2011). Effort has been taken to summarise the information accurately. However, the parties involved in preparing this report do not accept liability for losses arising from use of, or gaps in, the information it contains.

### **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.)

# Introduction

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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.

Underground infrastructure assets (pipes and cables) were particularly impacted. Unreinforced masonry structures and a number of reinforced concrete structures, including many owned by lifeline utilities, were also damaged.

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

## Brief History of Lifeline Group Activity in Christchurch

Vulnerability to earthquake damage to lifelines was given prominence in a comprehensive project undertaken by the Christchurch Engineering Lifelines Group in the first half of the 1990s. This, and other early lifeline projects in New Zealand, 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 added impetus to infrastructure vulnerability consideration.

The aptly named report *Risks and Realities* records the processes, findings and mitigation (risk reduction and readiness) recommendations identified as the Christchurch project was undertaken.<sup>1</sup> Damage from the recent earthquakes was successfully reduced by seismic risk reduction, in large measure resulting from that project. Similarly, the emergency response was assisted by a range of readiness preparations, much of it suggested as the project proceeded.

The Earthquake Commission (EQC) has been prominent in fostering discussion and promoting understanding of a range of issues relating to earthquake costs and mitigation for many years, working with the New Zealand Centre for Advanced Engineering (CAE) and other organisations. Much of the impetus behind establishment of lifeline groups in New Zealand can be traced to continued encouragement from these organisations.

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 from the recent earthquakes to foster further, well-targeted, seismic mitigation in New Zealand.

<sup>1</sup> See *Risks and Realities: A Multi-Disciplinary Approach to the Vulnerability of Lifelines to Natural Hazards*, prepared by the Christchurch Engineering Lifelines Group and published by the Centre for Advanced Engineering in 1997.

## SUMMARY

The main elements that contributed most strongly are as follows:

- **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.

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

# Risks and Realities – Main Mitigation Measures

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## 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.<sup>2</sup> These need to be brought up to standard. Another special case relates to bridges, where strengthening and other retrofitting were recommended.
- adopting best practice in design, choice of material and installation
  - › Includes installing flexible connections where assets (especially 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, including large items like generators and transformers (foundations should also be checked), smaller items such as computer equipment, and building service plant such as diesel tanks and light fittings, and equipment installed on rooftops.

<sup>2</sup> 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, is contained in an article by D. Brunsdon, *Categorisation of Post-Disaster Facilities*, published in the Journal of the New Zealand Structural Engineering Society in 2006. A particular area of ambiguity, noted in the 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
  - › ensuring 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 so on 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.

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 New Zealand Transport Agency (NZTA, known at that time as Transit) said that a rolling programme for strengthening State Highway bridges had commenced.

Cross-sector engagement between different lifelines also increased and became more systematic as a result of the work leading to *Risks and Realities*.

*Risks and Realities* notes that much of the potentially valuable mitigation work, including asset-related work, is not costly.<sup>3</sup> Restraining equipment, reviewing and improving spare parts practices, response planning and much of the seismic retrofitting, can be (and was) done without great expenditure.

A summary of many of the mitigation steps by individual Christchurch lifeline utilities following *Risks and Realities* is available in the full report. That summary states, for example, that 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.

<sup>3</sup> The approaches suggested in *Risks and Realities* – robust assets, coordinated responses and realistic end-user expectations – now form the basis of current work by the New Zealand Lifelines Committee on infrastructure resilience.

The Canterbury Lifeline Utilities Group has also undertaken ongoing collective projects and other activities aimed to mitigate seismic risks. The Group's actions that contributed to successful earthquake response included the following:

- **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 helped sharpen focus on the value of reliability, vulnerabilities and (in some cases) the need for back-up arrangements.
- **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 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.
- **Lifeline coordination protocols:** Lifeline coordination protocols (based on national arrangements) set out communication and reporting arrangements for emergency responses.

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.

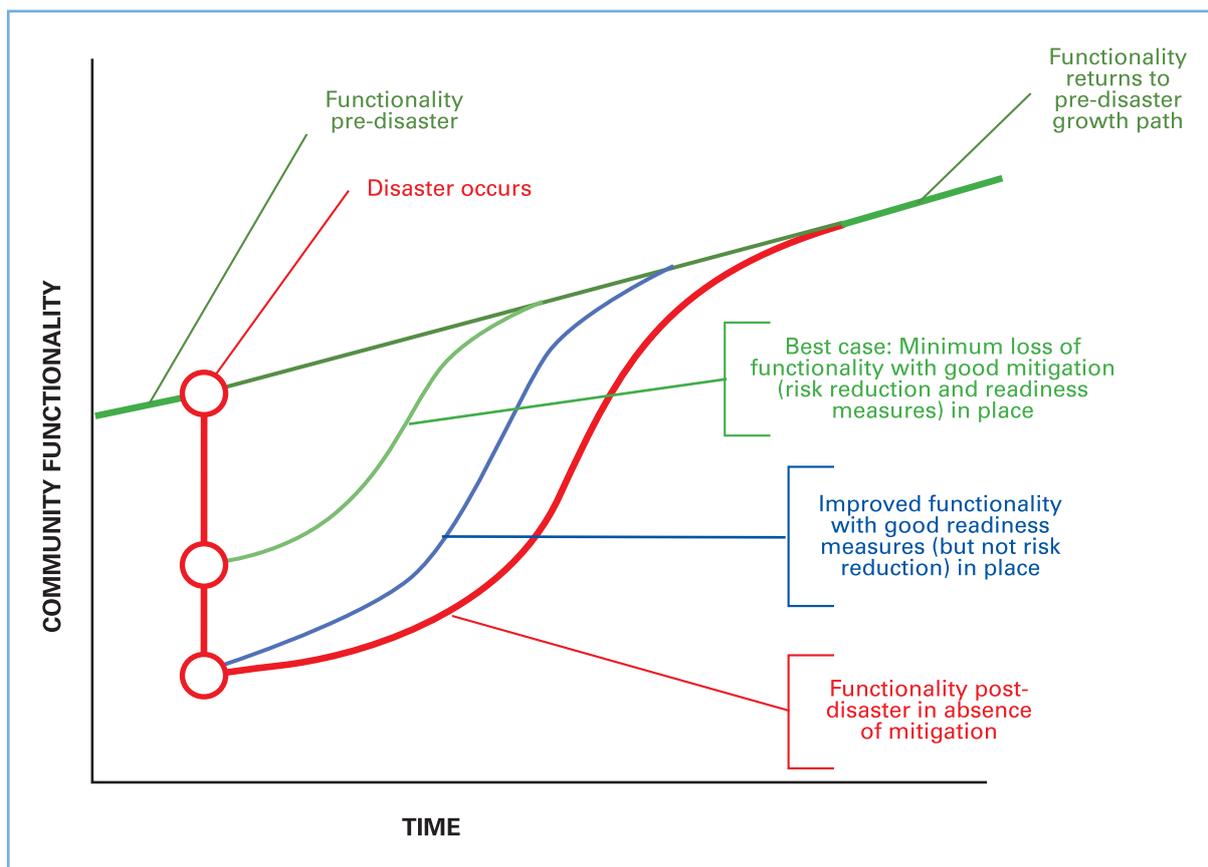
## Assessing the Merits of Mitigation

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Infrastructure outages impact households and businesses. Many of the impacts are relatively obvious. Households are vulnerable to outages over which they have very little control, small to medium sized enterprises (SMEs) are particularly exposed to outages, and 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 rely on infrastructure include infrastructure businesses (lifelines) themselves. The extensive interdependencies within this central group mean that infrastructure outages can cascade through the economy adding substantially to overall costs.

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

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 1 illustrates the issues.



**Figure 1: 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.

A range of 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”<sup>4</sup>

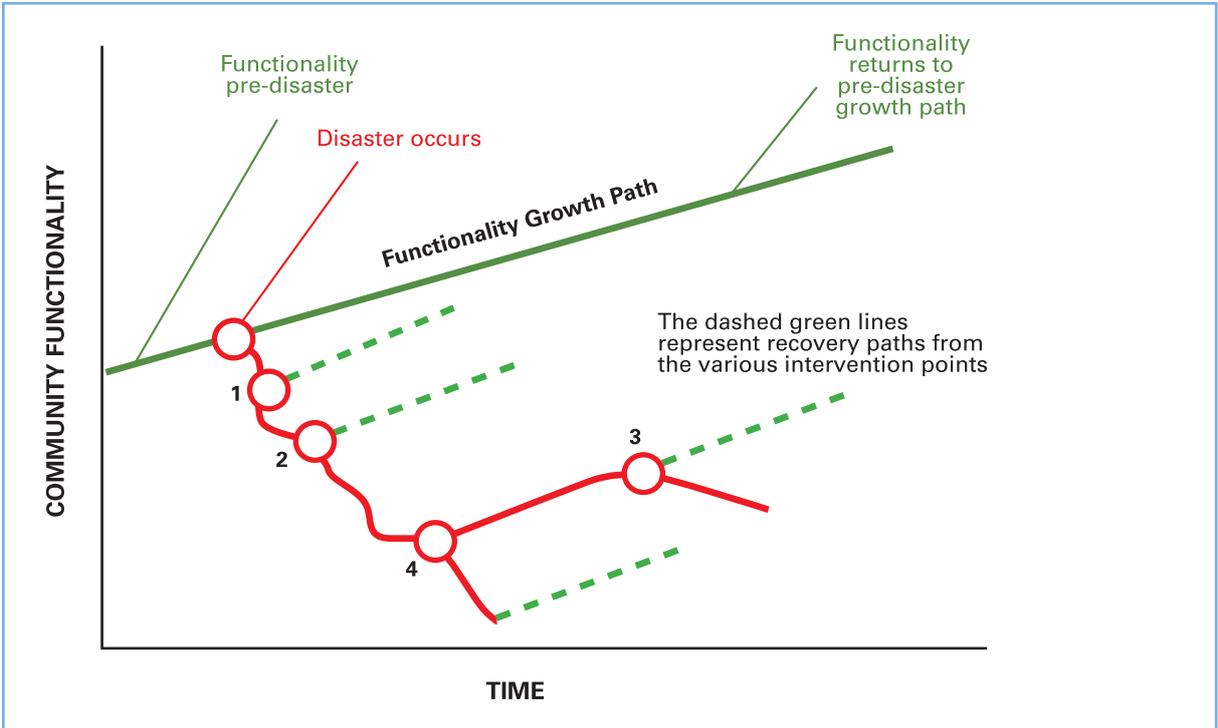
Related issues have also been explored within New Zealand by lifeline groups and others. For example, modelling by Market Economics associated with Exercise Ruamoko, a recent large civil defence exercise based on a volcanic eruption in Auckland, suggested the Auckland region would suffer a 47 per cent reduction in GDP, but that this could be reduced to 40 per cent if businesses had effective mitigation measures in place.<sup>5</sup> 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.”<sup>6</sup>

<sup>4</sup> See *Natural Hazard Mitigation Saves: An Independent Study to Assess the Future Savings from Mitigation Activities, Volume 1 – Findings, Conclusions and Recommendations*, prepared by the Multihazard Mitigation Council and published by the National Institute of Building Sciences (Washington, D.C.) in 2005.

<sup>5</sup> The Exercise Ruamoko report is available at [http://www.civildefence.govt.nz/memwebsite.nsf/Files/National%20Exercise%20Programme/\\$file/ExRuamoko-FINAL-REPORT-Aug08.pdf](http://www.civildefence.govt.nz/memwebsite.nsf/Files/National%20Exercise%20Programme/$file/ExRuamoko-FINAL-REPORT-Aug08.pdf).

<sup>6</sup> See *Infrastructure Investment: Supporting Better Decisions*, prepared by the New Zealand Centre for Advanced Engineering in 2010.

Figure 2 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 1).



**Figure 2: 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.

# Conclusion

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The New Zealand and overseas studies indicate that the very significant costs from earthquakes can be reduced by well-directed mitigation work 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.

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 who have contributed to collaborative lifelines engineering processes of which *Risks and Realities* is a prime example.



