Natural Hazard Road Risk Management Part III: Performance Criteria

P. Brabhaharan, L. M. Wiles & S. Frietag
Opus International Consultants Limited,

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© 2006, Land Transport New Zealand
PO Box 2840, Waterloo Quay, Wellington, New Zealand
Telephone 64-4 931 8700; Facsimile 64-4 931 8701
Email: *research@landtransport.govt.nz*
Website: *www.landtransport.govt.nz*

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Opus International Consultants, Wellington Office, Level 9,
Majestic Centre,100 Willis Street, PO Box 12-003, Wellington, New Zealand

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Contents

Executive summary

Introduction

Road networks are lifelines for the community and are essential for the social and economic well-being of New Zealand. Natural hazards cause considerable damage to road networks from time to time and cause widespread disruption to transportation, leading to significant repair costs to road controlling authorities, access difficulties for emergency services, and disruption to road users and the community at large.

Currently, we have no guidelines for setting levels of service or performance measures for roads which are subject to natural hazard events. As a result, roads which are subject to natural hazard events have been managed mainly reactively, which has led to high ongoing expenditure in terms of damage costs, disruption costs and adverse effects to the community.

This is the third part of a three part research project developed between 2002 and 2005 concerning the management of risks to road networks from natural hazards. Parts I and II of the Natural Hazard Road Risk Management research have led to the development of approaches to the identification, assessment and management of natural hazards risks to road networks and key approaches to implementation given New Zealand's road infrastructure management.

Literature Review

A review of current literature from overseas revealed little information on criteria for setting performance levels for road networks, except for design standards for bridges and some possible levels of performance for water supply systems. The review did reveal a useful of definition of resilience as a combination of service quality and recovery time during and after a natural hazard event.

Interviews with road user stakeholders

Interviews exploring the reaction of road management and user stakeholders to past natural hazard events indicated that travel disruption from natural hazards is generally tolerated as a consequence of the environment. However, the users are less tolerant of planned disruption (even to rehabilitate damage) and lack of information on road closures.

Road and emergency management sectors vary in their perception of the performance of road networks in natural hazards and in their performance expectations. The Civil Defence sector placed a high importance on access for emergency services and lifeline operators, and emphasised the need for risk reduction through mitigation work. State Highway managers (Transit) regarded that the risks to road networks are managed well, given the extent possible within budgetary constraints. The local authority road asset managers identified the wider social and economic costs to the community as a major factor in deciding performance criteria.

All asset managers considered funding as a key issue in encouraging and enabling proactive risk reduction. All sectors were averse to risk to life and this was seen as the most important issue, with emergency managers linking safety of life with the availability of access for emergency services.

Key factors and constraints on performance levels

The key factors affecting performance measures were identified as:

- safety of life,
- disruption,
- road access for emergency services and key lifelines utilities,
- community expectations,
- availability of alternative routes and
- the broader socio-economic impacts.

Other constraints on performance levels are:

- mitigation cost,
- availability of resources and skills,
- suddenness of event,
- feasibility of mitigation,
- other lifeline impacts and
- public perception.

All these factors were developed at a workshop with road and emergency management stakeholders, which explored performance measures and levels of service.

The framework for setting performance criteria

A framework has been developed for setting performance criteria and levels of service.

The framework comprises:

- Setting broad level performance measures for the network by assessing factors and constraints.
- A detailed review and setting of levels of service for the various links that form the network, through :
  - an assessment of the risks,
  - determining the ability of the network road links to meet the broad level performance measures,
  - consideration of the wider network and consulting with the other road controlling authorities, and
  - consideration of mitigation work required.
- Building performance measures and levels of service into asset and emergency response plans.

To facilitate the process, the resilience of each road link in the network can be assessed in terms of appropriate 'resilience states' developed as part of this study, namely:

- damage state,
- availability state, and
- outage state

These states are useful for representing the currently expected resilience in a certain hazard event, and the expected resilience from performance expectations. This would allow resilience shortfalls to be identified. It would also assist in developing mitigation measures to be included in asset management planning and implementation.

A pilot study on a section of the Wellington road network illustrates how the framework can be used to set performance levels.

We do not recommend specific performance levels, as it is considered that each road network or regional network would need to develop levels which are consistent with its particular network, vulnerabilities and constraints.

Abstract

Road networks are lifelines for the community and are essential for the economic and social well-being of New Zealand. Natural hazard events can cause significant and widespread damage to transportation networks, leading to significant repair costs to road controlling authorities, access difficulties for emergency services and disruption to road users and the community at large.

Currently, no guidelines for setting levels of service and performance measures for roads which are subject to natural hazard events are available. This study, made in 2002–2005, explores which performance criteria are acceptable for various hierarchies of road networks in order to develop a framework that can be used nationally by various road controlling authorities for setting performance measures and levels of service for road links forming New Zealand's road network.

1. Introduction

Road networks are lifelines for the community and are essential for the social and economic well-being of New Zealand. Natural hazards such as earthquakes, storms, floods, volcanic eruptions, snow, wind and slope failures are prevalent in New Zealand, and cause considerable damage to road networks from time to time. Significant natural hazard events can also cause widespread disruption to transportation, leading to significant repair costs to road controlling authorities (RCAs), access difficulties for emergency services, and disruption to road users and the community at large. The consequences for businesses and the economy in general can be very significant. Road networks are also crucial in enabling the community to survive in the aftermath of major natural disasters, and to recover from them.

Currently, no systematic approaches to natural hazard risk management for road networks in New Zealand are available. At present, roads subject to natural hazard event have no guidelines on performance criteria, with the result that roads have been managed to varying standards in an *ad hoc* manner. This has led to high ongoing costs in terms of damage costs, disruption costs and adverse effects to the community. The adverse effects would be large in the aftermath of major natural hazard events, such as a major earth-quake, storm or volcanic eruption.

The new Civil Defence and Emergency Management (CDEM) Act 2002 has been enacted to ensure that the country has measures in place to be resilient in the face of natural hazards. Among the requirements of the Act is a requirement that lifeline utility owners (such as water supply systems) have plans in place to manage the risks to lifelines, and are able to bring them into service as soon as possible after an event. The Act places the responsibility on the sectors concerned (in this case, the road sector) to determine what performance levels are appropriate. At present, the road sector has no performance criteria available.

Parts I and II of the natural hazard road risk management research (Brabhaharan et al. 2001, Brabhaharan & Moynihan 2002) have led to the development of approaches to the identification, assessment and management of natural hazard risks to road networks. The research has also led to developing key approaches to implementation, given New Zealand's road infrastructure management. Part II recommended that further research be carried out into performance criteria in order to help make decisions on appropriate levels of service in hazard events.

These recommendations have led to Part III of this study, with the focus on performance criteria. The research has involved:

- extending of the previous literature review,
- consulting road stakeholders to assess their response in past natural hazard events,
- consultating organisations and people involved in the management and funding of road networks, a workshop on performance measures,
- developing a framework for setting performance levels and
- applying the framework to a section of road network to illustrate its use.

This report presents the outcomes of this research into road performance criteria.

2. Risk management framework

2.1 Stages of research

This research is the third stage (Part III) of three stages of research identified as follows:

- Part I – natural hazard risk management strategies for road networks (Brabhaharan et al. 2001)
- Part II – natural hazard risk management for road networks – implementation (Brabhaharan & Moynihan 2002)
- Part III – Natural hazard road risk management - performance criteria

Figure 2.1 ,which was based on AS/NZS 4360: 2004 Risk Management (Standards New Zealand, 2004), provides an overview of the risk management framework with respect to research projects Parts I, II and III. This overview illustrates where each part of the research fits into the overall risk management process.

2.2 Part I – natural hazard risk management strategies for road networks

In Part I, Opus developed strategies for managing natural hazard risks to road networks. This research identified several approaches, firstly for assessing the spatial risk to road networks with the aid of a geographical information system (GIS); secondly, considering risk mitigation; and, finally, prioritising sections of road for management of the risk. It also presented methods for considering the intangible factors that need to be considered in managing risk. The study recommended that further research be carried out to consider how the risk management strategies can be implemented by various organisations involved in the planning, management and funding of road networks.

2.3 Part II – natural hazard risk management for road networks: implementation

In Part II, Opus presented different levels at which risk management should be addressed and discussed how this may be integrated to achieve a resilient road network. The following levels of implementation were proposed:

1. national strategy,
2. regional transport risk strategy,
3. local road network risk management,
4. emergency management planning and
5. project development.

This research also considered the current funding regime for roads, how this funding regime affects risk management, and what changes could facilitate a more proactive approach to managing risk. This study recommended that performance criteria and levels of service for different types of roads forming the road networks in New Zealand should be researched.

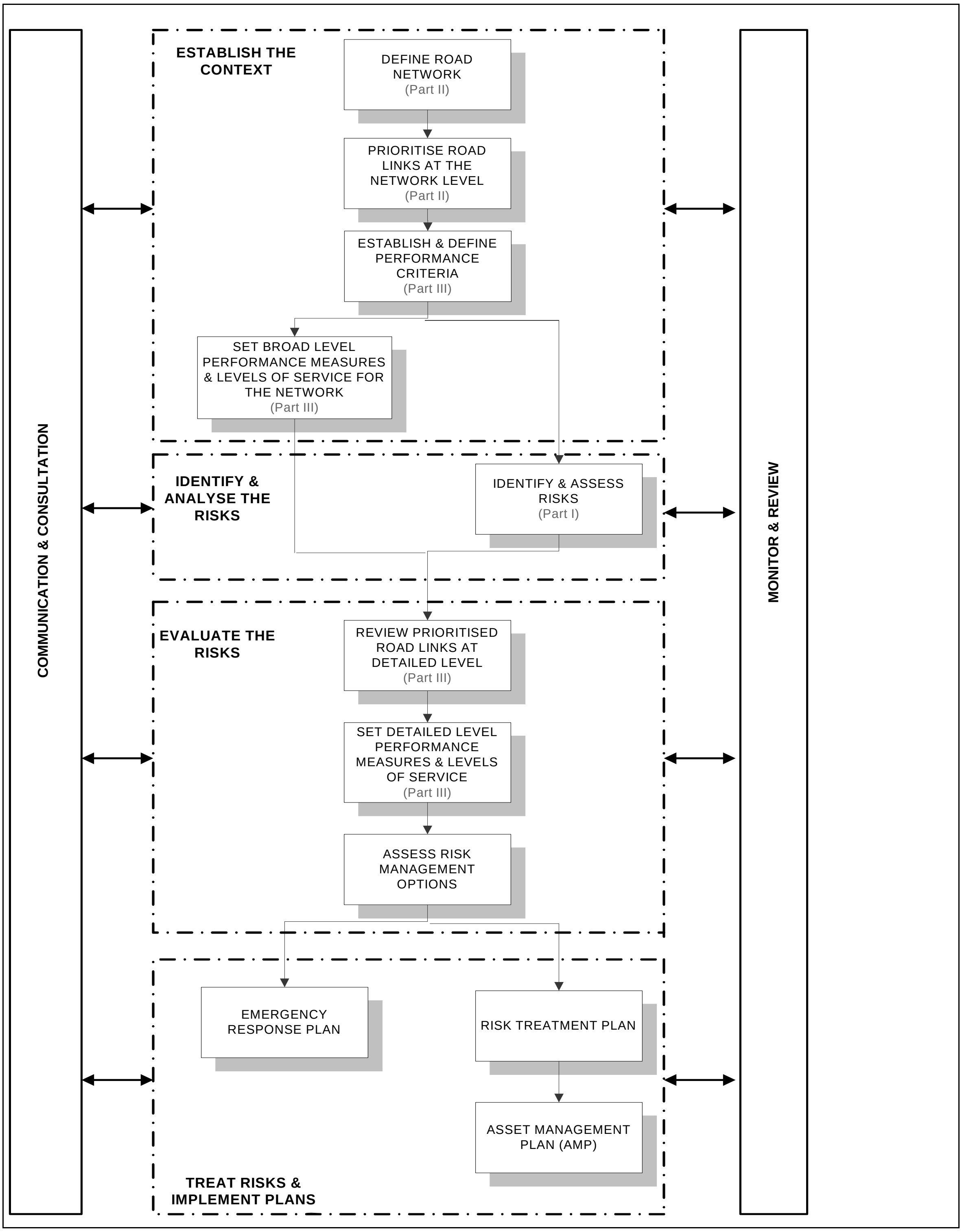


Figure 2.1 The road risk management process, showing where Parts I, II and III fit into this process.

3. Objectives and methods of research

3.1 Overall objective

The objective of this research is to develop a framework for setting performance measures and levels of service for road networks in New Zealand in relation to natural hazard events.

3.2 Research methodology

This research is the third stage of a programme of research aimed at developing approaches for the strategic management of natural hazard risks to road networks in New Zealand.

A methodology was developed to enable the development of robust criteria for setting performance levels for road networks regarding natural hazards risk performance. The methodology is outlined below.

3.2.1 Literature research

Comprehensive research into the management of risks to road networks was carried out during Parts I and II of the study. Additional literature published on risk performance criteria since the previous Parts was sourced with the aid of Opus' Information Centre, and reviewed.

In addition, the principal author of this report attended a conference at a US–NZ workshop on critical infrastructure held from 8–11 August 2005 in Rotorua and Taupo, New Zealand.

3.2.2 Reviewing road damage and disruption from past natural hazards.

In order to understand the effects of road disruption on road stakeholders and the wider communities, we assessed the responses of road stakeholders to a range of past events which have disrupted travel. This was done through a series of structured telephone interviews. This review was important in developing the criteria for performance levels.

3.2.3 Consulting road stakeholders

It is important to understand the issues facing RCAs, and the context in which they operate in order to manage the natural hazard risks to their road network. This understanding is a key part in developing performance criteria.

We also consulted selected representatives from RCAs and other organisations in or with links to the transport sector through face-to-face interviews and discussions to assess their responses to natural hazard events affecting road networks and gain an understanding of how they perceived risks.

3.2.4 Identifying issues and assessing factors which affect performance levels

The Opus research team identified and ranked all issues in their order of importance regarding performance levels based on experience in risk management and the roading industry, as well as the research, reviews and consultations described above.

3.2.5 Workshop on performance expectations

Representatives from organisations directly involved in or with links to the transport sector participated in a workshop where they brainstormed the factors which influence and constrain the setting of levels of service and performance measures. This workshop was an event where we were able to gather information on issues critical to RCAs and emergency management, and how to use this information in setting performance levels.

3.2.6 Developing a framework for setting performance levels

Our next step was to develop a framework for setting performance levels within the context of the risk management process. The framework was set up using flowcharts and tables to provide a basis for developing performance levels for road networks.

3.2.7 Pilot application of the framework to a section of the road network

A pilot study to trial the application of the framework and use it for risk management planning was carried out using a section of the Wellington road network. The framework was adjusted as required based on the pilot study. This demonstrates how the process can be applied in practice to assist practitioners in setting performance criteria that can be used as a basis for their road asset risk management planning.

3.3 Report

Finally, the information was compiled into this Land Transport New Zealand Research Report.

4. Literature review

4.1 The approach

Parts I and II of this study undertook comprehensive reviews of literature relating to the management of risks associated with road networks. These were presented by Brabhaharan et al. (2001) and Brabhaharan & Moynihan (2002).

A further review of additional literature was carried out, which focused on:

- any additional information that has become available since the previous parts and
- any information on the performance criteria used to manage risk to road networks.

The authors used Opus' Information Centre to search databases and source literature.In addition, the principal author attended and contributed to a conference on 'resilient infrastructure' in Rotorua on 8–9 August 2005, and a follow-on 2005 Joint United States–New Zealand critical infrastructure workshop.

4.2 Design philosophies

In recent years,designers and planners have increasingly recognised the need to consider 'performance' of road structures, rather than solely 'ultimate limit state' failure criteria.

4.2.1 Performance criteria proposed by Imbsen & Mesa (2002)

Imbsen & Mesa (2002) outline an approach used to develop seismic design criteria for South Carolina. They have expressed performance levels in terms of *Service Levels* and *Damage Levels*, which are categorised as follows:

Service Levels

- Immediate: Full access to normal traffic is available almost immediately following an earthquake.
- Maintained: Short period of closure to the public. Open to emergency vehicles.
- Recoverable: Limited period of closure to the public. Open to emergency vehicles.
- Impaired: Extended closure to the public. Open to emergency vehicles. Possible replacement needed.

Damage Levels

- Minimal damage: no collapse.
- Repairable damage: Although the risk of collapse is minimal, permanent offsets may occur in elements other than foundations.
- Significant damage.

They classify bridges into three categories of performance levels:

- Critical bridges: These will be open to all traffic once inspected after functional evaluation design earthquake (e.g. 2500 year return period); usable by emergency vehicles and for security/defence purposes after safety evaluation design earthquake.
- Essential bridges: At minimum, these will be open to emergency vehicles and for security/defence purposes after safety evaluation design earthquake (e.g. 2500 year return period).
- Normal bridges: any bridge not classified as critical or essential.

These bridge classifications are based on:

- whether a bridge is required to provide secondary safety of life,
- the economic impact created by closure caused by the time taken to restore full function,
- whether a bridge is designated as critical by a local emergency plan.

The period of closure described in *Service Levels* does not seem to have been carried through into the classification of the bridges for design. The approach focuses on bridges and does not appear to consider the whole road network/highway system.

4.2.2 Performance criteria used in Japan

Tamura (2002) describes revised design principles for earthquake-resistant designs for highway bridges in Japan, where three levels of seismic behaviour are considered, depending on the importance of the bridge:

- seismic performance 1: to secure integrity,
- seismic performance 2: to limit damage and secure rapid restoration of function, and
- seismic performance 3: to prevent fatal damage.

The seismic performance criteria are reproduced below in Table 4.1:

Table 4.1 Seismic performance criteria proposed by Tamura (2002) for highway bridges.

Seismic performance criteria	Safety	Serviceability	Repairability	
			Short term	Long term
Seismic performance 1	Safety secured against collapse.	Secure pre-earthquake function.	Needs no repair for restoration of function.	Needs minor repairs.
Seismic performance 2	Safety secured against collapse.	Secure rapid restoration of function.	Emergency repair enables restoration of function.	Possible to perform permanent repairs easily.
Seismic performance 3	Safety secured against collapse.	–	–	–

4.2.3 Seismic design approach developed by Mayes et al. (2002)

Mayes et al. (2002) describe the seismic design approach developed for highway bridges in the USA based on the LRFD (Load and Resistance Factor Design) approach. In terms of performance, this approach adopted these basic concepts:

- Loss of life and serious injuries caused by unacceptable bridge performance should be minimised.
- Bridges may suffer damage and may need to be replaced but they should have low probabilities of collapse caused by earthquake motions.
- The function of essential (critical lifeline) bridges should be maintained even after a major earthquake.

Using these concepts, Mayes et al. (2002) proposed the performance objectives (given in Table 4.2) which depend on earthquake severity.

Table 4.2 Seismic performance criteria and levels for bridges in earthquakes of differing probabilities of exceedance (Mayes et al. 2002).

Probability of exceedance – earthquake ground motions	Performance criteria	Performance level	
		Life safety	Operation level
Rare earthquake (MCE) (3% in 75 years)	Service	Significant disruption	Immediate
	Damage	Significant	Minimal
Expected earthquake (50% in 75 years)	Service	Immediate	Immediate
	Damage	Minimal	Minimal to none

Notes to Table 4.2

(a) The probability that this level of design earthquake ground motions will be exceeded in a 75-year period is given in brackets.

(b) The levels of service are defined as follows:

– Immediate: full access to normal traffic shall be available following an inspection of the bridge.

– Significant disruption: limited access (reduced lanes, light emergency traffic) may be possible after shoring, but the bridge may need to be replaced.

(c) MCE: Maximum Credible Event.

These performance levels are focused on bridges only and are limited to bridge design. Nevertheless, they provide a broad framework on the current thinking in terms of performance levels in the design of highway structures.

4.3 Performance criteria for highway systems

Buckle (2003) discusses a performance based design approach for highway systems, with particular reference to bridges. He proposes a performance criteria matrix, shown in Table 4.3.

Table 4.3 Performance criteria matrix for highway systems with bridges (Buckle 2003).

Earthquake	Highway system Type 1 (standard operating requirements)	Highway system Type 2 essential operating requirements
Frequent earthquake	T_{80} <2 days T_{100} <7 days	T_{80} <1 day T_{100} <1 day
Rare earthquake	T_{80} <30 days T_{100} <90 days	T_{80} <7 days T_{100} <30 days

Note: T_{80} & T_{100} = times for 80% and 100% restoration.

4.4 Performance criteria in other sectors

Graf et al. (2003) consider natural hazard performance objectives for water systems. They propose welfare-oriented parameters of:

- percent served (in total or by sector) within a specific number of days with raw water with adequate fire flow pressures, and /or
- percent served (in total or by sector) within a specific number of days with fully treated water.

Chang et al. (1997) considered natural hazard risks to water systems and proposed an example with the following performance level definitions for service areas and the system shown in Table 4.4.

Table 4.4 Performance level definitions for service areas and water systems (Chang et al. 1997).

Performance level	Level of operation
Service areas	
Level 1:full service	Flow ratio (r) >67%
Level 2: partial service	33%< r <67%
Level 3: no service	r <33%
System	
1: normal	No service areas at Levels 2 or 3.
2: localised damage	No service area at Level 3 and 1–2 areas at Level 2.
3: critical	No service area at Level 3 and 3+ areas at Level 2 OR 1 area at Level 3.
4: inadequate	2+ service areas at Level 3.

Note: Flow ratio (r) is defined as the ratio of post-earthquake flow to normal flow at nodes in the service area.

Chang et al. (1997) also proposed a life cycle cost analysis and selection of upgrading alternatives that minimise life cycle costs and meet the performance criteria.

Comerio (2005) outlined the seismic retrofitting programme for the University of California (Berkeley Campus) and explained the basis for the retrofit decision as being the unacceptable downtime for the university and closure for an extended period of time.

4.5 Civil Defence Emergency Management Act requirements

The *Director's Guidelines for Lifeline Utilities* (Ministry of Civil Defence & Emergency Management 2002) provide guidelines for lifeline utilities which include road networks. They provide the expectations of the CDEM Act 2002 for achieving a vision of a 'resilient New Zealand' through requiring lifeline utilities to plan and implement procedures to ensure service continuity to the fullest possible extent. It does not provide specific advice on performance levels and expects that the utilities themselves consider and establish this for these operations.

4.6 2005 Joint US–New Zealand critical infrastructure workshop

At the 2005 Joint US–New Zealand Critical Infrastructure Workshop, Professor Ian Buckle proposed defining resilience as a function of vulnerability and rate of recovery using the formula:

Resilience = f (vulnerability, rate of recovery)

This is shown in Figure 4.1.

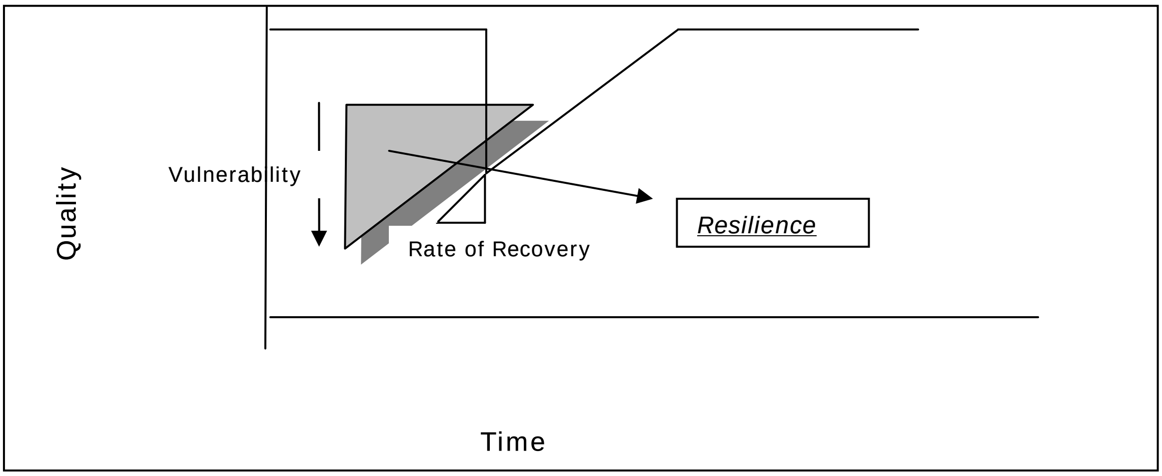


Figure 4.1 Graph depicting resilence, recovery rate and vulnerability as functions of service **quality and time.**

The resilience of an infrastructure can be defined as a combination of its low vulnerability to degradation from a hazard event and the ability of the infrastructure to recover quickly after an event. Conversely, loss of quality and outage are critical to define performance of infrastructure systems.

4.7 Summary

Little information is available in the literature regarding the criteria for setting performance levels for road networks. Recently, some attempt has been made to use performance levels in the design standards for bridges. In sectors other than roads, performance criteria have been used to define the desired level of performance to be achieved from risk mitigation of lifelines systems (e.g. water supply systems). However, little information exists as to how the performance levels are to be set.

Using Buckle's definition of resilience, performance levels need to be defined, based on a description of the level of service or quality and the time to recovery.

5. Impacts of past natural hazard events

5.1 Purpose

Responses of road stakeholders to past natural hazard events have the potential to provide an insight into the performance expectations and needs of road users and other stakeholders. In particular, road users who experienced disrupted road travel from past natural hazard events and road network managers who managed the consequences could provide insight into how the disruption affected their activities and how tolerant they are of the disruption caused. Their responses also provide an insight into the effects of road travel disruption on communities downstream.

5.2 Methodology

The information given by the road user stakeholders was used to develop appropriate criteria for performance levels. This research included telephone interviews and consultations with key stakeholders who had experienced past natural hazard events that affected road networks.

The review process comprised the following steps:

1. documenting the parameters of an event (trigger, consequence, closure period and cost);
2. interviewing stakeholders about responses from road users to the particular events;
3. analysing the relationship between the responses and the events.

5.3 Selected events

Five particular sections of road which had been affected by natural hazard events were selected for the interviews and analysis (see Table 5.1). These were:

- Coromandel,
- Desert Rd and Turangi ,
- Wanganui and Taranaki,
- Otago, Central Otago and Southland, and
- Wellington City.

It should be noted that these interviews and assessments were carried out prior to the large storms in December 2004–January 2005 that affected the Manawatu–Wanganui region, the lower North Island and the Bay of Plenty.

Very early in the interview process, we found that information about overall closure periods and costs was not readily available because the data on past events had not been summarised in a form suitable for review. People dealing with some of the events were no longer working for the organisation and some of the people interviewed had limited experience with the particular event identified. However, it was discovered that the people interviewed had other relevant experience and therefore the review was widened to include other events and general experience.

5.4 Stakeholder representatives

The selected target regions and the organisations interviewed are listed in Table 5.1.

Table 5.1 Regions suffering natural hazard events and details of organisations interviewed.

Region	Type of hazard	Specific event (date)	Interviews	
			Number	Organisations
Coromandel	Flooding	'Weather Bomb' (2002)	3	Transit, NZRTA[a], Civil Defence
Desert Rd/Turangi	Snow/ice, flooding	Extended snow/ice closure (1995);recurring flood events north of Turangi	4	Transit, NZRTA, contractors, community organisation
Wanganui/Taranaki	Slips, washouts	Anzac Parade washout (2000); Stockman's Hill (1998); Awakino Gorge (recurring slips and washouts)	4	Transit / local authority, NZRTA, contractors, AA[b]
Central Otago/Otago/ Southland	Slips, snow/ice	Nevis Bluff rock slide (2000) Frankton Rd slip (1999)	4	Transit, NZRTA, AA, community organisations
Nationwide	Slips, snow/ice	Waioeka Gorge (recurring slips)	2	National bus operators, NZRTA
Wellington City	Slips, flooding	Recurring slips	1	WCC[c]

Notes to Table 5.1:
a NZRTA: New Zealand Road Transport Association
b AA: Automobile Association of New Zealand
c WCC: Wellington City Council

Representatives were selected from RCAs, road user and community groups. The selected representatives who were consulted are summarised in Table 5.2.

Table 5.2 Selected representatives of road stakeholders interviewed.

Organisation	Number consulted
Transit New Zealand asset managers	4
NZ Road Transport district representatives	3
Bus and Coach Association members	1
CDEM planning manager	1
Community Organisations representatives	2
Local authority road project manager	1
Roading Ccntractors	1

5.5 Interview format

Road user responses are influenced not only by the parameters of the delay and the event that causes it, but also by other factors relating to their perception of the event and their expectations of how it should be managed. To understand the significance of such factors on the responses received, the interview was designed to examine the factors that might be strong influences, rather than just the parameters of the events themselves.

The factors relating to the road users were:

- the amount of information provided to them,
- their perceptions of expenditure on its management,
- purpose of travel, and
- individual circumstances.

The factors relating to the disruption itself were:

- the nature of the disruption,
- the duration of the disruption,
- the risk to safety caused or the level of disruption,
- whether it was predictable,
- whether it was controllable,
- whether it occurs regularly, and
- the combined effect of frequency and severity of disruption

Understanding the relative influence of these factors on community tolerance will allow RCAs to prioritise practices for managing travel disruption caused by natural hazards and also by events caused by humans, such as road works or traffic accidents.

The interviews were conducted by telephone and the results are summarised and presented in Appendix A. The overall outcomes from the interviews have been collated and reviewed, and are presented in the next chapter.

6. Factors influencing road user response

6.1 Impacts of road travel disruption

Travel disruptions have greater effects than simply being an inconvenience to travellers. Specific impacts described by the interviewees are discussed below.

6.1.1 Impact on safety

The safety of all road users can be affected by:

- using detours (or affected routes) that are unsealed, narrow, and poorly signposted, which results in an increased risk from inappropriate driver behaviour (inexperience or impatience) and traffic volumes;
- an increase in careless driving as drivers attempt to make up for lost time;
- the failure of drivers to see warning signs to observe road closures; and
- slower travel speeds exposing vehicles more to being hit by rock fall in affected areas.

In the heavy transport industry, delayed travel affects a driver's schedule of driving and rest time, and hence has an impact on safety.

6.1.2 Economic impact

Detours can add significantly to the costs of a business with increased travel time costs, fuel, wear and tear on the vehicle, and extra road user charges.

Bus companies

To the passenger bus company offering a network of scheduled services, the consequences of travel delays include:

- extra vehicle running costs;
- the cost of providing alternative transport to passengers who miss connections;
- the cost of providing replacement drivers when original driver reaches maximum driving hours, and when delays mean that original driver has to forego his next journey until after the required rest period;
- the cost of providing extra services (drivers and vehicles) to tourist destinations such as Milford Sound for tourists who have waited until the route has re-opened;
- the cost of refunding passengers for sections of itinerary cancelled or rescheduled; and
- lost business when a service cannot be provided.

Businesses

To businesses relying on passing traffic, delays or detours can mean significant reductions in sales. These sales include business based on the spontaneous decision of passing travellers, business from customers who believe that the destination is no longer accessible and business from customers who no longer have the time to stop because of delayed travel time.

Businesses in the Kawarau Gorge on either side of the Nevis Bluff slip were particularly affected by these factors. However, negative effects of natural hazards on businesses in such areas seem to be generally accepted as a risk associated with doing business in that particular location.

Disruption and potential losses can affect businesses which rely on goods or raw materials transported by road.

On the other hand, businesses may benefit from traffic that is detoured into the community. For example trade in Wanaka increased when traffic was diverted over the Crown Range to avoid the Kawarau Gorge.

Business Development and Growth

Services and industries in regional centres will be affected by delayed receipt of goods and supplies (particularly perishables), and by the inability to deliver goods on time to their customers. Opportunities for business development and growth in such centres could be limited if the main road access is prone to disruption. An example would be ports that compete with other ports, such as Westgate (New Plymouth), Tauranga and Auckland port facilities, which all compete for business from the Waikato.

The potential to attract tourists could be also limited if road access is perceived as difficult or unreliable. Visitors might not return to a regular holiday destination for a year or two after a holiday has previously been disrupted by road closures.

6.1.3 Emergency services

Road closures can disrupt emergency services, but they will have contingency plans for regular or predictable events so the impact is likely to be less severe than what they would have been otherwise. For example, on receiving a heavy rain warning, an ambulance service might arrange to station vehicles on both sides of a common flood site and would have identified local doctors able to assist in an emergency. In the Coromandel, basic hospital facilities are available in Whitianga for patients who cannot be transported off the peninsula because of flooding. The impact of road closure will vary between services. For example, ambulances often have to transport patients to regional (base) hospitals so their need for access is much greater than for fire services, which provide relatively localised services. Police also operate over a more localised range, although some of their activities might be affected. For example, their ability to detain people in custody requires access to cells.

When roads are closed because of bad weather, helicopter access is also prevented, although specialised rescue helicopters will fly in adverse conditions for life-and-death situations. Contractors will give priority to providing access for emergency services, providing all necessary assistance (e.g. guidance through a site). Nevertheless, Civil Defence recognises that emergency services sometimes cannot be provided when and where they are needed, hence their policy of promoting that every household should prepared to be self-sufficient for 72 hours. This period may have been selected as one that householders would not find too daunting – one interviewee believed it could take up to nine days to reach all Civil Defence centres in his area.

6.1.4 Impact on communities

If children cannot get to school, teaching programmes will be disrupted and parents may have to make arrangements for childcare. If children cannot get home after school, schools, particularly in rural communities, will have to accommodate their pupils until they can reach home safely and will have to contact parents to advise them of the arrangements.

Travel delays can have significant effects on the provision of effective health care services, not only within a community, but also between communities with a central provider. For example, Hamilton provides coronary care services for New Plymouth-based patients. Closure of the Awakino Gorge can turn a one-day journey for a check-up into a two-day journey, or a missed appointment and prolonged waiting time if the patient is unable to travel the extra distance. Obviously, the elderly and infirm are the most likely to be affected, and they are also most likely to find alternative routes more difficult to cope with. As noted above, emergency health care provision may be reduced, but all communities will have contingency plans to ensure that some medical service is available if an ambulance cannot reach a patient or cannot transport him or her to a primary hospital.

Residents in urban areas may lose the convenience of parking on the street near their homes, either because of damage to the road or because parking restrictions are imposed so that the road can be used as a detour around an affected site. They may also have to contend with dust, dirt and noise from remedial works, and may have to provide access through their properties to affected sites.

The operations of contractors involved in clearing slips can be significantly delayed by requirements put in place to minimise traffic disruption. On urban routes, it may be more efficient for work to halt during periods of peak traffic flow, so that extra road width is available for traffic and travelling to landfills to dispose of spoil is not delayed by traffic.

RCAs themselves are also affected by disruption to their normal activities. Geotechnical assessment of a slip in an urban area can take several days of council and consultants' time, delaying work on other projects. Significant time and stress is involved in dealing with claims for liability lodged by property owners and road users, and such claims may result in increased public liability insurance costs.

6.2 Effect of the nature and type of event

Road users generally accept delays caused by road closures or detours caused by natural events as part of the nature of that part of the countryside, provided they understand the reason and particularly if an alternative route is available. Dissatisfaction is more often related to inadequate information about the cause of the delay, its likely length and/or the alternative route. Good information enables drivers to make appropriate plans to accommodate the delay and minimise its effects. One interviewee reported that the success of managing an event is related as much to managing the outrage as managing the event itself. Planned delays caused by remedial works were tolerated much less than delays caused by the event that necessitated the work.

The magnitude of delay that is acceptable varies, depending on the road user and the nature of the journey. For example, for a bus company operating connecting services, schedules can be significantly affected by delays of more than 15 minutes. Doubling a 10-minute journey can also cause frustration. A detour that turns a 3-hour journey into a 7-hour journey might deter a private motorist, but commercial operators would accept it as long as they know about it in advance and do not have to turn around (or wait because they physically cannot turn round). One heavy transport representative reported that a 20-minute delay at a site is acceptable but delays of 40 minutes or longer eat into permissible driving times (i.e. logbook times) unless rest periods can be planned around them. The predictable nature of some natural events makes disruptions more acceptable, such as flooding that is related to tides, where drivers know that the road is likely to reopen when the tide falls. Closures caused by snow cause more frustration because it can be difficult to predict when the road can be cleared, particularly once the weather improves.

In contrast to delays caused by natural hazards, delays caused by police investigating traffic accidents drew universal criticism. The delays were considered excessive (5–7 hours) and little or no information was provided to waiting traffic. Detours were often poorly managed, the routes being physically unsuitable and poorly signposted. Adverse comment was also received about fire trucks blocking city streets without traffic control, and about poor co-ordination between emergency services.

6.3 Duration of the disruption

As with the cause and length of the delay, its duration did not draw much negative comment provided an alternative route and good information about both the cause and the detour were given. Nevertheless, reinstatement of the original route earlier than expected was appreciated.

One local authority representative felt that disruptions lasting more than one week were unacceptable, but observed that road users complained irrespective of actual durations if progress was not obvious or if the rate of progress appeared to slow down. He also commented that preconceptions about council workers being lazy tended to prejudice public reaction.

When the Desert Road was closed for more than two to three days, many commercial and private travellers were putting off their journeys rather than taking alternative routes (this may have been because of uncertainty over the alternative routes being open). A delay of several months before a road was fully reinstated drew some negative comment.

6.4 Safety

Safety at the actual site of the hazard was not a major concern, as road users generally respected the decision to close the road, with the odd exception of the 4x4 drivers wanting to test their vehicles or people wanting to see what was happening. Only two comments were made about a road not being closed when it should have been. No criticism of protocols that allow a road to be closed for assessment was reported if any doubt arose about its safety. This suggests that a short closure might be acceptable in the interests of safety. One interviewee mentioned the importance of keeping traffic moving at rockfall sites because stationary or slow vehicles are more likely to be hit.

Interviewees showed more concern about safety associated with lack of adequate and/or timely warning signs, and particularly with the nature of alternative routes that may be unsealed, poorly signposted and unsuited to heavy traffic and high traffic volumes. Interviewees were also concerned about driver behaviour that would increase the risk of accident, including:

- the inclination of drivers to make up time by driving too fast for road or traffic conditions and
- the tendency to drive on 'autopilot' and not see warning signs or even to ignore signs, queues or barriers.

6.5 Predictability

Whether or not the event was predictable did not influence responses as much as other factors, (e.g. the control that was put in place or the information provided once an event was predicted). Some negative responses suggested that people considered that snow/ice hazards could be better predicted.

One interviewee pointed out that although severe weather can be predicted that the accuracy of such predictions is limited, and although flooding at particular sites often can be predicted one cannot predict exactly when and where slips will occur. Another mentioned that flooding has become easier to predict now that rainfall statistics are collected from more sites. This increase in data enables better assessment of drainage requirements.

6.6 Control

Responses relating to controls used to prevent or minimise disruption were linked to the regularity and predictability of the event. Interviewees gave negative feedback about:

- previous failures to control snow and ice,
- inadequate crossings over flood-prone waterways, and
- clearance of waterways.

We heard positive comments about flood prevention works, removal of potential rockfall material and the potential for anti-icing techniques such as Calcium Magnesium Acetate (CMA) to reduce closures caused by snow/ice. In contrast, although the Nevis Bluff rockfall could have been predicted (and thus prevented) if it had been monitored more closely, it was not a regular event so it was surprising that no-one commented about whether it could have been prevented.

Inconsistent traffic management at a site also has an effect. For example, drivers do not like seeing some vehicles getting preferential treatment, e.g. a stock truck being guided through floodwaters by contractors or musicians being allowed through an accident site to get to their venue on time.

On urban arterial routes, major traffic delays can develop very quickly if traffic management plans are not effective or well enforced.

Road users' perceptions of what can be controlled might not be realistic. It is not possible for personnel and equipment to clear every flood site on the Coromandel Peninsula simultaneously. Weather patterns may have changed since the days when the Desert Road was 'never closed' because of snow. Their perceptions are also related to their understanding of how expenditure is prioritised.

Information about preventive and remedial work generally increases acceptance of the disruption. As stated above, planned disruptions are not tolerated as well as disruptions caused by natural events, and little goodwill is felt when operations do not go according to plan. For example one driver complained that a road was opened earlier than expected after blasting to remove potential rockfall material at Nevis Bluff because it meant she had left home unnecessarily early and her effort had been wasted.

A prompt response with a timetabled solution is seen as critical. The public will generally accept a 'system fault' but have little tolerance of apparent incompetence.

6.7 Regularity

Regular natural hazard events are largely accepted as being part of the nature of New Zealand. But frustration was expressed at the lack of preventive measures at particular sites which are prone to repeated slips or flooding. Other comments suggest that explaining Transfund's method of prioritising maintenance could alleviate some of this dissatisfaction.

6.8 Frequency and severity

How the frequency and severity of disruptions affected tolerance was not clearly indicated. Overall, most interviewees thought that major disruption would be less acceptable. However, many also reported general acceptance of travel disruption caused by major events. This is probably because more information is available, or because people believe that the scale of such events could not be predicted or made them uncontrollable. Similar positive comments were made about the overall acceptability of natural hazard events with different severity and frequency. Unexpected disruptions of all types generated negative responses because neither drivers nor RCAs were prepared for them. One interviewee felt that any frequent disruptions, irrespective of magnitude, were not well tolerated.

6.9 Information

Road users' satisfaction is closely related to their perceptions and expectations. Both can be managed by providing accurate and timely information. We received more comment about information than about any other factor. Transit representatives reported putting major effort into providing information about travel disruption, and the amount of feedback received about information substantiates the need for such effort.

In the absence of any information provided about the cause or nature of the natural hazard event, what drivers know is what they can see. If they can't see the hazard, all they will know is that their plans have been disrupted. This makes them frustrated. If they can see the damage and/or remedial activity at the site, then they are likely to be more accepting. If they don't know about an alternative route, they are unable to take it.

One interviewee believed that much of road users' frustration stemmed from a sense of powerlessness, and that providing good information about the site and works would help to counteract this by enabling them to make travel plans appropriate to their needs.

Involving road users in the management of a road or specific event will improve the flow of information and increase acceptance, as demonstrated by positive feedback about disruption at Stockman's Hill.

Provision of appropriate information will help to ensure that expectations are realistic. Expectations which are exceeded elicit positive response, whereas unmet expectations draw criticism.

Road users need to receive information about the expected delay at a time and location that allows them to choose whether to delay the start of their journey, take a detour, or wait at the site, whichever minimises negative effects on their activities. If the journey is already underway when road users receive the information and no alternative route is available, or information is received too late to use it (e.g. a long vehicle which is between the detour and the hazard site and cannot turn around), then timely and accurate information will minimise frustration and behaviour (such as rubbernecking, ignoring barriers, or trespassing onto worksites) that might compromise safety or the efficiency of work to remove the hazard. Providing information is also important for managing expectations about the length and duration of the delay.

Timely and accurate information is also essential to enable effective response from the contractors, consultants and emergency services involved in managing the hazard.

Information was also seen as critical in communities that meet to discuss matters that affect them, because if not dealt with quickly, minor issues can quickly become major concerns that are difficult to allay.

6.10 Expenditure

One interviewee reported that cost was immaterial to the public, who 'just want it fixed and complain if it isn't fixed'. He considered that an event or travel disruption related to lack of expenditure was unacceptable to the public.

Most responses related to state highways. A few comments suggested that people might be more tolerant of disruption on local authority-controlled roads because users know that councils have responsibilities other than roading, whereas Transit's primary function is clearly to provide road access. Some people do not understand that Transit only manages some roads, and might complain to them about situations over which they have no jurisdiction. One interviewee commented that he receives much of the criticism on behalf of roading authorities because people do not know whom else to contact. Another commented that the public might become better informed about infrastructure costs in general because the Local Government Act (2002) now requires consultation with stakeholders. He thought that local authority roading and other services might benefit from the public demanding infrastructure services rather than expenditure to attract business to inner city areas.

One interviewee observed that expenditure on roading projects may be perceived as excessive, and could elicit unfavourable comment unless the community is well informed about the benefits of the works.

6.11 Purpose of travel

Private travellers have more emotion invested in their journey than do business travellers and are likely to be less tolerant of having their plans disrupted, even though the main consequence is usually just inconvenience. Overseas tourists are less tolerant than New Zealand holidaymakers of having their itineraries disrupted. Tourists in campervans may be more inclined to complain about inadequate quality of detours.

People in urban areas are less tolerant than rural people of travel disruption because their lifestyles are dictated more by timetables, and this intolerance is likely to extend to their travel in rural areas. RCAs come under more political pressure from communities to improve road access as lifestyle blocks increase in previously rural communities. City dwellers are more likely to be aware of RCAs' obligations to road users and therefore be more demanding in terms of safety and liability issues.

Commercial operators are generally better informed than private motorists about travel disruptions because they have good internal communication systems, and having better access to information may make them more tolerant of delays. The costs associated with delayed travel mean that commercial operators may be more inclined to lobby about ongoing problems.

6.12 Conclusions

The principal findings of the interview and discussion with stakeholders are:

- Travel disruption caused by natural hazards is generally considered as a feature of the particular environment concerned and is therefore tolerated well, even by those who incur direct financial costs.
- Planned (machine-made) disruptions to travel are not well tolerated, even if they are related to rehabilitating a site damaged by a natural event.
- Providing timely and accurate information is a key factor in the response of road users to travel disruption caused by natural hazards (and other events).
- Private travellers tend to be more frustrated by travel disruption than commercial road users, and people in rural communities are more tolerant of travel disruptions than people from urban areas.
- The hazard itself (e.g. the debris blocking the road after a slip) is believed to be safe enough, but traffic management at the site, downstream from it, and on detour routes may be less safe.
- Travel disruptions affect communities as well as road users. Effects include:
  - financial costs to the transport industry,
  - loss of revenue to businesses,
  - reduced business development potential,
  - the need for isolated communities to have some degree of self-sufficiency for emergency services,
  - reduced effectiveness of centralised health services,
  - increased demands on rural schools,
  - inconvenience to residents of affected urban streets and
  - increased workload for the RCAs.
- Frustration can arise from a lack of preventive measures.
- The perceived cost of unplanned/unexpected delays is significantly higher than those associated with expected delays.

The interviews and discussions with stakeholders highlighted the importance of what happens after natural hazard events that affect the road network (for example, providing information to assist road users to adjust to the circumstances).

Beyond the general acceptance of disruption from natural hazards, people have an underlying concern regarding the impact of the disruption on society (such as schools and health provision), businesses and growth. This is an underlying concern and the socio-economic costs are becoming greater because of a number of factors such as:

- businesses increasingly relying on just-in-time supplies, raw materials etc.,
- increased rural lifestyle living,
- a trend towards rural family members working in towns and depending on transport.

Addressing these socio-economic needs requires a paradigm shift in thinking about the resilience of the road network infrastructure beyond the response issues after the event.

The focus on information after a natural hazard event and its consequences implies that the economic and social impact of unexpected disruptions which lead to unplanned delays is greater than delays from planned disruptions. This implies that the increased travel time costs associated with natural hazard events which occur unexpectedly are greater than costs associated with known delays such as congestion, which can be planned for. This has an important consequence for the economic analysis of road risk mitigation initiatives.

7. Consultation with road stakeholders

7.1 Methodology

The purpose of consulting key stakeholders responsible for management of the road infrastructure and emergency response was to elicit information on the criteria affecting the expected performance levels for road networks, and their expectations regarding appropriate levels of performance of the road infrastructure.

To achieve this, a methodology was carefully developed to ensure that the consultation is producing the required information.

The methodology developed comprised the following steps:

1. identification of principal factors that affect performance criteria,
2. selection of key representative stakeholders for interviews,
3. development of typical hazard scenarios,
4. preparation of a mini-presentation and questionnaire,
5. interviews and discussions with key stakeholders,
6. assessment of responses, and
7. drawing conclusions.

The approach in each step and the outcomes are presented in the sections that follow.

7.2 Identifying the principal factors that affect performance criteria

The principal issues were identified so that they could form the basis of the questionnaire and the discussions in a focused manner. Five principal issues were identified which covered a broad spectrum of performance criteria in relation to natural hazard events. The five principal issues are:

- safety,
- delays and disruptions,
- access for emergency services and lifelines,
- cost, and
- public response.

7.3 Selecting stakeholders for interviews

A range of representatives from RCAs and other parties within, or with links to, the transport sector were interviewed and consulted to assess their res-ponses to natural hazard events affecting their road networks. Table 7.1 presents the organisations and the position of those selected for consultation.

Table 7.1 Selected representatives for consultation regarding performance criteria.

Organisation	Position
Wellington City Council (WCC)	Infrastructure Manager Roading Manager
Wellington Regional Council	Civil Defence Manager
Wanganui District Council	Roading and Public Spaces Manager
Wanganui District Council	Emergency Manager
Palmerston North City Council	Roading Manager
Palmerston North City Council	Emergency Services Manager
Environment Canterbury	Civil Defence Manager
Environment Canterbury	Civil Defence Emergency Management Planner
Banks Peninsula District Council	Asset Manager
Banks Peninsula District Council	Roading Manager
Thames–Coromandel District Council	Roading Manager
Thames–Coromandel District Council	Emergency Manager
Transit Wanganui	Regional Manager
Transit Canterbury	Regional Manager Operations Manager
Transit – National Office	Highway Control Manager
Transit – National Office	National Operations Manager
Transit – National Office	Assurance and Compliance Manager
Transit – National Office	Asset Management Team Leader
Transit – National Office	Acting National Highway Manager
Transfund	Operations Manager
Transfund	Senior Policy Analyst
Ministry of Civil Defence & Emergency Management (MCDEM)	Emergency Management Planner
Local Government New Zealand	Manager: Development & Infrastructure
National Lifelines	National Lifelines Coordinator

7.4 Developing typical hazard scenarios

In order to produce a questionnaire that encompassed all the principal issues identified in Chapter 7.2, we developed some typical natural hazard scenarios. The purpose of the scenarios was to enable the consultation to be based on some realistic scenarios on which the stakeholders could relate to and provide meaningful comment.

The scenarios shown in Table 7.2 were used as examples of natural hazard events:

Table 7.2 Natural hazard scenarios shown to road user stakeholders during the interviews

Scenario	Description
Scenario One	SH3 Manawatu Gorge closure (February 2004): a storm led to very large slips resulting in the closure of Manawatu Gorge for a period of almost 3 months. This important link has two alternative routes. However only one alternative route (the Pahiatua Track) was available, as the other (Saddle Road) was also closed because of the loss of a bridge in the storm.
Scenario Two	SH1 Paekakariki debris flow closure (October 2003): a flash storm and resultant debris flow resulted in the overnight closure of SH1 at Paekakariki. This is a key access route into Wellington with high traffic volumes. No suitable alternatives routes were available.
Scenario Three	Large earthquake in a major urban centre (e.g. Wellington Fault rupture in Wellington City): this has potential to result in a high number of casualties, loss of road access to emergency services and other key lifelines such as power, water and telecommunications.
Scenario Four	Large earthquake affecting rural region: this would result in isolation of rural communities as a result of damage to the road network.

7.5 Preparing the questionnaire and mini-presentation

A mini-presentation was also prepared which comprised an outline of this research project including background on the previous parts as well as a description of the four chosen scenarios. The purpose of the presentation was to set the scene and provide background information before beginning the questionnaire during each interview.

We designed a questionnaire which was based on the five principal issues identified above in order to facilitate discussion, draw out the experience of the interviewees and ascertain their level of risk acceptance to natural hazard events affecting road networks. The questionnaire was divided into five sections, each covering one of the five principal issues.

Most of the questions within each section referred to the scenarios described above. For example, under the section 'Safety', the following question was prepared:

'Describe your reaction if fatalities had resulted from the landslides along SH3 Manawatu Gorge caused by the February 2004 storm event?'

To ascertain the interviewee's level of risk acceptance, some questions were prepared about acceptable consequences for events with given return periods, using scenarios of natural hazard events as examples.

7.6 Interviews and consultation

The interviews were held with each of the stakeholders listed in Table 7.1 and were structured in the following manner:

1. The interviewee was shown a mini-presentation which outlined this research project, background on the previous stages of research and the four scenarios described above.
2. Interviewees were presented with a sheet of paper which listed the five principal factors and were asked to rank these criteria in order of importance from their perspective.
3. Interviewees were asked questions from each section of the questionnaire, following the order of their chosen ranking of the principal factors.
4. Following the completion of the questionnaire, interviewees were asked to re-rank the five principal factors.

During the interviews, discussions were encouraged and wider issues were explored, depending on the particular role, expertise and experience of each interviewee.

Details of the questions and responses are provided in Appendix A.

7.7 Assessing the responses

7.7.1 Approach to assessment

The responses from the consultation are presented below, divided into the five principal issues and presented in the order of importance revealed by the interviewees.

The responses were generally related to the organisation and position. For example, Emergency Managers from local authorities, the Ministry of Civil Defence and Emergency Management (MCDEM) and national lifelines provided similar responses to most questions as did Transit Regional Managers and Transfund personnel. Given the importance of the organisational perspectives, the results are presented for the organisational groupings rather than as individual differences. This perhaps represents the organisational culture and thinking with respect to natural hazards and their impacts on road networks. The participants were divided into three groups as follows:

- Civil Defence personnel,
- Transit/Transfund personnel, and
- Local authority roading managers.

7.7.2 Safety

Safety of life was regarded as the most important issue in determining performance measures across all organisations. The responses of the three groups are summarised as follows:

Civil Defence personnel

Fatalities from natural hazard events are generally unacceptable although natural hazards are a fact of life and risk to life has to be accepted to some degree.

Risk to life from isolated rock fall is not being adequately managed, although evidently, the hazard is being managed well on some particular road links e.g. SH 74.

RCAs should manage their exposure to liability by identifying, analysing and evaluating the risks to the network as well as undertaking measures to mitigate the risks.

Transit / Transfund personnel

Any fatalities from natural hazard events are generally unacceptable.

Risk to life and risk of injury from isolated rock fall is being adequately managed given the constraints on budget. The fact that very few fatalities have resulted from isolated rock fall indicates that this risk is being adequately managed.

Managing exposure to liability involves having an audited process in place to identify, assess and mitigate safety risks.

Local authority roading managers

Fatalities from natural hazard events are generally unacceptable.

Risk to life and risk of injury from isolated rock fall is being adequately managed. Most local authorities have an ongoing programme of rock fall mitigation.

The key factors in managing exposure to liability are:

- comprehensive asset management plans which identify the risks and how they will be managed,
- the regular monitoring of the risks to ensure they are correctly assessed and managed in accordance with the asset management plans.

To measure the level of risk acceptance/aversion to loss of life, the interviewees were asked to provide acceptable return periods of natural hazard events that lead to loss of life. Scenarios of natural hazard events were used as examples. Comparison of the responses to acceptable frequency of fatalities is presented in Figure 7.1 and Figure 7.2.

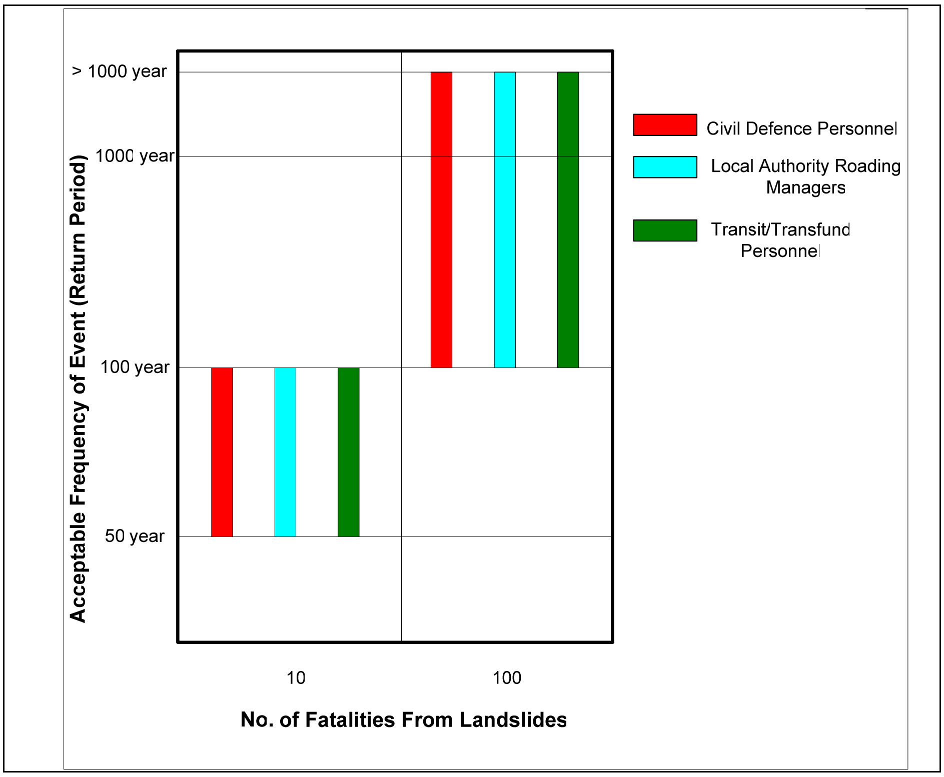


Figure 7.1 Acceptable frequency of event for a given number of fatalities from landslides.

Figure 7.1 indicates that the response to fatalities from landslides was similar across all sectors, although some individuals differed. It also indicates a low tolerance for fatalities from landslides.

But when fatalities from localised rock fall were considered, more tolerance for some fatalities was shown, probably reflecting the lower number of fatalities, widespread rock fall issues around the country and the difficulty of managing them (see Figure 7.2). The sectors differed greatly, with the lowest level of tolerance to such fatalities coming from Transit and Transfund.

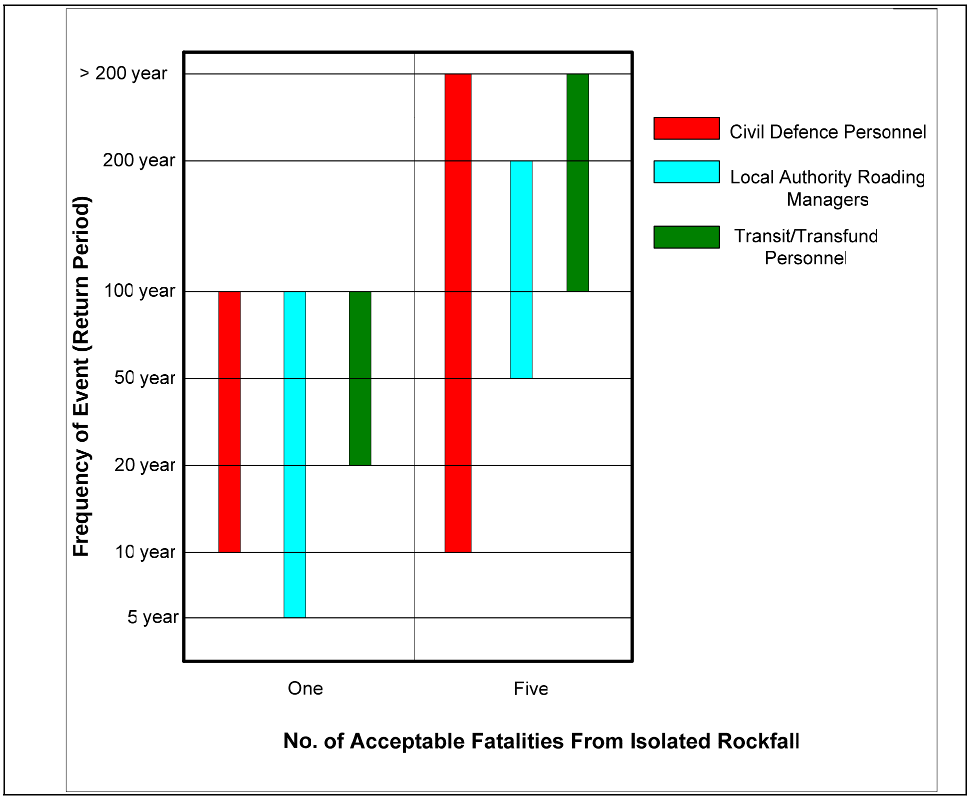


Figure 7.2 Acceptable frequency for fatalities from isolated rockfall.

7.7.3 Delays and disruptions

For the majority of those consulted, delays and disruptions followed closely behind safety of life in terms of importance. The general response from all groups was similar and therefore the responses presented below are representative of all groups.

- The 3-month road closure of SH3 Manawatu Gorge Road throughout February, March and April 2004 was too long. However, the closure may be somewhat acceptable given the geological characteristics of the route, the fact that an alternative route existed and the low frequency (100 year return period?) of the event.
- The overnight closure of SH1 at Paekakariki in October 2003 may be somewhat acceptable (even though no suitable alternative route exists), given the unpredictable nature of the event and the short duration.
- In circumstances where the nature of the route is such that mitigation is either almost impossible or very costly, the frequency of the event is low and the consequences are major, road users generally accept that road closures of this duration are inevitable.
- The availability of alternative routes is a key factor in considering acceptable road closure periods.
- Mitigation work, based on an evaluation of the risks, is a fundamental strategy for minmising the delays and disruptions to the road network and similar consequences of natural hazard events.
- Identifying alternative routes at a local and regional level as well as improving alternative routes is regarded as the most important category of mitigation work.
- Transit should work with local authorities to identify alternative routes to vulnerable SH links and accept that these become temporary SHs after natural hazard events.

- Although road access for rural communities is important, RCAs cannot be expected to provide the same level of service in the provision of reliable road access as they do for urban centres.

To measure acceptable road closure times, the interviewees were required to provide acceptable periods of time for road closures in two different scenarios:

- SH3 Manawatu Gorge closure from the February 2004 storm and resulting landslides, or closures of roads of similar importance, and
- SH1 Paekakariki closure from the October 2003 storm and resulting debris flow, or closures of roads of similar importance.

The response of the interviewees on the issue of acceptable road closure periods for a range of event frequencies, for closures of roads of similar importance, and failures of a scale similar to the SH3 Manawatu Gorge closure in February 2004 and the SH1 Paekakariki landslip in October 2003 events are summarised on Figure 7.3 and 7.4 respectively.

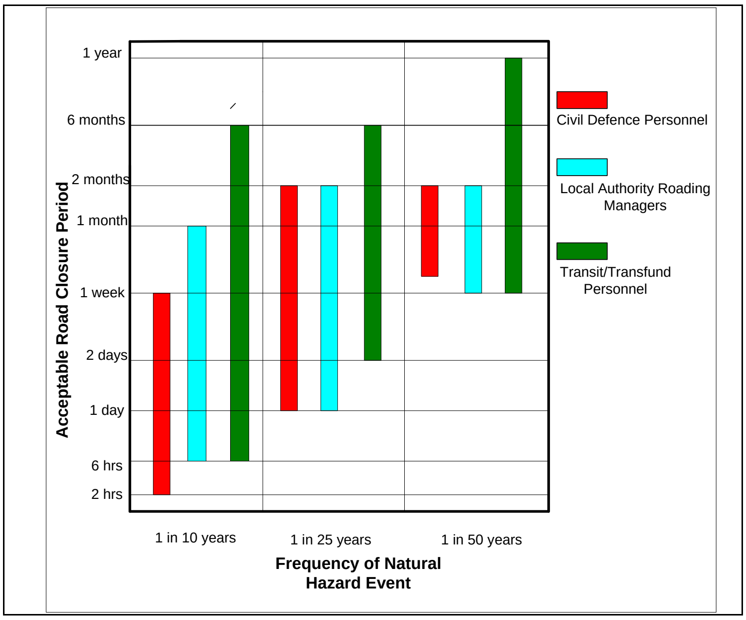


Figure 7.3 Acceptable road closure periods for events similar to the Manawatu Gorge closure in 2004.

Transit/Transfund personnel were more accepting of road closures of longer durations than the other groups (see Figure 7.4). This may have been influenced by using SH3 Manawatu Gorge as an example. This link had an alternative route and Transit/Transfund personnel stressed that the existence of alternative routes is a key factor in determining acceptable road closure periods.

It should be noted that the other groups indicated that no closure greater than 2 months is acceptable for the frequency range of events discussed.

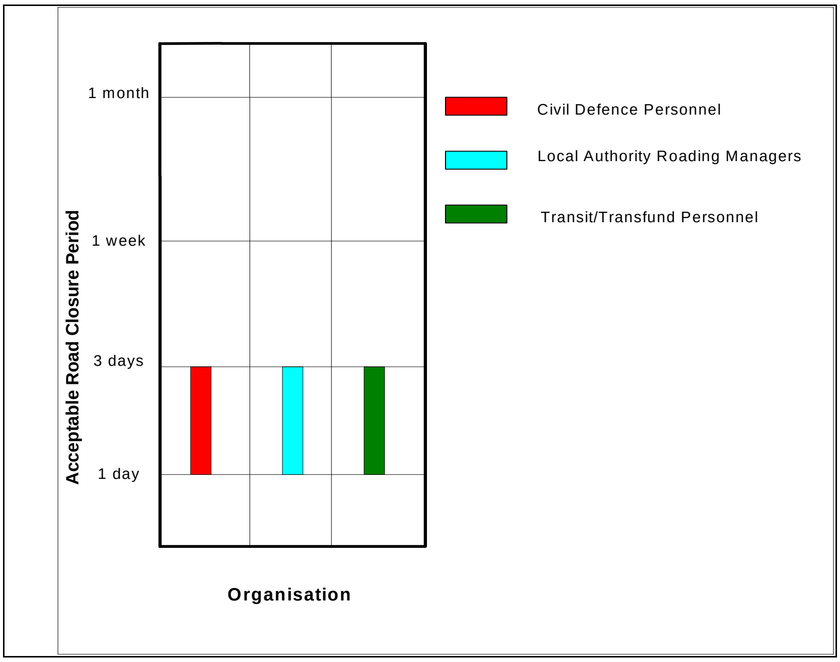


Figure 7.4 Acceptable road closure periods for events similar to the 2003 SH1 Paekakarki closure.

For closures affecting key routes like SH1 north of Wellington, all groups indicated a low tolerance for closure periods of 1 day to 3 days, as illustrated in Figure 7.4.

7.7.4 Access to emergency services and lifelines

For the majority of those consulted, access to emergency services also followed closely behind safety of life in terms of importance. For some Emergency Managers, access to emergency services was deemed to be the most important criteria as immediate access to hospitals is critical to safety of life. The outcomes, grouped by organisation, are summarised as follows:

Civil Defence personnel

Following a large earthquake in a major urban centre, immediate road access to emergency services (such as hospitals) is vital from the perspective of saving lives. In this type of urban earthquake, restoration of road access for key lifeline utilities such as water, power and telecommunications is very important.

Risks to lifeline routes are currently being managed on a reactive basis.

The requirements of the CDEM Act (CDEM 2002) include collective planning to ensure continuity of lifelines following a natural hazard event, working with other RCAs, resolving inter-sector dependencies and identifying and treating risks.

Transit/Transfund personnel

Restoring road access following a large earthquake in a major urban centre is very important but access to emergency services would be primarily provided by air or sea, thereby reducing the pressure to provide road access to emergency services.

Risks to lifeline routes are currently managed more proactively than in the past.

Establishing response plans with key partners (such as territorial authorities, consultants and contractors), and identifying major routes and major hazards are key requirements of the CDEM Act.

Local authority roading managers

Following a large earthquake in a major urban centre, restoring road access to all key lifeline utilities such as hospitals, water, power and telecommunications is extremely important.

Risks to lifeline routes are being managed proactively to the extent that most councils have identified and prioritised lifeline routes.

Planning collectively for reopening roads, recognising interdependencies of other utilities, identifying lifelines and assessing their criticality are key requirements of the CDEM Act.

7.7.5 Duration of lost access

To explore the thinking of stakeholders regarding an acceptable length of time for the loss of lifeline routes for emergency services following a natural hazard event, interviewees were asked to provide acceptable periods of time for loss of access for emergency services under two different scenarios as follows:

- a large earthquake with major consequences in a large urban centre (frequency of 1 in 500 years), and
- a moderate earthquake with moderate consequences in a large urban centre (frequency of 1 in 100 years)

The different views between the groups as to acceptable periods within which road access for emergency services should be restored are illustrated in Figure 7.5. Transit/Transfund personnel placed less importance on road access for emergency services as they believed access would primarily be provided by other means – air or sea. Emergency managers, on the other hand, believed that primary access would need to be provided by road.

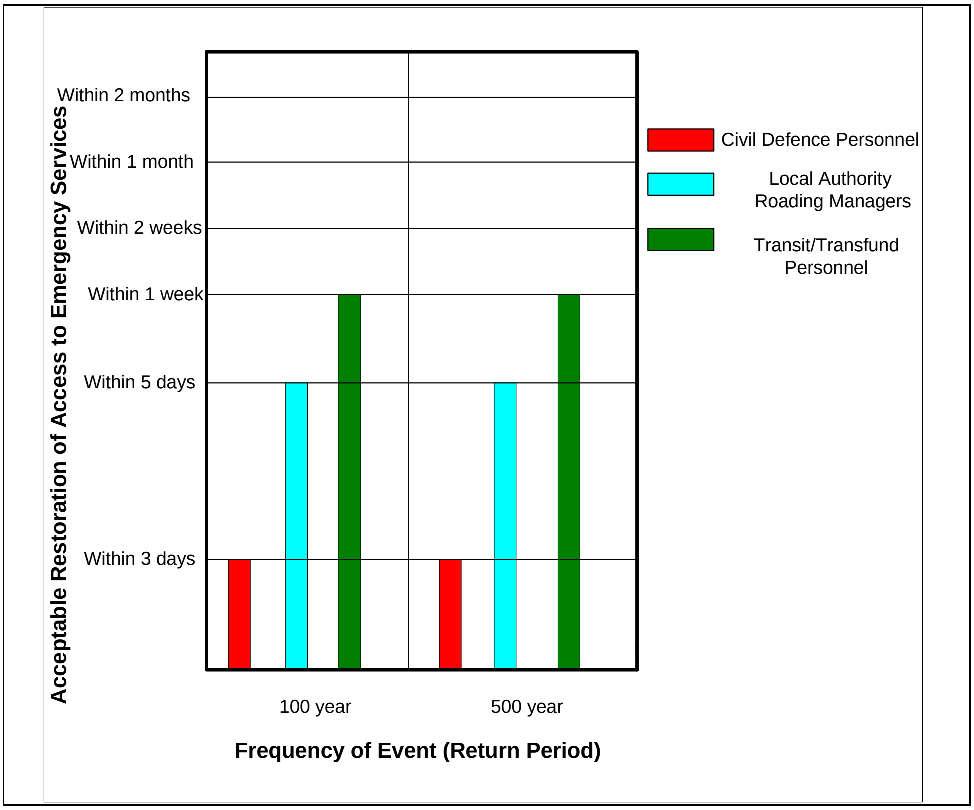


Figure 7.5 Acceptable time for restoration of emergency vehicle access after earthquakes in an urban area.

7.7.6 Cost

Cost, although considered significant, was deemed to be not as important as the preceding criteria in determining performance measures. The general response from all groups was similar and therefore the responses presented below are representative of all groups.

- The cost to repair damaged roads following a natural hazard event of low frequency with severe consequences is justifiable where the nature of the route is such that the cost to mitigate is prohibitive. The SH3 Manawatu Gorge landslides in February 2004 are an example.
- Mitigation measures against a natural hazard event of low frequency and major consequences along a road link has the advantage of eliminating damage during smaller events that can also affect the road link.
- A reactive approach to managing risks of low frequency with severe consequences is appropriate where the cost of mitigation is prohibitive.
- A proactive approach to risk mitigation is appropriate, provided the risks are assessed and mitigation work can be carried out at a reasonable cost.
- Prior planned and staged expenditure to mitigate risks to the road network can minimise peak unplanned expenditures from natural hazard events in the future; small up-front mitigation costs can save substantial future repair costs.
- Spending more money initially on mitigating risks to the road network has wider social benefits, as road closures adversely affect the community. The benefits include growth in employment and improvements among lower socio-economic groups, and a reduction in social and community costs.

- In terms of the balance between benefits and costs, the wider social and economic factors should be taken into account when evaluating the benefits for risk mitigation work. In terms of a benefit to cost ratio (B/C), the Transfund criteria for evaluating benefits for roading projects should not be applied to mitigation work and the B/C (including wider benefits) should be between 1 and 2 for risk mitigation work which safeguards the existing network.

In order to gauge the circumstances under which a reactive approach to managing risks to lifeline routes was considered appropriate, interviewees were asked to suggest acceptable return periods (frequencies) of natural hazard events for which a reactive approach may be appropriate. Their responses are summarised in Figure 7.6.

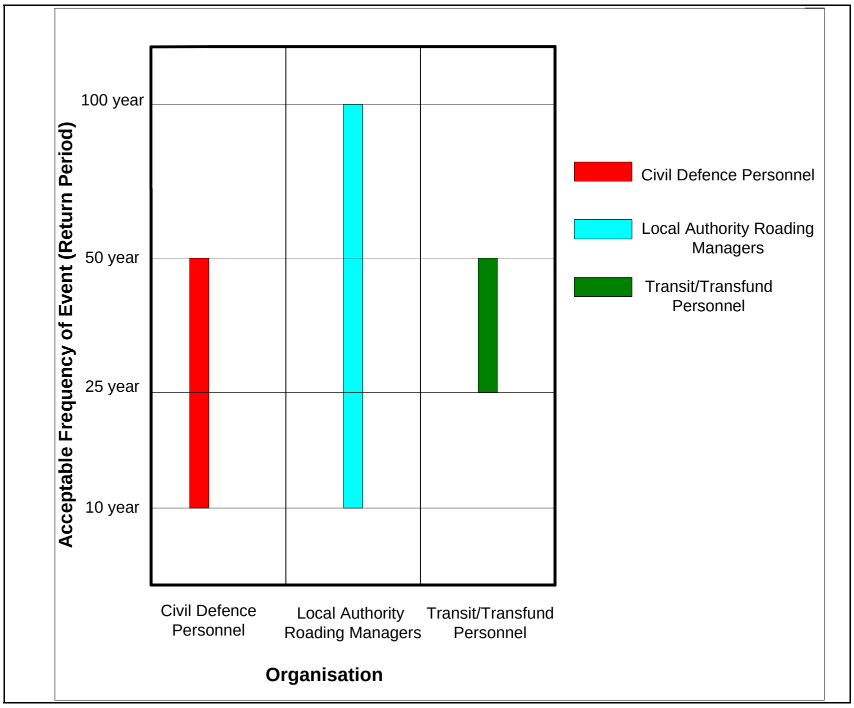


Figure 7.6 Range of event frequencies for which a reactive approach to managing natural hazard risks is appropriate.

Some Civil Defence personnel and local authority roading managers supported a reactive approach to managing risks which occur on a more frequent basis (10 year return period) than the frequency indicated by Transit/Transfund personnel (25 year return period) and other local authority staff.

7.7.7 Public response

A range of improvements were proposed by all groups. These could form the basis of performance measures and levels of service in terms of public response. In summary form, they are:

- verified, accurate and frequent information from one source, and
- improved coordination between groups managing emergency response.

The stakeholders interviewed did not consider public response as important as the other principal factors, but did consider that public response to natural hazard events was a vital factor in determining performance measures. The responses with respect to organisational groupings are summarised as follows:

Civil Defence Personnel

Public response should be properly managed following a natural hazard event. This involves understanding how the public react and planning a management strategy for dealing with the public to ensure that the emergency response is not driven by public reaction.

The level of information provided to the public following a natural hazard event is an area which needs to be addressed. Information provided to the public is often fragmented and inaccurate, and comes from a variety of sources.

Transit / Transfund Personnel

Managing public response is important but it needs to be put into perspective. These groups believed that provided other factors (safety, access to emergency services, delays and disruptions) were addressed, public response would not be a significant issue.

Improved coordination is needed between groups managing emergency response.

Local Authority Roading Managers

Adverse public reaction was an accepted public response which needed to be managed by being up-front and empathetic with the issues.

7.8 Conclusions

7.8.1 Civil Defence personnel: key responses

The responses from this group were strongly influenced by the requirements of the CDEM Act (particularly regarding managing natural hazard risks through reduction, readiness, response and recovery). The importance this group placed on access to emergency services and lifelines when asked to prioritise performance criteria made this evident, as did the emphasis they placed on risk reduction through mitigation work.

This group, like others, was averse to risk to life. Providing access to emergency services and lifelines was identified as the way to reduce risk to life. Focusing on safety of life was also identified as crucially important in reducing the impact of public reaction following a natural hazard event. What the public perceives as a risk to the road network is directly related to their experience of the road network. If a fatality results from a natural hazard event along a road link then the public perception of risk increases.

7.8.2 Transit / Transfund personnel: key responses

Like all groups, the Transit/Transfund representatives were very averse to risk to life. Although they held the view that any fatality was unacceptable, they agreed that it depended on the scale of the event and whether or not the fatality was preventable.

From this group's perspective, risks to the network from natural hazard events were widely known and managed well, predominately through preventative maintenance, given the constraints on budget. Transit road managers regarded constraints on budget as a major obstacle to making a network more resilient to the effects of natural hazard events. However this group acknowledged that under the new Land Transport Management Act, with the focus on safety, consultation and sustainability, funding for risk mitigation work was more readily available than in the past.

7.8.3 Local authority roading managers: key responses

The responses from this group were predominately community focused. The influence of the Local Government Act 2002, with its emphasis on community outcomes, was evident. Not only was this group averse to risk to life, but they also expressed a strong aversion to adverse impacts on the community from the consequences of natural hazard events. The wider social and economic costs to the community were identified as a major factor which would shape how performance criteria for road links subject to natural hazard risks would be determined.

However, this group felt that the current funding framework discouraged proactive mitigation work, as subsidies for emergency works are greater than subsidies for preventative maintenance.

8. Identifying issues and assessing factors which affect performance levels

8.1 Factors and constraints affecting performance

A number of sources (including the research, reviews and consultations described previously, as well as previous experience in risk management and the roading industry) were used to compile the principal issues and their importance. These are:

Factors affecting performance measures

- safety of life,
- disruption,
- road access to emergency services, and
- road access to key lifeline utilities.

Constraints affecting performance measures

- cost,
- community response,
- road user expectations, and
- alternative routes.

8.2 Level of service used as parameters

Possible levels of service for the various performance measures were identified for discussion at the workshop described in Chapter 9. The levels of service were framed in terms of parameters for factors affecting performance measures, as presented in Table 8.1.

Table 8.1 Level of service parameters affecting performance measures.

Performance measure	Level of service parameter
Safety of life	Number of fatalities for events of various frequencies
Disruption	Duration of road closure for events of various frequencies
Road access for emergency services	Time taken to re-open road access after events
Road access for lifeline utilities	Time taken to re-open road after events

8.3 A framework for setting performance measures

A framework was also developed for setting performance measures and levels of service. This was based on a two-stage framework:

- Stage 1: setting broad level performance criteria for a network.
- Stage 2: setting detailed level performance measures for important road links.

Process diagrams illustrating the process for setting performance measures were developed, and these were later refined after the workshop. They are presented in Chapter 10 (Figures 10.2 and 10.8).

9. Workshop on setting performance levels

9.1 Workshop objectives

A workshop for representative stakeholders from the road management and emergency management sectors was held to brainstorm the factors which influence and constrain how levels of service and performance measures are set.

The purpose of the workshop was to draw on the collective experience of the participants on important issues for setting performance measures. This pooled experience would provide information for developing a framework for setting performance criteria.

The objectives of the workshop were:

- to identify and discuss factors which influence and constrain performance measures and levels of service from the perspective of the participants;
- to consider performance expectations, and develop performance measures and levels of service from the factors identified above; and
- to present and solicit feedback on the proposed framework for setting performance measures and levels of service.

The workshop participants were carefully chosen to represent a variety of representatives in the road management and emergency management sectors who had policy and operation experience across urban and rural road environments.

9.2 Location and time

The workshop was held on 22 June 2004, at Opus International Consultants' offices, Majestic Centre, Wellington from 10 a.m. to 3 p.m.

9.3 Workshop participants

The workshop was attended by selected representatives from a range of organisations as follows:

- MCDEM,
- Transfund New Zealand,
- Transit New Zealand head office,
- Transit New Zealand regional offices,
- regional local authorities,
- territorial local authority road asset departments,
- CDEM offices,
- lifeline group co-ordinators,
- Audit New Zealand and
- Opus International Consultants.

We selected these participants to ensure that areas with significant natural hazards and a range of geographical locations, as well as participants representing those with a national perspective. Although the turnout was slightly lower than we had planned, the twelve participants represented organisations from Auckland to Dunedin in most categories of organisations.

A list of the workshop participants is shown in Table 9.1.

Table 9.1 Participants at the road risk management workshop, 22 June 2004.

Participant	Position	Organisation
Rian van Shalkwyk	Senior Evaluation Analyst	Greater Wellington Council
Ian Hunter	Regional Manager Central	Transfund New Zealand
Terry Boyle	Area Engineer	Transit New Zealand, Auckland
P. Brabhaharan	Principal Geotechnical Engineering & Risk	Opus International Consultants, Wellington
Colin Giles	Roading Manager	Manawatu District Council
John Jarvis	Area Manager	Transit New Zealand, Dunedin
Steve Moynihan	Senior Engineering Economist	Opus International Consultants, Wellington
Hans Brounts	Emergency Management Planner	Ministry of Civil Defence & Emergency Management
Kailash Mehrotra	Roading Manager (retired)	Tararua District Council (formerly)
Peter Duncan	Roading Manager	Rangitikei District Council
Len Wiles	Asset Management Engineer	Opus International Consultants, Wellington

9.4 Format and agenda

The workshop was facilitated by P. Brabhaharan and Len Wiles from Opus International Consultants, Wellington, with the following agenda:

1. Introductions.
2. Background: brief summary of prior research (Parts I & II), followed by a brief summary of the current research (Part III) (Opus).
3. Workshop objectives (Opus).
4. Presentation on 'The effects on the road network from volcanic eruption in Auckland' by Terry Boyle of Transit Auckland.
5. Presentation on 'The importance of the road network from an emergency management perspective' by Rian Van Shalkwyk.
6. Presentation of the proposed framework for setting performance measures and levels of service including factors and constraints affecting performance measures and levels of service (Opus).
7. Group session: brainstorming to consider and discuss:
   - the factors which influence and constrain performance measures and levels of service, and
   - how to develop performance measures and levels of service from the identified factors.
8. Closing discussion: general feedback.

9.5 Outcomes from the workshop

9.5.1 Factors influencing performance measures and levels of service

The factors which influence performance criteria identified by the workshop participants are summarised in Table 9.2.

Table 9.2 Factors influencing performance measures, as identified by workshop participants.

Factor influencing performance measures	Description
Safety of life	This was identified as a key influencing factor and driver for setting performance measures and levels of service.
Disruption	Two aspects of disruption were identified: the disruption to people's activities and the disruption to commercial activities.
Emergency services access	Identified as vital to safety of life.
Lifeline importance	The importance of a road link in terms of providing access for lifeline utilities was regarded as an important factor.
Community expectations	The expectations of both the general community and the business community were identified as key influencing factors in setting performance measures.
Communication	Providing information prior to natural hazard events and the ability to provide information following a natural hazard event was considered an important factor.
Broader economic impact	The aggregate of local economic impacts was seen as an important factor to consider.
Growth	Traffic growth on road links and road networks was regarded as an important factor. It was recognised that this was a factor already considered when prioritising the road links as part of the risk management process.
Alternative routes	The availability of alternative routes was regarded as a factor which would influence the setting of performance criteria. For example, a road link which has numerous alternative routes may have a different set of performance criteria than one with no alternative routes.
Damage repair cost	The cost of repairing damage after the event.

9.5.2 Factors constraining performance measures and levels of service

The factors which constrain performance measures identified by the workshop participants are summarised in Table 9.3.

Table 9.3 Factors constraining performance measures as identified by workshop participants.

Factor constraining performance measures	Description
Mitigation cost	While the cost of reinstatement after an event is a factor which drives performance measures, the cost to mitigate is a key constraining factor in achieving the required performance.
Resources and skills	The performance criteria set must be realistic in terms of the available resources. Setting levels of service for reopening a road for emergency access in a given time frame was regarded as short-sighted if sufficient resources and skills were not available to clear the road. Sharing resources was considered as a possible solution to this issue.
Suddenness of event	A natural hazard event like a landslide from an extreme storm was regarded as an event with a degree of predictability (as opposed to an earthquake). Therefore, the performance measure for safety of life may be higher for an earthquake than for a storm.
Feasibility of mitigation	Whether it was feasible to mitigate the risk to the road link was regarded as an issue which affected setting performance criteria. It was agreed however that this would be assessed when the cost to mitigate were considered.
Other lifeline effects	Other lifelines which run along a road link (e.g. gas or water mains) would affect how performance criteria are set.
Public perception	The way the public perceives risks to the network is a function of their previous exposure to the risks. For example, a road user who narrowly missed being hit by rock fall will have a different perspective of risk from rock fall than a road user with no experience of rock fall. The level of service set for a road link is therefore constrained by what level of risk the public perceives as acceptable.

9.5.3 Development of performance measures and levels of service

The workshop participants, in four groups, developed performance measures and levels of service for the following criteria:

- safety of life,
- access to emergency services,
- access to lifeline utilities, and
- disruption and broader economic impact.

The outcomes from the group sessions are summarised in the next parts of this chapter.

9.5.3.1 Safety of life

Some participants noted that it would be difficult to set performance measures for safety of life in terms of numbers of fatalities, given the public expectation of zero tolerance. Nevertheless, the workshop participants felt it was appropriate to set performance measures with respect to fatalities, but these need to be developed through community consultation.

It was proposed to use the number of fatalities per year on the road network from natural hazards as a starting point to derive a tolerable level of fatalities per vehicle–kilometres.

The participants also identified that in setting performance measures and levels of service, the trade-off between risk to life and acceptable road closure periods needs to be considered through community consultation. In other words, the road may need to remain closed for safety reasons, even though opening would benefit the community by providing access.

9.5.3.2 Access to emergency services

The workshop participants expanded the criteria to include access for emergency services vehicles. The participants regarded that access to emergency services and access for emergency service vehicles are important for safety of life (e.g. rescue and hospitalisation).

In addition, access needs to be considered with respect to the time to restore road access and the standard to which road access should be restored. Table 9.4 summarises the possible performance measures and levels of service developed during the workshop for road access for emergency service vehicles.

Table 9.4 Possible performance measures and levels of service for road access for emergency services vehicles.

Level of Service	Performance Measure
Time to provide temporary access to hospitals along key prioritised roads.	Immediate.
Time to provide temporary access to emergency service vehicles along key prioritised roads.	Immediate.
Maximum height of level changes along temporary access roads.	Maximum 200 mm road surface undulations.
Maximum water level along temporary access roads.	Maximum 400 mm of water over road surface.
Notification of access via road communication systems.	Immediate.

9.5.3.3 Access to lifeline utilities

The participants identified the following key lifeline utilities:

- water,
- electricity,
- telecommunications,
- ports,
- airports,
- fuel, and
- radio & television.

Other lifelines that could also be important from health and safety perspectives as well are gas and sewage.

The participants emphasised that performance measures and levels of service needed to be determined with respect to the following factors:

- time to restore access, and

- standard of restoration necessary.

The time to restore road access for lifeline utilities was regarded as dependent on the time each utility could operate without road access, as well as depending on what could realistically be provided by the RCA.

Table 9.5 summarises the performance measures and levels of service for road access to lifeline utilities.

Table 9.5 Levels of service for road access to lifeline utilities.

Level of Service	Performance measure
Time to provide temporary road access for utility contractor for inspection and repair.	Timing is a function specific to a utility's requirements and the road controlling authority's capabilities.

Clearly, setting of performance measures with respect to lifelines would require co-ordination between the different lifeline utility organisations, including the RCAs. This could happen as part of the Civil Defence Emergency Management Groups (CDEMG) set up under the CDEM Act.

9.5.3.4 Disruption and broader economic impact

The workshop participants in this group had the task of developing performance measures for disruptions in travel which take the broader economic issues such as the effect on commercial activities into account.

Table 9.6 shows the performance measures and levels of service which categorise disruptions to road travel (taking prioritisation and the broader economic issues into consideration).

Table 9.6 Prioritised levels of service for road travel, considering broader economic impact.

Priority level	Level of service	Performance measure
1	Re-open roads for 4x4 access to ensure life support.	As soon as possible.
2	Re-open roads for 4x4 access to key services/utilities.	1 day to 2 days
3	Re-open national transportation links.	1 week
3	Re-open local transportation links.	1 week to 2 weeks
4	Re-open roads sufficient for local commercial business continuity (light trucks and all cars travel slow).	2 weeks
5	Re-open roads sufficient for discretionary travel (all cars travel slow).	3 weeks to 5 weeks
6	Re-open roads for all vehicles.	6 months

A participant stressed that performance measures and levels of service needed to be expressed in terms which a roading engineer can understand. For example, in relation to recovery from a major event, specific levels of service needed to be developed for specific types of vehicles providing specific services. The levels of service and performance measures developed would represent a graded process of recovery.

Levels of service were prioritised based on the intensity and extent of the event, as well as the location (urban/rural). Participants identified that, regarding economic issues, performance measures needed to be developed in consultation with the local and wider business communities.

This group also identified that levels of service should be adaptable enough to take into account adverse environmental effects where appropriate.

Emergency management sector participants suggested that levels of service should be described in terms of the consequences of the natural hazard events, and not the frequency or return period.

9.6 Additional issues raised at the workshop

Some other key issues drawn from the workshop discussions are:

- Primarily, the issues and factors affecting performance criteria and the processes required for developing performance measures and levels of service are more important than the performance measures and levels of service themselves.
- Performance measures and levels of service need to be flexible enough to cover the range of issues and factors associated with the range of consequences from natural hazard events.
- Setting levels of service and performance measures is one layer in the risk management framework. It is important to establish the appropriate stage or stages in the process of risk management to set performance measures and levels of service for road networks and road links.
- Levels of service and performance measures should be consistent with an organisation's asset management plans (AMPs) and strategic goals. They should be set in the short, medium and long term, as appropriate.
- Community involvement is important to ensure that the adopted levels of service are understood and accepted by the community.

10. Developing a framework for setting performance measures

10.1 Introduction

An overview illustrating where setting performance measures and levels of service fits into the risk management process is shown in Figure 10.1.

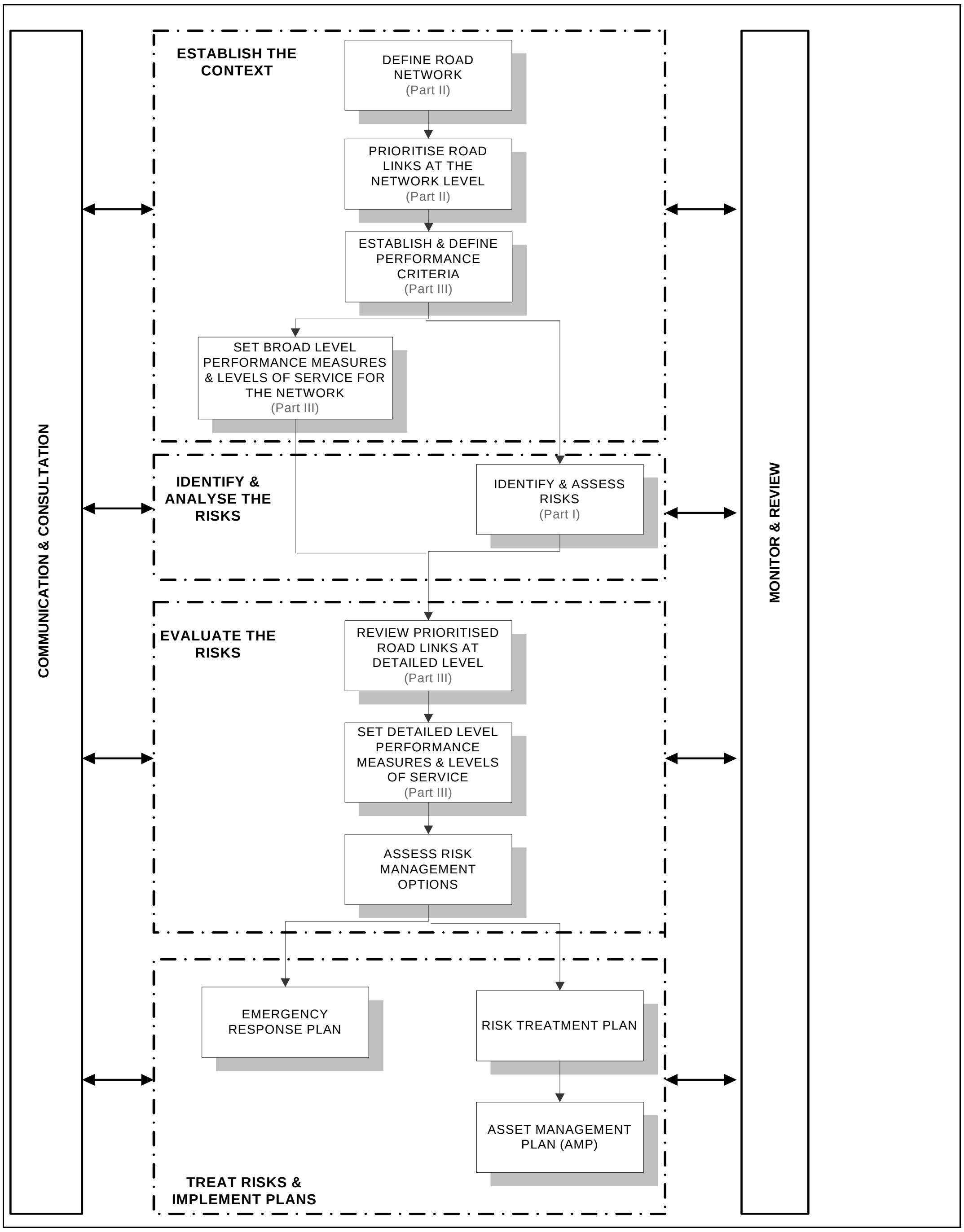


Figure 10.1 Overview of road risk management process, showing where setting performance measures fit in.

This overview demonstrates that setting performance criteria is not an activity which is undertaken in isolation but is built into the risk management process, which is constantly evolving to adapt to new risks, changes in legislation, changes in the road and utility networks, changes in socio-economic conditions and changes in community expectations.

This section describes the framework to set performance measures and levels of service at the broad level followed by the detailed level.

10.2 Broad level criteria

10.2.1 The framework

It is important to identify and assess the issues affecting performance measures and levels of service for the road network at a broad level before focusing on the issues at the road link level. Figure 10.2 outlines a framework for determining broad level performance measures and levels of service for the network.

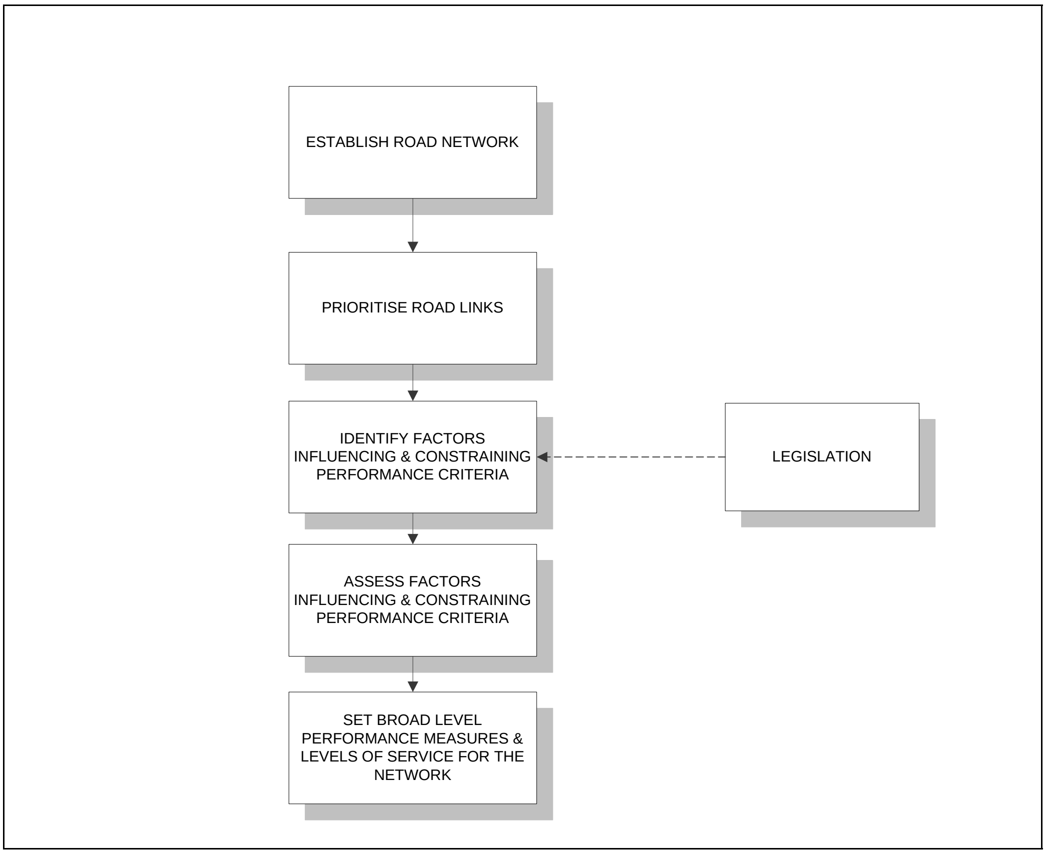


Figure 10.2 Outline of the process used to set broad level performance measures.

Once the road network has been established and the road links prioritised, the factors which influence and constrain performance criteria must be identified and assessed in order to set broad level performance measures and levels of service.

10.2.2 Prioritise road links

Before broad level performance measures and levels of service can be set, road links within the road network must first be prioritised at a broad level. In the first stage of this research project, Brabhaharan et al. (2001) proposed a method for prioritising road links based on the following factors:

- traffic volumes,
- commercial importance of route,
- importance of route in relation to access to lifeline utilities and emergency services,
- importance of route in relation to public transport,
- risk situation (the natural hazard risks to which the road link is exposed), and
- availability of alternative routes.

This methodology has been applied to some road networks, such as Wellington City.

10.2.3 Legislation

Legislation is a key force behind the development of performance measures and levels of service. Legislative drivers are summarised as follows:

- Under the Local Government Act (LGA) 2002, local authorities have an obligation to promote the social, economic, environmental, and cultural well-being of communities in the present and in the future. The provision of a safe, efficient and environmentally sustainable roading network is critical in providing for the needs of the community both in the present and in the future. A Long Term Community Council Plan (LTCCP) is required to provide a long-term focus for the decisions and activities, and provide an opportunity for participation by the public in decision-making. In terms of the road network, provision of access in natural hazard events can be considered important to provide for the needs of the community in the long term (Local Government Act 2002).
- RCAs are required to deliver road users a road network that is integrated, safe, responsive and sustainable. Transit's new objective focuses on providing a land transport system that is integrated, safe, responsive and sustainable (see 'An important note to the reader' in the preliminary pages of this report). To meet these criteria, risks to the network (including risks from natural hazards) must be identified and assessed, and strategies must be developed to mitigate these risks (Land Transport Management Act 2003).
- A road utility must:
  - be able to function to the fullest possible extent during and after an emergency, and
  - have plans for being able to function which can be made available to the Director of CDEM. This means that an RCA is expected to plan for natural hazard events which present risks to the road network and ensure continuity of service after such an event. In addition, an RCA is expected to develop plans cooperatively within its sector and with other sectors (Civil Defence and Emergency Act 2002).

10.2.4 Key factors influencing performance measures

Key factors influencing performance measures are summarised in Table 9.2. These were identified and developed in broad terms, based on the findings of Chapters 7, 8 and 9.

Safety of life

Risk to life has been identified as the most important consequence to be considered in setting performance measures. In order to set performance measures and levels of service, safety of life needs to be considered in terms of the acceptable or tolerable number of fatalities for a particular event associated with a particular frequency or return period. The relationship between the frequency of an event and number of fatalities is illustrated simply in Figure 10.3.

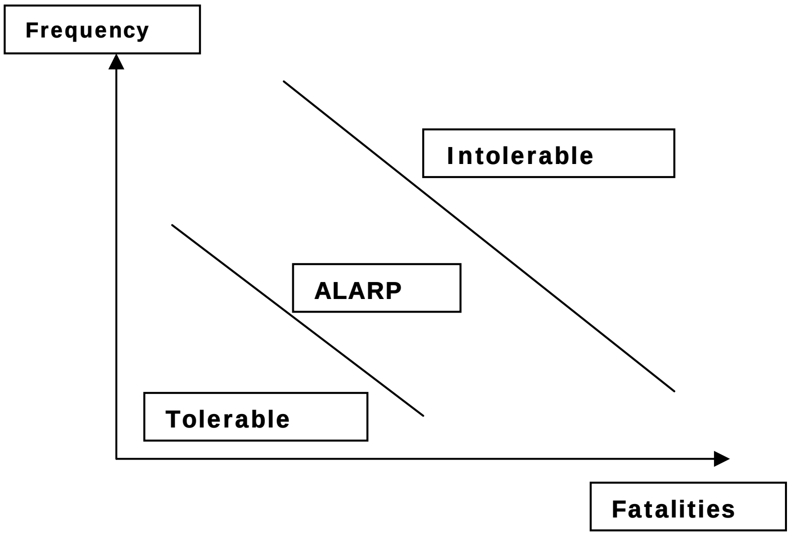


Figure 10.3 Chart illustrating the relationship between the frequency of an event and the number of fatalities tolerated.

Note:
ALARP (As Low As Reasonably Practicable) represents the range within the band between the low fatalities/low frequency and high fatalities/high frequency section of the graph.

The frequency of the event and number of fatalities will differ depending on the road use and road hierarchy. This chart (which was based on one developed by the UK Health and Safety Executive (1992) for nuclear power plants and chemical process facilities) is only useful for events and failures causing multiple deaths. This may not be common for road network situations.

A process for determining an acceptable number of fatalities for events of given frequency or consequence (and which involves community consultation) needs to be established before setting performance measures and levels of service. A starting point prior to community consultation could be to establish the number of fatalities per year which result directly from natural hazard events. This figure could be converted to fatalities per km of road network or fatalities per vehicle–kilometres travelled.

Road access for emergency services

Road access for emergency services following a natural hazard event has been identified as very important and closely tied to safety of life. In particular, the ability to transport casualties to hospitals and medical centres for emergency treatment, especially in urban areas, is essential. In terms of saving lives, the first three days after an event are critical. Road access for emergency services must be considered in terms of route availability and the standard of route access. Levels of service and performance measures should be set in terms of re-opening times and quality of access for emergency services and their vehicles.

Road access for other lifeline utilities

Lifeline routes are distinguished from direct access routes to the emergency services mentioned above. In this context, lifeline routes are recognised as those routes crucial to facilitate restoration of other key lifeline utilities, such as power, water, telecommunications and access for emergency services from the outside such as ports and airports. Restoration of access routes must be considered in terms of re-opening times and quality of road access. Consultation with representatives of key lifeline utilities will be necessary to determine target levels of service which reflect the interdependencies and road access requirements of other utilities and what can be realistically achieved.

Disruption

Travel disruption caused by natural hazard events affects communities as well as road users. Communities are affected by the wider social and economic costs such as loss of access to schools and hospitals, disruption to business and tourism activities, inconvenience to residents and increased pressure on social services. Road users, and in particular the transport industry, are affected by increased financial costs.

Levels of service must be considered with respect to re-opening times and the quality of route appropriate for a staged process of recovery. For example levels of service and performance measures can be developed for one-lane access for 4x4 vehicles to provide access in the short term, one-lane access for commercial vehicles in the medium term and two-lane access for all vehicles in the long term.

Broader economic impact

The broader economic issues such as the effect of disruption on commercial activities are an important factor influencing levels of service and performance measures. Consultation with the local and wider business communities is vital in order to set levels of service and performance measures which reduce the economic impact of disruptions on critical economic routes.

Availability of alternative routes

The availability of alternative routes is a crucial factor in determining levels of service and performance measures. The availability of alternative routes is already considered to some extent at the route prioritisation stage but not in terms of setting performance measures. The availability of alternative routes will affect the extent to which levels of service and performance measures are set. For example, a higher level of service would be appropriate for a route with commercial importance but without alternative routes, compared to a similar route with robust alternative routes.

Community expectations

Community expectations influence the determination of levels of service and performance measures. Many of the factors identified above like safety of life, disruption, and access to emergency services and lifeline utilities represent community expectations.

The LGA 2002 requires local authorities to specify community outcomes. This Act sets out principles for consultation with the community and includes a requirement that affected communities be provided with relevant information. Providing timely and accurate information following a natural hazard event and providing information in advance of natural hazard events is an important factor influencing the development of performance measures.

The LGA 2002 also requires local authorities to consult with communities on any issues or proposals which will affect the community. Public feedback must be sought during the development of performance measures.

10.2.5 Key factors constraining performance measures

Constraining factors in this context are regarded as factors which limit and control the development and achievement of acceptable performance.

Mitigation cost

Mitigation cost is recognised as a significant constraint on achieving performance levels. The cost of mitigation work prior to a natural hazard event must be weighed up against the cost of repairs, the likely disruption costs and the socio-economic impacts following a natural hazard event.

In determining the cost of mitigation, the benefits must be considered in terms of the reduction in social and community costs.

The level of funding available affects the level of service. Restrictions on available funds may require levels of service to be determined in the short and long term.

Public reaction

Managing public reaction to natural hazard events affecting roads is another aspect which places constraints on achieving the desired performance. Consultation with communities during the development of performance measures and provision of co-ordinated, timely and reliable information after the events is vital for managing public reaction.

Public perception

The levels of service and performance measures set for road links are constrained by the level of risk the public perceive as acceptable. For example, a road link subject to rock fall which has incurred several fatalities will be perceived as a higher risk than an equivalent road which has incurred no fatalities. Again, providing information and public consultation are both critical to setting and achieving desired levels of performance.

Availability of resources and skills

The availability of resources and skills that would constrain the achievement of road access should be taken into consideration in the development of performance measures. Realistic levels of service and performance measures must be set which reflect the resources and skills that are currently available and that are likely to be available following a natural hazard event.

Other lifelines

Other lifeline utilities which run alongside a road link will constrain the setting of performance measures and levels of service. For example, a road link which also carries a gas main will limit the performance level that can be achieved and would require close coordinated action through CDEMG.

The nature of the event

The suddenness and predictability of the event can be a constraint on setting levels of service and performance measures. For example, flooding following a severe storm is more predictable (as storms can be predicted in advance) than damage from earthquakes. Therefore, the performance measures may be different for an earthquake compared to flooding from a storm.

10.2.6 Setting target performance measures

The final step in setting performance measures at the broad level is to set levels of service and performance measures for each group of prioritised road links.

Examples of performance measures and levels of service at broad level are presented in Table 10.1 for different priority groups of roads. These performance measures are given as an example only and specific measures need to be developed for each road network, depending on the particular issues, constraints and expectations.

It would be inappropriate to provide specific performance levels as the needs, risk acceptance and resources will vary for different networks and also different communities. Therefore, the performance measures indicated in Table 10.1 should be considered for illustration of the measures only, rather than being recommended specific performance measures.

The target performance measures should be set by considering the nature of the network, and emergency response and network availability requirements, and then agreed upon through consultation with the community.

Table 10.1 Examples of levels of service and performance measures for different priority groups of roads.

Service provided	Road link prioritised group	Level of service	Performance measure
Safety of life	–	Maximum number of fatalities from natural hazard event every 25 years.	2
Temporary access to emergency services for emergency service vehicles	Very high	Restore temporary road access to hospitals and emergency centres.	Within 2 hours
	Very high	Condition of road for access.	accessible for emergency service vehicles
	High	Restore temporary access to hospitals and emergency centres identified by the District Health Board.	Within 2 days
	High	Condition of road for access.	accessible for emergency service vehicles
Access to lifeline utilities		Restore 4x4 road access to power, water and telecommunication utilities for inspection and repair.	Within 3 days
		Restore two-wheel drive road access to power, water and telecommunication utilities for utility personnel.	Within 1 week
		Minimum width of access route for 4x4 vehicles.	2.5 metres
Network availability	Very high	Re-open one lane for heavy trucks and buses.	Within 12 hours
		Re-open two lanes for all traffic.	Within 36 hours
	High	Re-open one lane for heavy trucks and buses.	Within 24 hours
		Re-open two lanes for all traffic.	Within 48 hours
	Medium	Re-open one lane for heavy trucks and buses.	Within 36 hours
		Re-open two lanes for all traffic.	Within 72 hours
	Low	Re-open one lane for heavy trucks and buses.	Within 1 week
		Re-open two lanes for all traffic.	Within 2 weeks

To provide background information for the process of setting performance measures, the responses of the road management and emergency management stakeholders have been summarised in the form of charts, which are presented Figure 10.4.

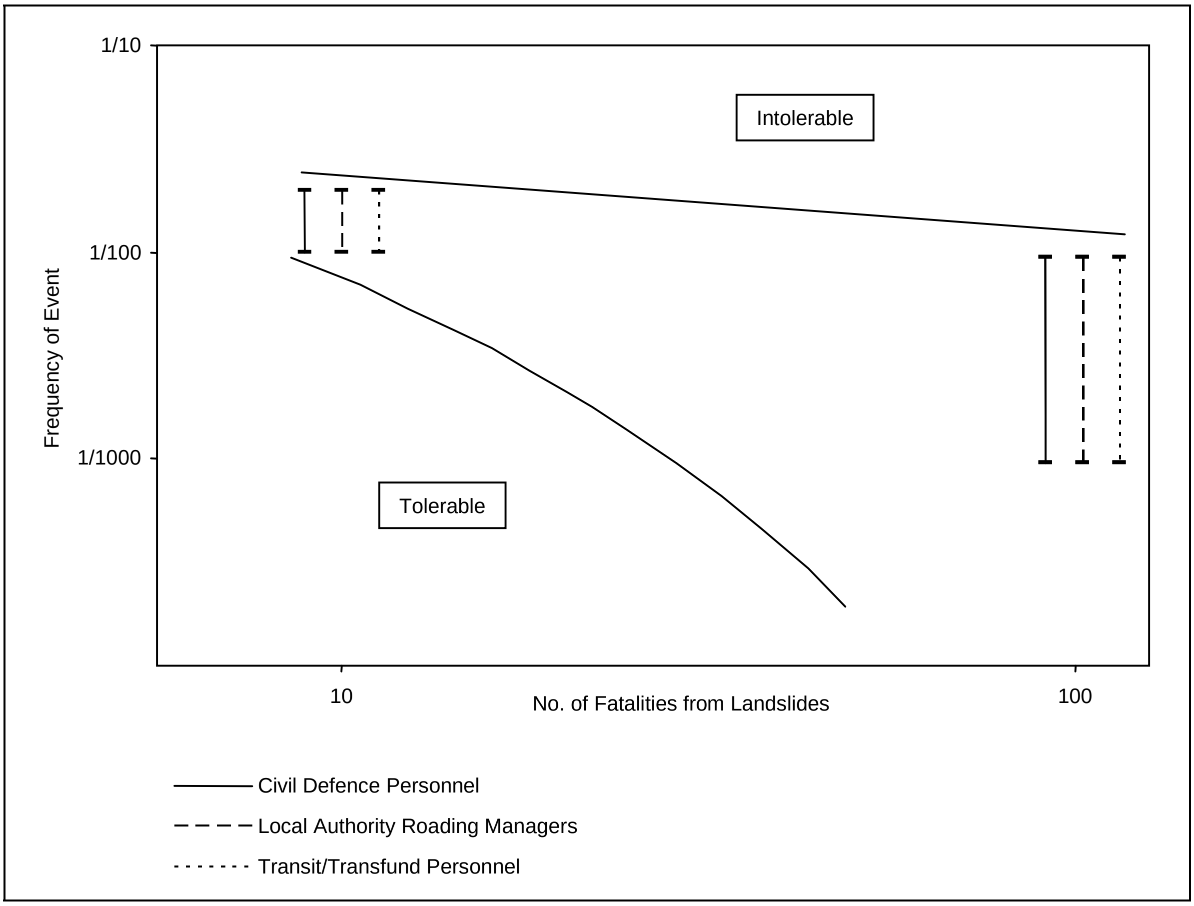


Figure 10.4 Stakeholder perception of how frequently a given number of fatalities should result from landslides.

Figure 10.4 indicates the stakeholders' perceptions of what the community would find an acceptable frequency of fatalities caused by landslides. It should be noted that people's perceptions differ as to how frequently even large events should lead to 100 deaths (or numbers of that order). Some had indicated that this would be unacceptable regardless of the severity of the event.

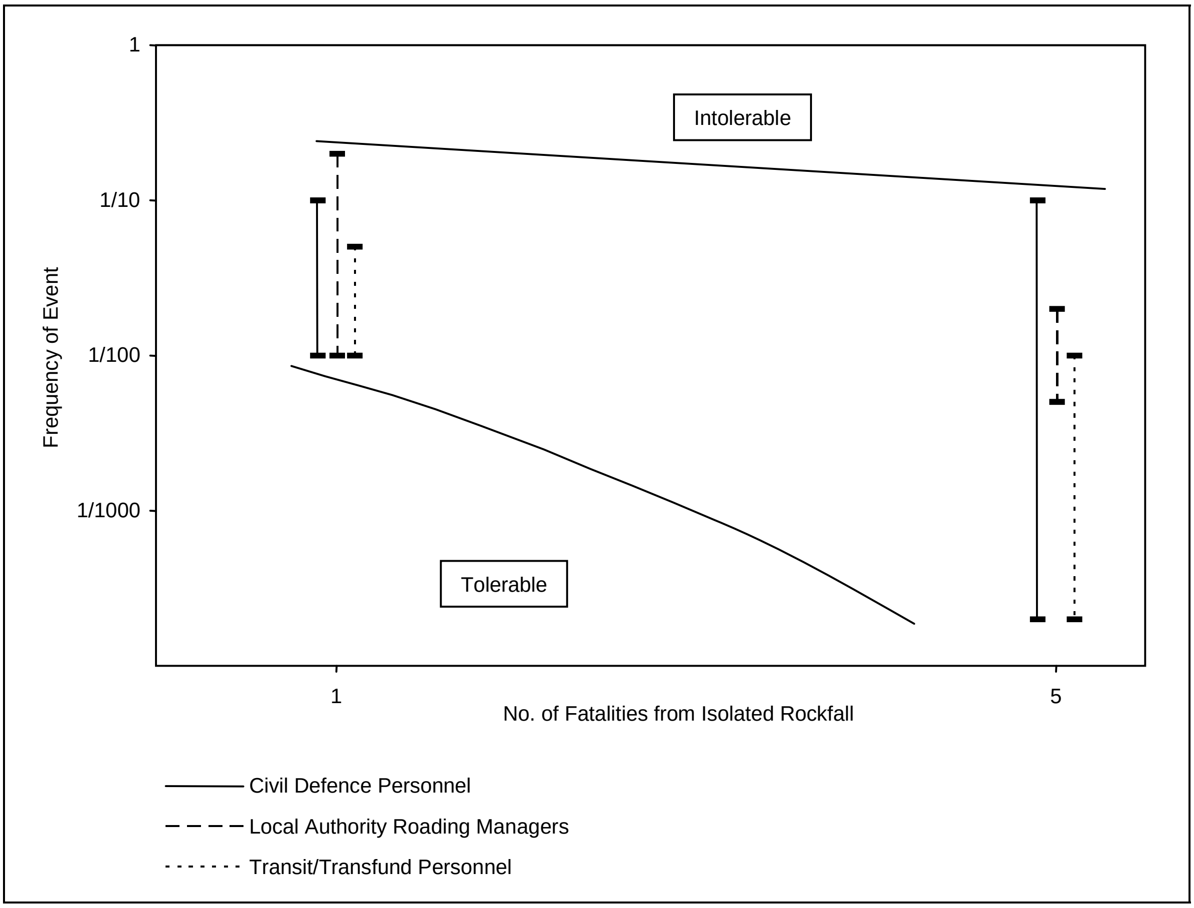


Figure 10.5 Stakeholder perceptions on acceptable frequency of fatalities caused by isolated rock fall.

Figure 10.5 presents the stakeholders' perceptions of what they expect the community as a whole would consider to be an acceptable frequency of fatalities caused by rock falls. Again, this chart shows a wide range of views regarding high fatality frequency. This illustrated how risk-averse planning should be when a high number of fatalities is possible.

Figure 10.6 shows the view of stakeholders as to how long the community would accept the Manawatu Gorge being closed in an event such as the February 2004 storm. The duration of closure considered acceptable may be related to the actual 3-month closure of the Manawatu Gorge after the February 2004 storm. It also illustrates the wide range in perception of which performance measure would be appropriate both within sectors and across the local authority, transit and emergency management sectors.

The perception of how quickly road access needs to be provided to emergency facilities also varies significantly between sectors and even within sectors. The perception of the different stakeholders is illustrated in Figure 10.7. The variation within the emergency management sector reflects the difference in expectations between rural and urban communities. The RCAs still expect a slower recovery to provide access than the emergency managers.

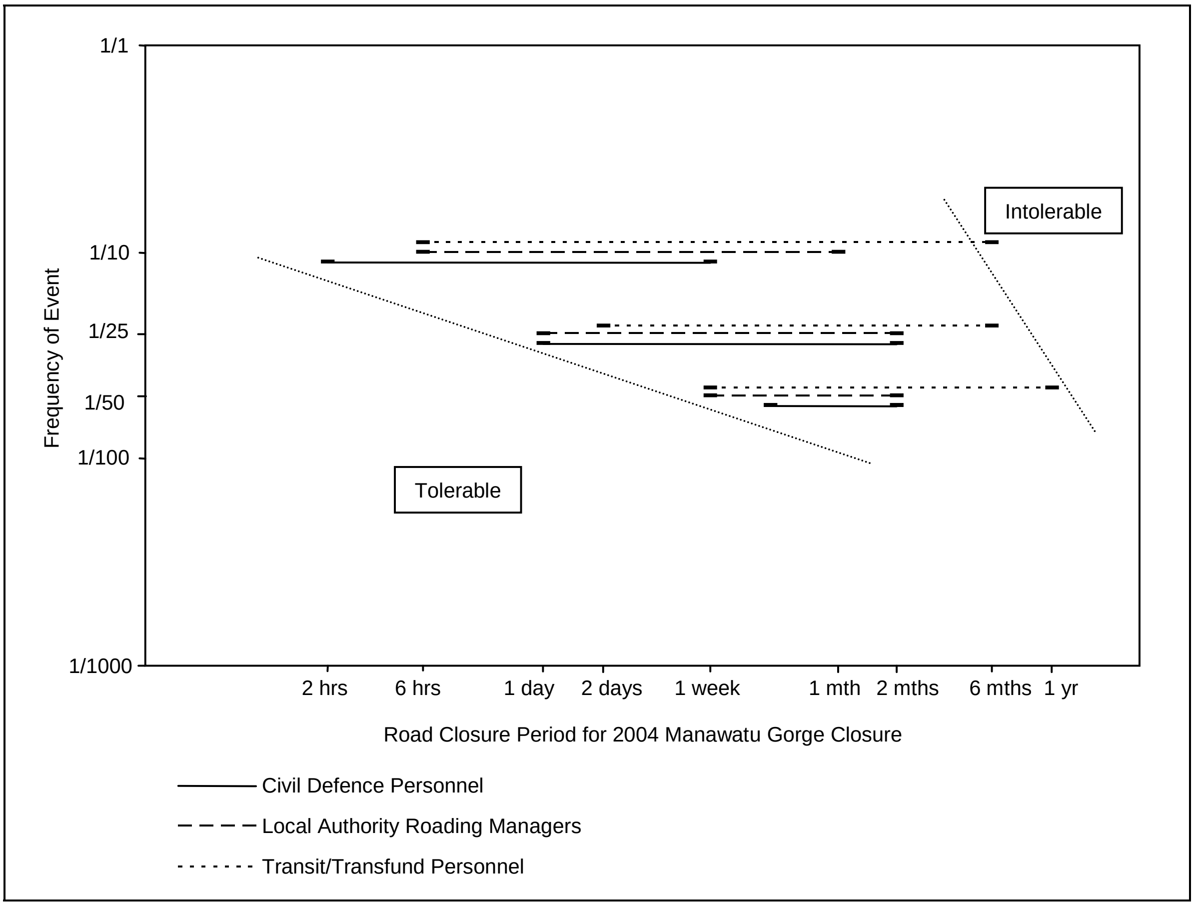


Figure 10.6 Stakeholder perceptions on acceptable duration of closure of the Manawatu Gorge in an event like the February 2004 storm.

The differences in perception are significant, and this requires the issues to be resolved by discussion of the issues. The new CDEM Act expects such co-ordination between stakeholders through the CDEMG that have been established in each region.

It is important to consider the road network as well as other alternative forms of transport (e.g. by air using helicopters or by sea using boats), in considering the performance levels for road networks. This should also take their likely availability into consideration as well as the demand on them and limitations in their use.

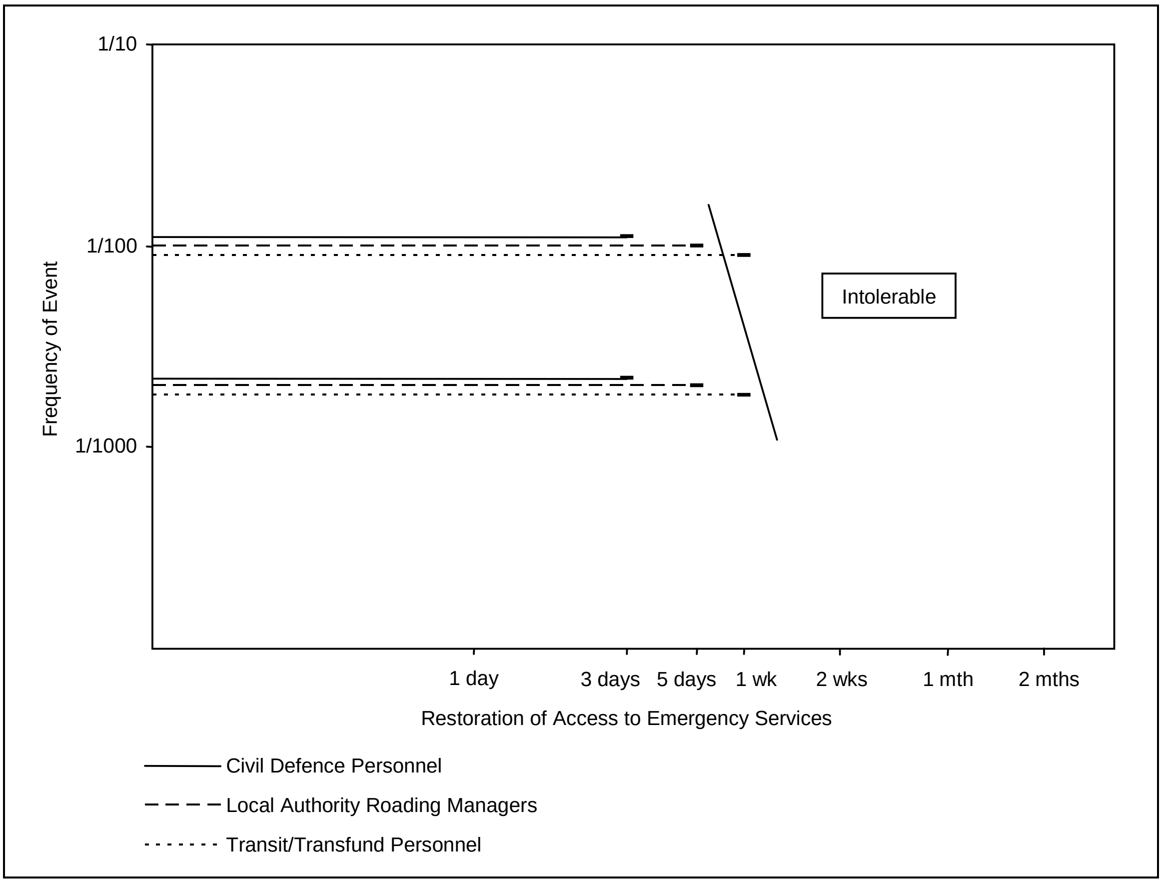


Figure 10.7 Stakeholder perceptions on acceptable time for reopening roads for emergency services access.

10.3 Detailed level criteria

10.3.1 Framework

Setting detailed levels of service and performance measures for road links forms part of the ‘evaluation of the risks’ phase in the risk management process where risks to road links are evaluated against performance criteria to develop acceptable levels of service and performance measures. The process which was proposed to set levels of service and performance measures for road links in the context of the risk management framework is illustrated in Figure 10.8.

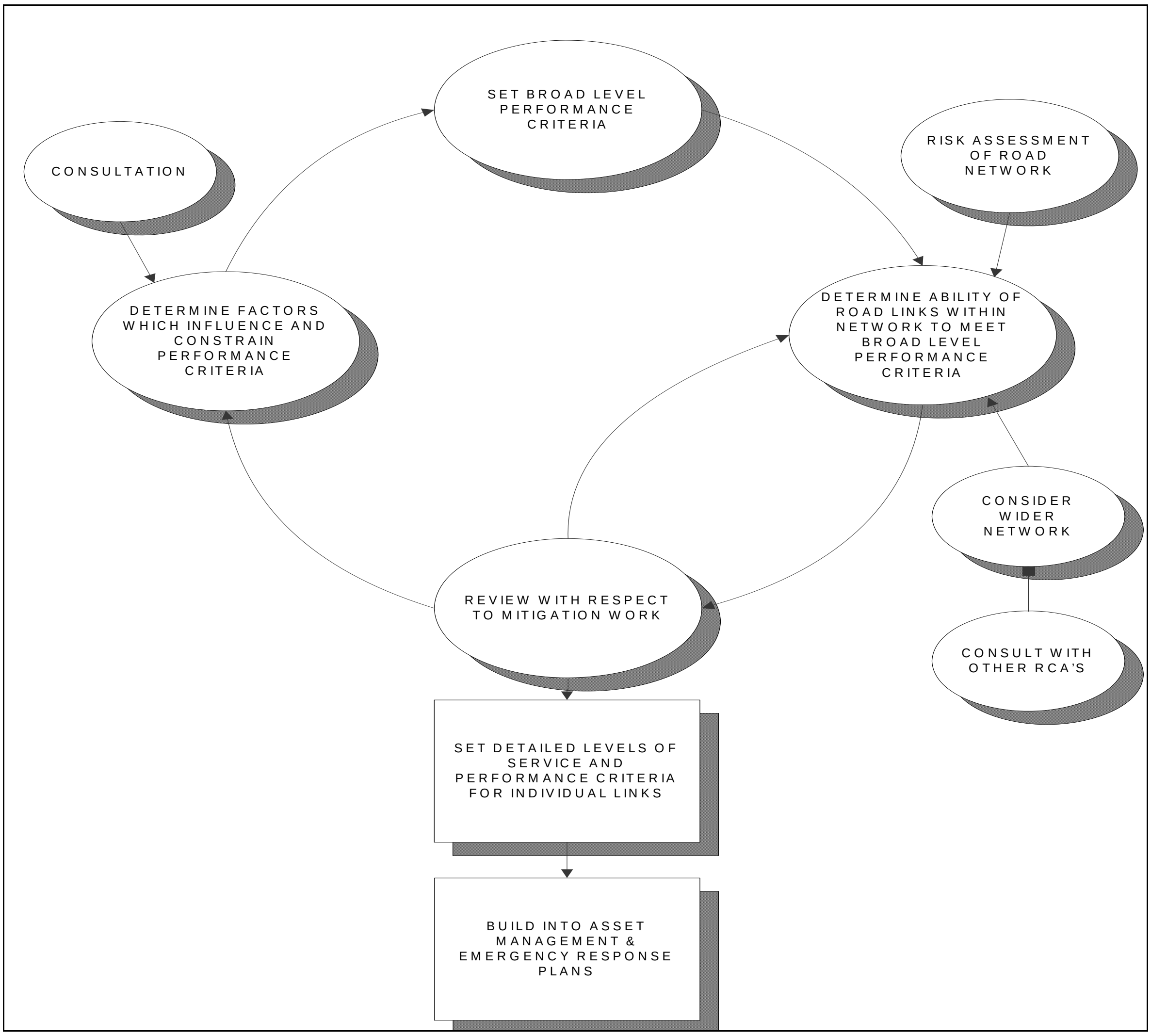


Figure 10.8 Process map for setting detailed performance criteria.

10.3.2 Risk assessment of road network

It is important to carry out a risk assessment for the road network, or the key parts of the road network, so that the risks are known. This will facilitate the setting of performance levels. The first part of this research project (Brabhaharan et al. 2001) developed and outlined a methodology for characterising the risks affecting the road network. This approach would be valuable in characterising the risks for the road network.

It would also be useful to characterise the expected performance or resilience of the road network at the present time, so that this can be compared with the broad level performance expectations. The characterisation of the expected performance can be readily carried out from the risk characterisation discussed above. This would depend on the road network and its context, and the broad level performance criteria set.

An example of such performance characterisation would be to define the resilience through a series of performance indicators, such as those presented in Table 10.2.

Table 10.2 Examples and definitions of road network resilience states.

Resilience states	Description
Damage	The degree of damage to the road after a particular event. A series of damage states can be developed for different events, as necessary. The damage state will be an indicator of the cost of repair.
Availability	The degree of service that the road is able to provide for road users. This gives how functional the road is after a particular event.
Outage	The expected duration for which the road will be in the damage or availability state. This gives an indication of the time to recover.

Examples of damage, availability and outage states for a rural road network are presented in Table 10.3, Table 10.4 and Table 10.5 respectively.

For the road network under consideration, the resilience states are best illustrated through a series of maps showing the road network and the likely performance levels shown in colour.

Table 10.3 Damage levels and states described for a rural road network.

Damage level	Damage state	Description
1	Slight	Only slight damage that requires routine maintenance.
2	Light	Minor damage requiring a clean-up of small slips (of only a few cubic metres) or other debris and minor repairs to culverts.
3	Moderate	Moderate damage requiring removal of a moderate volume of slip debris (tens of cubic metres), small scale repairs to underslips (walls less than 2 m high) and minor repair to walls, culverts and other structures.
4	Severe	Severe damage requiring removal of large volumes of slip debris (hundreds of cubic metres), stabilisation, significant structures to repair underslips and major repair to walls, replacement of culverts and other structures.
5	Extensive	Extensive damage requiring removal of major volumes of landslides and stabilisation, large structures to repair underslips, and damages to walls or other structures.

Table 10.4 Availability states and levels described for a rural road network.

Availability level	Availability state	Availability
1	Full	Full access, although conditions may require care.
2	Poor	Available for slow access, but difficulty may be experienced by normal vehicles caused by partial lane blockage, erosion or deformation.
3	Single lane	Single lane access only with the poor condition of the remaining road causing difficulty.
4	Difficult	Single lane road accessible by 4x4 off-road vehicles only.
5	Closed	Road closed and unavailable for use.

Table 10.5 Outage states and levels described for a rural road network.

Outage level	Outage state	Description
1	Open	No closure, except for maintenance.
2	Minor	Condition persists for up to 12 hours.
3	Moderate	Condition persists for 12 hrs to 3 days.
4	Severe	Condition persists for 3 days to 21 days.
5	Long term	Condition persists for > 3 weeks.

A disruption state parameter could also be derived as an indicator of the performance by combining the *availability state* and the *outage state*.

The disruption state can be defined as a combination of the availability and outage, and thus represent resilience, as illustrated in Appendix B. However, the individual availability and outage states in Table 10.5 are more useful in setting and achieving performance measures.

10.3.3 Ability of road links to meet broad level performance criteria

The next step would be to compare the expected resilience, as defined by the broad level performance criteria, with the currently likely performance as defined by the component resilience states of damage, availability and outage. This would help us to understand the *resilience gap* in the road network. It will also be important for understanding the deficiencies in the road network performance. A series of maps of the road network is the best way to illustrate this.

10.3.4 Considering the wider network

The process diagram (Figure 10.8) illustrates that road links which form part of a local network must also be assessed at the regional level. For a Local Authority this may involve liasing with other RCAs from within the region as well as with Transit at the regional level to establish road links which are critical to the network as a whole.

For example, following the storm in February 2004, SH3 Manawatu Gorge Road and Saddle Road were closed for several months leaving the Pahiatua Track as the only route linking the east and west through the main Tararua ranges. Under these circumstances, the Pahiatua Track became a strategic link of importance, but was of limited standard to cope with the traffic demands. The Pahiatua Track falls within the jurisdiction of both the Tararua District Council and Palmerston North City Council. Its importance as an alternative route only becomes apparent when considered at a regional level.

Performance measures and levels of service need to be determined in terms of the service area they are intended for within the road network management and development structure. Performance measures and levels of service should be determined in the areas of project planning, project design and network maintenance. For example, in addition to setting performance criteria to safeguard the existing network from natural hazard risks, performance criteria should also be set during the design stage of roading projects for new roads or upgrading of existing routes.

10.3.5 Consulting other RCAs and utilities

Given the interdependencies and integrated nature of the road networks, it would be important to consult with the neighbouring RCAs within the region and perhaps in adjacent regions to consider the inter-relationships and the deficiencies in the regional road network. This will assist in understanding redundancies and help local authorities agree how to set performance measures at a regional level.

It would also be important to liase with other lifeline utility organisations sharing the road corridor and those dependent on the road network in order to understand inter-dependencies and shared risks.

10.3.6 Reviewing performance levels with respect to mitigation work

It is important to consider the necessary mitigation measures as well as their practicality and to outline the costs, so that the performance measures can be considered in the light of how feasible mitigation is, as well as the cost of this mitigation. Part I of this research (Brabhaharan et al. 2001) sets out a framework for considering mitigation at a broad level across the network.

As an example, if the practicality and cost of mitigation for the SH 3 Manawatu Gorge Road is known, this may help in setting realistic performance levels for different road links. For example, the high cost of upgrading Manawatu Gorge may raise the importance of the alternative routes – Saddle Road or the Pahiatua Track (or both) – which will in turn raise the performance levels of these routes.

10.3.7 Setting detailed levels of service and performance criteria

The detailed levels of service and performance measures can be set for the various key road links in the road network, with the knowledge of the likely resilience of the road network in different events, alternative access routes, resilience gaps, mitigation feasibility and the adjacent networks and their resilience.

The levels of service and performance measures should be discussed with the community (including businesses) and agreed upon.

It is inappropriate to provide generic performance measures as the need will vary from network to network and will be dependent on the actual situation.

10.3.8 Integrated asset management

It is important that the performance measures related to natural hazard events and consequential risks be considered alongside other performance expectations for the road network (such as road safety, congestion or future growth needs) so that integrated asset management and development planning can be carried out to develop action plans that collectively meet the different requirements. This will maximise opportunities to achieve the desired levels of service from these different perspectives by choosing actions that could well improve performance in a number of these issues.

The levels of service, performance measures, mitigation and other actions required to meet the target performance should be considered alongside other aspects of managing the road network. They should then be incorporated into long term asset and financial management strategies and planning, and into the AMPs, so that they become integral part of managing the road network.

10.3.9 Asset development and design

The performance expectations for the different road links in the network should also be taken into consideration when developing new assets (new roads or road improvement projects). This will ensure that these new sections of road are designed and constructed to a level that would meet the performance expectations for that link. For example, a primary road link for emergency facilities and where no resilient alternative routes exist should be designed to a higher level than that for a secondary link with a number of alternative routes.

In principle, this is reflected in the new AS/NZS 1170.0:2002 *Structural Design Actions Part 0: General Principles* (Standards New Zealand, 2002). However, these principles are not yet reflected in road or highway design practice, for example in the *Bridge Manual* (Transit New Zealand, 2004).

11. Case study: applying the framework to the Wellington road network

11.1 Purpose

The purpose of applying the framework outlined in Chapter 10 to the Wellington road network is to demonstrate how the process can be applied in practice to assist practitioners in their road asset and risk management planning.

It should be noted that this case study is a hypothetical example of applying the framework to part of the Wellington road network for illustrative purposes only and has not been used in an actual decision-making for managing the risks to the road network

11.2 Methodology

The methodology follows the process map shown on Figure 10.8. The Wellington road network has been chosen because it is subject to a range of hazards. In particular, several key links from population centres (e.g. Ngaio and Khandallah) to the Central Business District (CBD) are exposed to high risks from natural hazard events.

A risk assessment of Wellington's road network has been undertaken and provides the input for setting performance levels. Road links have been prioritised based on the following:

- exposure to natural hazards,
- traffic volumes,
- public and commercial use, and
- access to emergency services.

This case study focuses on part of the road network providing links between Wellington's northern suburbs and the CBD, and to the Wellington Hospital in the south.

11.3 Applying the framework

11.3.1 Establishing influences and constraints

The first step is to establish factors which influence and constrain performance criteria in the context of the Wellington road network. These factors should be determined in consultation with representatives from RCAs, road transport authorities, road user groups, community groups, lifeline groups and emergency management personnel.

Factors which may influence and constrain performance criteria in Wellington are :

Influencing factors

- risk to safety of life,
- disruption of public and commercial transport,
- loss of access to and from the CBD for emergency service vehicles,
- loss of access to hospitals for ambulances, and
- whether or not alternative routes are available.

Constraining factors

- cost of mitigation work,
- availability of skills and resources, and
- the public's perception of the risks to the road network.

11.3.2 Establishing broad level performance requirements

In consultation with road stakeholders, broad level performance measures and levels of service can be determined for prioritised road links for each service provided. Table 11.1 sets out examples of some broad level performance measures and levels of service which could be determined for the Wellington road network. The levels of service and performance measures shown below are examples only and are not based on consultation with road stakeholders.

Table 11.1 Examples of broad level performance criteria for the Wellington road network.

Service provided	Road link priority	Level of service	Performance measure
Safety of life	Very high	Maximum number of fatalities from a natural hazard event with a frequency of 1 in 100 years.	2
	High	Maximum number of fatalities from a natural hazard event with a frequency of 1 in 100 years.	1
	Medium	Maximum number of fatalities from natural hazard event with a frequency of 1 in 100 years.	1
Access to hospitals for emergency service vehicles	Very high	Restore temporary road access to hospitals and emergency centres identified by the District Health Board.	Within 2 hours
	High	Restore temporary road access to hospitals and emergency centres identified by the District Health Board.	Within 3 hours
	Medium	Restore temporary road access to hospitals and emergency centres identified by the District Health Board.	Within 6 hours
Network availability	Very high	Restore one–lane access for all vehicles.	Within 6 hours
		Restore two–lane access for all vehicles.	Within 12 hours
	High	Restore one–lane access for all vehicles.	Within 12 hours
		Restore two–lane access for all vehicles.	Within 24 hours
	Medium	Restore one–lane access for all vehicles.	Within 24 hours
		Restore two–lane access for all vehicles.	Within 48 hours

11.3.3 Prioritising road links

This step involves identifying critical road links within the network with respect to traffic volumes, public use, commercial use and emergency services use. The important road links (ranked by priority) between Wellington's northern suburbs, the CBD and the Wellington Hospital – the part of the Wellington road network covered by this case study – are shown in Figure 11.1. The importance of the road links is outlined in Table 11.2.

Table 11.2 Critical Wellington road links ranked by priority and described.

Road link	Priority	Description
Burma Road	High priority.	It provides the critical link between Johnsonville and the Northern suburbs. No alternative routes are available nearby.
Ngaio Gorge Road /Kaiwharawhara Road to Hutt Road	High priority.	This link has no alternative route nearby. The only alternative route is Onslow Road/Cashmere Road and other smaller roads.
OnslowRoad/Cashmere Road to Hutt Road	High priority.	No alternative routes exist nearby. The only alternative route is Ngaio Gorge Road/ Kaiwharawhara Road to Hutt Road.
Hutt Road to Aotea Quay	Very high priority.	It carries commercial traffic and services to the port and the ferry terminal. This link has SH1/Wellington Urban Motorway as an alternative route nearby.
Aotea Quay to Jervois Quay	Very high priority.	Hutt Road/Thorndon Quay provides a secure alternative route nearby.
Jervois Quay to Basin Reserve	High priority.	It provides the critical link between the CBD and Basin Reserve, which leads to Wellington Hospital.

Figure 10.5 presents the stakeholders' perceptions of what they expect the community as a whole would consider to be an acceptable frequency of fatalities caused by rock falls. Again, this chart shows a wide range of views regarding high fatality frequency. This illustrated how risk-averse planning should be when a high number of fatalities is possible.

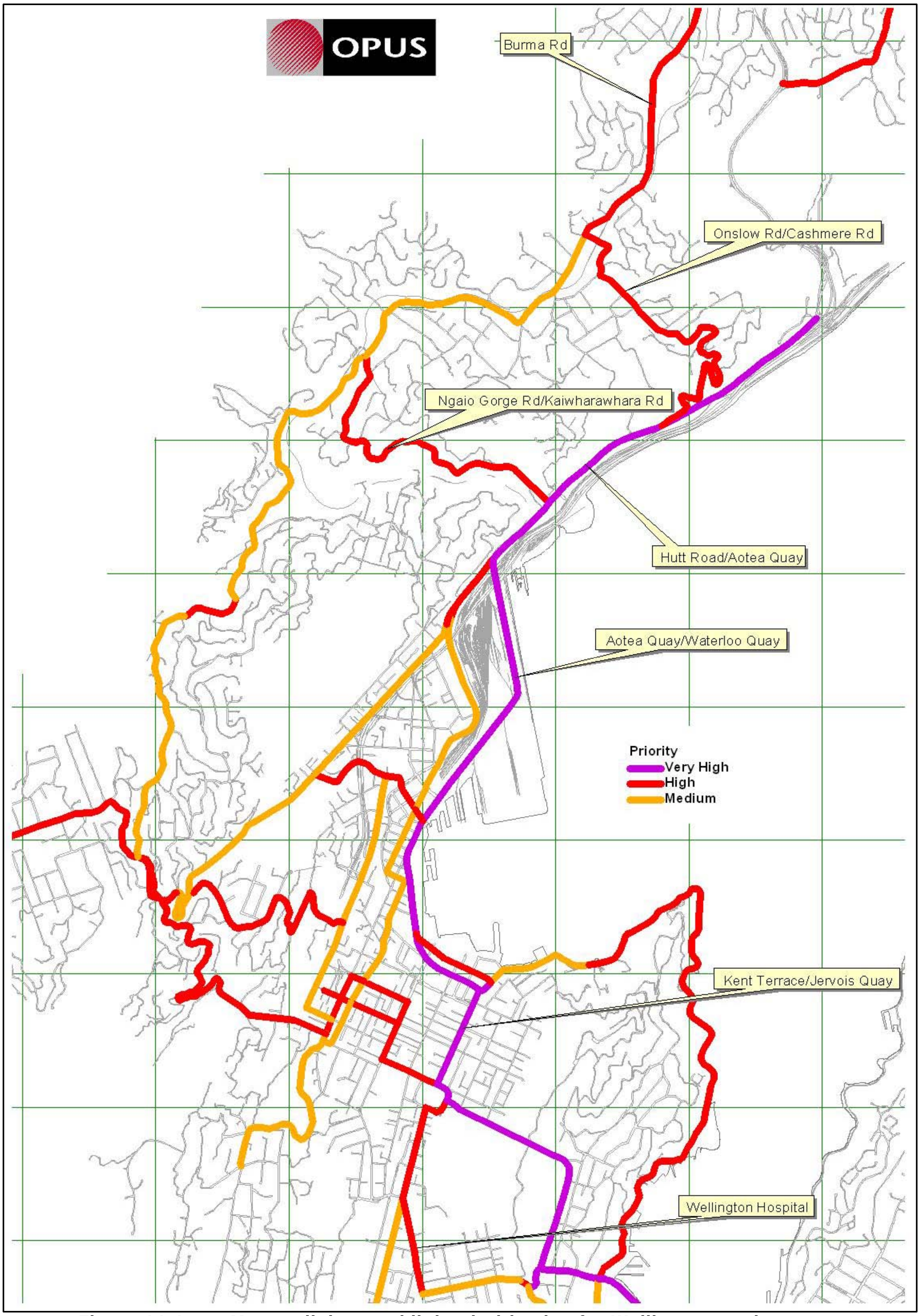


Figure 11.1 Map outlining road link prioritisation for Wellington roads.

11.3.4 Vulnerability of road links to natural hazards

Figure 11.2 shows the risks and consequences along the road links identified in Table 11.2 which could result from an earthquake (Wellington fault movement and large regional earthquake) or a storm (50 year event). Each critical link described is assessed n Table 11.3 regarding risks to the road links from natural hazard events i.

Table 11.3 Risk to critical road links in the Wellington urban area.

Road link	Risk description
Burma Road	The southern section of this link is subject to significant risk from earthquakes and storms with significant consequences. The northern section of this link is subject to moderate risks from earthquakes and storms. The consequences could be significant.
Ngaio Gorge Road/ Kaiwharawhara Road to Hutt Road	This link is exposed to various levels of risk from both earthquakes and storms. A large section of this link is exposed to very high risks from earthquakes and storms. The consequences could range from severe to catastrophic.
OnslowRoad/Cashmere Road to Hutt Road	This link is also exposed to various levels of risk from both earthquakes and storms. Sections of this link are exposed to extreme risks from earthquakes and storms. The consequences could be severe to catastrophic.
Hutt Road to Aotea Quay	The northern section of this link is subject to extreme risk from earthquakes and storms, with catastrophic consequences. The southern side of this link is subject to low risks from earthquakes and storms. Any consequences would be insignificant.
Aotea Quay to Jervois Quay	Sections of this link are subject to a high risk of liquefaction from a Wellington fault movement with major consequences.
Jervois Quay to Basin Reserve	This link is at low risk from earthquakes and storms. Any consequences would be insignificant.

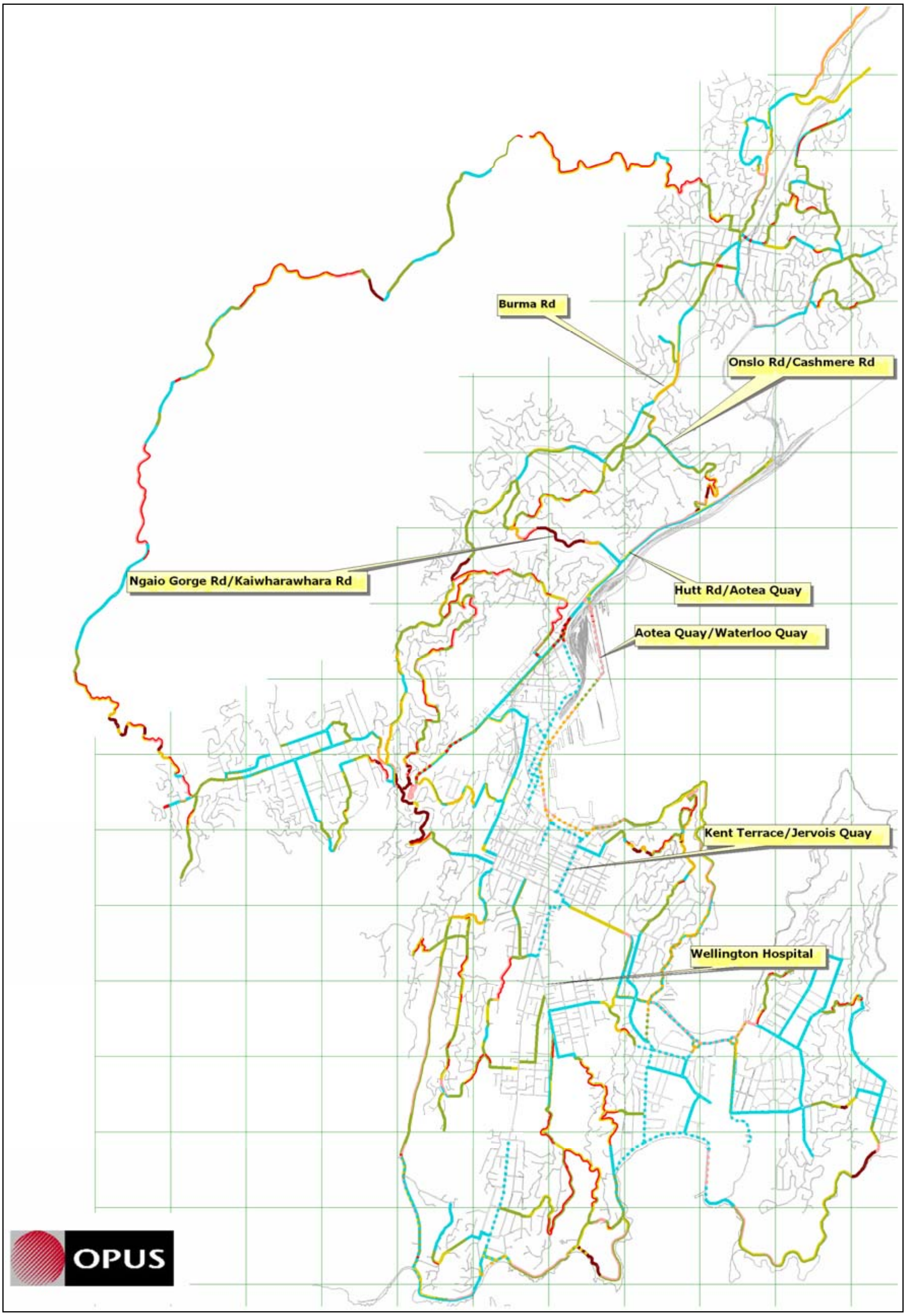
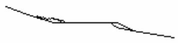
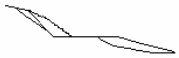
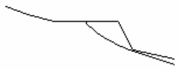
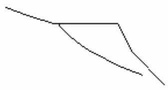
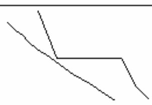


Figure 11.2 Vulnerability of key roads in Wellington City to earthquake and storm events.

Consequences to roads from slope failure hazards			
Map Colour	Natural hazard		
	Wellington fault event	Large regional earthquake	50-year storm
	Insignificant 	Insignificant	Insignificant
	Minor 	Insignificant	Insignificant
	Moderate 	Minor	Minor
	Significant 	Moderate	Moderate
	Major 	Significant	Significant
	Severe 	Major	Severe
	Catastrophic 	Severe	Severe

Consequences to roads from liquefaction and Wellington fault rupture hazards			
Map colour	Earthquake		
	Wellington fault		Large regional earthquake
	Fault rupture	Liquefaction	
		Insignificant	Insignificant
		Minor	Insignificant
		Moderate	Minor
		Significant	Moderate
		Major	Significant
	Severe		
	Catastrophic		

Table 11.4 Key to Figure 11.2, illustrating type and scale of earthquakes and liquefaction.

11.3.5 Reviewing each link against each performance criteria

The purpose of this step is:

- to determine whether or not the broad level performance criteria set for each link can be met when compared with the natural hazard risks to each link established in the preceding steps;
- to identify those links which require mitigation work in order to meet the broad level performance criteria; and
- to determine which performance criteria are applicable to each link given the characteristics of each link (emergency services use, public and commercial use and traffic volumes).

The process of reviewing each link against each performance criterion is demonstrated below. The performance criteria for the services provided have been extracted from Table 11.1. The levels of service are examples and used only to demonstrate the process.

11.3.5.1 Performance criterion: access to hospitals for emergency service vehicles

The level of service will be higher for routes which are regarded as critical for access to emergency services, compared to those which are not regarded as critical. The routes which are deemed as providing emergency service access within the Wellington road network are shown in Figure 11.3.. Reference should be made to this figure to facilitate the process of reviewing each link against the performance criteria set out in Table 11.5.

Sample levels of service for emergency services access are presented in Table 11.5. The ability of the existing road network to meet the expected performance is assessed by comparing the likely and expected performance (Table 11.6).

Table 11.5 Possible performance measures and levels of service for emergency services access to hospitals.

Service provided	Road link priority	Level of service	Performance measure
Access to hospitals for emergency service vehicles.	Primary route	Restore temporary road access to hospitals and emergency centres.	Within 2 hours
	Secondary route	Restore temporary road access to hospitals and emergency centres.	Within 3 hours

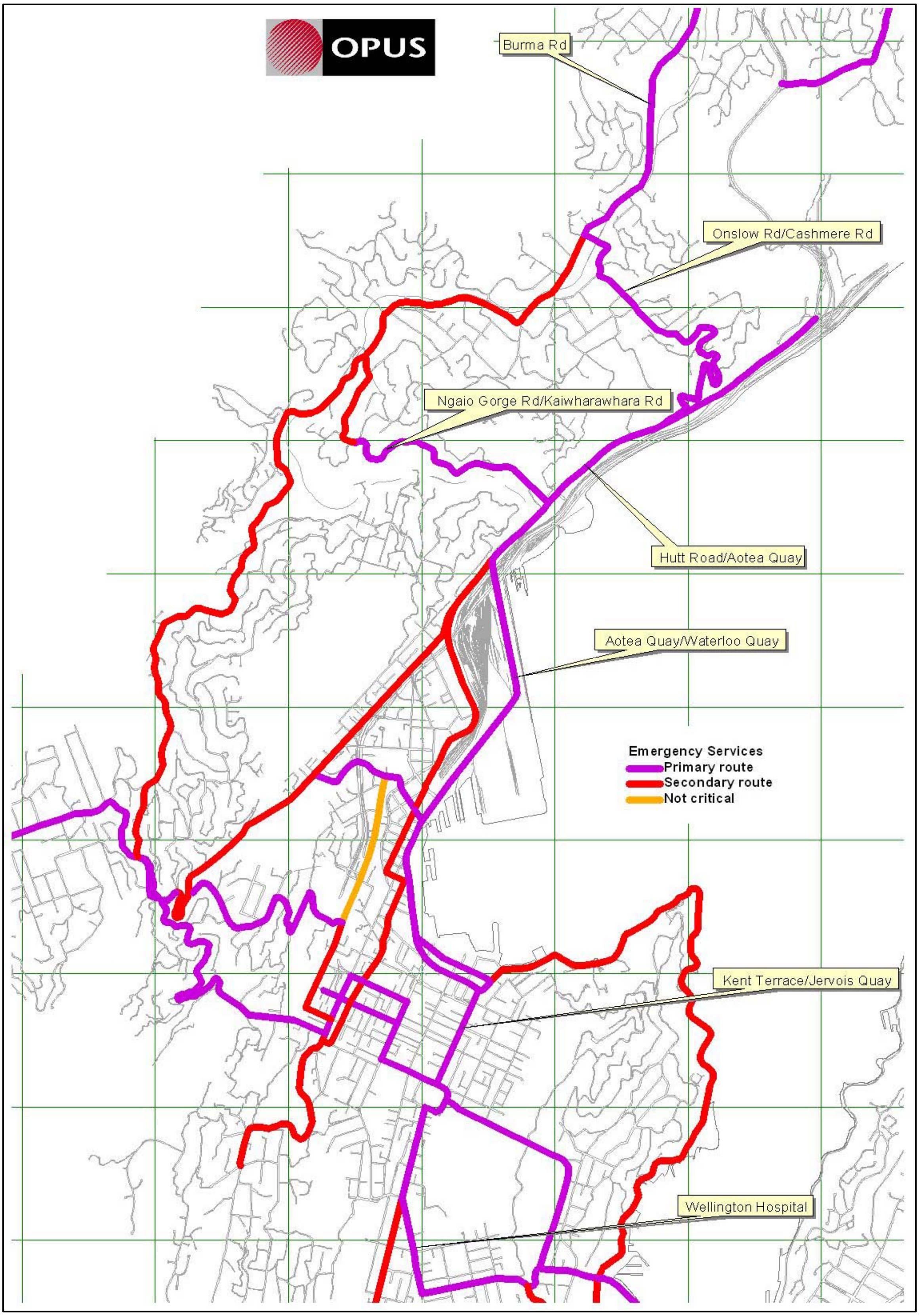


Figure 11.3 Emergency services priority routes in Wellington.

Table 11.6 Performance level for emergency services access for various critical road links within Wellington.

Road link	Comparison of likely and expected performance
Burma Road	This link is designated as a primary route for emergency services. This link may generally meet the performance expectations subject to having adequate emergency response plans.
Ngaio Gorge Road/ Kaiwharawhara Road to Hutt Road	Both of these links are designated as primary routes for emergency services. These links are unlikely to meet the level of service requirements given the risk of slope failures from earthquakes and storms. These links need to be assessed further regarding the mitigation work required to improve the performance levels.
Onslow Road/Cashmere Road to Hutt Road	
Hutt Road to Aotea Quay	This link is designated as a primary route for emergency services. It is subject to extreme risks from natural hazard events with catastrophic consequences. Mitigation work needs to be carried out to improve the ability of this link to meet the level of service requirements.
Aotea Quay to Jervois Quay	This link is designated as a primary route for emergency services. It is subject to risks of liquefaction resulting from a Wellington fault movement. This link also has a secure alternative route nearby and may not be required to meet the level of service requirements above.
Jervois Quay to Basin Reserve	This link is not exposed to any significant risks and it appears that this link can meet the broad performance criteria for access without any mitigation work.

11.3.5.2 Performance criterion: network availability

A higher level of service and performance is required for more important routes that carry larger amounts of traffic and public transport compared to other routes. This is important, particularly for an urban road network where availability is crucial for minimising the broader socio-economic impacts of the hazard event. Typical examples of levels of service which depend on the traffic volumes are shown in Table 11.7.

Table 11.7 Example levels of service for network availability.

Service provided	Road link priority	Level of service	Performance measure
Network availability	AADT* >16 000	Restore one-lane access for all vehicles	Within 6 hours
		Restore two-lane access for all vehicles	Within 12 hours
	AADT 8000 – 16 000	Restore one-lane access for all vehicles	Within 12 hours
		Restore two-lane access for all vehicles	Within 24 hours
	AADT 2000 – 8000	Restore one-lane access for all vehicles	Within 24 hours
		Restore two-lane access for all vehicles	Within 48 hours

*AADT: Annual Average Daily Traffic

The traffic volumes for the Wellington road network are shown on Figure 11.4. Reference should be made to this figure to facilitate the process of reviewing each link with the performance criteria in Table 11.7.

Table 11.8 shows the ability of the existing road network to meet the expected performance criteria for network availability, which was assessed by comparing the likely and expected performance.

Table 11.8 Performance levels for network availability for various road links within Wellington.

Road link	Risk description
Burma Road	The traffic volume along this link (8000–16 000 vehicles per day) mark it as a secondary route with respect to traffic. However, this link is designated as a primary route for emergency services. Therefore, emergency services access may control the setting of performance levels for this route.
Ngaio Gorge Road/ Kaiwharawhara Road to Hutt Road	The traffic volume along this link is 8000–16 000 vehicles per day, which indicates that it is a secondary route in terms of catering to traffic. However, it is a primary link for emergency services. Therefore, emergency service access may control the setting of performance levels for this route.
OnslowRoad/Cashmere Road to Hutt Road	The traffic volume along this link is 2000–8000 vehicles per day, which is significantly lower than the traffic volumes for Ngaio Gorge and the Hutt Road. However, this link is regarded as a primary route for emergency services. Therefore, emergency services access may control the setting of performance levels for this route.
Hutt Road to Aotea Quay	The traffic volume along this link is greater than 16 000 vehicles per day, which indicates it is a primary route for traffic. Mitigation work should be considered to assess whether this link may be improved to a standard which would provide the required level of service.
Aotea Quay to Jervois Quay	The traffic volume along this link is greater than 16 000 vehicles per day, which indicates it is a primary route in terms of catering to traffic. However, this link also has a secure alternative route nearby and may not be required to meet the levels of service proposed above.
Jervois Quay to Basin Reserve	This link is not exposed to any significant risks and therefore it appears that this link can meet the broad performance criteria for network availability without any mitigation work.

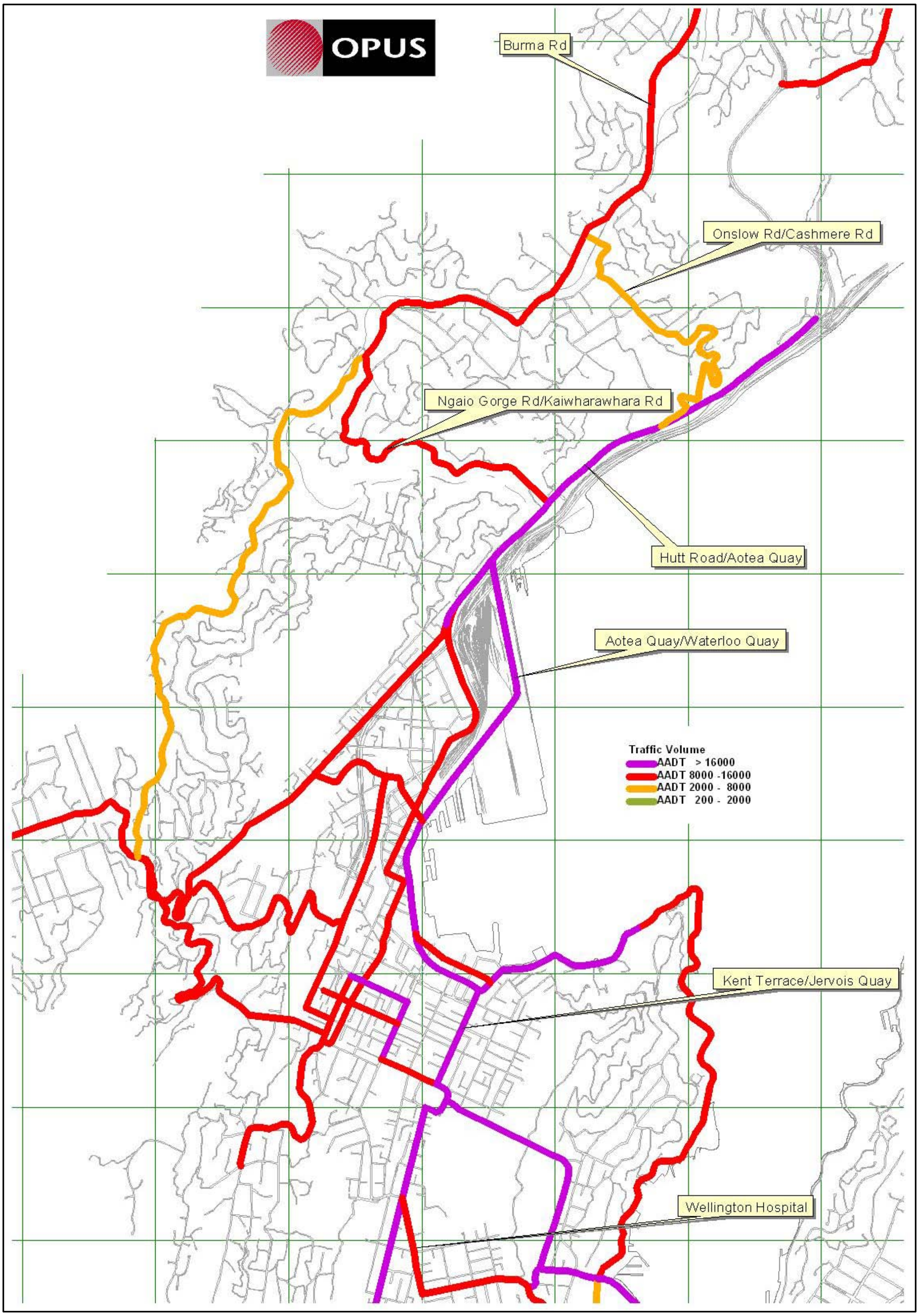


Figure 11.4 Road traffic volumes for the Wellington road network.

11.3.6 Reviewing each road link's mitigation requirements

Most of the links identified in this section are exposed to various levels of risk. These various levels of risk affect their ability to function as important links in the network in terms of providing access for large volumes of traffic and/or access to hospitals for emergency service vehicles.

The levels of service set for these links need to be reviewed with respect to the mitigation work required to reduce the risks to these links. The B/C for mitigation work to reduce the risk along these links is shown in Figure 11.5.

The mitigation measures and the economics of mitigation in terms of B/C for each of the links are discussed in Table 11.10.

Table 11.10 Mitigation of road inks.

Road Link	Risk Description
Burma Road	The mitigation work proposed has a low B/C indicating that reducing the risks to this link may not be cost-effective. It appears this link will not meet the broad performance criteria set above and the wider network needs to be considered in terms of locating a suitable alternative route.
Ngaio Gorge Road/ Kaiwharawhara Road to Hutt Road	This link requires a wide variety of mitigation work to reduce the risks from natural hazard events. The figure above shows high B/Cs for most of the mitigation work required. This link has no alternative routes nearby and is critical in terms of providing access to hospitals for emergency service vehicles. Therefore short, medium and long term levels of service should be set with respect to mitigation work planned in the short, medium and long term.
OnslowRoad/Cashmere Road to Hutt Road	This link requires a large amount of mitigation work to reduce the risk from natural hazard events. However, low B/Cs for most of the mitigation work required are low. This indicates that reducing the risks to this link is not cost-effective. It may be more beneficial to relax the levels of service along this link and strengthen alternative routes like Ngaio Gorge.
Hutt Road to Aotea Quay	Very little mitigation work has been proposed for this link as no cost-effective measures can prevent slope failure along most of this route. Therefore it is not possible for this link to meet the broad performance criteria. However, SH1/Wellington Urban Motorway provides a close alternative route and needs to be considered (in consultation with Transit) in terms of its ability to meet the broad levels of services.
Aotea Quay to Jervois Quay	Like Hutt Road to Aotea Quay, no cost-effective measures can mitigate the risks along this route and therefore it is not possible for this link to meet the broad performance criteria. However this link has Hutt Road/Thorndon Quay as a secure alternative route nearby. Hutt Rd/Thorndon Quay needs to be assessed with respect to its ability to meet the broad performance criteria.
Jervois Quay to Basin Reserve	This link requires no mitigation work and therefore it appears that it can meet the broad performance criteria without mitigation measures.

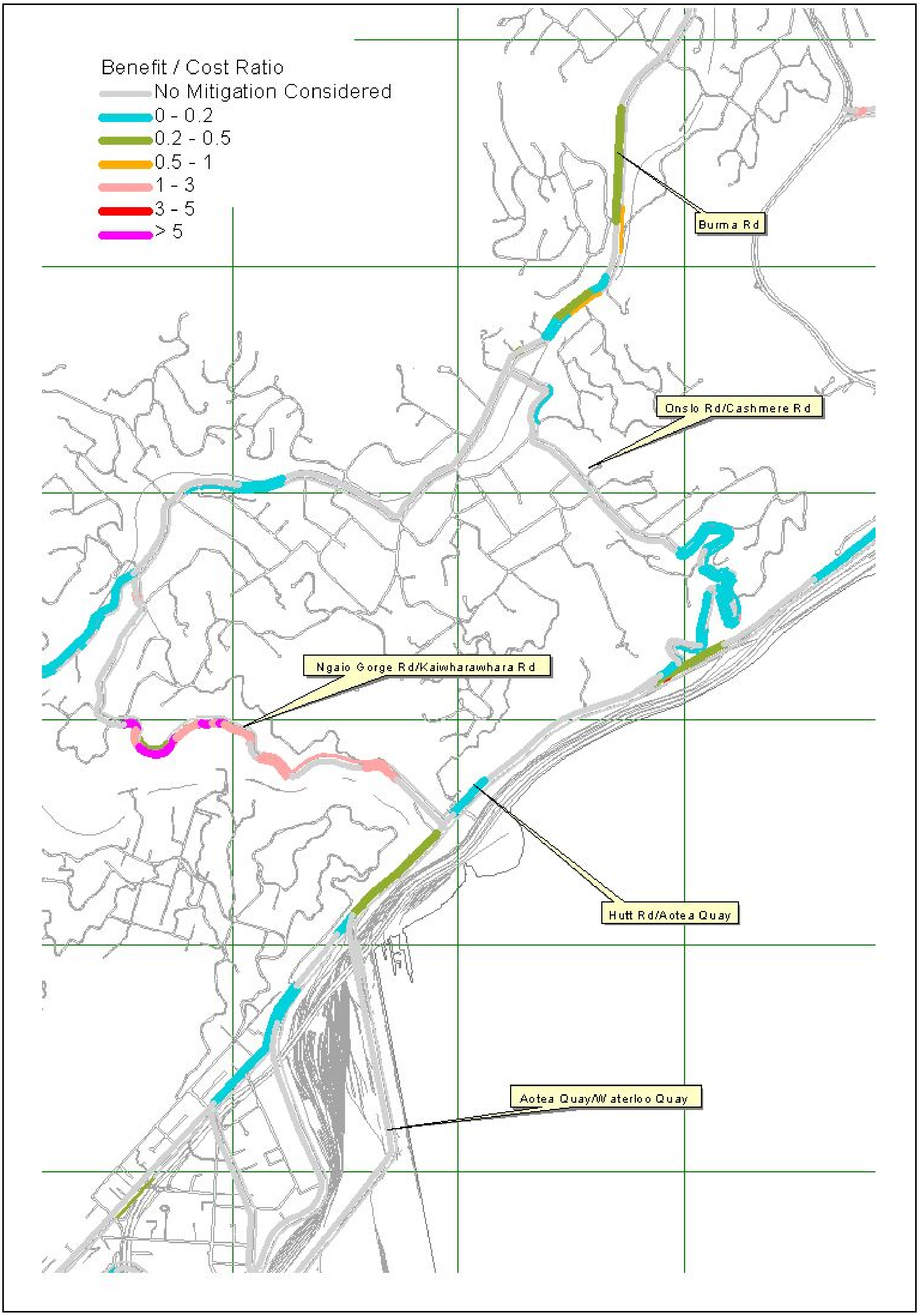


Figure.11.5 B/C for mitigation work on critical links in the Wellington road network.

11.3.7 Reviewing links with respect to the wider network

In the context of Wellington, the wider road network comprises the State Highway 1 urban motorway. Sections of SH1 provide an alternative route for the following road links.

- Hutt Road to Aotea Quay: the SH1 urban motorway from the Hutt Road/Aotea Quay intersection has been seismically retrofitted to reduce the risk of failure from an earthquake and therefore provides a secure alternative route along this link.
- Burma Road: this route is an important link between Johnsonville and the Khandallah/Ngaio road network. SH1 from Johnsonville provides an alternative route from this population centre to the CBD.

11.3.8 Setting detailed levels of service and performance measures

Detailed levels of service can be set for links which can meet the broad level performance criteria without requiring mitigation work. Short, medium and long term levels of service can be set for links where mitigation work is cost effective and planned for.

It may not be possible to set detailed levels of service for road links which cannot meet the broad level service requirements and where mitigation work is not likely to be cost effective. However, if alternative routes exist for these links, then performance criteria should be assessed for these alternative routes following the same method described above.

Examples of potential levels of service and performance measures at the detailed level focusing on Ngaio Gorge/Kaiwharawhara Road and Jervois Quay to Basin Reserve:

Ngaio Gorge Road / Kaiwharawhara Road to Hutt Road

This link is a primary route for emergency services and an important route which caters to large volumes of traffic. The only close alternative route is Onslow Road/Cashmere Road.

Onslow Road/Cashmere Road is also a primary route for emergency services but does not cater for the same volumes of traffic as Ngaio Gorge Road/Kaiwharawhara Road. Mitigation work is required for both these links to meet the broad level performance criteria but mitigation work is more cost-effective for Ngaio Gorge Road/Kaiwharawhara Road. Therefore short, medium and long term performance criteria have been set with respect to the mitigation work planned for this link (see Table 11.10).

Table 11.10 Ngaio Gorge: detailed performance levels and levels of service.

Service provided	Road link priority	Level of service	Period	Performance measure
Access to hospitals for emergency service vehicles	Primary route	Restore temporary road access for emergency service vehicles	Short term	Within 12 hours
		Restore temporary road access for emergency service vehicles	Medium term	Within 6 hours
		Restore temporary road access for emergency service vehicles	Long term	Within 2 hours

Jervois Quay to Basin Reserve

This link requires no mitigation work and is exposed to low risks from natural hazard events which have insignificant consequences.The broad performance criteria can be retained as the detailed performance level.

The performance measures that may be adopted for the Jervois Quay to Basin Reserve link are shown in Table 11.11.

Table 11.12 Jervois Quay to Basin Reserve: detailed performance levels and levels of service.

Service provided	Road link priority	Level of service	Performance measure
Access to hospitals for emergency service vehicles	Primary route	Restore temporary road access to hospitals and emergency centres identified by the District Health Board	Within 2 hours
Network availability	AADT>16 000	Restore one-lane access for all vehicles	Within 6 hours
		Restore two-lane access for all vehicles	Within 12 hours

11.3.9 Building performance criteria into AMPs

The levels of service and performance measures set for road links within the road network must be built into the RCAs' AMPs and Emergency Response Plans. The levels of service and performance measures must be consistent with mitigation work which has been identified, proposed and planned for selected road links. For example, a staged programme of strengthening a critical road link may be proposed as a result of setting detailed performance criteria within a road network in the short, medium and long term.

12. Conclusions

12.1 Literature review

The literature review confirmed that no criteria are available for setting performance levels for road networks, except for performance-based design standards for bridges. Although some have attempted to define the desired levels of performance for a water supply system, little consideration has been given on how to decide on these levels of performance. No information is available to build on from past literature. Guidance for deciding appropriate levels of performance has been developed on the basis of the new research reported here.

12.2 Questionnaire and survey

Our survey of experiences in past natural hazard events showed that road users were generally tolerant of travel disruption from natural hazards as it is a consequence of the environment we live in. However, they are less tolerant of lack of information on road closures and of planned disruption even if these planned disruptions are for restoring damage from natural hazards. Some also become frustrated over the lack of preventative measures (reduction) and the time taken to re-open roads (response). The survey results suggest that society places a significantly higher value on the cost of unplanned and unexpected delays than that associated with expected delays.

The views of road management and emergency management sectors on the performance expectations for roads in natural hazards are highly variable. Although all sectors were averse to risking lives, the emergency managers see a clear link between potential indirect loss of life and unavailability of road access for emergency services. The civil defence sector placed a high importance on road access for emergency services and lifeline operators, and emphasised the need for proactive mitigation work. The SH managers consider that the risks to road networks are well managed to the extent possible within budgetary constraints. The local authority road asset managers view the wider social and economic impact on the community as a major factor that needs to be considered. The differences in views identified by the questionnaire and survey highlight the need for more engagement between the various sectors to facilitate an approach to risk management that meets the needs of the community.

Funding was identified as a key issue in encouraging and enabling proactive risk management for road networks. Funding agencies need to be part of the engagement between the sectors to ensure that the need for funding and constraints are well understood and taken into consideration.

12.3 Key factors

Safety of life, disruption, road access for emergency services and lifeline utilities, community expectations, availability of alternative routes, and the broader socio-economic impacts are key factors that need to be considered in deciding the level of performance of the roads in hazard events. The constraints of mitigation costs, availability of resources and skills, the suddenness of the event, feasibility of mitigation, the effects of other lifelines, and public perception should also be recognised in setting performance levels.

12.4 Setting performance levels

Each local road network or regional network would need to develop performance levels that are consistent with the particular network's vulnerabilities, constraints and community needs. The framework for setting performance levels developed in this research provides flexibility in its approach. It comprises:

- setting broad level performance measures for the network by assessing the factors and constraints discussed,
- a detailed review and setting levels of service for the various links that form the network, and
- building the performance measures and levels of service into asset and emergency response plans.

The detailed review would comprise:

- assessment of the risks from natural hazards to the road network,
- determination of the ability of the network's road links to meet the broad level performance measures,
- consideration of the wider network,
- consultation with other RCAs, and
- consideration of mitigation work required.

The proposed resilience states of *damage*, *availability* and *outage* provide a means of assessing the resilience of a road link. The resilience states would also help to compare the current resilience expected in hazard events against the performance expectations for the road link in that network. This would facilitate identification of the existing *resilience gap*.

The pilot study for part of the Wellington Road network demonstrates that the proposed framework provides a useful and practical way of setting performance levels for a road network.

13. Recommendations

We make the following recommendations based on the outcomes from the research:

- Land Transport New Zealand should promote this research widely to the RCAs and emergency sectors.
- Increased and more meaningful engagement should take place between the road management, emergency management sectors and other lifeline utility operators through the newly established CDEMG, with a view to develop a common understanding as to the levels of performance of roads in natural hazard events and to work towards resilient road networks (and eventually communities).
- Land Transport New Zealand, as the funding agency, should take a more proactive role and increase participation in the cross-sector deliberations with a view to aligning their funding programmes to achieve resilient road networks.
- RCAs should work together to understand the risks and the existing level of resilience, and to develop performance levels for various links in their road networks, using the approach developed in this research.
- The performance levels should be built into road asset management and emergency management plans, and a proactive strategy should be put in place, including actions to be taken in order to achieve the target performance levels through maintenance, new capital infrastructure and other mitigation works. Appropriate finances should be provided for this objective.
- Land Transport New Zealand should promote a regional project to assess the risks to the road network, to develop performance levels using the approach developed in Parts I, II and III of this research, and to develop a co-operative programme of mitigation, funding and management measures to improve the resilience of the road networks and other lifelines. This would serve as an example to the rest of the country.

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Appendix A Responses from consultation on risk management with key stakeholders

A1 Safety of life – summarised responses from key stakeholders.

A1.1 Describe your reaction if fatalities had resulted from the landslides along SH3 Manawatu Gorge following the February 2004 storms?

Table A1 Key stakeholder responses in reaction to hypothetical fatalities resulting from the Manawatu Gorge landslides.

Organisation	Range of comments from each organisation (summarised)
Transit/Transfund	Unacceptable. Deeply concerned. If death had resulted Transit would be under inquiry. Fatalities in these circumstances are a fact of life.
Local authorities – roading and infrastructure managers	Unacceptable. Not good. Not totally unacceptable. Need to expect that risk is everywhere. Not good; safety is the first priority.
Local authority, MCDEM and lifelines managers	Not unacceptable, as safety of people is first priority. Not unacceptable. Unacceptable if RCA allowed traffic to continue and death resulted. If a fatality had resulted, public reaction would turn this into a major event.

A1.2 If the Manawatu Gorge scenario resulted in the deaths of 10 people, what would be an acceptable return period?

Table A2 Responses from key stakeholders about the acceptable return period for 10 fatalities caused by the Manawatu Gorge scenario.

Organisation	Range of comments from each organisation
Transit/Transfund	1in 100 years. 1 in 20–25 years. 1 in 100–500 years.
Local authorities – roading and infrastructure managers	1 in 50–100 years. 1 in 20–25 years. 1 in 200 years.
Local authority, MCDEM and lifelines emergency managers	1 in 50–100 years. 1 in 100 years.

A1.3 If the Manawatu Gorge scenario resulted in the deaths of 100 people, what would be an acceptable return period?

Table A3 Responses from key stakeholders about the acceptable return period for 100 deaths resulting from the Manawatu Gorge scenario.

Organisation	Range of comments from each organisation
Transit/Transfund	Never. Not acceptable. 1 in 500 years. 1 in 100 years. 1 in 500+ years.
Local authorities – roading and infrastructure managers	1 in 100 years. 1 in 200 years. 1 in 500 years. 1 in 1000 years.
Local authority, MCDEM and lifelines emergency managers	1 in 300–400 years. Unacceptable. Not acceptable.

A1.4 How do you feel risks of injury from rockfall are being managed (e.g. Nevis Bluff)?

Table A4 Responses of key stakeholders regarding managing risks of injury from rockfall.

Organisation	Range of comments from each organisation
Transit/Transfund	Well, as fatalities from rockfall are low. Not well because of financial limitations. Yes, several examples where mitigation work has been done.
Local Authorities – roading and infrastructure managers	Yes. Yes, where risks are known. Not managed adequately; more precautions required.
Local authority, MCDEM and lifelines emergency managers	Managed adequately where resources are available. Not managed well compared to international standards.

A1.5 If isolated rockfall resulted in one fatality along a road link what would be an acceptable return period?

Table A5 Responses of key stakeholders regarding return frequencies of one fatality resulting from isolated rockfall.

Organisation	Range of comments from each organisation
Transit/Transfund	1 in 20 years. 1 in 50 years.
Local Authorities – roading and infrastructure managers	1 in 5 years. 1 in 10–20 years. 1 in 50 years. 1 in 100 years.
Local authority, MCDEM and lifelines emergency managers	1 in 10 years. 1 in 50 years. 1 in 100 years. No death is acceptable.

A1.6 If isolated rockfall resulted in five fatalities along a road link, what would be an acceptable return period?

Table A6 Responses of key stakeholders regarding return frequencies of five fatalities resulting from isolated rockfall.

Organisation	Range of comments from each organisation
Transit/Transfund	1 in 50 years. 1 in 75 years. 1 in 100 years.
Local authorities – roading and infrastructure managers	1 in 10 years. 1 in 50 years. 1 in 100 years. 1 in 200 years.
Local authority, MCDEM and lifelines emergency managers	1 in 10 years. Greater than 1 in 50 years. Unacceptable.

A1.7 How do you feel about an RCA being made liable for failing to manage natural hazard risks to the road network?

Table A7 Responses from key stakeholders as to whether RCAs should be held liable for failing to manage natural hazard risks.

Organisation	Range of responses from each organisation
Transit/Transfund	Not fair if funding not available. Not fair unless negligence was shown. Fair enough.
Local authorities –roading and infrastructure managers	Not fair unless RCA found wanting. RCA should be liable if risks are known. Not acceptable.
Local authority, MCDEM and lifelines emergency managers	Should be liable for level of performance specified. Depends on circumstances; there should be some degree of accountability. Justified if RCA disregarded information on known hazards.

A1.8 What do you think RCAs should be doing to manage their exposure to liability?

Table A8 Responses from key stakeholders as to what RCAs should be doing to avoid liability.

Organisation	Range of comments from each organisation
Transit/Transfund	Identify key vulnerabilities. Establish rational process to assess key vulnerabilities and assess risks. Need to have auditing process in place to show how decisions are reached and why network is managed in the way it is. Have appropriate processes and AMPs in place based on risk exposure.
Local authorities – roading and infrastructure managers	Good knowledge of assets. Identify risks. Establish AMPs to manage risks. Regular monitoring to ensure risks are managed in accordance with the AMP. Should be fully aware of their assets and the associated risks. Comprehensive asset management plans.
Local Authority, MCDEM and lifelines emergency managers	Sound corporate governance. Hedging risk with insurance, mitigation etc. Consider consequences of exposure. Risk analysis should include exposure to liability. Identify, analyse, determine consequences and act.

A2 Summarised responses of key stakeholders regarding disruption

A2.1 What is your reaction to an important road link like SH3 Manawatu Gorge being closed for almost three months following the February 2004 storm events?

Table A9 Road stakeholder reactions to important road links like SH3 Manawatu Gorge being closed for almost three months.

Organisation	Range of comments from each organisation
Transit/Transfund	Not acceptable but tolerable. Embarrassing not to provide 100% availability. Disastrous. Massive work involved for Transit during road closure. Not unduly concerned as there were alternative routes.
Local authorities- roading and infrastructure managers	Unhappy; huge impact. Created problems, greater burden on local authority roads. Not OK. National strategy required. Over 2 months too long.
Local authority, MCDEM and lifelines emergency managers	Unacceptable. Major economic impact; however should expect this to happen in this geology. Not unacceptable; quite normal for this route. It has a known performance category of its own. Unavoidable. Acceptable given scale and having two alternative routes. Triple redundancy good.

A2.2 What is an acceptable road closure period for this scenario if it occurs at a frequency of 25 years?

Table A10 Road closure periods found acceptable by road stakeholders for events with 25-year frequency.

Organisation	Range of comments from each organisation
Transit/Transfund	Major closure every 20–25 years OK. Three–four weeks max. Depends on location and traffic volume. Three–six months, given that Saddle and Pahiatua were available. One month max.
Local Authorities – roading and infrastructure managers	One week. Two months. Three–four days, provided an alternative route exists. Within 1 week
Local authority, MCDEM and lifelines emergency managers	One week maximum. Two months OK as triple redundancy. Two months not OK for 25 return period. Up to one week.

A2.3 What is an acceptable road closure period for this scenario if it occurs at a frequency of 10 years?

Table A11 Acceptable road closure period for Manawatu Gorge type scenarios with a 10 year frequency period.

Organisation	Range of comments from each organisation
Transit/Transfund	Two days. One week too long. Two weeks. One–two weeks. Two–three 2-3 months assuming alternatives. One–two weeks if no alternatives (if no alternative routes, then tenfold reduction in delay).
Local authorities – roading and infrastructure managers	One day. One month. Two–three days, provided an alternative route exists. Within one week.
Local authority, MCDEM and lifelines emergency managers	Three–four days. Less acceptable. Public reaction would force shorter delays. Up to one week. Within hours.

A2.4 What is an acceptable road closure period for this scenario if it occurs at a frequency of 50 years?

Table A12 Acceptable road closure length times for a Manawatu Gorge type scenario with a frequency of 50 years, according to road stakeholders.

Organisation	Range of comments from each organisation
Transit/Transfund	One week. One–two months. Two months. One–two weeks. Six months to 1 year assuming alternatives.
Local Authorities – roading and infrastructure managers	Three weeks. One month. Two–three days provided an alternative route exists.
Local authority, MCDEM and lifelines emergency managers	Two–three weeks.

A2.5 With the benefit of the SH3 Manawatu Gorge experience, what could be done to minimise disruption ?

Table A13 Road stakeholders' opinions as to how disruption could be minimised, using experience from the SH3 Manawatu Gorge closure.

Organisation	Range of comments from each organisation
Transit/Transfund	Provide and improve level of service of alternative routes. Better study of the risks. Mitigation. Work with local authorities to look at alternative routes in high risk areas. Not much in this particular situation.
Local Authorities –roading and infrastructure managers	Upgrade and secure alternative routes. Consider the network as a whole. Provide alternative routes. Adopt regional level strategies. Depends on alternative routes and level of redundancy.
Local authority, MCDEM and lifelines emergency managers	Mitigation work including alternative routes. Alternative routes. Adequate routes. Adequate maintenance. Strengthen alternative routes. For this particular scenario, nothing, given topography and money available.

A2.6 How do you feel about a road closure between 1 day and 1 week for a major strategic route with no alternative routes?

Table A14 Road stakeholder opinions as to whether a major strategic route (with no alternatives) should be closed for one week to one day.

Organisation	Range of comments from each organisation
Transit/Transfund	Unacceptable. Level of service provided not acceptable for that volume of traffic. Learnt from flooding in 1977. We try to minimise effects with proper drainage. One day is OK but 1 week is unacceptable.
Local authorities –roading and infrastructure managers	One day acceptable, one week unacceptable. One day OK; 4–5 days unacceptable. One day too long; one week totally unacceptable.
Local authority, MCDEM and lifelines emergency managers	One day acceptable. Without redundancy, unacceptable. I would ask why. One day verging on unacceptable; one week totally unacceptable. One week less acceptable.

A3 Summarised responses of key stakeholders regarding lifelines

A3.1 Describe your reaction to the loss of lifeline routes in and out of the city from a seismic event like the one described in Scenario Three?

Table A15 Road stakeholder reactions to loss of lifeline routes in and out of a city in an earthquake like that described in Scenario Three.

Organisation	Range of comments from each organisation
Transit/Transfund	Must have contingency plans. SH management plans for emergencies. Responses that people can manage. We are prone to this event. High probability that it will happen. OK, as we live with this risk. Provide appropriate level of protection which society can afford.
Local Authorities – roading and infrastructure managers	Important because of broader social and community issues. Essential and should not be considered in terms of economics. Important for recovery. Lifeline very important. A lot can be done to prepare lifelines.
Local authority, MCDEM and lifelines emergency managers	Not unacceptable because it is not preventable. Need to know if RCA took all steps and precautions and did they invest appropriately. Major priority. Air rescue cannot be applied indefinitely. Communities come to a halt. Disappointed that the asset managers in some sectors have been unable or unwilling to co-operate in planning for this event. Cross-sector dependencies need to be assessed. Important. Key routes must be opened to respond and recover.

A3.2 Using Scenario Three as an example, what is your reaction to the loss of road access into the city for emergency services such as ambulance, fire and police?

Table A16 Road stakeholder reactions to the loss of road access foremergency services such as fire, police and ambulance in an earthquake like that described in Scenario Three.

Organisation	Range of comments from each organisation
Transit/Transfund	Depends on other options (sea and air); roads may not be important. Our roads will need to open in a natural hazard event. Plan that a hierarchy of roads will be in place. Very high priority. Needs roads cleared for emergency services. Important. Key lifelines must be recognised and prioritised. Would rely on air ambulance (6–8 within 1.5 hours).
Local authorities – roading and infrastructure managers	Unacceptable. Essential for survival. Routes to save lives more important than property. Roads to emergency services very important. Road access is crucial. Helicopter rescue is limited.
Local authority, MCDEM and lifelines emergency managers	Road access most important immediately following event. Links essential to hospitals. Cannot restore utilities without road access. Safety depends on access. Alternative routes are important. Decentralised health services are better. If WCC had not identified key routes, that would be unacceptable. If key routes have been identified then we would expect other issues to be explored. What if key route is lined with EQ* prone buildings? Not ideal. Need to consider air rescue. Identify key roads to hospitals and other emergency services beforehand.

*EQ: earthquake

A3.3 If Scenario Three has a low frequency of 500 years, within what period of time should road access for emergency services be restored?

Table A17 Speed of restoring road access for emergency services after a Scenario Three–type earthquake with a return frequency of 500 years, according to road stakeholders.

Organisation	Range of comments from each organisation
Transit/Transfund	Can't say, as it depends on sea and air. As fast as possible. We would use air services and not rely too much on roads. Roads will be cleared as fast as possible. More than one day but <1 week. Within three days.
Local authorities – roading and infrastructure managers	One day for emergency services. Three days for normal access. Three–five days. Air service would be used for first three days. Realistically, a couple of weeks. Opening roads within hours is unrealistic.
Local authority, MCDEM and lifelines emergency managers	Within three days. First three days are critical for life. Immediately for safety of life. Access within days as opposed to weeks. Three days too long. Within 24 hours for life. Need to think about what performance levels to set. Days are acceptable; weeks are not. Must be <24 hours. Under CDEM Act, people are expected to survive for 72 hours.

A3.4 If Scenario Three has a higher frequency of 50–100 years, what would be an acceptable period of time for road access to emergency services to be restored?

Table A18 Acceptable time taken to restore road access for emergency services in a Scenario Three–type earthquake with a frequency of 50–100 years, according to road stakeholders.

Organisation	Range of comments from each organisation
Transit/Transfund	Same as above (Table A17)
Local authorities – roading and infrastructure managers	Within hours. Three–five days. Days or weeks. Within one week
Local authority, MCDEM and lifelines emergency managers	Within three days. No difference to above (Table A17). Should be tying frequency of event to life not time. Fifty to 100 years is totally unacceptable. Reduction measures would have to be made.

A3.5 Scenario Three describes severe consequences as a result of the loss of key lifelines providing access in and out of the city? How do you feel this risk is being managed? Proactively? Reactively?

Table A19 Road stakeholder beliefs regarding proactive or reactive risk management for emergency service road access in a Scenario Three–type earthquake.

Organisation	Range of comments from each organisation
Transit/Transfund	Bit of both. Roading sector is now starting to move on this. Full impact of CDEM not felt yet. Proactively. We work with local authorities in lifeline activities. Bridges have been focused on. We have contingency plans for detours. Proactively. Very good work being done by lifeline groups. Opportunity with CDEM Act to organise this better.
Local authorities – roading and infrastructure managers	Reactively. Still a lot of work to be done. However, some examples of proactive management. Proactively. Most councils have identified roads as lifelines and prioritised these. Reactively. Only managed for normal use. Managed reactively but should be proactively. Proactively but on a small scale. Hard to manage.
Local authority, MCDEM and lifelines emergency managers	Proactively. There are examples of mitigation work being done. Management adequate. Proactively in terms of Land Transport Emergency Sub-group (how well? Not sure). A function of the scale of degree of difficulty. Christchurch and Auckland do not have degree of difficulty. The harder it is, the harder to get started. Towards reactively. Must be realistic of levels of risks. Some work done at proactive end. CDEM Act will assist in proactive approach.

A3.6 The CDEM Act 2002 describes new requirements for RCAs in terms of natural hazards. What do you consider you would need to do under this Act?

Table A20 Actions that road stakeholders consider necessary for RCAs to meet the CDEM Act.

Organisation	Range of comments from each organisation
Transit/Transfund	Lifelines meetings. Identify major routes and major hazards. Awareness of communication channels. Transit is checking all initiatives in place and audit against CDEM Act. Awareness of risks and have adequate procedures in place. Flexible depending on severity. Processes in place to respond to event. Have appropriate plans in place. Establish plans with key partners. Participate with City Councils. Communications set up with consultants and consultants with contractors. Respond to Civil Defence controller. Build requirements into contracts. Have consultants in place to assess hazards after event.
Local authorities – roading and infrastructure managers	Not sure. Planning collectively for reopening roads. Recognising interdependencies of other utilities. Identify lifelines, assess their criticality and consider alternative routes. Actively participate in lifeline projects. Need a methodology to be applied within regional council. Linkage of national utility to regional level. Identify key routes; identify key resource provisions. Involvement in lifelines.
Local authority, MCDEM and lifelines emergency managers	Identify risks and vulnerable areas; mitigate risks. Collective planning to formulate road access plan. Continuity planning so business can continue in its own right. Working with other RCAs in own sector. Resolving inter-sector interdependencies. Continue to operate under an emergency. Produce a list of things to do and operate to best of ability. Understand your infrastructure's exposure to risk. Interact with other groups. Come up with more comprehensive plans than in AMP. RCAs should go through systematic process. Set criteria and follow it through. Review policy relative to 'four Rs'* in the light of the intent of Act. Expectation that RCAs and lifelines review planning. Safer communities through comprehensive emergency plans.

* The four Rs are: Reduction, Readiness, Response and Recovery.

A4 Cost: summarised responses of key stakeholders

A4.1 How do you feel about the cost to repair the road following a natural hazard event, using Scenario One (SH3 Manawatu Gorge - $5M) as an example? Are the high costs justifiable? Why?

Table A21 Road stakeholder responses as to whether it was justifiable to spend $5M to fix the road after Scenario Option (Manawatu Gorge closure).

Organisation	Range of comments from each organisation
Transit/Transfund	Acceptable. Unavoidable because of magnitude. Yes, given risk mitigation cost ($70M). Not much choice. Reactive not suitable if big difference in cost to mitigate v.cost to repair. Need to assess risk. Reactive approach may be OK. Case for moving to proactive approach. Sometimes mitigation not possible. Nothing that could be done at reasonable cost.
Local authorities – roading and infrastructure managers	Yes, due to low frequency. Not large in terms of national expenditure. Costs are justifiable. Intergenerational costings. Have to accept. Manage as best you can. Need to subject it to a risk analysis. OK to an extent. Proactive better. We tend to forget about previous experiences. In this situation, reactive more cost effective. Need to do risk analysis before adopting a mitigation approach.
Local authority, MCDEM and lifelines emergency managers	Unavoidable. Yes, but earlier risk analysis should have been done. No adverse reaction to cost. Preventative work could be done to reduce costs. Mitigation, mitigation, mitigation. Sometimes not cost effective to mitigate. Mitigation. B/C for big event. Mitigation against big one would help eliminate the smaller events. Reduction and readiness important. No choice about response.

A4.2 At what frequency would a reactive approach be acceptable?

Table A22 Frequency of events that should (according to road stakeholders) be managed reactively.

Organisation	Range of comments from each organisation
Transit/Transfund	One in 10–20 years. One in 50 years. Should do an economic analysis to determine. One in 10 years. Proactive approach OK, provided within reasonable cost.
Local authorities – roading and infrastructure managers	Depends on cost. Depends on consequences. One in 100 years. One in 50 years. One in 50 years. One in 5–10 years.
Local authority, MCDEM and lifelines emergency managers	One in 25–50 years. Should be related to risk to life, not frequency. Not acceptable at all. All maximum credible scenarios should be taken into account. One in 50 years and above.

A4.3 How do you feel about mitigating risks of this nature using a proactive approach (i.e. spending more money up front to minimise peak expenditures)?

Table A23 Acceptability of proactive approach for mitigating risks of a Manawatu Gorge–type scenario, according to road stakeholders.

Organisation	Range of comments from each organisation
Transit/Transfund	Support. Support it when it can be shown that the return is better. We are doing this in preventative maintenance. Proactive approach will not help eliminate those peaks. Spend more on being proactive & understanding the big risks.
Local authorities – roading and infrastructure managers	Agree. We call it preventive maintenance. There is merit in this approach. Need to consider costs and risk. Saddle Road bridge is a good example where bridge was taken out in flood because of scour of bridge piers. Cost to replace: $4M. Cost to repair (deeper bridge piers): $70,000. Also, reactive approach in the form of emergency repairs is often not done to as good a standard as under normal conditions. Positive. Need to minimise peaks. Depends on outcome of risk analysis.
Local authority, MCDEM and lifelines emergency managers	Proactive mitigation as a preference to all others. Important because costs will be reduced in other areas, e.g. growth in employment and improvements among lower socio-economic groups. Hazard mitigation is what we are all about. Agree.

A4.4 Using a proactive mitigation approach what do you feel should be the balance between benefits and cost?

Table A24 Ideal balance between benefits and costs when using a proactive mitigation approach.

Organisation	Range of comments from each organisation
Transit/Transfund	Reduction in indirect costs (social costs). B/C of 4 (includes wider costs). Give consideration to B/C but need to consider other factors (in-tangibles, etc. – refer to new Land Transport Management Act). B/C >1. Safeguarding existing network is important. Minimum of 2 takes into account all economic benefits. [Consultants] say 2.5.
Local authorities – roading and infrastructure managers	B/C = 1 (not including benefit to community). More than 3, including benefit to community. B/C approach is not appropriate as it does not consider wider (social and community) benefits. Same B/C as for other work. Coming back to B/C of 2. Includes wider costs. B/C >1
Local authority, MCDEM and lifelines emergency managers	B/C must include socio-economic as well as traditional engineering and finance. Would like to see modifier in B/C approach for extreme events. Two benefits to one cost. Not too clear on benefits in terms of costs. B/C >1, maybe 2–3 (includes economic benefits).

A5 Key road stakeholder responses regarding public reaction

A5.1 How important is public reaction to the consequences of events like road closures, casualties and loss of access for emergency services?

Table A25 The importance placed on public reaction to consequences like road closures by road stakeholders.

Organisation	Range of comments from each organisation
Transit/Transfund	Not too important. Pretty important, but need to rationalise importance. Important. Given consideration in everything we do. Important, especially if fatalities result.
Local authorities – roading and infrastructure managers	Very important. RCAs are trustees of these assets. Reasonably important. Political dimension. Very important. Try to avoid. People should be realistic of hazards. Average importance.
Local authority, MCDEM and lifelines emergency managers	Very important. Hugely important. Public perception is reality. Need to know how public reacts. Satisfying public demand can drive things in wrong order. Need to get PR right. Crucial. Public has high consequences. Important but not main driver. Very important to manage the outrage.

A5.2 How would you feel about adverse public reaction to the current reactive approach to low-frequency, high-cost events like those described in Scenarios One and Three?

Table A26 Road stakeholder opinions of adverse public reaction to low-frequency, high-cost events being managed reactively.

Organisation	Range of comments from each organisation
Transit/Transfund	Public concerned about issues they perceive. Accept we will get it, but need to respond in a proactive way. Need to manage public reaction. Be up-front. Do not like negative public reaction. Need responsive approach. Need to show empathy to issues.
Local authorities – roading and infrastructure managers	Have to accept adverse public reaction. Public reaction is capturing views which need to be considered. Do not want adverse public reaction. People should be realistic.
Local authority, MCDEM and lifelines emergency managers	Need to make public feel safe and confident. Public needs to feel something is being done. Need to redirect adverse public reaction into something constructive. Is justified and healthy as it makes organisations realise importance of high consequence events. Unfair. Public don't realise. In their minds, they have service level expectations. Will always get it, but needs to be skilfully managed.

A5.3 How do you feel about the current level of information provided to the public following a natural hazard event?

Table A27 Road stakeholder opinions regarding the current level of information provided to the public in a natural hazard event.

Organisation	Range of comments from each organisation
Transit/Transfund	Could be better. Working on 0800/Web. Would like to do more. We have remote message signs, arrangements with army to deal with safety issues following Desert Road closures. Reasonably good. Good, e.g. Transit had a feature article in the Manawatu Standard. We can demonstrate we have programmes to manage rivers which cause aggradations.
Local Authorities – roading and infrastructure managers	More could be done. Public not made aware of risks. OK, but a bit intermittent. Periodic press releases. Not bad. Pockets of areas not informed. AA not very timely.
Local authority, MCDEM and lifelines emergency managers	Not bad. Important to keep public informed. Media can give wrong impression. However, this scenario was an example where poor info was provided. Radio station was not manned. Non-verified information was broadcasted. Reasonable but could be better. Manawatu demonstrated good level of info. Needs addressing. Better coordination. People need to know what agency to seek. Coordinated info required. Info fragmented.

A5.4 Scenario Four illustrates loss of access for rural communities. How do you feel about rural public reaction to loss of access to their homes?

Table A28 Road stakeholder opinions about reactions from the rural public regarding loss of access to their homes in Scenario Four.

Organisation	Range of comments from each organisation
Transit/Transfund	Rural community very important. Very important. Rural community very dependent on SH access, e.g. West Coast. Rural communities important. However, low volume; less priority. Not as much as urban community. More self sustaining and resilient. Public reaction is still important. Regrettable but different level to urban areas. Different levels of expectations.
Local authorities – roading and infrastructure managers	Rural community very important. Rural communities should be more resilient. Rural community is important but also very tolerant. More accepting of economic argument not to fix roads. Public need to accept. Public less accepting of closures than in the past. Roads are very important to rural people. Women come into towns to work. Lifestylers less tolerant to road closures. Rural communities more important as they have less support.
Local authority, MCDEM and lifelines emergency managers	Rural community very important. They provide livelihood of urban people. Small core of farmers making lots of noise. Rural community seen as more realistic. However, this is changing and not correct anymore. Farmers more dependent on services. Accept longer closure for remote rural areas than for key transport links. Rural communities tend to be stocked up with supplies. Lower traffic volumes. Spread resources to priority areas.

Appendix B Resilience states

Table B1 Damage states and levels: possible definitions.

Damage level	Damage state	Damage description
1	Slight	Only slight damage that requires routine maintenance.
2	Light	Minor damage requiring a clean-up of small slips (a few cubic metres) and debris and repairs to culverts.
3	Moderate	Moderate damage requiring removal of a moderate volume of slip debris (tens of cubic metres), small scale repairs to underslips (walls less than 2 m high) and minor repairs to walls, culverts and other structures.
4	Severe	Severe damage requiring removal of large volumes of slip materials (hundreds of cubic metres), stabilisation, significant structures to repair underslips, major repairs to walls and replacement of culverts and other structures.
5	Extensive	Extensive damage requiring removal of major volumes of landslide debris, stabilisation and large structures to repair underslips and damages to walls and other structures.

Table B2 Availability states nd levels: possible definitions.

Availability level	Availability state	Availability description
1	Full	Full access, except conditions may require care.
2	Poor	Available for slow access, but difficult for normal vehicles because of partial lane blockages, erosion or deformation.
3	Single lane	Single-lane access only with difficulty caused by poor condition of remaining road.
4	Difficult	Single-lane road accessible by 4x4 off-road vehicles only.
5	Closed	Road closed and unavailable for use.

Table B3 Outage states and levels: possible definitions.

Outage level	Outage state	Damage description
1	Open	No closure, except for maintenance.
2	Minor	Condition persists for up to 12 hours.
3	Moderate	Condition persists for 12 hrs to 3 days.
4	Severe	Condition persists for 3 days to 21 days.
5	Long term	Condition persists for >3 weeks.

Table B4 Disruption levels and equivalent disruption states.

Disruption level	Disruption state
1	Slight
2	Limited
3	Moderate
4	Severe
5	Extensive

Table B5 Disruption states derived from outage states and levels, and availability states and levels.

Disruption state			Outage state & level				
			Open	Minor	Moderate	Severe	Long term
			1	2	3	4	5
Availability state & level	Full	1					
	Poor	2	Slight	Slight	Limited	Limited	Limited
	Single lane	3	Slight	Limited	Moderate	Moderate	Severe
	Difficult	4		Limited	Moderate	Severe	Severe
	Closed	5		Moderate	Severe	Extensive	Extensive

Appendix C Abbreviations

AA: Automobile Association

AADT: Annual Average Daily Traffic

AMP: Asset Management Plan

AS/NZS: Australian and New Zealand Standard

B/C: Benefit to Cost ratio

CBD: Central Business District

CDEM: Civil Defence and Emergency Management

CDEMG: Civil Defence and Emergency Management Groups

CMA: Calcium Magnesium Acetate

DHB: District Health Board

EQ: Earthquake

GIS: Geographical Information System

LGA: Local Government Act

LRFD: Load Resistance Factor Design

LTCCP: Long Term Community Council Plan

MCDEM: Ministry of Civil Defence and Emergency Management

MCE: Maximum Credible Event

NZRTA: New Zealand Road Transport Association

RCA: Road Controlling Authority

SH: State Highway

WCC: Wellington City Council

Natural Hazard Road Risk Management Part III: Performance Criteria

Land Transport New Zealand
Research Report 296