Fire Research Report

Fire following earthquake: Identifying key issues for New Zealand

Wellington Lifelines Group

October 2002

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The aim of this specific study is to develop a comprehensive framework that will assist in the co-ordination of research on fire following earthquake in New Zealand. The project objective is to put fire following earthquake in context for the many organisations involved in managing this risk.

A multi-agency Project Focus Group was established by the Wellington Lifelines Group to provide input and overview for this project. Members of this group included representatives from the NZ Fire Service, local and national emergency management agencies, national utilities and research organisations.

Systematic application of the risk management steps defined in the Australian and New Zealand Risk Management Standard AS/NZS 4360 during this study highlighted a number of gaps in the consideration of the risk posed by fires following earthquake.

It is recommended that in the short term, further consideration be given to promoting low-cost risk reduction measures that can be directly undertaken, and such measures are discussed. In the medium term, it is recommended that a multi-agency strategy for addressing fire following earthquake must be developed at regional level.

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Fire Following Earthquake:

Identifying Key Issues for New Zealand

Report on a Project Undertaken for the New Zealand Fire Service Contestable Research Fund

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Fire Following Earthquake: Identifying Key Issues for New Zealand

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This document was completed in October 2001 and submitted to the New Zealand Fire Service for review.

Fire Following Earthquake: Identifying Key Issues for New Zealand

Executive Summary

Fire Following Earthquake is a complex subject, involving many sequential and situational components. Much of the research work carried out to date has focused on the development of analytical models which capture these components, and more recently creating linkages with GIS packages.

The aim of this specific project has been to develop a comprehensive framework that will assist in the co-ordination of research on fire following earthquake in New Zealand. The project objective is to put fire following earthquake in context for the many organisations involved in managing this risk.

Project Process

A multi-agency Project Focus Group was established by the Wellington Lifelines Group to provide input and overview for this project. Members of this group included representatives from the NZ Fire Service, local and national emergency management agencies, national utilities and research organisations.

The project process involved the following key steps:

- Undertaking a high-level review of recent NZ work and relevant overseas research, including earthquake reconnaissance reports
- Convening meetings of the Project Focus Group to work through the key risk management steps from AS/ NZS 4360. Emphasis was placed on (i) establishing the context of fire following earthquake in general, and in the NZ context in particular, (ii) identifying the risk components and (iii) reviewing the effectiveness of the currently identified risk treatment options
- Forming a view on the short, medium and long term research needs in this area

The risk components of fire following earthquake have been analysed and summarised in an event sequence, under the following element headings:

1. Earthquake effects
2. Ignition sources
3. Establishment of fire
4. Spread of fire
5. Detection/ containment/ extinguishment

Summary of Findings

Systematic application of the risk management steps defined in the Australian and New Zealand Risk Management Standard AS/NZS 4360 during this project has highlighted a number of gaps in the consideration of the risk posed by fires following earthquake. These include:

- The ***context*** of fire following earthquake has not been fully established
  - The primary *hazard context* is that of fire, with earthquake being the indirect initiator. Earthquake itself is a low probability but high consequence event that is difficult to plan for. Fire conflagrations can develop from situations other than earthquake, although both local and international experience confirms that earthquake is a major initiator of large-scale urban fires.
  - The *organisational context* is that fire following earthquake is a multi-agency risk because of the complexity of the factors involved. Accordingly, it should not be regarded as only being the responsibility of the Fire Service.

- Although most of the research work in this area has focused on the ***assessment*** step, as yet there are no tools with which to undertake a high-level evaluation of the level of risk at a regional level
  - While comprehensive models have been developed, they largely rely upon empirical relationships that are specific to local areas in terms of the structural and fire resistance characteristics of the built environment.
  - These detailed models are not particularly effective in establishing the broader regional (or national) overview of whether fire following earthquake is a significant risk that warrants active management

- Risk ***evaluation*** criteria for fire following earthquake have yet to be established.
  - Such criteria will be influenced by
    - more empirical data on the fire following earthquake threat
    - the perception of the emergency management community
    - the perception of the general public and business
    - legal (statutory) requirements
  - Applying the qualitative risk rating procedure contained in the NZFS Community Risk Management Framework, which takes into account likelihood and consequence, generates an overall risk rating for fire following earthquake of <u>*significant*</u>.

- Risk ***treatment*** processes for fire following earthquake are essentially non-existent.
  - Building regulations do not consider fire as a concurrent hazard with earthquake
  - Very few examples of integrated response procedures by utility organisations and the Fire Service are in evidence

- ***Communication and consultation*** processes for fire following earthquake have been limited in comparison to other hazards
  - It is considered that if fire following earthquake was treated more directly as a fire-related hazard, more appropriate perceptions and greater involvement in risk reduction processes would result
  - If for whatever reason Fire Service teams are unable to meet their response performance requirements for a significant urban fire, this could replicate many aspects of a fire following earthquake scenario

The key issue is understanding the circumstances and factors that can transform isolated individual fires into full conflagrations. The two dominant questions at a regional level are:

1. The extent to which fires would become established after earthquakes; and
2. The extent to which those fires which did become established would spread

Key factors are *building density*, *type of construction, effectiveness of boundary barriers* and *wind conditions and topography*. It is noted that current and recent building regulations and codes in New Zealand are predicated on a rapid response from the Fire Service. The current New Zealand Building Code also places emphasis on early detection and active suppression. Accordingly, limited passive protection is required in most new ordinary fire hazard buildings in New Zealand. The combination of variable wind conditions in conjunction with the steep, gorse-laden hillsides in some urban areas of New Zealand also requires specific consideration.

The broader risk context for New Zealand is that this country has not had a significant earthquake affecting a major urban area since the 1931 Napier earthquake, which itself featured extensive fires. As a consequence, there is a lack of familiarity with large-scale emergency response processes in general, and specifically in dealing with fires following earthquakes.

Despite the high level of awareness of earthquake hazards, the ‘additional’ hazard for fire following earthquake has not been subject to any form of structured approach. If research is to continue in this field, a more structured approach would appear warranted.

It is concluded that in the first instance, fire following earthquake should be addressed by the relevant elements of the *emergency management community* as internal stakeholders, comprising:

- NZ Fire Service
- Local authorities (emergency management, water supply management, regulatory)
- Other utility organisations
- Research and hazard information providers

Other stakeholders that have an interest in seeing this risk addressed include:

- The insurance industry
- Building owners and/or managers
- Environmental and community planners
- The general public

Recommendations

As a result of this research project, recommendations are made under the headings of (i) *short-term mitigation actions*, (ii) *medium-term planning processes* and (iii) *further research activities*.

Short-term Mitigation Actions

It is recommended that further consideration be given to promoting the low-cost risk reduction measures that can be directly undertaken, including:

- Emphasising seismic restraint of heavy and vulnerable items such as boilers, heating units, stoves and tanks and valve room alarm control panels in commercial, industrial and apartment buildings. This owner responsibility should be particularly highlighted in the case of new facilities.
- The installation of flexible connections in regions of high seismicity for electricity, gas and water mains at points of entry into new and upgraded buildings, and at key network junctions
- Developing integrated procedures for the post-earthquake shutting off and restoration/ reconnection of electricity and gas services

Consideration should be given to the risk factors associated with fire following earthquake at a regional level before decisions are made to install further automatic shut-off valves in major water supply reservoirs.

Medium-term Planning Processes

A strategy for addressing fire following earthquake must be a multi-agency one, and should be developed at regional level. The agencies involved should include:

- The New Zealand Fire Service
- Civil Defence and Emergency Management agencies
- Utility organisations (water, electricity and gas)
- Research and hazard information providers

A collaborative inter-agency approach similar in nature to the successful regionally-based Lifelines Groups would appear to be a suitable model. The most appropriate vehicle to facilitate this strategy should be the Civil Defence Emergency Management Groups to be formed under the new legislation. The initial focus should involve the agencies above giving consideration to the overall level of fire following earthquake risk in the region. If the risk is considered to be significant, medium-term risk reduction measures should be identified in addition to the short-term measures outlined above.

It is suggested that this programme would feed in to the Civil Defence Emergency Management Group planning process for regions to address. Since perceptions of the risk need to be changed, which is itself a long-term process, the outcome could take the form of a ten year plan. Other stakeholders, such as those mentioned earlier, would form part of this process.

It is also recommended that a framework for this regional approach should be developed at a national level. Piloting of the process in regions of different characteristics is also likely to prove beneficial. This could for example involve a region with a major metropolitan centre and a region with smaller cities and towns. Given the significant urban earthquake risk, prevailing winds and urban fire risk in Wellington, this in turn suggests that a pilot process should be set up in Wellington to identify high occupancy/ high risk communities.

Development of the Wellington City Council/ Geological & Nuclear Sciences GIS-based *City Aware* project model would be greatly informed from such a dialogue.

Further Research Activities

In keeping with the recommendations outlined above, the focus for future research is to establish whether the current passive New Zealand approach towards fire following earthquake is appropriate, or if a more pro-active approach should be taken.

It is recommended that a more detailed review of international earthquakes be undertaken to better understand why no conflagrations have occurred in more recent earthquakes. In particular, studies of earthquake-generated fires in the context of New Zealand's climate with significant prevailing winds should be conducted. Also there is a need to research the performance of modern plastic gas reticulation in permanent ground deformation situations. A scoping project on the performance of buried services in earthquakes is being co-ordinated by the National Lifelines Co-ordinating Committee.

Another research project identified is an extension of basic fire design research to look at the fire spread potential of high-rise CBD buildings in a post-earthquake situation. This could feature the same building design to the three significantly differing fire resistance design eras of pre-1965, 1965 to 1991 and post-91. Part of such a project could involve review of the pro-active building regulatory approach for fire following earthquake adopted by cities such as Vancouver.

Development of an education programme is recommended to increase understanding of the impacts and consequences, and to enable movement from short-term community awareness to long-term community resilience. Such a programme needs to have input from social and behavioural sciences.

It is considered that the adoption of a structured short- and medium-term operational planning process as recommended above will generate specifically focused research projects.

1. Introduction

1.1 Background

The threat posed by fire following earthquake has been highlighted by recent overseas earthquakes, notably Northridge, Los Angeles USA (1994), and Kobe, Japan (1995). Scenario studies of future large-scale earthquakes in San Francisco and Tokyo indicate that Fire Following Earthquake will be a major factor in subsequent property damage and lives lost.

Fire following earthquake is of concern to a range of organisations, particularly the emergency services, insurance and utility services sectors. Principal issues relate to identifying the key factors that lead to an appropriate accommodation of fire following earthquake in response management programmes. This includes identifying factors that cause fires to rapidly spread through earthquake-damaged areas, how to reduce the risk posed by this secondary impact, and how to plan to respond, particularly in the context of the design and use of reticulated water systems for fire suppression management.

Equally challenging is understanding why in the recent destructive earthquakes in Colombia, Greece, Turkey and Taiwan there were few widespread post-event fires, and no conflagration situations.

To date, however, only limited research has been undertaken with regard to fire following earthquake in New Zealand. Moreover, the research that has been conducted has not been the subject of a co-ordinated research programme.

1.2 Aims and Objectives

The aim of this project has been to develop a comprehensive framework that will assist to co-ordinate research on Fire Following Earthquake in New Zealand. The framework will apply a risk management approach by applying the basic steps recommended by the NZ/ Australian risk management standard NZS 4360: 1999.

The project objective is to put Fire Following Earthquake in context for the many organisations involved in managing this risk.

The following outcomes from this high-level process were sought:

1. Placing NZ-based research and associated activities in an appropriate context in order to highlight linkages, overlaps and gaps
2. A clearer indication of the principal risk factors for fire following earthquake in New Zealand and how the differences from (i) other countries and (ii) between regions within New Zealand can be established.

1.3 Project Methodology

A multi-agency Project Focus Group was established by the Wellington Lifelines Group to provide input and overview for this project. Members of this group were:

David Allen (Office of the Fire Marshal, Ontario; formerly Auckland City Council)

Neil Britton (Earthquake Disaster Mitigation Research Centre, National Research Institute for Earth Sciences and Disaster Prevention, Japan; formerly Ministry of Civil Defence and Emergency Management)

David Brunsdon (Wellington Lifelines Group)

Bill Butzbach (NZ Fire Service)

Jim Cousins (Institute of Geological and Nuclear Sciences)

Roger Crimp (Telecom NZ)

Jim Dance (NZ Fire Service)

The project process involved the following key steps:

- Undertaking an high-level review of recent NZ work and relevant overseas research, including earthquake reconnaissance reports
- Convening meetings of the Project Focus Group to work through the key risk management steps from AS/ NZS 4360. Emphasis was placed on (i) establishing the context of fire following earthquake in general, and in the New Zealand context in particular, (ii) identifying the risk components and (iii) reviewing the effectiveness of the currently identified risk treatment options
- Forming a view on the short, medium and long term research needs in this area

It should be noted that this project has been undertaken as a national activity, with the Wellington Lifelines Group being the organisation responsible for project co-ordination and delivery.

2. Review of Relevant Research and Associated Activities

2.1 International Research

Internationally, much of the early significant contextualising and analytical modelling of fire following earthquake has been led by Scawthorn. In conjunction with international colleagues he has developed models for post-earthquake fire hazard in urban regions that are applicable to both specific earthquakes and for determining annual expected losses on a probabilistic basis (*Scawthorn 1986, 1987, 1993*). Factors included in these models are building density, wind velocity, deterioration of fire-fighting response and seismic intensity. He has evaluated the fire impacts of a number of contemporary and historic earthquakes (*Scawthorn, 1997*).

Work by John Robertson of Vancouver City Council (*Robertson & Mehaffey, 2000*) has looked at how Fire Following Earthquake can be addressed through performance-based codes for building design. This work recommends that performance based building codes contain a framework to prevent undue reliance on sprinkler and other life safety systems that are dependent on seismically vulnerable water and electrical services. A two-level design procedure is proposed to be applied to the fire safety design of buildings located in areas of high seismicity. The first level is based on the design fire scenarios occurring under normal conditions with detection and suppression systems considered fully operable, along with fire service response within normal operational parameters. The second level design would be based on impaired lifelines services and fire service response following a major earthquake, with special fire factors being developed to reduce the design fire depending on the vulnerability of the building and its surrounding area to post-earthquake fire.

Recent work undertaken for the Pacific Earthquake Engineering Research (PEER) Center (*Williamson and Groner, 2000*) investigated the causes and impacts of fires following earthquakes from the perspective of natural gas and electricity distribution systems. Following the analysis of eleven major earthquakes, a series of ignition scenarios was developed. This study concluded that the current stock of buildings housing one and two family units does not pose a significant life-safety risk for post-earthquake fires. However the older multi-family residential buildings susceptible to structural damage and potential collapse were found to pose an increased risk due to the concurrent fire hazard. A set of ignition scenarios relating to the various aspects of gas and electricity distribution systems were developed for planning and analysis purposes.

Post-impact scenarios undertaken by *Risk Management Solutions* estimating contemporary losses for a repeat of the 1906 San Francisco and the 1923 Tokyo earthquakes indicate that fire following earthquake would be a major factor to contend with. In the San Francisco scenario, although wooden houses are less dominant (from 80% of dwellings in 1906 to approximately 20% today), denser development of wood structures could result in property losses between $US 12,000 - $18,000 million. This assumes a dry season event with average wind conditions (about 15 km/h; more extensive fire damage would be expected under stronger wind conditions). The study noted that the vast majority of property fires would be left to burn themselves out because the fire service's capacity to suppress concurrent fires would be hampered.

In the Tokyo scenario, estimates for a repeat of the 1923 event suggest that up to 30% of residential and commercial properties could be consumed by fire, with costs in the range of $US 300,000 – 450,000 million. This scenario assumes a dry season event with average wind conditions (about 4+ meters per second); more extensive fire damage would be expected under stronger wind conditions. Both Tokyo and Yokohama have significant densities of wooden structures, and many industrial zones, contiguous to residential areas, store cocktails of hazardous materials. These estimates take into account the efforts by utilities such as gas companies to retrofit homes with automatic shut-off valves, and the fact that cooking by open fire (a feature in the 1923 event) is no longer common practice. Once again the vast majority of fires in a future Tokyo earthquake would be left to burn themselves out.

HAZUS is a hazard assessment modelling programme developed by the Federal Emergency Management Agency. This programme assesses damage to the buildings and facilities in a Geographic Information Systems environment. For fire following earthquake, HAZUS follows the logical steps involved in estimating fire losses. It estimates the number of ignitions that have the potential to consume one or more buildings, estimates the burned area (which depends on both fire spread rates and suppression efforts), and estimates the population and building exposures affected by the fires.

The expected number of ignitions is determined from an empirical relationship between the number of ignitions and the estimated peak ground acceleration. There is an acknowledged high degree of uncertainty in the model because it ignores factors, such as time of day and season of year, that have a large influence on the numbers of potential sources of ignitions.

Fire spread within the HAZUS model is based on a Japanese model (*Hamada 1975*) that estimates rates of spread through a set of identical, square, regularly spaced buildings. The input variables are wind speed and direction, and the average plan dimensions, average separation and fire resistance of the structures. Ground slope does not seem to be accommodated.

Fire suppression takes account of a wide range of variables, including:

- elapsed times for reporting, response, control and mop-up,
- engine and water requirements (as functions of fire status (size), fuel types) and availability, and
- natural fire breaks (probability of crossing as function of width, wind speed, suppression efforts).

The procedures for estimating losses are not described in the technical manual for HAZUS, but are likely to be straightforward given that HAZUS is run in ARC-VIEW .

Many simplifying assumptions are built in to the system, but most can be over-ridden by a user if sufficient data is available.

2.2 New Zealand Research

The most significant NZ research in this field was work by Cousins et al in 1991, in which losses due to fires triggered by major earthquakes in central New Zealand were estimated. A scenario-based approach was adopted, using expected numbers of ignitions from a relationship based on data from 20th century earthquakes in North America.

Because it was clear that active fire suppression would only rarely be practicable given the post-earthquake situation, it was assumed that most fires would burn to natural boundaries. The boundaries of the burn zones, and hence the losses, were assessed by on-site inspection of a suite of semi-randomly located ignition points.

Assuming 100-160 ignitions throughout the study zone, and average wind speeds that were not expected to have a significant impact on fire spread, mean losses due to fire were found to be approximately 5% of the mean losses due to shaking damage.

Note, however, that there is very great uncertainty inherent in any estimates of losses due to post-earthquake fires. Historical evidence shows that such losses can vary from insignificant (e.g. Izmit earthquake 1999, Turkey; ChiChi earthquake 1999, Taiwan), to even greater than the losses arising directly from shaking damage (e.g. San Francisco 1906, USA; Tokyo 1923, Japan). The 95% confidence interval for an estimated mean loss due to shaking appears to be almost a factor of 10, and the same interval for losses due to post-earthquake fire may well be more than a factor of 10 greater. This is to be expected because post-earthquake fire depends on many highly variable factors in addition to those already involved in the level of damage caused to a structure by earthquake shaking. Some of the additional variables are:

- time of day, day of the week and season (all of which affect both the numbers of potential ignition sources and suppression efforts), and
- wind, terrain, weather (e.g. rain) and season (which affect the rate and extent of fire spread).

A Master of Engineering project carried out by *Botting* (formerly of Telecom NZ Ltd) at the University of Canterbury in 1998 focused on the impact of post-earthquake fire on the urban environment. The project report addressed the issue on three levels:

1. A consideration of the dynamics of fire in buildings under normal conditions, and the standard fire protection responses to it
2. An analysis of fifteen major earthquakes to discover the sequence of events and responses to fire in the aftermath of major earthquakes
3. A discussion of candidate post-earthquake fire damage mitigation measures

The report suggested various ways in which fire protection and fire engineering measures may reduce post-impact fire losses in urban building stock. Emphasis in the recommendations was placed on fire brigade response, urban water supplies, urban macro-scale fire protection and further analytical modelling.

A recent report for the Wellington Regional Council on the natural hazards risk associated with petroleum storage in the Wellington region (*Opus International Consultants, 2000*) highlighted the total dependence of some of these facilities on the response of the Fire Service-fighting capability. This dependency in conjunction with the siting of many of these facilities on potentially vulnerable reclaimed or estuarine land led to this being identified as a significant risk.

A review of the current approaches taken by Los Angeles and Tokyo fire departments to fighting fires after earthquakes following on from the Northridge and Kobe earthquakes was undertaken as part of this project. In more than 20 reports and papers, little reference was made to possible mitigation activities, indicating that the focus remained on *response activities of the departments*.

2.3 Other Associated Activities

Recent, current and proposed work being carried out in this field in New Zealand is a blend of operational mitigation and preparedness activities as well as research, as summarised below:

New Zealand Fire Service Commission

NZFS have been developing a Community Risk Programme. This project involves establishing a framework for assembling building risk profiles (structural configuration/ contents aspects location, fuel loading/ evacuation planning). The resulting software package is intended for use as a tool from which NZFS mitigation work can be prioritised and information needed during response made directly available. This project process has involved discussions with owners to understand their response priorities, and has also strengthened the relationship with territorial authorities.

Wellington City Council

The Institute of Geological and Nuclear Sciences (GNS) has recently developed a GIS-based system for modelling losses due to a range of earthquake related phenomena including ground shaking, landslides, liquefaction and fire. The system, called "CityAware", was developed for the Wellington City Council's Emergency Management Office. As a pilot project it included a qualitative module for modelling and displaying the spread of fire. Factors taken into account by the module included *building separation*, *ground slope*, and *wind*.

The fire module is now being further developed jointly by GNS and Victoria, University of Wellington, in a project partly funded by the Contestable Research Fund of the New Zealand Fire Service. A principal aim of the work is to make the module quantitative so that it can be used for both high-level and detailed modelling of fire spread. High-level modelling is intended for planners and policy makers, to provide answers to questions such as "is it worth creating parks in certain areas of the city to provide firebreaks?", or "what are the potential losses due to post-earthquake (uncontrolled) fire spread?". At a detailed level the module is intended to assist risk modellers and emergency managers visualise and respond to the spread of a major fire (Cousins et al, 2002).

The project represents the most significant element of research in this field currently underway in New Zealand, but full development of the fire-spread module is likely to take some years. Important features that are expected to need further work beyond the term of the present project include the rate of spread, the effect of vegetation between houses, fire-spread throughout essentially contiguous built-up commercial areas, and fire-spread between high-rise towers.

Earthquake Commission

The Earthquake Commission (EQC) has implemented an earthquake loss assessment process as part of its operational suite of computer modeling systems. At this time EQC earthquake loss assessments do not specifically model fire following earthquake. This is because the losses are assessed on the basis of actual earthquake insurance claims data which includes allowance for the additional losses arising from fire following earthquake.

It is felt that considerable model development and extensive data collection are still necessary for implementation of a fire following earthquake loss assessment system that can be expected to provide realistic earthquake insurance loss results. For example the increment of damage costs on buildings already subject to ground shaking damage. The computer system used for assessing EQC earthquake insurance losses is developed in a modular format that enables the addition of models for fire following and other contingent damaging effects.

The Wellington Lifelines Group

The Wellington Lifelines Group (WeLG) co-ordinates the risk management activities of Wellington utility and transport service operators in relation to regional scale events that are beyond the ability of specific organisations to respond to and control.

The Group has had an active interest in the field of fire following earthquake, with the study tours organised by the Group after the 1994 Northridge and 1995 Kobe earthquakes being a strong influence. Water supply managers on those tours experienced first-hand the conflict that exists between seeking to maintain water in the mains for fire fighting purposes and preserving stored water in reservoirs rather than being lost through fractured mains (*WeLG 1994, 1995*).

WeLG has subsequently been an advocate of the introduction of automatic shut-off valves at reservoirs, and policies along these lines have been implemented with Fire Service support in a number of regions. There is nevertheless a need to revisit this policy using a more systematic risk management based approach as proposed.

2.3 Emergency Management and Community Preparedness

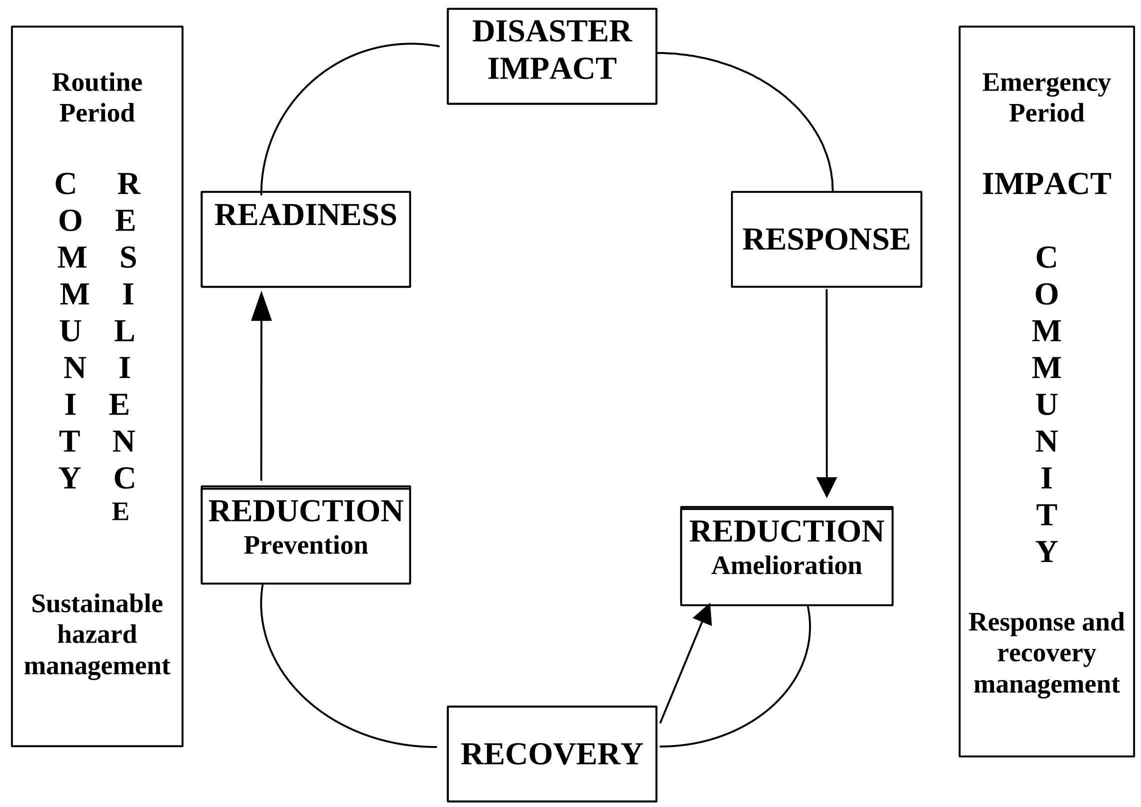
New Zealand commenced major reform of its emergency management framework in the mid-1990s. The modifications are designed to transfer the nation's overtly response-focused counter-disaster approach into a system that is grounded within a more expansive risk-based sustainable hazard management framework (*Britton and Clark, 2000*). This approach is designed to enhance community resilience and reduce the nation's social and financial risk from natural and technological hazards, while at the same time recognising the inherent vulnerability stemming from New Zealand's dynamic physical and constructed environment.

The reform that is taking place calls for a refocusing of attention and action onto the management of risk and the options available for reducing or managing different levels of potential impact. It also necessitates attention being paid to understanding economic activities rather than focusing primarily on economic assets.

Hence, the broader thrust of emergency management is to improve community preparedness by making institutions and citizens better understand their responsibilities across a range of emergency situations. This involves:

- increasing understanding of impacts and consequences through an education programme which is integrated across the Emergency Management sector
- appreciating the difference between *awareness* and *understanding* – sometimes raising awareness can lead to a reduction in understanding
- moving from *short-term community awareness* to *long-term community resilience*
- enabling the community to help themselves - breaking through the *dependence on authority* syndrome

To help shape long-term strategies as well as to implement shorter-term programmes, the emergency manager needs to co-ordinate the systems that typify the domain of emergency management. Figure 1 attempts to illustrate the major components of this domain and shows the relationship between the major components.



- Emergency management spans routine periods as well as emergency periods. During the former, the task of the emergency manager is to facilitate sustainable hazard management practices that lead to community resilience.
- During periods of hazard impact, emergency management focuses on co-ordinating response and recovery requirements.
- ***Prevention*** (i.e. long-term reduction) actions are designed to decrease existing levels of danger, enhance overall resilience and provide sustainable hazard management measures. These actions are deliberately designed to prevent or impede the occurrence of a future disaster event and/or prevent such an occurrence having harmful and long-lasting effects on communities. In this respect, they are proactive measures.
- ***Readiness*** policies and programmes are usually involved with the development of response plans, identification of resources, the training of emergency services personnel, and public awareness programmes.
- ***Disaster impact*** is the occasion when major community dislocation occurs.
- ***Response*** policies and programmes are those that become operational once a disaster occurs or threatens
- ***Amelioration*** (i.e. short-term reduction) are policies and programmes that help limit the magnitude of future impacts. They are introduced following disaster impact as a direct result of the damage or disruption caused by a specific impact. In this respect, they are reactive and are designed to restore the community to pre-impact levels.
- ***Recovery*** policies and programmes address the immediate problems of stabilising the affected community and assuring that life-support systems are operational. These programmes also extend into the longer-term programmes for community rehabilitation and restoration.

Source: In Britton and Clark, 1999. Adapted from Britton (Wellington Earthquake Lifelines Group 1994)

Figure 1: The Emergency Management Domain

3. About Fire Following Earthquake

3.1 The Components of Fire Following Earthquake

The risk components of Fire Following Earthquake can be summarised in an event sequence, under the following element headings:

1. Earthquake effects
2. Ignition sources
3. Establishment of fire
4. Spread of fire
5. Detection/ containment/ extinguishment

The highly situational nature of the risk posed by fire following earthquake is indicated in the flow diagram in Figure 2. Whether or not an earthquake gives rise to a conflagration situation depends on a combination of physical effects that will vary from location to location.

EARTHQUAKE OCCURS

Causes structural damage, failure of fire-resistant construction, and damage to active fire protection systems e.g. detection and suppression systems

↓

FIRES break out initially and then spread (depending on building construction, building density, wind etc) before fire-fighting team arrives

↓

FIRE-FIGHTING teams fight fires, but also respond to other emergencies, such as chemical spills, building collapses etc. Since all fires may not be responded to, some fires spread. Fire-fighting may also be impaired due to loss of water supplies, communications or other systems.

↓

RESULT: SOME SMALL FIRES, OR A CONFLAGRATION?

Figure 2: Post-earthquake Fire Potential

In order to generate the potential for significant fires, the earthquake must be in itself a major regional-scale event. This is important from a fire management perspective since it assumes that all potentially available suppression resources will either be fully committed or are unavailable (as a result of post-earthquake effects such as road blockages or fire building collapses, etc.) Hence, the possible fire effects represent an additional layer of harm on top of the earthquake itself.

Figure 3 below attempts to portray this layering effect in terms of the impact on the process of returning to ongoing societal routines.

The key issue here is the gap between the *isolated* and *conflagration* curves – and understanding the circumstances that can give rise to these two significantly different outcomes.

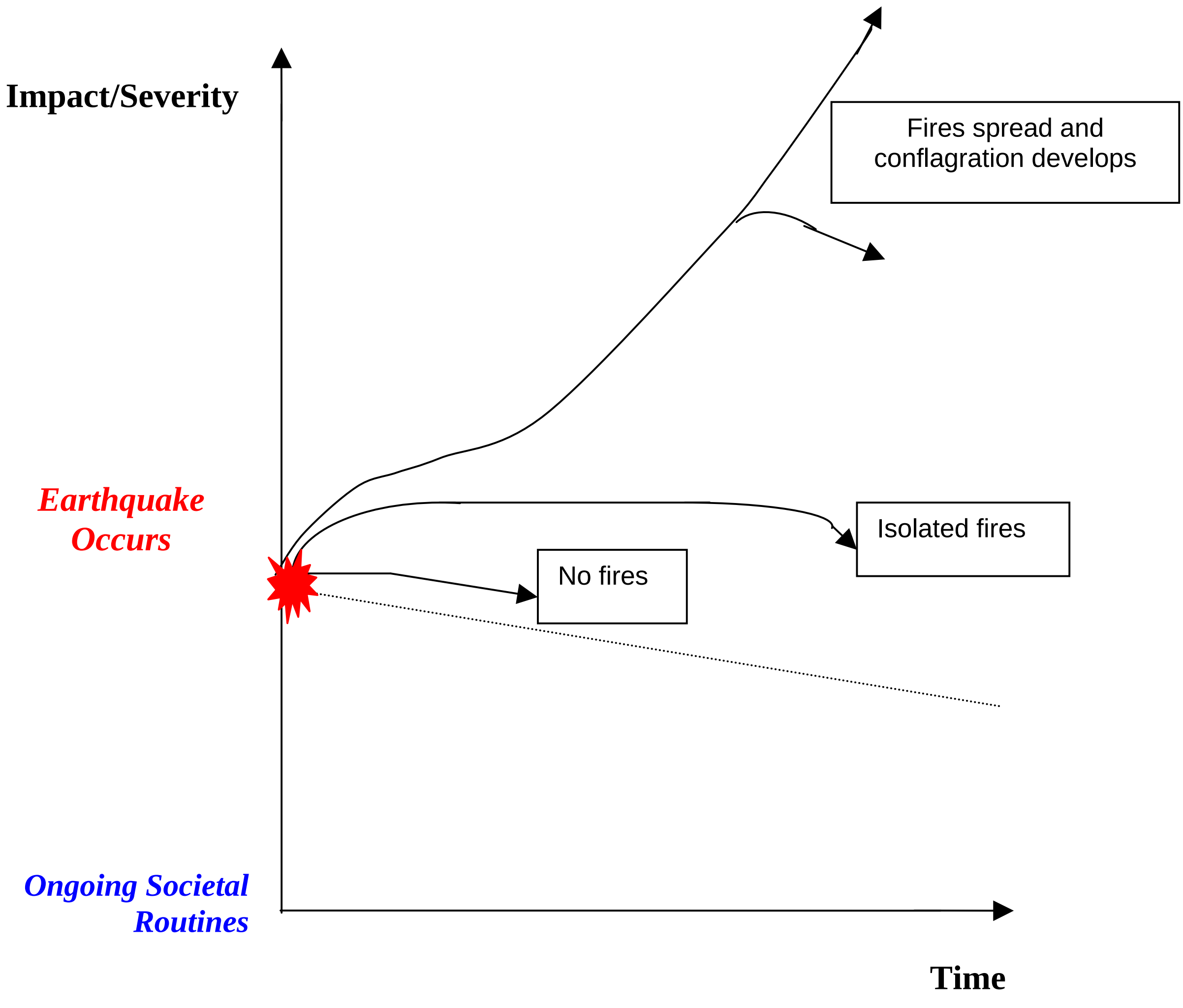


Figure 3: Scenario Outcomes for Fire Following Earthquake

3.2 New Zealand's Experience of Fires and Earthquakes

Napier (Hawke's Bay) 1931

The magnitude 7.8 1931 Hawke's Bay earthquake was New Zealand's greatest earthquake disaster from many points of view. Casualties, damage and fire losses all were severe. Major conflagrations developed in the main business district of Napier and also in the suburb of Port Ahuriri. Post-earthquake fire was probably the major cause of loss to commercial buildings.

In all there appear to have been more than 10 separate ignitions within a short time of the earthquake, 4 in Napier (including Port Ahuriri), 4 to 6 in Hastings, 2 in Wairoa, and others throughout rural Hawke's Bay. In most cases only one or two buildings were lost for each ignition. According to *Conly* (1980), "Two houses were lost in Wairoa, while in rural Hawke's Bay many homes were lost". In Hastings seven premises were destroyed, including the Grand Hotel, a chemist shop, a plumbers shop, department store, a fruiterers, and a home cookery shop. Fires in two other buildings, the Union bank and a few days later the Commercial bank, were extinguished before a great deal of damage was done.

However in Napier, where there were just three ignitions, the fires were not able to be contained and spread widely, eventually consuming the bulk of the business district. There were two reasons for the lack of containment, an initial high intensity and a lack of water. Three of the fires started in chemist shops where naked flames were in close proximity to very highly flammable chemicals. In one case several bottles of ether were stored on a high shelf not far from two naked flames. A worse combination is hard to imagine!

Napier had a permanent fire force of 5 staff (with two engines) supported by 25 volunteers. It also had ample water in reservoirs at the time of the earthquake, but damage to pipes and lack of electricity for distribution pumps meant that not enough water could be delivered to the fire scenes in the crucial early period. Hence the fires were able to burn essentially unchecked for 36 hours. Final control seems to have been a combination of open spaces and fire fighting efforts (*Conly 1980*).

At Port Ahuriri the fire fighting efforts were directed at saving oil storage tanks, with success, but the whole business district of the suburb was burnt out. Burnt out areas in Napier and Hastings (buildings and yards but excluding streets) were as follows (*Dowrick 1998*):

- Napier commercial: 86,000 m^{2,}
- Port Ahuriri: 21,000 m^2, and
- Hastings: 9,000 m^2.

The actual costs of the fire losses have not been able to be estimated to date.

Other major New Zealand earthquakes

Although New Zealand has been shaken regularly by major earthquakes during its 160 years of European history, post-earthquake fire has only once been significant. That was following the 1931 Hawke's Bay earthquake. Most of the other major earthquakes occurred late at night so that most people were asleep and there were few fire sources available, and/or the strongest shaking, MM8 and higher, affected only sparsely populated parts of the country. Some brief notes on the major historical earthquakes follow.

Marlborough, 1848 (M_W 7.8)
Time and season: 1:40 am in late spring (16th October). Although centred in a sparsely populated part of New Zealand it generated strong shaking to the then town of Wellington (MM8). There was severe damage to some brick and clay buildings, but no fires were reported (*Eiby 1980*).

Wairarapa, 1855 (M_W 8.1)
Time and season: 9:17 pm in summer (21st January). Possibly qualifying as a "Great Earthquake", this was New Zealand's largest historical earthquake. Severely affected were the provinces of Wellington, Wairarapa and Marlborough. Fortunately the strongest shaking (MM10) was centred on the Rimutaka range a little over 15km to the east of Wellington, but the settlement of Wellington still experienced very strong shaking (MM9). Damage followed the same patterns as in 1848, only more so (*Grapes & Downes 1997, Grapes 2000*). There appear to have been no post-earthquake fires.

Murchison 1929 (M_W 7.8)
Time and season: 10:17 am in mid winter (16th June) in a sparsely populated part of New Zealand. Within the MM9 zone there was just two small towns, Murchison and Lyell, but the MM8 zone encompassed the towns and cities of Westport, Reefton, Nelson, Motueka and Takaka. Although there was widespread damage to chimneys (*Dowrick 1994*) there appear to have been no fires.

Pahiatua 1934 (M_W 7.4)
Time and season: 11:46 pm in late summer (5th February). The area of strongest shaking (MM9) affected only sparsely populated rural areas (*Downes et. al. 1999*). The closest towns, Masterton, Eketahuna and Pahiatua all were in the MM8 zone. Some buildings suffered structural damage, and there was widespread breakage of chimneys. There appear to have been no fires related to the earthquake.

Wairarapa 1942 (M_W 7.2 and 6.8)
Time and season: 11:16 pm (24th June) and 00:34 am (1st August) respectively. The intensity is thought to have reached MM9 near Masterton in the larger of the two events, but otherwise the highest intensities were MM8. Several house fires were reported following the first event but most were extinguished before major damage occurred. Only one farm homestead, near Carterton, was destroyed (*Downes et. al. 2001*).

Inangahua 1968 (M_W 7.2)
Time and season: 5:24 am in late autumn (23rd May), centred in a sparsely populated part of New Zealand. The small town of Inangahua experienced MM10, Reefton MM9, and Westport and Murchison MM8 (*Dowrick et. al. 2001*). There were no post-earthquake fires (*P.N. Davenport, pers. comm. 2001*).

Edgecumbe 1987 (M_W 6.6)
Time and season: 1:42 pm on a work-day afternoon in late summer (2nd March). The small towns of Edgecumbe and Te Teko, part of Kawerau, and major industrial sites near Kawerau (pulp and paper mill) and Edgecumbe (dairy factory) all experienced MM9 shaking. There was no mention of post-earthquake fire in a major study of damage (*Butcher et. al. 1998*). Reasons for the lack of ignitions were probably the warm weather, which meant that few if any fireplaces were in use at the time, and also that a foreshock a few minutes ahead of the mainshock had disrupted the power supply.

Other Significant Urban Fires

The Hawker St. fire of 1901 was not a post-earthquake fire, but simply a house fire that got out of control. Hawker St. is part-way up the side of Mount Victoria, Wellington. The fire, which started in a house on the downhill side of Hawker St., was not able to be to be prevented from spreading to two close neighbouring houses because of a lack of water pressure. Very strong north-westerly winds then spread the fire uphill across Hawker St. and eventually across also the parallel Shannon Street. Altogether approximately 30 houses were consumed. Further downwind (uphill), spreading of the fire was prevented only by a lack of fuel; the fire having reached the open space of the “town belt”. Spreading in the cross-wind direction was largely prevented by two streets, Moeller St. and Kennedy St., though separations of 2-3 metres plus fire fighting measures seem to have been sufficient for saving a few houses. The fire did not spread at all in the upwind (downhill) direction.

The evolution of New Zealand (and in particular Wellington’s) early building stock reflects an ironic inter-relationship between fires and earthquakes. The frequent loss of early timber buildings from fires led towards a trend to construct in more fire-resistant masonry. The extensive use of brick in the late 19th and early 20th century led to the significant urban earthquake risk that is still being addressed today.

Awareness vs Reality

New Zealand communities are generally well aware of the threat posed by earthquake. This has led to a reasonable, although not optimal, level of preparedness by many individuals in higher seismicity areas. The overall level of preparedness is however highly variable, with many key organisations and businesses thought to have inadequate response plans in place.

Of greater concern is the lack of experience of the *reality* of earthquakes in New Zealand. Figure 4 shows that there were only 4 earthquakes of magnitude M_W greater than 7 in the past 50 years, and that none of these affected a significant urban area. This is in contrast with the experience over the preceding 110 years (1840 to 1949) where a number of earthquakes of magnitude M_W greater than 7 occurred in much closer proximity to what are now major cities. Comparable events today in those locations would cause appreciable damage.

Only 9 lives have been lost in earthquakes in NZ in the past 70 years. This ‘good fortune’ has led to a lack of urgency towards earthquake mitigation and preparedness work in many sectors. Moreover, there is a lack of familiarity with large-scale emergency response processes.

The ‘awareness’ referred to above does not necessarily relate to fire – note the number of new timber-framed houses being built on ridges that are either on rural-urban interfaces (with gorse vegetation), or on slopes fanning out from fault lines.

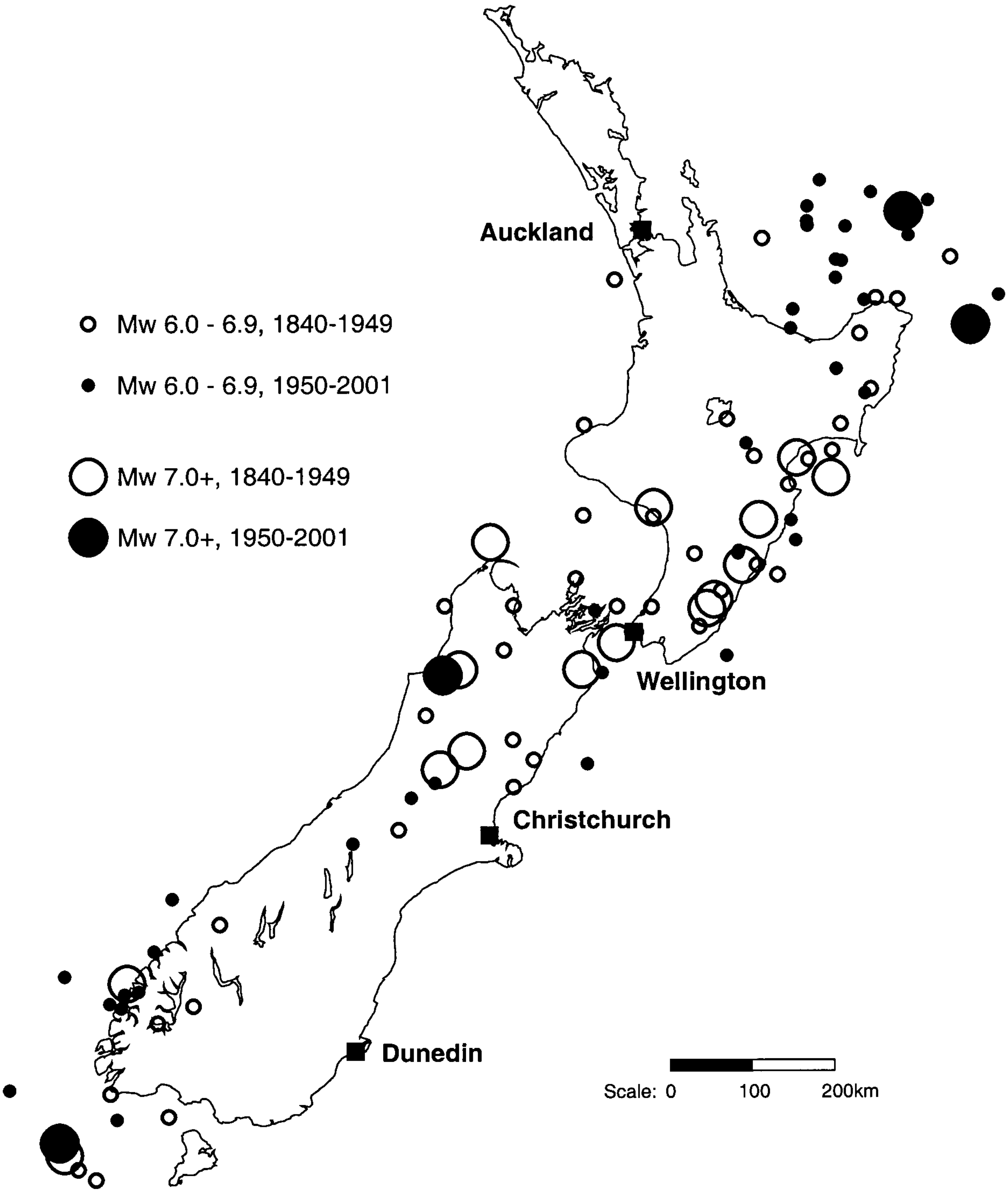


Figure 4: Large Historic Earthquakes in New Zealand *(Dowrick & Cousins, 2002)*

4. Risk Management Generally

4.1 The Risk Management Standard AS/ NZS 4360: 1999

Until recently, the hazard and disaster management community has operated almost solely on the relief paradigm. In this response-based approach to disaster management, specially trained disaster managers (usually government officials), co-ordinate the relief efforts (usually mounted by other government agencies) of both the affected community and the wider aid benefactors.

In recent years, however, as both the number and cost of natural and technological hazards continues to grow, both nationally and internationally, relief measures after impact have become increasingly inadequate to protect personal or community assets, safeguard social and economic investments, or to ensure a community's commitment to its own disaster resistance. This situation, as well as other similar scenarios associated with risky activities that have caused concern, such as environmental management, commercial financing, information technology, Y2K, outsourcing, and business continuity management prompted Standards Australia and Standards New Zealand to establish a Joint-Technical Committee to develop a risk management standard. In doing so, Australia and New Zealand became, in 1995, the first countries in the world to formally develop and adopt a general standard on risk management.

The enormous interest throughout the private and public sectors in risk management is no accident. The drive for efficiency and effectiveness has generated the development of new management tools. The Australian and New Zealand Risk Management Standard (*AS/NZS 4360:1999 2nd Edition*) provides a formalised, systematic decision-making process with which to identify solutions to issues as diverse as a nation's vulnerability to natural hazards on the one hand, to an understanding of the competitive environment of a small business on the other hand. No matter what the scale of event or the specific application, the risk management process focuses on identifying problems and/or opportunities before they happen. It is the systematic analysis of risk and decisions about the acceptability of risks which distinguishes the approach in the Standard.

Three features of the Standard warrant highlighting. They are (1) the definition of risk management; (2) the process of risk management; and (3) the context within which the risk activity takes place.

4.2 Defining Risk Management

The Joint Technical Committee defined risk management as 'the culture, processes and structures that are directed towards the effective management of potential opportunities and adverse effects' (AS/NZS 4360:1999:4). This definition implies that risk management relates to a wide array of quantitative and qualitative factors that requires insight and input from many sources. It deliberately does not identify any specific group or agency that might be required to undertake the tasks. Instead, it encourages an understanding of the complexity and inter-connectedness of issues and offers up a process as a way to accomplish the objectives.

In this context, risk management is not seen as a practice that is restricted to a specific setting, such as the board of directors of a private enterprise, or an officials committee developing public policy, or to a particular set of skilled individuals, such as engineers or scientists. Rather, it is regarded as a practice that is integral to good management per se and which is independent of any specific industry, sector or system level.

4.3 The Risk Management Process

The Standard defines the *process* of risk management as 'the systematic application of management policies, procedures and practices to the tasks of establishing the context, identifying, analysing, evaluating, treating, monitoring and communicating risk' (AS/NZS 4360:1999:4). This is illustrated in Figure 5.

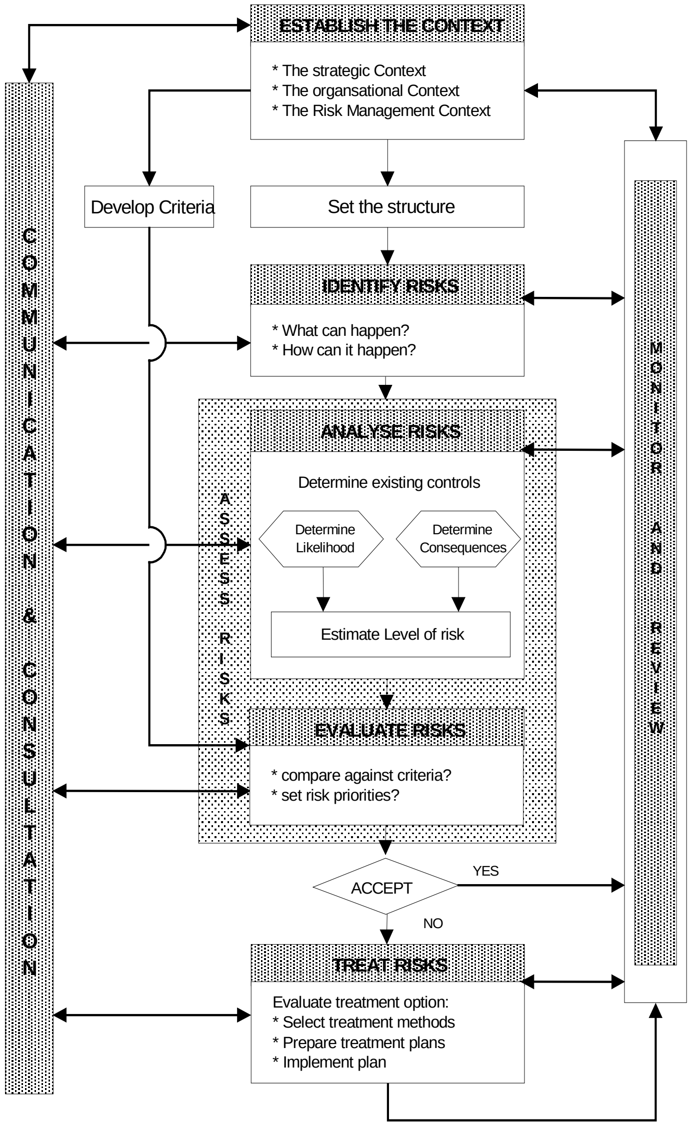


Figure 5: The Risk Management Process *(AS/NZS 4360:1999)*

4.4 Establishing the Context

A third feature of the Standard is its emphasis on the context within which the organisation or activity operates. Risk, and hence risk management, is situational. Whether risk is positive or negative, an opportunity or a constraint, depends on the context within which one operates. The Standard establishes criteria so that the risk management elements of *risk identification*, *risk assessment*, *risk treatment*, *consultation and communication*, and the *monitoring/review* process are directed toward issues that are relevant. In doing this, the Standard places emphasis on understanding the significance of the context within which the risky activity is undertaken: indeed, the emphasis on context is a distinguishing feature of AS/NZS 4360:1999.

Three contextual components identified are the ***Strategic Context,*** *the* ***Organisational Context*** and the ***Risk Management Context.***

Strategic Context**:** This defines the relationship between the organisation and the wider environment within which the activity will reside. The section seeks to determine the crucial elements which might support or impair the ability of the project to meet the risks it faces. These risks can be identified by management tools which direct attention to strengths, weaknesses, opportunities and threats that might affect project functioning.

The strategic context also points to the need to identify the project's internal and external stakeholders, and considers their objectives, taking into account their perceptions. In particular, the strategic context points to the need to establish a communication and consultation policy with these parties. Another component of the strategic context is to develop and internalise the project's mission and strategic objectives. In this way, the organisation is able to develop a management strategy for the risks the project is exposed to.

Organisational Context: Before a risk management study commences, there is a need to understand key attributes of the organisation such as:

- Capabilities to undertake the project or activity
- Goals that the organisation has (of which the project or activity might only be a sub-set of a wider goal-set)
- Objectives of the organisation (which might be broader than that of the project or activity)
- Strategies to achieve the organisation's wider mission
- Individual aspirations and expectations of key organisational members (which may be quite different from the declared organisational goals and objectives).

The organisational policy and goals help to define the criteria by which it is decided whether a risk is acceptable or not. The capabilities and individual aspirations/expectations determine how members of the organisation will define and act on those risks. Hence, the organisational context is of particular importance to the overall success of the project since these factors will be the actual drivers of the strategic context. Focusing on the organisational context reminds us that strengths, weaknesses, opportunities and threats to a project are also internal, and not only external.

Risk Management Context**:** The goals, objectives, strategies, scope and parameters of the activities to which the risk management process is being applied should also be established. This needs to be done with full consideration of the need to balance the *costs, benefits, boundaries* and *opportunities*.

Setting the scope and boundaries involves the following:

- Defining the project or activity
- Establishing its goals and objectives
- Defining the extent of the project in time and space
- Identifying studies needed and their scope, objectives and the resources required.

5. A Risk Management Perspective of Fire Following Earthquake

This section summarises the outcome of applying the risk management steps of Figure 5 to fire following earthquake. The principal objectives of this approach are:

(1) To provide a basis for identifying which are the principal fire following earthquake risk factors in New Zealand

(2) To be able to put previous and future research in context, and identify gaps

(3) To establish realistic risk reduction aims for fire following earthquake and identify where to most effectively place risk reduction efforts

The initial risk management steps, or elements, lead to a better understanding of the risk and its context. The later steps enable gaps in previous and current work to be identified, and future actions to be structured and prioritised. The process is iterative and ongoing.

Element 1: Establishing the context

Consideration of the *strategic*, *organisational* and *risk management* context of fire following earthquake involves understanding several overlapping strands. The following questions provide the necessary framework:

- **What is the primary hazard context for fire following earthquake?**

  The primary hazard context is that of fire, with earthquake being the indirect initiator. The broader context of fire following earthquake is that earthquake itself is a low probability high consequence event that is difficult to plan for.

- **What are the statutory mandates?**

  The responsibility for mitigating fire risk generally is held by the NZ Fire Service. Fire following earthquake is a subset of this wider responsibility.

  However, the complexity of fire following earthquake means that it should more appropriately be regarded as multi-agency risk. As highlighted later in this section, it should therefore not be regarded only as a responsibility for the NZ Fire Service.

- **Who are the organisation/sectors involved?**

  The concept of the 'emergency management community' as an institution that is applying the risk management process to fire following earthquake is useful in identifying the internal stakeholders. The emergency management community comprises:

  - NZ Fire Service
  - Local authorities (emergency management, water supply management, regulatory)
  - Other utility organisations
  - Research and hazard information providers

External stakeholders (i.e. those outside the emergency management community) include:

- The insurance industry
- Building owners and/or managers
- Environmental and community planners – these are more appropriate action-oriented groups to target as they communicate issues to all sectors and are in a position of influence
- The general public – they are involved in the impact but it may not be realistic to expect all sectors to be proactive in mitigation

- **What is the relationship with other current emergency management activity strands?**

  There are a number of current emergency management-related activities that are relevant to fire following earthquake. These include:

  - the multi-agency project to develop an integrated capability for Urban Search and Rescue in New Zealand
  - the Ministry of Civil Defence and Emergency Management project to establish the national capability for a range of emergency events, and
  - the ongoing implementation of the multi-agency response focused Co-ordinated Incident Management System (CIMS).

The principal challenge in seeking to address the risk associated with fire following earthquake is in getting the many agencies within the sectors outlined above to *understand* their roles and responsibilities (rather than to just be aware of the facts and figures associated with an earthquake impact).

This position is defensible because the commercial reality seems to be that organisations and individuals will undertake mitigation and preparedness actions ***if*** they are informed about how to avoid the consequences ***and*** if the need to take action is perceived.

Element 2: Identify the risks

As indicated in Section 3, the occurrence of a significant conflagration following an earthquake requires coincident circumstances to occur.

These circumstances represent risk factors or components, which can be summarised in terms of the event sequence as in Table 1.

Table 1: Summary of the Fire Following Earthquake Risk Components

Elements & Sequence	Primary Risk Factors Identified
1. Earthquake Effects	Building damage Displacement of contents Fracturing of gas and/ or electricity connections and/ or reticulation
2. Ignition Sources	Open fires, hot surfaces Boilers, plant toppling Short circuit from structural damage Fallen live wires Premature restoration of electricity supply
3. Establishment of Fire	Fuel (Contents) Failure of active suppression within buildings • *Sprinklers* – supply mains or connection to building • *Pressurisation* – loss of power or seals (due to movement damage)
4. Spread of Fire	General (local) factors • high density of buildings • boundary barriers not designed to modern fire spread resistance requirements Event or site–specific • wind (strength & direction) • damage to passive measures
5. Detection/ Containment/ Extinguishment	Locations of fires may not be known – alarms systems damaged/ disturbed Impairment of Fire Brigade response Loss of water pressure due to reticulation damage

Element 3: Assess the risks

The scope of this project did not extend to exploring the ***analysis*** aspects of *likelihood* and *consequence* parameters in detail. As noted earlier, this has been the domain of most international fire following earthquake research to date. However despite extensive research efforts, modelling of fire following earthquake remains a complex problem given the many situational uncertainties.

With reference to the risk factors listed in Table 1 and the diagrammatic representation in Figure 3, the two dominant issues are:

(1) The extent to which fires would become established; and

(2) The extent to which those fires which did become established would spread

There are significant variables and uncertainties relating to the ***establishment*** of fires, including:

- ***Ignition sources*** - time–dependence (eg meal times) and seasonality (eg heaters in winter).
- ***Performance of active suppression systems*** - uncertainty associated with the response of sprinkler systems in earthquakes.

Regarding the potential ***spread*** of fires, it is useful to profile the nature of NZ's building stock in terms of construction era. Buildings designed in accordance with NZS 1900 Chapter 5 which was first issued in 1964 are considered to have high standards of fire separation. These separation requirements have been relaxed somewhat by the NZ Building Code in 1992, which placed more emphasis on early detection, active suppression systems and rapid response. Even the NZS 1900 Chapter 5 requirements did not necessarily provide full resistance to a prolonged fully developed fire – they are intended to contain an inferno for a realistic period. They too are predicated on a rapid NZFS response.

But for fire to spread from one central city building to a non-burning neighbouring building requires the failure of passive fire spread resisting systems in both buildings. While this could foreseeably happen in a major earthquake, this mode of transmission/ initiation has not been widely experienced internationally following major earthquakes. Most dramatic conflagrations have come from low or medium-rise buildings predominantly of timber construction, with inner city proximity. This in itself sends a signal as to where the main areas of risk are likely to lie in NZ.

Modelling the process of fire spread generally continues to represent a challenge, quite apart from the added complicating layer of earthquake factors. Calibration of models via back-analysis of major earthquakes generates reasonable agreement with actual earthquake experiences (eg. *Scawthorn*). However this work has typically involved careful and specific tuning of a general model to actual circumstances (eg. wind conditions). It is therefore apparent that general models cannot be expected to yield 'accurate' results in any given region without full consideration of the variable and situational factors.

With regard to risk ***evaluation,*** there is a need to establish a framework for developing criteria for *risk acceptability* and *prioritisation.* Evaluation criteria must relate to the method(s) of analysis to be used. The criteria will be influenced by:

- more empirical data on the fire following earthquake threat
- the perception of the emergency management community
- the perception of the general public and business
- legal (statutory) requirements

It is interesting to consider the qualitative risk rating for fires following earthquake from the *NZFS Community Fire Risk Management Guidebook*. This document provides qualitative descriptors based on AS/ NZS 4360 for *likelihood* and *consequence* under the headings of low, moderate, significant and high. Based on the combination of likelihood and consequence, a level of risk of low, moderate, significant or high is arrived at.

Fire following earthquake has a *low* likelihood but a *high* consequence. This combination yields a risk rating of *significant*.

Element 4: Treat the risks

Treatment of risks involves consideration of both *physical mitigation* and *planning to respond* options. Risk treatment options for the principal risk factors are indicated in Table 2, along with the suggested agencies responsible. The right-hand column of this table highlights the multi-agency nature of this risk – no single agency can effect a major reduction in the overall risk.

Physical mitigation

The practical reality is that there is only limited potential for physical (pre-event) mitigation of existing facilities to address the risk of fire following earthquake. Moreover, in New Zealand fire following earthquake is not specifically addressed under codes and regulations for new facilities. This is in contrast to cities such as Vancouver, where the design of buildings for fire resistance takes into account the possible damage resulting from earthquake effects *(Robertson and Mehaffey, 2000)*.

Accordingly, one of the key areas for future research is to establish whether the current New Zealand regulatory approach is appropriate or if a more pro-active approach should be taken.

There is an important connection between general fire risk mitigation and fire following earthquake mitigation. Good general fire risk mitigation practices will also reduce the risk of fire following earthquake (eg. banning plug-in heaters in office buildings).

Planning to respond

Planning to respond to fires occurring as a result of earthquakes is extremely difficult given the backdrop of damage and access disruptions, and the many demands that are placed on the emergency services.

The main factors affecting the ability of the Fire Service to respond to the fires that occur after earthquakes can be summarised as:

- Not being made aware of the fires at an early stage (if at all) due to alarm systems not working
- Not being able to get to the sites due to lack of access resulting from both direct physical damage and congestion
- Unable to effectively fight fires when at sites due to lack of water

There are also many human response issues that fire fighters and other emergency services personnel face in extreme events, including the increased potential for personal injury. Uniformed emergency services officials have many demands placed upon them for which their training and experience hasn't necessarily prepared them for.

Table 2: Possible Risk Treatment Measures

Elements & Sequence	Primary Risk Factors Identified	Risk Treatment Options			Agency Responsible for
		Acceptance	Reduce Incidence (pre-event)	Improve Response	
1. Earthquake Effects	Building damage	Separate risk reduction programme			Owners
	Displacement of contents		Restraint against movement		Owners/ Tenants
	Fracturing of gas and/ or electricity connections		Install flexible connections		Gas/ Electricity Utilities
	Fracturing of gas and/ or electricity reticulation		Maintain appropriate installation standards		Gas/ Electricity Utilities
2. Ignition Sources	Open fires, hot surfaces		Restraint against movement		Owners/ Tenants
	Boilers, plant toppling		Restraint against movement		Owners/ Tenants
	Short circuit from structural damage		Difficult to mitigate		
	Fallen live wires		Difficult to mitigate	Rapid cut-off procedures in damaged areas	Electricity Utilities
	Premature restoration of electricity supply			Integrated service restoration/ reconnection procedures	Gas/ Electricity Utilities

Table 2: Possible Risk Treatment Measures (*Continued)*

Elements & Sequence	Primary Risk Factors Identified	Risk Treatment Options			Agency Responsible for
		Acceptance	**Reduce Incidence (pre-event)**	**Improve Response**	
3. Establishment of Fire	Fuel (Contents) Oxygen	General fire safety regulations			Owner
	Failure of active suppression • *Sprinklers* – supply mains or connection to building		On-site storage & diesel pumps Install flexible connections		Owner
	• *Pressurisation* – loss of power or seals (due to movement damage)				Owner/ water supply utility
4. Spread of Fire	General (local) factors • Boundary barriers • Density of bldgs	General fire safety regulations	Emphasise/ maintain Code Compliance		Territorial Authority
	Event/ site – specific				
	• Wind (strength & direction)	Yes			
	• Damage to passive measures	Yes			
5. Detection/ Containment/ Extinguishment	Locations of fires may not be known – alarms systems damaged/ disturbed		Provide seismic restraint to control panels, etc	'First-aid' fire-fighting equipment in buildings and operator training	NZFS/ Owner
	Impairment of Fire Brigade response				
	Loss of water pressure due to reticulation damage	Yes	Utility resilience	Increase availability of fire-fighting supplies from urban water system (network improvements)	NZFS/ water supply utility

The development of broad response strategies is therefore important, and involves an understanding of where the principal areas of risk lie (with reference to the primary risk factors listed in Table 1). The response strategy for fire following earthquake must be a multi-agency one.

A prime example of this is the increasingly common approach by water supply authorities of installing automatic shut-off valves at the outlets of major reservoirs. The purpose of this is to preserve stocks of treated water rather than letting them run to waste through damaged mains. This strategy requires the understanding and acceptance of the local fire service, with agreement usually following on a 'this sounds logical' basis. Ideally however, a more considered review of the specific risk factors for fire following earthquake should be undertaken.

Installing shut-off valves may not be wise in situations where spread of fire is a real possibility. Alternative approaches such as those used by Japanese water supply authorities involve dividing reservoirs into two compartments, one of which is retained, and the other left to run for fire-fighting purposes (*WELG, 1995*).

There is also a need for a co-ordinated approach for the re-connection of electricity and gas following earthquakes. The ignition of escaping gas from the rapid re-livening of electricity mains following the Kobe earthquake is suspected of causing some of the fires. By contrast, a combination of the rapid shutdown of gas following the 1999 Taiwan earthquake and the slower restoration of electricity supplies in the affected areas (2 to 3 days) is credited for there being no fatalities from mains-related fires (*Ban-Jwu Shih, pers. comm. 2001*).

Element 5: Communicate and consult

The results from work carried out under each of the preceding elements have to be communicated to both the internal and external stakeholders, involving specific consultation where appropriate.

The stakeholders that have a responsibility to carry out this role must be identified (for the work resulting from this project and beyond).

Part of the 'communicate and consult' component is the development of a specific risk perception and understanding programme for fire following earthquake. This will be a very significant component of any long-term strategy for risk reduction that will overcome the current lack of appreciation that almost all sectors of the NZ community have of the fire following earthquake risk potential.

Element 6: Monitor and review

The risk management steps are intended to be applied in an iterative and ongoing process. In addition to the *Communicate and Consult* element, *Monitor and Review* provides a prompt to establish a set of arrangements whereby progress in each of the core elements is reviewed. Table 2 of this report could be used as a monitoring tool in this regard.

Summary of Section

The issues outlined above under each of the risk management elements provide a basis form which the ‘gaps’ and ‘needs’ can be identified from both research and operational perspectives.

It is hoped that this simple framework will provide a mechanism for systematically reviewing the scope of research into fire following earthquake, and thereby establishing where future efforts should be applied.

Despite the high level of awareness of earthquake hazards, the ‘additional’ hazard of fire following earthquake has not been subject to any form of structured approach. If research is to continue in this field, a more structured approach would appear warranted.

6. Discussion of Gaps and Needs

By applying the discipline of the risk management steps as presented in the previous section, the following key questions have emerged:

1. How can we identify situations where fire following earthquake is a risk that warrants active management? (ie. distinguishing from those low risk situations where pro-active consideration is clearly not warranted)
2. What are the research and information needs in order to develop/ define this distinction?

Given the range of risk factors involved, it is apparent that the application of detailed modelling is not necessarily helpful in addressing the higher level question in 1. above. There is therefore a need for a process to identify *firstly* whether key risk attributes or factors exist within a given region, and *secondly* if there is a need to carry out a detailed analysis and further modelling.

Accordingly it is suggested that a coarser screening approach be adopted, focusing on the question of '*Could a conflagration situation forseeably occur?'* Implicit with a coarser approach is seeking to define those factors which can be excluded from detailed consideration.

If it is assumed that fires could become *established* in a given situation after an earthquake (ie. adverse earthquake effects and ignition sources assumed), then the general factors under *spread of fire* are clearly the most influential. These factors are *building density*, *type of construction, effectiveness of boundary barriers* and *wind conditions and topography*. This identifies that these factors should receive the greatest emphasis in modelling terms.

A qualitative framework could readily be developed to assess in broad terms the vulnerability of a community or suburb to the spread of fire in the (assumed) absence of an effective Fire Service response following an earthquake. The basis for such a framework is suggested in Table 3.

Table 3: Possible Qualitative Measures for Assessing Local Vulnerability to Spread of Fire Following Earthquake

	Level of Vulnerability				
	Low	Moderate	Significant		High
	1	2	3	4	5
Building density			*(vulnerability parameters to be developed)*		
Predominant type of construction	Modern concrete and steel		Modern timber		Earlier timber
Effectiveness of building barriers (era of design)			*(vulnerability parameters to be developed)*		
Wind conditions & topography	Calm, flat				Gale force, steep-sided ridges

The numerical values for each of the four factors could be arithmetically combined to produce a relative risk measure. The framework could be applied using judgement or more systematically using GIS.

Looking beyond the vulnerability assessment aspects, a mechanism is needed for enabling the emergency management community to work together to identify (i) the areas of high fire following earthquake risk, and (ii) appropriate mitigation and/ or response measures. It would be desirable for such a mechanism and the associated tools to be integrated with the NZFS Community Risk Management Framework.

A collaborative inter-agency approach similar in nature to the successful regionally-based Lifelines Groups would appear to be a suitable model. This in turn could be readily accommodated within the new Civil Defence Emergency Management Group environment.

Such a mechanism would be more of an *operational process* than a *research-based activity*. However the outcomes would provide a fundamental focus for future NZ-based research.

Development of the Wellington City Council/ Geological & Nuclear Sciences *City Aware* project model would be informed from the inter-agency discussions. This GIS-based system represents an excellent tool to illustrate the issues and factors. Given the significant urban earthquake risk in Wellington, this in turn suggests that a pilot process should be set up in Wellington to identify high occupancy/ high risk communities.

Following such a pilot process, a national inter-agency risk reduction programme could be developed to address the issues of:

(i) Current fire following earthquake risk status;

(ii) Desired risk reduction objectives;

(iii) The priorities for action; and

(iv) The responsibilities of the respective organisations in order to achieve this

It is suggested that this programme could take the form of a ten year plan, and would feed in to the Civil Defence Emergency Management Group planning process for regions to address.

7. Summary and Recommendations

7.1 Summary of Findings

Fire Following Earthquake is a complex subject, involving many sequential and situational components. Much of the research work carried out to date has focused on the development of analytical models which capture these components, and more recently creating linkages with GIS packages.

A review of fires following major historical and contemporary earthquakes has established that most major conflagrations extending over a significant area have come from low or medium-rise buildings constructed predominantly from timber.

Systematic application of the risk management steps defined in the Australian and New Zealand Risk Management Standard AS/NZS 4360 during this project has highlighted a number of gaps in the consideration of the risk posed by fires following earthquake. These include:

- The ***context*** of fire following earthquake has not been fully established
  - The primary *hazard context* is that of fire, with earthquake being the indirect initiator. Earthquake itself is a low probability but high consequence event that is difficult to plan for. Fire conflagrations can develop from situations other than earthquake, although both local and international experience confirms that earthquake is a major initiator of large-scale urban fires.
  - The *organisational context* is that fire following earthquake is a multi-agency risk because of the complexity of the factors involved. Accordingly, it should not be regarded as only being the responsibility of the Fire Service.

- Although most of the research work in this area has focused on the ***assessment*** step, as yet there are no tools with which to undertake a high-level evaluation of the level of risk at a regional level
  - While comprehensive models have been developed, they largely rely upon empirical relationships that are specific to local areas in terms of the structural and fire resistance characteristics of the built environment.
  - These detailed models are not particularly effective in establishing the broader regional (or national) overview of whether fire following earthquake is a significant risk that warrants active management

- Risk ***evaluation*** criteria for fire following earthquake have yet to be established.
  - Such criteria will be influenced by
    - more empirical data on the fire following earthquake threat
    - the perception of the emergency management community
    - the perception of the general public and business
    - legal (statutory) requirements
  - Applying the qualitative risk rating procedure contained in the NZFS Community Risk Management Framework, which takes into account likelihood and consequence, generates an overall risk rating for fire following earthquake of <u>*significant*</u>.

- Risk ***treatment*** processes for fire following earthquake are essentially non-existent.
  - Building regulations do not consider fire as a concurrent hazard with earthquake
  - Very few examples of integrated response procedures by utility organisations and the Fire Service are in evidence
- ***Communication and consultation*** processes for fire following earthquake have been limited in comparison to other hazards
  - It is considered that if fire following earthquake was treated more directly as a fire-related hazard, more appropriate perceptions and greater involvement in risk reduction processes would result
  - If for whatever reason Fire Service teams are unable to meet their response performance requirements for a significant urban fire, this could replicate many aspects of a fire following earthquake scenario

The essentially passive approach towards fire following earthquake adopted in New Zealand to date may be justifiable – but only after a conscious risk analysis and evaluation is undertaken.

The key issue is understanding the circumstances and factors that can transform isolated individual fires into full conflagrations. The two dominant questions at a regional level are:

1. The extent to which fires would become established after earthquakes; and
2. The extent to which those fires which did become established would spread

Key factors are *building density*, *type of construction, effectiveness of boundary barriers* and *wind conditions and topography*. It is noted that current and recent building regulations and codes in New Zealand are predicated on a rapid response from the Fire Service. The current New Zealand Building Code also places emphasis on early detection and active suppression. Accordingly, limited passive protection is required in most new ordinary fire hazard buildings in New Zealand. The combination of variable wind conditions in conjunction with the steep, gorse-laden hillsides in some urban areas of New Zealand also requires specific consideration.

The broader risk context for New Zealand is that this country has not had a significant earthquake affecting a major urban area since the 1931 Napier earthquake, which itself featured extensive fires. As a consequence, there is a lack of familiarity with large-scale emergency response processes in general, and specifically in dealing with fires following earthquakes.

Despite the high level of awareness of earthquake hazards, the ‘additional’ hazard for fire following earthquake has not been subject to any form of structured approach. If research is to continue in this field, a more structured approach would appear warranted.

It is concluded that in the first instance, fire following earthquake should be addressed by the relevant elements of the *emergency management community* as internal stakeholders, comprising:

- NZ Fire Service
- Local authorities (emergency management, water supply management, regulatory)
- Other utility organisations
- Research and hazard information providers

7.2 Recommendations

As a result of this research project, recommendations are made under the headings of (i) *short-term mitigation actions*, (ii) *medium-term planning processes* and (iii) *further research activities*.

Short-term Mitigation Actions

It is recommended that further consideration be given to promoting the low-cost risk reduction measures that can be directly undertaken, including:

- Emphasising seismic restraint of heavy and vulnerable items such as boilers, heating units, stoves and tanks and valve room alarm control panels in commercial, industrial and apartment buildings. This owner responsibility should be particularly highlighted in the case of new facilities.
- The installation of flexible connections in regions of high seismicity for electricity, gas and water mains at points of entry into new and upgraded buildings, and at key network junctions
- Developing integrated procedures for the post-earthquake shutting off and restoration/ reconnection of electricity and gas services

Consideration should be given to the risk factors associated with fire following earthquake at a regional level before decisions are made to install further automatic shut-off valves in major water supply reservoirs.

Medium-term Planning Processes

A strategy for addressing fire following earthquake must be a multi-agency one, and should be developed at regional level. The agencies involved should include:

- The New Zealand Fire Service
- Civil Defence and Emergency Management agencies
- Utility organisations (water, electricity and gas)
- Research and hazard information providers

A collaborative inter-agency approach similar in nature to the successful regionally-based Lifelines Groups would appear to be a suitable model. The most appropriate vehicle to facilitate this strategy should be the Civil Defence Emergency Management Groups to be formed under the new legislation. The initial focus should involve the agencies above giving consideration to the overall level of fire following earthquake risk in the region. If the risk is considered to be significant, medium-term risk reduction measures should be identified in addition to the short-term measures outlined above.

It is suggested that this programme would feed in to the Civil Defence Emergency Management Group planning process for regions to address. Since perceptions of the risk need to be changed, which is itself a long-term process, the outcome could take the form of a ten year plan. Other stakeholders, such as those mentioned earlier, would form part of this process.

It is also recommended that a framework for this regional approach should be developed at a national level. Piloting of the process in regions of different characteristics is also likely to prove beneficial. This could for example involve a region with a major metropolitan centre and a region with smaller cities and towns. Given the significant urban earthquake risk, prevailing winds and urban fire risk in Wellington, this in turn suggests that a pilot process should be set up in Wellington to identify high occupancy/ high risk communities. Development of the Wellington City Council/ Geological & Nuclear Sciences GIS-based *City Aware* project model would be greatly informed from such a dialogue.

Further Research Activities

In keeping with the recommendations outlined above, the focus for future research is to establish whether the current passive New Zealand approach towards fire following earthquake is appropriate, or if a more pro-active approach should be taken.

It is recommended that a more detailed review of international earthquakes be undertaken to better understand why no conflagrations have occurred in more recent earthquakes. In particular, studies of earthquake-generated fires in the context of New Zealand's climate with significant prevailing winds should be conducted. Also there is a need to research the performance of modern plastic gas reticulation in permanent ground deformation situations. A scoping project on the performance of buried services in earthquakes is being co-ordinated by the National Lifelines Co-ordinating Committee.

Another research project identified is an extension of basic fire design research to look at the fire spread potential of high-rise CBD buildings in a post-earthquake situation. This could feature the same building design to the three significantly differing fire resistance design eras of pre-1965, 1965 to 1991 and post-91. Part of such a project could involve review of the pro-active building regulatory approach for fire following earthquake adopted by cities such as Vancouver.

Development of an education programme is recommended to increase understanding of the impacts and consequences, and to enable movement from short-term community awareness to long-term community resilience. Such a programme needs to have input from social and behavioural sciences.

It is considered that the adoption of a structured short- and medium-term operational planning process as recommended above will generate specifically focused research projects.

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