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**Physical and social impacts of past and future
volcanic eruptions in New Zealand**

**A thesis presented in partial fulfilment of
the requirements for the degree of
Doctor of Philosophy
in Earth Science**

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September 1997

ABSTRACT

The North Island of New Zealand contains a number of active and potentially active volcanoes. Although the probability of an eruption affecting a significant portion of the North Island is relatively low in any one year, the probability of one occurring in the future is high. The potential impacts of a large eruption are significant and the risk cannot be ignored. The timing of the next eruption cannot yet be determined but its probable effects can reasonably be assessed.

The 1945 eruption of Mount Ruapehu dispersed ash over a wide area of the North Island over a period of several months. Individual ash falls were only a few millimetres thick in communities closest to the volcano (< 50 km) and trace amounts in communities farther away. Ash falls were mostly of nuisance value in affected communities, causing minor eye and throat irritations, soiling interiors of houses and damaging paintwork. More significant impacts included crop damage, low wool quality on farms close to the mountain, disruption to skiing, the removal of army vehicles from Waiouru and numerous disruptions to water and electricity supplies. The 1995-1996 eruptions caused similar physical effects to the 1945 eruption but had considerably greater social and economic impacts. Over the past 50 years the risk has increased significantly due to an increased population, higher visitor usage and a more technologically advanced infrastructure. With increasing development and population growth the risk from similar or larger eruptions will continue to increase.

A community's infrastructure provides the services and linkages which allow society to function. These 'lifelines', involving electricity, water, sewerage and roading, are vulnerable to damage and/or disruption from a range of volcanic hazards. The most threatening hazards include pyroclastic falls, pyroclastic flows and surges, lava extrusions (flows and domes), lahars, debris avalanches and volcanic gases. Unfortunately there are very few quantitative measurements of the impacts of volcanic eruptions on community 'lifelines'. With direct observations of eruption impacts, combined with theoretical considerations, it is possible to form a conceptual model of the likely impacts of a given event. These can then be used to predict likely effects, which may then be utilised in risk analysis (and scenarios).

Two eruption scenarios are considered: 1) a 0.1 km³ andesitic eruption of Ruapehu composite volcano during a northwesterly wind, affecting Hastings District; 2) a 4 km³ rhyolitic eruption from the Okataina caldera during a westerly wind, affecting Whakatane District. The choice of scenarios is designed to illustrate the contrast between a disruptive moderate-sized eruption from a cone volcano (Ruapehu) and the destructive impacts of a large caldera eruption (Okataina). The Ruapehu scenario will have disruptive short term impacts on Hastings District, with the recovery process spontaneous, immediate and rapid. The infrastructure of Whakatane will be severely damaged by the Okataina eruption scenario and suffer effects for many years. The social and economic impacts of both scenarios will be determined not only by direct physical consequences but also by the interaction of social and economic factors.

Residents of both Whakatane and Hastings were surveyed in February 1995 to measure their understanding of volcanic hazards. This was repeated following the Ruapehu eruptions in November 1995. Few residents have copies of specific volcanic hazard information and few have undertaken any form of information searching prior to the 1995 Ruapehu eruption. The 1995 eruption resulted in a small increase in the numbers searching for information on volcanic hazards in both communities. Although some agencies are perceived as more credible than others as the source of volcanic hazard information, no one agency has a monopoly on perceived credibility (i.e. different people recognise different agencies as the best source of information on volcanic hazard information and warnings). During the 1995 Ruapehu eruption the media (TV, radio and newspaper) were the principal sources of information about what was happening. Different people rely on different channels for information and this should also be acknowledged when issuing warnings and releasing public information. Whakatane and Hastings supply interesting contrasts. Both were subjected to intense media coverage during the 1995 Ruapehu eruption, but Whakatane was spared any direct effects, whereas Hastings experienced the hazard directly, in the form of ash falls in September and October 1995. Only Hastings' respondents showed a significant change in the perceived volcanic threat. However, even though there was no significant change in the perception of volcanic threat in Whakatane, residents still continued to perceive the volcanic threat as being higher than Hastings residents. Experiencing the direct and indirect impacts of the 1995 Ruapehu eruption may make subsequent warnings and information releases more salient, thereby enhancing the likelihood of engaging in protective actions or other forms of response. This is likely to be the case for those individuals and organisations that experienced the greatest impacts. However, the relatively benign impacts may make many prone to a "normalisation bias", whereby individuals or organisations believe that the volcanic eruptions did not affect them negatively, therefore the negative impacts of future volcanic events will also avoid them. This may be prevalent in communities close to Ruapehu which escaped the direct ash falls as a consequence of favourable wind directions. This conclusion suggests that the 1995-1996 Ruapehu eruptions may have both improved and reduced individual, organisational and community preparedness for future volcanic events.

ACKNOWLEDGEMENTS

My first thanks must go to Bruce Houghton and Vince Neall for supporting the initial idea and for setting up the structure that allowed the project to start. I am also grateful for their continuing support, helpful guidance and assistance over the entire course of my study. My other supervisors, Nigel Long and Chin Dew Lai, have also provided valuable support and practical help throughout the project, for which I am appreciative.

I would like to thank the Institute of Geological & Nuclear Sciences for providing a three year studentship to allow me to study at Massey University. I am also grateful for the financial assistance provided by the Ministry of Civil Defence, Environment BoP, Hawke's Bay Regional Council, Whakatane District Council, Hastings District Council and Telecom New Zealand.

Over the past three and half years many individuals and organisations have provided me with information for the project and for this I am grateful. I would also like to thank Mike Elliot, Russ Martin, Carol MacDonald, Douglas Paton, Kevin Ronan, Alan Hull, Colin Wilson, Ian Nairn, Brad Scott, Michele Daly, Brent Alloway, Ian Smith, Chris Boswell and Neil Britton for useful discussions on many aspects of my project.

Any acknowledgements would not be complete without a special mention of Ruapehu. The timely eruptions of 1995 and 1996 created a unique and unplanned opportunity for me to build on the research that had been completed up to that time.

My final thanks must go to the support I received from family and friends during the past few years. Without their support the road would have been longer and the hills higher.

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CHAPTER 1

INTRODUCTION

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1.1 INTRODUCTION

The North Island of New Zealand contains a number of active and potentially active volcanoes (Fig 1.1). Although the probability of an eruption affecting a significant portion of the North Island is relatively low in any one year, the probability of one occurring in the future is high. The potential impacts of a large eruption are significant and the risk cannot be ignored. The timing of the next eruption cannot yet be determined but its probable effects can reasonably be assessed. Recent eruptions overseas, such as Mount Unzen in 1991-1995, Mount Pinatubo in 1991, and Rabaul in 1994 have demonstrated the devastating impacts of volcanic activity on nearby landscapes and communities. Even the 1995-1996 Ruapehu eruptions, although small by world standards, highlighted the vulnerability of society to even small eruptions. Volcanic crises must be planned for using a comprehensive emergency management approach that links mitigation, preparedness, education, response and recovery.

1.2 SCOPE OF THIS THESIS

This thesis aims to investigate a number of issues related to the physical and social impacts of past and future volcanic eruptions in New Zealand. It is divided into four parts: 1) investigations into the physical and social impacts of the 1945 and 1995-1996 Ruapehu eruptions; 2) assessment of potential impacts of two eruption scenarios on two North Island communities (in Hastings and Whakatane); 3) measurements of community understanding and perceptions of volcanic risk in the same two communities (Hastings and Whakatane) before and after the 1995 Ruapehu eruptions; and 4) a review of volcanic hazard management issues in New Zealand.

PART 1 THE PHYSICAL AND SOCIAL IMPACTS OF THE 1945 AND 1995-1996 RUAPEHU ERUPTIONS

In **Chapter 2** an assessment of the physical and social impacts of the 1945 eruption is detailed for the first time. Previous accounts have concentrated on an eruptive narrative but little has been published about the effects on North Island communities beyond newspaper accounts of the time. The chapter discusses the eruption in the context of impacts on society and the environment and attempts to bring together a previously dispersed set of references recording the eruption. In addition, **Appendix 1** presents a daily summary of observations of the 1945 eruption and **Appendix 2** provides a photographic record of many previously unpublished photos. The eruptions of Ruapehu in 1995 and 1996 have provided an opportunity to compare the impacts of a similar eruption sequence on a more technologically advanced society. A summary of the effects of the recent eruptions is given, along with a discussion on specific aspects of hazard management during the crisis.

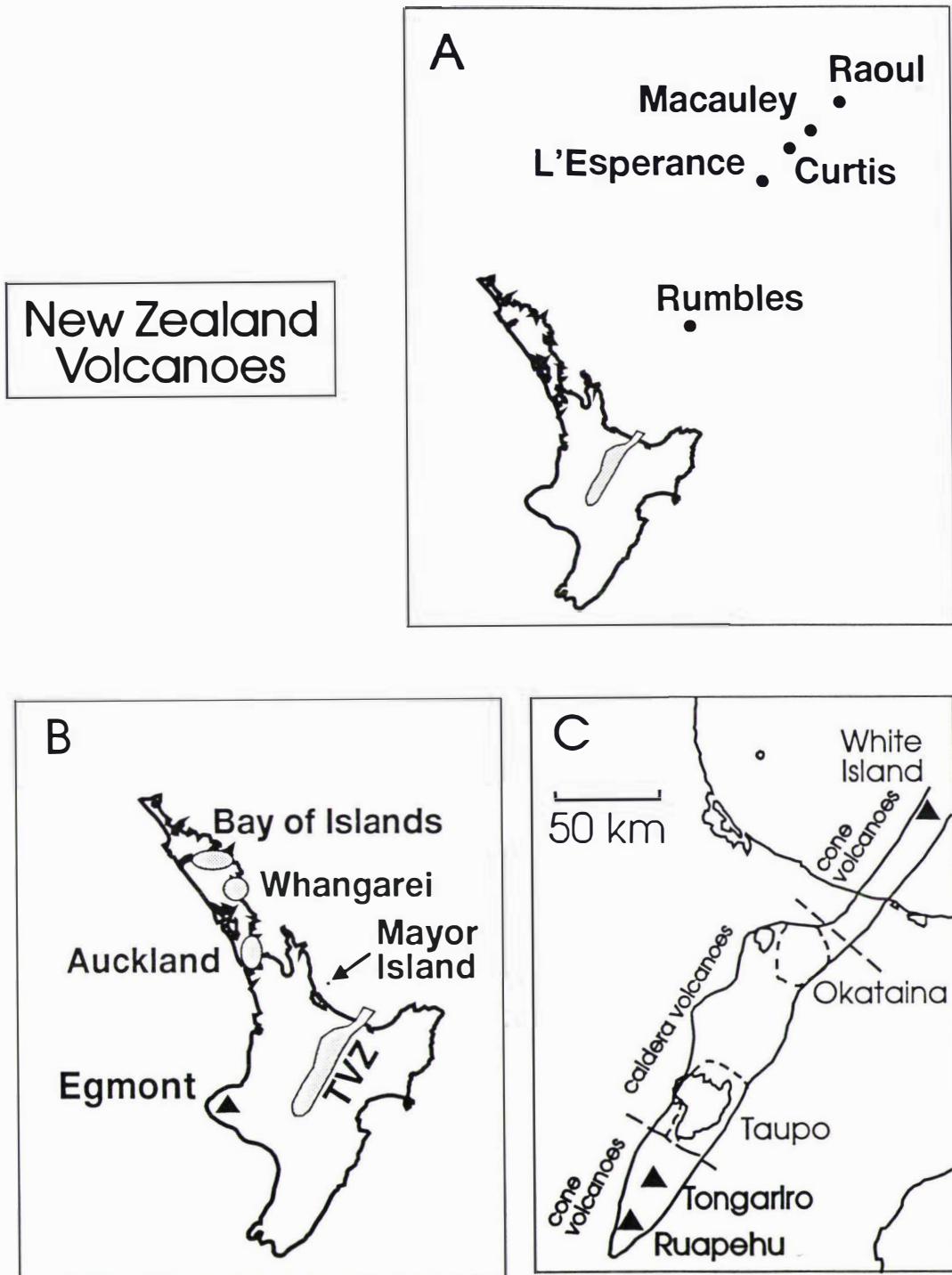


FIGURE 1.1 Maps showing the locations of the young volcanoes in New Zealand

- (a) Main map of the positions of the Kermadec Islands (Raoul, McCauley, Curtis, L'Esperance) relative to the North and South Island.
- (b) Location of volcanic fields in Northland (Bay of Islands and Whangarei) and Auckland (ovals), the cone volcano of Egmont, caldera volcano of Mayor Island, and the Taupo Volcanic Zone (TVZ).
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PART 2 POTENTIAL IMPACTS OF TWO ERUPTION SCENARIOS ON TWO NORTH ISLAND COMMUNITIES

A community's infrastructure provides the services and linkages which allow society to function. These 'lifelines', involving electricity, water, sewerage and roading, are vulnerable to damage and/or disruption from a range of volcanic hazards. The most threatening hazards include pyroclastic falls, pyroclastic flows and surges, lava extrusions (flows and domes), lahars, debris avalanches and volcanic gases. In **Chapter 3** a detailed review of impacts is presented. Pyroclastic falls have the most variable impacts since volcanic ash can be deposited hundreds to thousands of kilometres from source, making it the product most likely to affect the largest area and the greatest number of people. Ash falls are therefore the principal focus of the chapter. Unfortunately there are very few quantitative measurements of the impacts of volcanic eruptions on community 'lifelines'. With direct observations of eruption impacts, combined with theoretical considerations, it is possible to form a conceptual model of the likely impacts of a given event. These models can then be used to predict likely effects, which may then be utilised in risk analysis (and scenarios).

Chapter 4 develops a simple semi-quantitative vulnerability assessment methodology for analysing the risk to 'lifelines' from volcanic ash. The methodology is adapted from those used in other 'lifelines' studies in Australasia, but is the first to consider volcanic hazards. An exploratory scenario methodology is also developed for use in later chapters.

In order to predict the distribution of volcanic ash falls a number of computer ash fall models have been developed and are now currently available. The program ASHFALL is used in **Chapter 5** to generate ash fall isopach maps for two eruption scenarios, developed in the following chapters. The input parameters for the model are derived from analysis of past eruptions and actual meteorological observations from the central North Island.

Chapters 6 and 7 develop two eruption scenarios: 1) a 0.1 km³ andesitic eruption of Ruapehu composite volcano during a northwesterly wind, affecting Hastings District; 2) a 4 km³ rhyolitic eruption from the Okataina caldera during a westerly wind, affecting Whakatane District. The choice of scenarios is designed to illustrate the contrast between a disruptive moderate-sized eruption from a cone volcano (Ruapehu) and the destructive impacts of a large caldera eruption (Okataina). In both communities (see Fig. 1.2) two risk assessments are undertaken: 1) the general vulnerability of key utilities to ash falls; 2) the vulnerability of the same utilities to the specific eruption scenario.

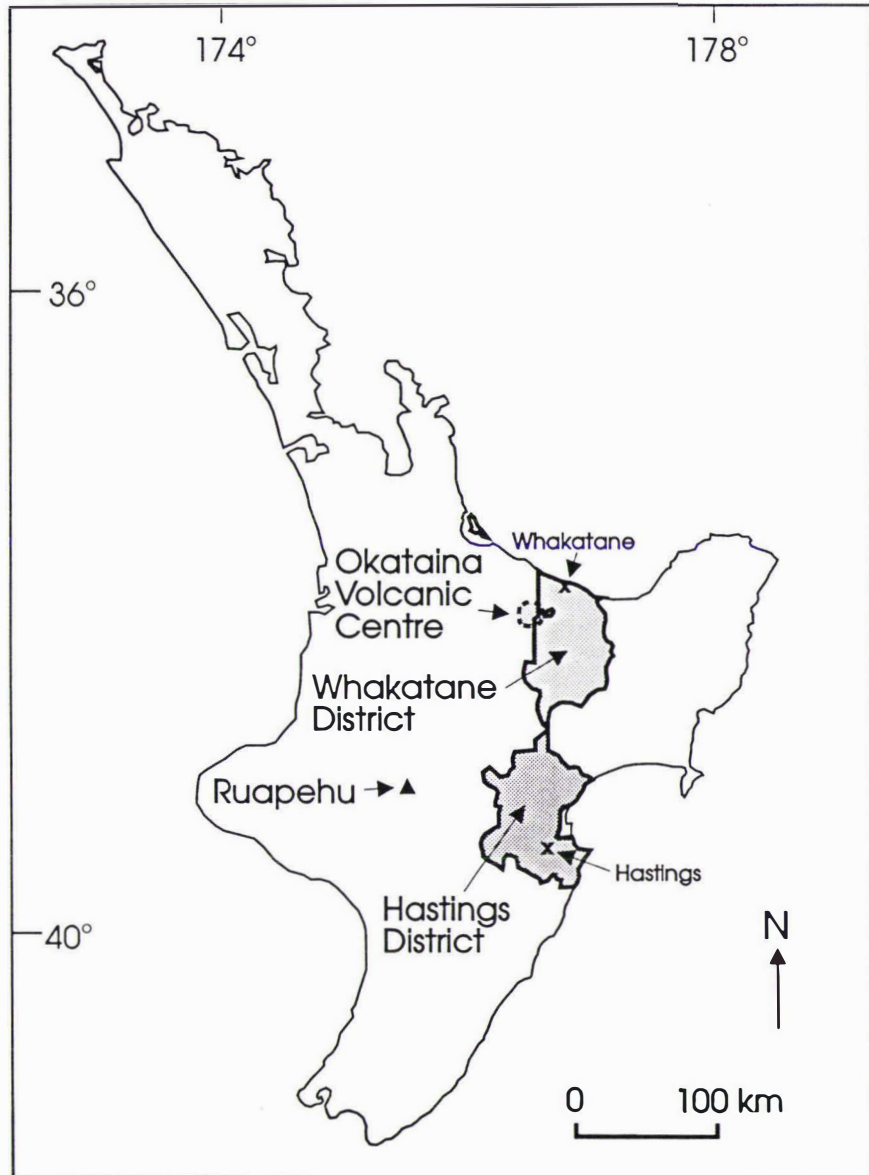


FIGURE 1.2 Location map of Whakatane and Hastings districts (and towns) relative to the Okataina Volcanic Centre and Ruapehu volcano.

PART 3 COMMUNITY UNDERSTANDING AND PERCEPTIONS OF VOLCANIC RISK IN TWO NORTH ISLAND COMMUNITIES

Chapter 8 examines changes in perceptions in two communities as a consequence of the 1995 eruptions of Ruapehu involving the largest volcanic event in New Zealand this century. It utilises a unique and unplanned opportunity to test the effect of a large natural event on a population's perceptions of natural hazards. The original survey was conducted in February 1995 in the Hastings and Whakatane towns, evaluating individuals' hazard knowledge and perceptions of volcanic risk and documenting individuals' sources of volcanic hazard information and the perceived credibility of each information source. A repeat of the survey was undertaken in November 1995 to establish the immediate effect of the 1995 Ruapehu eruption on perceptions, awareness and response in these communities. Whakatane and Hastings provide an interesting contrast. Both localities were subjected to intense media coverage about the eruptions. Whakatane was spared any direct effects, whereas Hastings experienced ash fall in September and October 1995. A copy of both questionnaires is provided in **Appendix 4**.

PART 4 REVIEW OF VOLCANIC HAZARD MANAGEMENT ISSUES IN NEW ZEALAND

The aim of **Chapter 9** is to identify and review significant issues that need to be considered in developing a response to a volcanic crisis affecting New Zealand. Most volcanoes have long intervals of repose between damaging eruptions ranging from years to many centuries. The management of volcanic hazards can therefore be divided into two distinct time frames: non-crisis and crisis times. Non-crisis or quiescent times represent the most common situation and afford the best opportunity to develop mitigation strategies and prepare society for an eruption. This chapter outlines a number of principles that should be considered in preparing volcanic contingency plans and is based on findings presented in the previous chapters together with a review of the general emergency management literature. It seeks to illustrate the links between specific volcanic hazard management issues and a wider "all hazards" approach to emergency management.

CHAPTER 2

IMPACTS OF THE 1945 AND 1995-1996 ERUPTIONS
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2.1 INTRODUCTION

Ruapehu is an active, multivent, andesite composite volcano in the central North Island, New Zealand (Houghton *et al.* 1987). The sole active vent is occupied by Crater Lake. Phreatic and phreatomagmatic events have been common in historical times without significant modification to the lake. The only periods in which the lake has been temporarily absent are during and following the 1945 and 1995-1996 eruptions. A more detailed description of the geological history of Ruapehu volcano is presented in Chapter 7.

The 1945 and 1995-1996 eruptions were relatively small in comparison to many past eruptions. Over the last 1800 years, 18 distinct tephras from Ruapehu are preserved in the cover bed stratigraphy on the southeastern ring plain, but none in the past c. 150 years (Donoghue *et al.* 1995).

2.2 THE 1945 ERUPTION

Previous accounts by Reed (1945), Oliver (1945), Cotton (1945, 1946), Beck (1950) and Gregg (1960) concentrated on an eruptive narrative but little was published about the effects on North Island communities beyond the newspapers of the time. The following section discusses the eruption with an emphasis on the impacts on society and the environment. It has been compiled from newspapers, published articles, letters and telegrams, and attempts to bring together a previously dispersed set of references recording the eruption. Appendix 1 presents a daily summary of observations of the 1945 eruption.

2.2.1 The eruption

The first activity in 1945 was noticed on 8 March, when the pilot of a Union Airways plane, en route to Wellington, reported a long plume of steam originating from the crater (*New Zealand Herald*, 12 March 1945). This was confirmed by staff at the Waiouru Military Camp on the same day. Further steam discharges were observed up until 19 March when a lava dome was first seen emergent from the crater lake (Reed 1945). Activity increased with the continued growth of this dome accompanied by high eruption plumes of steam observed from as far away as Palmerston North and Wanganui (*Manawatu Evening Standard*, 19 March 1945).

Mild but spectacular explosive eruptions were seen on the 26 March, with Taupo residents describing an explosion in the afternoon which sent a plume of steam to 2500 m above the mountain (Reed 1945). The following day a steaming Crater Lake was observed but the lava dome had disappeared. Activity remained relatively quiet throughout April with sporadic

expulsions of water, ash and mud from the lake (*Auckland Star*, 16 April 1945).

A second larger dome was first observed on 7 May, growing at the same location as the first dome (*Dominion*, 10 May 1945). During the first two weeks of May steam and ash were emitted in a continuous plume, and loud rumblings were heard in communities around the mountain (*Dominion*, 15 April 1945). The growth of the lava dome appeared to stop during the latter half of May. Visitors to Crater Lake on 2 June described the once growing lava dome as now reduced to a circular reef in the middle of the lake (*The Dominion*, 26 June 1945). On 17 June activity increased with a large ash and steam plume observed above the crater from Ohakune in the evening (*Ohakune Times*, 22 June 1945). The first ash falls to be recorded away from the cone (Fig. 2.1) were reported on 19 June in Taupo (*The Bulletin of the Ruapehu Ski Club*, 30 September 1945).

The lava dome grew steadily through the rest of June, slowly and progressively displacing the entire crater lake (*Ohakune Times*, 22 June 1945). There was a change in eruptive style during July with a series of increasingly violent explosive eruptions that produced plumes of steam and ash higher than in previous months. In August and early September the large explosive eruptions sent ash and steam columns high above the mountain. Accompanying rumbling noises were heard far from the mountain during a number of these explosive events. The prevailing winds dispersed this ash up to 250 km downwind, as far away as Upper Hutt, Wanganui, Whakatane and Opotiki (refer Appendix 1). Numerous ash falls coated Ohakune, Waiouru, Hawke's Bay and the Chateau.

Visitors to the crater area on 17 August 1945 described three vents: a main vent towards the eastern rim of the crater emitting ash and steam, and two smaller steam vents to the west. Intermittent explosions were observed ejecting ash, ballistic blocks and steam in columns that rose several thousand metres above the crater, often with lightning discharges within the plumes. Activity appeared to reach its peak on 21-22 August 1945 (Beck 1950).

During September activity remained at a moderate level with continuing emission of steam and ash and the enlargement of the main vent. The intensity of activity increased on 27 September 1945 with a number of large explosions, again producing a high eruption column and dispersing ash over a wide area. During October ash fell in Taupo, Rotorua, Whakatane, Napier and Hastings, as well as on communities around the base of the cone.

Explosive eruptions continued into November and early December with Waiouru, Ohakune, the Chateau and Hawke's Bay receiving most of the ash falls (refer Table 2.1 and Appendix 1).

The last reported ash falls to affect Napier and Hastings were reported on 6 December (*Hawke's Bay Herald-Tribune*, 6 December 1945) and only intermittent activity occurred thereafter. The last strong explosive event occurred on 15 December and only small amounts of ash and steam issued from the crater during the remainder of December (J. Healy, unpublished report to New Zealand Geological Survey, 31 December 1945).

After the cessation of explosive activity the crater consisted of a steep walled vent about 300 m deep, occupied by a hot turbulent lake. The crater lake gradually refilled and by 1953 it had returned to approximately its previous level (O'Shea 1954).

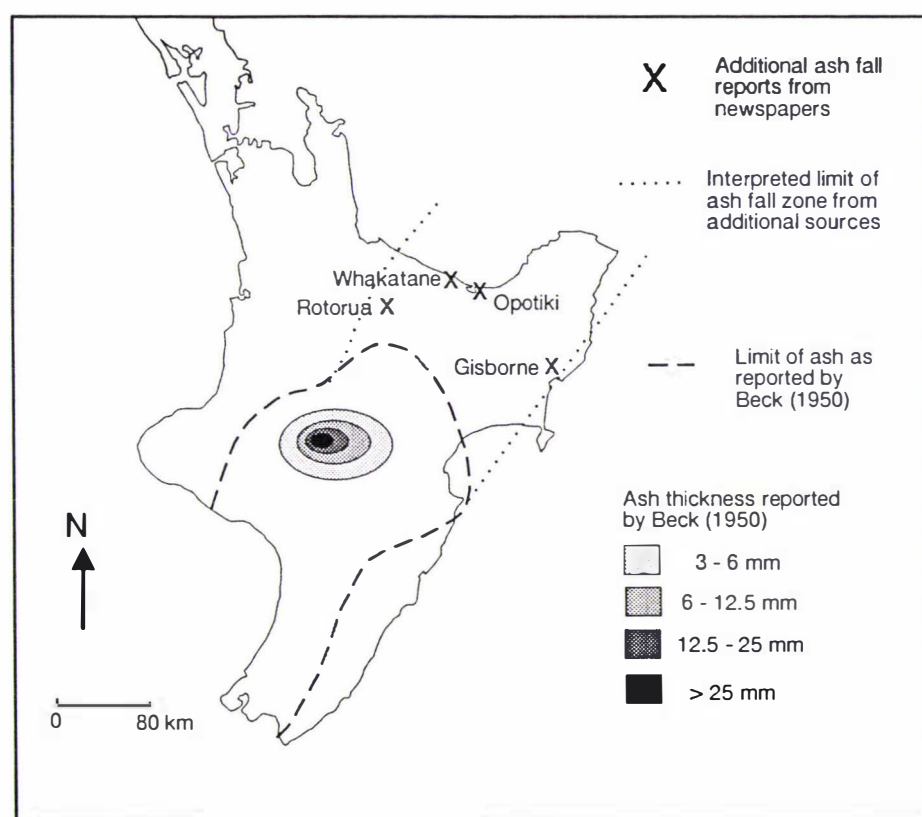


FIGURE 2.1 The distribution of reported ash falls from the 1945 eruption of Ruapehu volcano.

TABLE 2.1 Reported ash falls on North Island towns in 1945.

Town	Date of Reported Ash Fall	Reference	Note
Whakatane	5-7 October	Bay of Plenty Beacon, 9 October 1945	town "almost snow-white" under ash
Opotiki	6 October 20 November	Opotiki News, 9 October 1945 Opotiki News, 20 November 1945	"fine deposit of dust" observed
Rotorua	21 August 9 October	Rotorua Morning Post, 22 August 1945 New Zealand Herald, 9 October 1945	"traces of volcanic ash" "grey deposit lightly dusting"
Taupo	19 June 17 August 19 August 1 October 6 October 9 October 10 October 24 October	New Zealand Herald, 20 June 1945 New Zealand Herald, 18 August 1945 Letter to N.Z Geol. Surv. from R.Ward. New Zealand Herald, 2 October 1945 New Zealand Herald, 8 October 1945 Dominion, 10 October 1945 Daily Telegraph, 10 October 1945 NZ Herald, 25 October 1945	"light dusting of ash" "heavy coating of ash" light coating of ash heavy dusting of ash heavy fall of ash "quantities of dry grey ash" "quantities of dry ash" "coated in heavy dusting overnight"
The Chateau	27 June 27 July 31 July 2 August 17 August 17 September 30 September 1 October 15 October 19 October 20 October 21 October	Ruapehu Ski Club Bulletin, September 1945 Auckland Star, 28 July 1945 Wanganui Chronicle, 31 July 1945 GNS file Letter to Geol.Surv. from Beck, 17 August 1945 Wanganui Herald, 17 September 1945 Wanganui Herald, 2 October 1945 GNS file GNS file Wanganui Herald, 22 October 1945 Letter to Geol Surv. from Beck 23 October 1945 Letter to Geol Surv. from Beck 23 October 1945	"dust .. fell ..throughout the day" ash covered the snow ash deposits form "graphite-like" substance Chateau downpipes blocked "heavy coating of ash" "heavy shower "of ash 1/8 inch of ash "ash laden wind" "ash laden wind"
Ohakune	24 June 28 June 30 June 24 July 31 July 5 August 6 August 21-22 August 25 August 26 August 27 August 28 September 27-30 September	Wanganui Herald, 25 June 1945 Wanganui Herald, 29 June 1945 Taranaki Herald, 3 July 1945 Waimarino Call, 24 July 1945 Wanganui Chronicle, 31 July 1945 Dominion, 6 August 1945 New Zealand Herald, 9 August 1945 Dominion, 23 August 1945 Auckland Star, 25 August 1945 Wairapa Times Age, 27 August 1945 Telegram to Geol.Sur. from Fyfe, 27 August 1945 Wanganui Herald, 28 September 1945 Wanganui Herald, 29 September 1945	"liberal coating of volcanic ash" ash fall overnight " fall of ash" "paddocks grey in Hihitahi area" 1/8 inch of ash ash falling at intervals since 22 August "ash still falling" fine ash falling
Waiouru	29 June 4 August 5 August 7 August 17 August 12-13 November	Wanganui Herald, 29 June 1945 Taranaki Herald, 7 August 1945 Dominion, 6 August 1945 Dominion, 8 August 1945 Letter to Geol. Surv. from Beck, 17 August 1945 Dominion, 14 November 1945	"liberal coating" heavy falls several fairly heavy falls over past few days ash falls force removal of vehicles

TABLE 2.1
Cont.

Taihape	2 August	Dominion, 8 August 1945	"heavy ashfalls"
	4 August	Dominion, 8 August 1945	
	5 August	Dominion, 9 August 1945	"ash falling heavily"
	6 August	New Zealand Herald, 9 August 1945	
Napier - Hastings - Hawke's Bay	26 July	Auckland Star, 28 July 1945	ash "noted in Hawke's Bay"
	27 July	Auckland Star, 28 July 1945	ash "noted in Hawke's Bay"
	8 August	Daily Telegraph, 8 August 1945	"light dust-like coating"
	9 August	Daily Telegraph, 9 August 1945	ash deposited over Hawke's Bay
	12 August	Dominion, 13 August 1945	ash made streets hazy
	15 August	Dominion, 22 August 1945	ash falls on Hawke's Bay
	10 October	Daily Telegraph, 10 October 1945	ash reported in Napier
	14 October	Dominion, 16 October 1945	streets heavily coated
	29-30 October	Daily Telegraph, 31 October 1945	plentiful supply of "Ruapehu dust"
	2-3 November	New Zealand Herald, 16 November 1945	ash descends over Napier-Hastings
	10 November	Daily Telegraph, 10 November 1945	ash on Hastings and district
	12 - 13 November	Dominion, 14 Nov. 1945	ash falls on Napier
	20 November	Daily Telegraph, 21 November 1945	ash reported falling in Hastings
	1 December	Daily Telegraph, 1 December 1945	ash falls in Napier
3 December	Daily Telegraph, 3 December 1945	ash falls in Hastings	
6 December	Hawke's Bay Herald-Tribune, 6 December 1945	Napier coated with grey ash	
Wanganui	30 June	Taranaki Herald, 3 August 1945	"coating of fine dust"
	22 August	Wanganui Herald, 23 August 1945	coating of grey dust
Palmerston North	25-26 August	Manatawu Evening Standard, 27 August 1945	"ash fell in Palmerston North at the weekend"
Wellington	23 August	Dominion, 24 August 1945	fine grey dust on Hutt Valley

2.2.2 Ash fall impacts

Public health effects

Ash falls proved to be mostly a nuisance, with eye and throat irritations reported in most ash-affected communities from June to December 1945. During heavy ash falls descriptions of "*most people remaining indoors*" were recorded (e.g. Taupo, 6 October; *New Zealand Herald*, 8 October 1945). Frequent ash falls in Napier and Hastings brought about the term "*Ruapehu throat*" (*NZ Herald*, 16 November 1945) with hundreds of cases reported to doctors and chemists. One newspaper reported that sunglasses were in demand in the Hawke's Bay, to prevent eye irritations (*Dominion*, 14 November 1945).

Ejected blocks posed a hazard close to the active vent (<1 km). The most serious injuries of the eruption period occurred on 1 July when two trampers, who had camped the night near the crater, witnessed an explosion which showered them with hot rocks. Both received burns and one was knocked unconscious (*New Zealand Herald*, 3 July 1945). A group of sightseers on the Dome were peppered by small blocks and lapilli on the 1 September 1945, after an explosion from the crater, but no injuries were reported (Letter to Director of New Zealand Geological Survey from A. Beck and H. Fyfe, 2 September 1945).

The increased activity in the first week of August caused some concern in communities around the mountain (*Dominion*, 6 August 1945). Authorities in Ohakune and Waiouru made arrangements for a possible evacuation, although this was never necessary.

Agriculture

A number of occurrences of crop damage were recorded during the eruption. Around Ohakune ash falls in August caused rotting of cabbages (*New Zealand Herald*, 22 August 1945). One commercial gardener at Rangataua reported that he had lost an acre of Brussels sprouts (*Wanganui Herald*, 6 August 1945). Further reports from Ohakune, in October, describe that "*vegetables were well impregnated with ash and needed a thorough washing before cooking*" (*Wanganui Herald*, 8 October 1945). In November market gardeners from the same area reported "*the ash is having a disastrous effect on growing vegetables, causing rotting among cabbages in particular. The rot pierces right to the heart of the cabbage and market gardening is becoming a problem*" (*Taumarunui Press*, 21 November, 1945).

Pastures covered by ash were often described as being unpalatable to stock but no significant pasture damage occurred. No stock losses due to lack of feed were reported. Cunningham (1946) reports on tests carried out on rats, where they were fed the ash at up to 40% by weight of their food ration over a five week period and yielded no obvious ill-effects. In

another set of tests a sheep and cow were drenched twice daily for 23 days with 30 g of ash in water and again no obvious effects on animal health were observed. The *Waikato Times* on 8 January 1946 reported speculation about possible stock losses and reduced butter fat production in ash-affected areas of the central King Country. The paper describes "*that the stomach of a bullock killed near Turangi was found to contain about 10 lb of the ash*". Farmers in the Taihape area reported that ash found in the wool of sheep during shearing had reduced its quality and caused blunting of hand-shears (D. Livingston *pers.comm.*).

Transportation

Reduced visibility on roads was common. On 12 August falling ash made street lights hazy in Hastings and whitened roads (*Dominion*, 13 August 1945). Recently-deposited ash was easily lifted by passing vehicles. During ash falls in Wanganui on 22 August 1945 vehicles using the streets "*raised dust almost to the same extent as though travelling on an unsealed highway*" (*Manawatu Evening Standard*, 23 August 1945). Reduced speeds were a common consequence of ash on roads. In fact on the Desert Road one driver was forced to reduce his speed to 15 mph (*Wanganui Herald*, 5 November 1945).

The New Zealand Automobile Association warned motorists to "*treat the ash with the greatest respect as it has a high abrasion value and can destroy paintwork. A dry rag should not be used*" (*Evening Post*, 27 August 1945). Despite warnings, damage to vehicle paintwork was commonly reported. Windscreen abrasion also occurred when wipers were used on ash-covered windscreens. (*Wanganui Herald*, 8 August 1945). On 17 October 1945, ash falling with rain caused problems for a bus en route to the Chateau blocking its windscreen wipers (*Wanganui Herald*, 22 October 1945). Two days later further problems were reported "*on the return trip the driver stopped to see whether his lights had failed, but discovered ash was so thick on the headlamps that they were blacked out.*"

During November the New Zealand Army moved some 700 vehicles from Waiouru to Linton due to the deleterious effect of the acidic ash on the canvas tops of vehicles and its reported corrosive effects on metal (*New Zealand Herald*, 13 November 1945; *Dominion*, 14 November 1945).

Water and Electricity Supplies

Contaminated domestic water tanks were reported in a number of cases when households failed to disconnect their downpipes prior to ash falls (*Wanganui Herald*, 24 August 1945). On the 22 August 1945 the Ohakune fire brigade was reported to be busy filling home water tanks with river water after an ash fall (*Auckland Star*, 25 August 1945).

On 23 November 1945 Taumarunui's water supply was disrupted by the large quantity of ash being carried in the Wanganui River, the sediment blocking water intake filters. Pumping was reduced from 20 000 gallons/hour to 7000 gallons/hour due to the high turbidity of the river water. Eventually filtration became impossible and pumping ceased (*Taumarunui Press*, 23 November 1945). By the following day water quality had improved sufficiently for pumping to resume but the public was advised to boil water for a few days (*Taumarunui Press*, 24 November 1945).

At the Chateau Tongariro, which was a hospital at the time, numerous disruptions to both water and electricity supply were reported over several months due to ash in the streams feeding the water supply and ash in the electricity generating plant. Staff members report that the fine ash in the stream made the filters useless and water was no longer able to pass through the settling ponds. Taken directly from the mountain stream to the hospital the water was described as more like "liquid mud" (*Wanganui Herald*, 23 November 1945). The hospital was eventually forced to close on 22 December, resulting in the relocation of its 180 patients to Raverthorpe Hospital (Nordmeyer 1946; *The Dominion*, 22 December 1945). The reworking of ash further affected the water supply of the Chateau in 1946 (*The NZ Herald*, 23 August 1946) and during the warm summer of 1955 (Houghton *et al.* 1987).

Rivers

The large quantities of ash deposits on the flanks of Ruapehu were easily eroded and resulted in increased turbidity in rivers flowing from the mountain. Few accounts exist of the effects on the ecology of the rivers. On 22 August 1945, the Conservator of Fish and Game, Department of Internal Affairs inspected streams along the Desert Road. Most rivers were found to be running clear despite the large amount of ash on the surrounding country. Only a few streams close to the mountain were found to be carrying ash and were therefore discoloured (*Memorandum for The Under-Secretary, Department of Internal Affairs*, 29 August 1945). Parry (1946) states "*the long-continued eruption of Ruapehu Mountain and resulting deposit of volcanic silt in the Tongariro River and its tributaries also had a detrimental effect on fish and fishing*".

On 13 November 1945 Manawatu Evening Standard reported "*The Wangaehu River, which rises on the slopes of Mt. Ruapehu, was discoloured till it resembled slate on Sunday, said a Palmerston North resident, who had occasion to pass the river. In the shade, the water seemed almost black and it appeared that the river must have gathered great quantities of the grey ash erupted from the mountain in order to carry so much as far as the Wangaehu village near Wanganui.*"

On the eastern side of the mountain high turbidity levels were reported in a number of streams and rivers including those affecting the water and power supplies at the Chateau Tongariro (e.g. *Wanganui Herald*, 23 November 1945) and water supplies in Taumarunui (*Taumarunui Press*, 24 November 1945).

Miscellaneous

The fine ash that fell on communities away from the mountain was generally a nuisance although minor damage was commonly reported. A Napier doctor was quoted in the *Daily Telegraph* (13 November 1945) "*I would say that thousands of pounds of damage is being done to machinery..... Even our watches, clocks and other fine machinery is suffering irreparable damage*". Ash frequently penetrated houses and shops, often soiling carpets and curtains, and causing owners to undertake additional cleaning. In the Ohakune area ash was reported to plaster roofs, windows and flat surfaces like a cement when it got wet. Removal of the resulting deposits was described as difficult (*Wanganui Herald*, 29 September 1945). A common complaint was the soiling of washing hung out to dry.

Ash falls severely disrupted skiing at the Whakapapa skifield. By the end of August skiing was abandoned (*Dominion*, 27 August 1945). The decrease in activity in early September led to the hope conditions would improve but this did not eventuate (*The Bulletin of the Ruapehu Ski Club*, 30 September 1945).

2.2.3 1953 Lahar - Tangiwai Disaster

On 24 December 1953 a portion of the ice, rock and debris barrier formed after the 1945 eruption and confining Crater Lake at a level higher than 1945 suddenly collapsed due to an unproven but clearly non-volcanic reason (O'Shea 1954). Approximately 340 000 m³ of water was released through an ice-cave as the lake was lowered by about 6 m. The waters followed the sinuous course of the Whangaehu River to Tangiwai arriving at about 10.20 pm. The Limited Express was travelling from Wellington to Auckland and when the train was half way across the bridge collapsed with the engine plunging into the opposite bank. Six carriages fell into the lahar and 151 lives were lost in New Zealand's worst railway disaster. One of the carriages was carried 2.4 km downstream and a 125 tonne pier of the bridge was shifted 64 m laterally.

2.3 1995-1996 ERUPTIONS

A new sequence of eruptions began on 18 September 1995 (Bryan *et al.* 1996) followed by a spectacular explosion through Crater Lake on 23 September 1995 which received world wide media coverage. Further significant peaks of activity occurred on 25 September and 7, 11 & 14 October 1995. Eruptions continued through late October and early November. Early eruptions through Crater Lake generated lahars down the Whangaehu, Whakapapaiti, Wahianoa and Mangaturuturu rivers, with over 90% of the volume of the lahar material flowing down the Whangaehu River in 35 lahars (Cronin *et al.* 1997). Later phreatomagmatic eruptions as the lake disappeared were drier and more sustained and deposited ash up to 250 km from the volcano. During October and November high discharges of sulphur dioxide produced a brown volcanic smog ("vog") covering much of the central and southern North Island. Much of the ejected pyroclastic material was deposited on the flanks of the volcano and was subject to remobilisation during heavy rain. An estimated 19 secondary lahars were produced between October 1995 and May 1996, principally in the Whangaehu catchments as well as the Mangatoetoeui, Whakapapanui, Mangaturuturu and Wahianoa catchments (Hodgson and Manville 1996).

On 15 June 1996 seismic activity resumed and a second sequence of eruptions commenced on 17 June. Over 17-18 June ash fell over a wide sector north and west of Ruapehu. Eruptions continued through July and the first week of August, again spreading ash over much of the North Island (refer to Table 2.2). The last eruptive activity occurred on the evening of 1 September 1996 producing a minor ash fall on the Turoa skifield.

2.3.1 Lahar impacts

During early phases of the eruption lahars were the principal hazard (Fig. 2.2). Most of the lahars, and certainly the larger ones, were confined to the Whangaehu River between 18 September and the end of October 1995. Lahars had a major impact on the river's channel, in places actively degrading the channel by 5 m and in most places aggrading the channel by up to 2 m. The 18 September 1995 lahar removed a foot-bridge on the "round-the-mountain" track. On 25 September 1995 lahars caused irreparable damage to ECNZ's monitoring gauge at the foot of the volcano and silted up Tranz Rail's lahar warning gauge (Fig. 2.3). Lahars destroyed a concrete ford used for access to the Wahianoa aqueduct and damaged siphon pipes on the aqueduct beneath the river. Realignment work and replacement of the ford has cost ~\$250 000. Due to river aggradation the river channel has eroded a steep cliffside across which the Whangaehu Valley Road crosses and \$35 000 has been expended on repairs by the Ruapehu District Council. Contamination of the river resulted in shell fish deaths on the Wanganui coast just north of the mouth of the Whangaehu River (*Wanganui Chronicle*, 30

September 1995).

The 23 September explosions also produced lahars in the Mangaturuturu and the Whakapapaiti catchments. The Mangaturuturu lahar killed fish in that stream and in the Manganuioteao River, which it feeds (Maxwell 1996). The Whakapapaiti lahars passed through one of three skifields at Ruapehu (Fig. 2.3). Fortunately the ski-field had closed one hour earlier and was largely deserted. The lahar passed within two metres of a t-bar drive station and through an area where skiers form queues for the lift.

On 28 October a lahar was triggered by heavy rainfall and consequent remobilisation of pyroclastic fall deposits on the flanks of the volcano. This descended the Mangatoetoeu Stream and destroyed a second foot-bridge on the "round-the-mountain" track (Manville & Hodgson 1996).

Electricity generation

Remobilisation of ash during the 1995 spring melt and by secondary lahars during periods of heavy rain has had a major ongoing impact at the Rangipo hydro-electric power station which normally supplies 120 MW of power. Ash washed into the upper Tongariro River from the Mangatoetoeu Stream, upstream from the Rangipo intake, entered the intake structure causing considerable abrasion damage to the station's turbines (Malcolm & van Rossen 1997). This was first noticed on 22 December 1995 and by 25 April 1996 both turbines had been shut down. The total value of loss of generation is estimated in excess of \$12 million. Loss of generation has also occurred when water was diverted to the river's natural course in an attempt to flush out ash from above the intake. It has been estimated that 5 tonnes of sediment had passed through the turbines and in seven months 15 years of the turbine life was lost. New ceramic and plasma-nitride-coated stainless steel blades have been installed at a cost of around \$6 million and are designed to resist wear. A large volume of tephra still remains in the river's catchment and will continue to be released during heavy rain falls, although the supply will diminish with time. ECNZ has investigated a number of additional options for reducing ongoing damage, including interceptor dams, increased filtering, diversion of worst-affected tributaries and re-arrangement of intake points. Turbidity instrumentation has now been installed at the station's intake which is closed when levels are high.

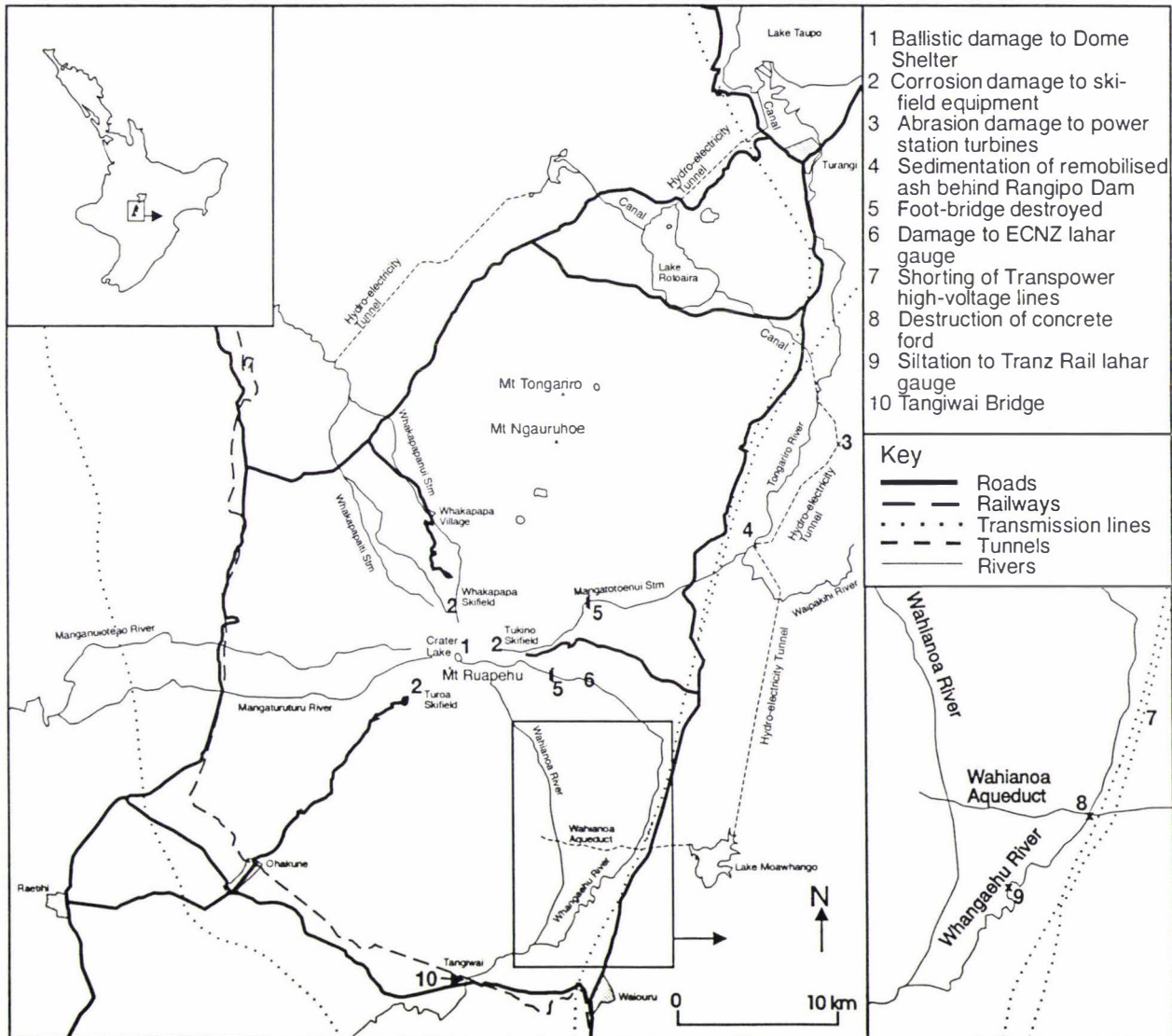


FIGURE 2.2 Map of proximal impact locations from the 1995-1996 eruptions. Impacts at locations 3-6, 8 & 9 are due to lahars.

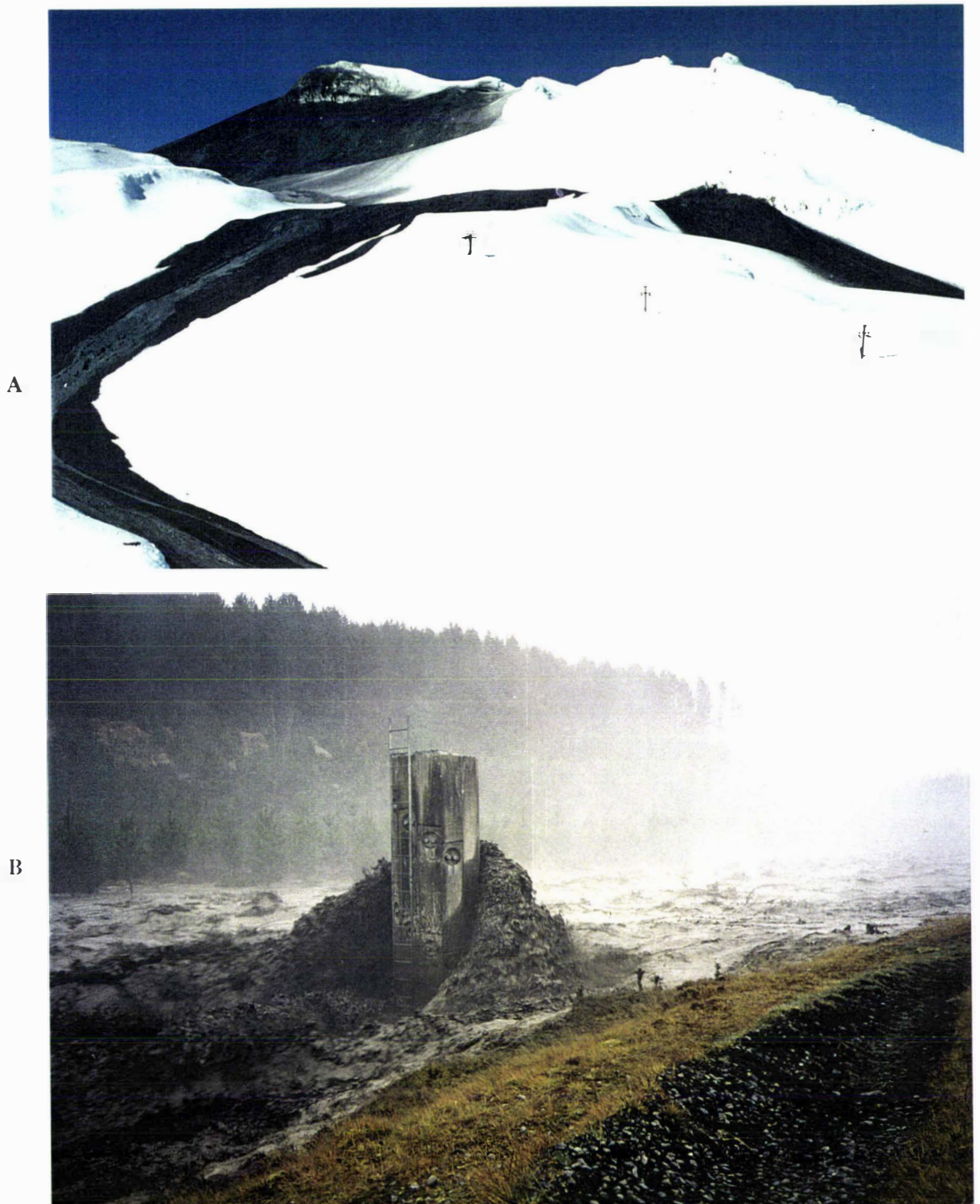


FIGURE 2.3 Lahar impacts from 1995 eruptions.

- A. The lahar deposits from 23 September 1995. The lahar divided into two tongues to flow down valleys on either side of the 'Far West T-bar' on the north-western side of Ruapehu. Photograph: B. Houghton
- B. The Tranz Rail lahar warning gauge in the Whangaehu River early on the morning of 25 September 1995. The concrete tower rises 6.5 m above normal river level. The flow depth is ~2.5 m above normal river level. Photograph: R. Grant.

2.3.2 Ash fall impacts

Volcanic ash falls have had the most widespread effects, spreading ash over much of the North Island. The thickest ash falls resulted from the eruptions of 11-12 & 14 October 1995 and 16-18 June 1996 impacting on more than 20 communities, large areas of agricultural land and unpopulated forest land (Fig. 2.4).

TABLE 2.2 Reported ash falls on North Island towns in 1995-1996.

Town	Date of Reported Ash fall	Reference	Note
Auckland	18 June 1996	GNS file	trace
Hamilton	18 June 1996	GNS file	trace
Whakatane	17 June 1996	GNS file	trace
Opotiki	25 September 1995 12 October 1995	Gisborne Herald, 27 September 1995 GNS Science Alert V95/39	trace 0.25-0.5 mm
Gisborne	25 September 1995 12 October 1995	Gisborne Herald, 27 September 1995 GNS Science Alert V95/39	trace 1 mm
Waipara	25 September 1995 27 September 1995 12 October 1995	Gisborne Herald, 27 September 1995 Gisborne Herald, 28 September 1995 GNS Science Alert V95/39	trace trace 1-2 mm
Rotorua	17 June 1996	GNS file	0.5-1 mm
Taupo	17 June 1996 10 July 1996 20 July 1996 24 July 1996	GNS file GNS Science Alert V96/31 GNS Science Alert V96/45 GNS Science Alert V96/49	trace trace trace trace
The Chateau	3 October 1995 18 June 1996 27 July 1996	GNS Science Alert Bulletin V95/39 GNS file GNS Science Alert Bulletin V96/51	trace trace trace
Iwikau Village	3 October 1995 10 October 1995 11 October 1995 13 October 1995 14 October 1995 18 October 1995 17 June 1996 18 June 1996 8 July 1996 11 July 1996 27 July 1996 30 July 1996	GNS Science Alert Bulletin V95/29 GNS Science Alert Bulletin V95/37 GNS Science Alert Bulletin V95/37 GNS file GNS file GNS Science Alert Bulletin V95/48 GNS file GNS file Manawatu-Wanganui R. C. Ash fall Report GNS Science Alert Bulletin V96/34 GNS Science Alert Bulletin V96/52 GNS Science Alert Bulletin V96/56	trace trace trace trace trace < 1 mm 1 mm 1-2 mm > 1 mm trace trace trace trace

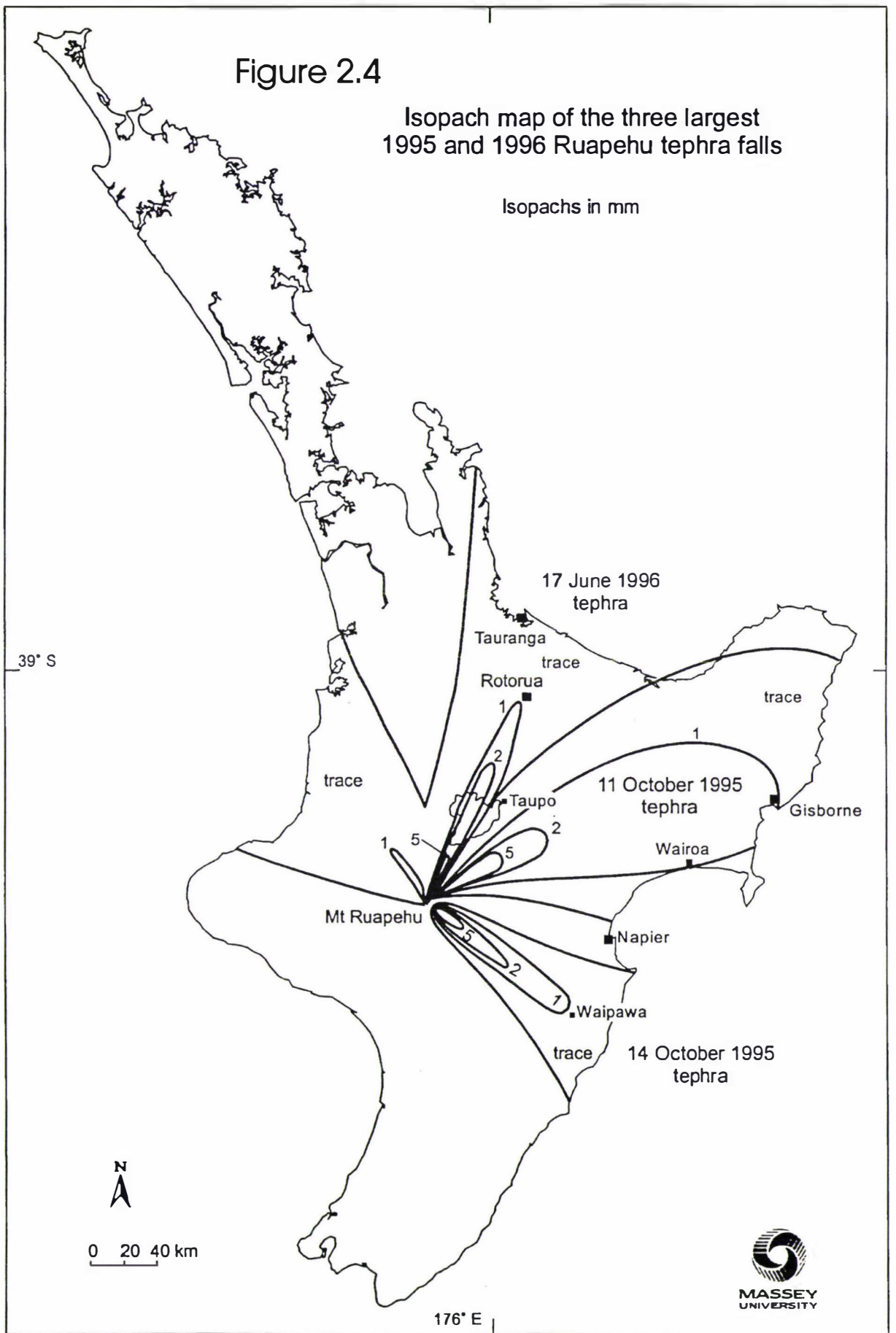
TABLE 2.2
Cont.

Ohakune	20 July 1996	GNS Science Alert Bulletin V96/44	trace
Waiouru	25 September 1995	GNS file	trace
	26 September 1995	GNS file	trace
	14 October 1995	GNS Science Alert Bulletin V95/43	0.5-1 mm
Taihape	14 October 1995	GNS Science Alert Bulletin V95/43	trace
Napier - Hastings- Hawke's Bay	25 September 1995	Hastings D. C. Ashfall Report, 25/9/95	trace
	26 September 1995	Hastings D. C. Ash fall Report, 26/9/95	trace
	27 September 1995	Hastings D. C. Ash fall Report, 27/9/95	trace
	28 September 1995	Hastings D. C. Ash fall Report, 28/9/95	trace
	29 September 1995	Hastings D. C. Ash fall Report, 29/9/95	trace
	12 October 1995	Hastings D. C. Ash fall Report, 12/10/95	trace
	13 October 1995	Hastings D. C. Ash fall Report, 13/10/95	trace
	14 October 1995	Hastings D. C. Ash fall Report, 14/10/95	1-2 mm
	15 July 1996	Hawke's Bay R. C. Ash fall Report, 15/7/96	trace
	21 July 1996	Hawke's Bay R. C. Ash fall Report, 21/7/96	trace
	23 July 1996	Hawke's Bay R. C. Ash fall Report, 23/7/96	trace
	24 July 1996	Hawke's Bay R. C. Ash fall Report, 24/7/96	trace
	25 July 1996	GNS Science Alert Bulletin V96/50	trace
3 August 1996	Hawke's Bay R. C. Ash fall Report, 3/6/96	trace	
4 August 1996	Hawke's Bay R. C. Ash fall Report, 4/8/96	trace	

Figure 2.4

Isopach map of the three largest
1995 and 1996 Ruapehu tephra falls

Isopachs in mm



Public Health

No communities received more than a few millimetres of ash so ash falls were generally a nuisance, affecting eyes and throats. Public health officials advised residents in affected communities to remain indoors during ash falls and to wear masks if they were required to be outdoors. A number of schools were closed as a precaution for a day following ash falls (Table 2.3).

TABLE 2.3 School closures as a result of the 1995-1996 Ruapehu eruption

Date	Area	Note	Reference
26-27 September	Waiouru	The school, kohanga reo and daycare centre closed for three days as a response to the potential escalation of volcanic activity. Only minor ash falls over the period.	Ruapehu Bulletin, 3/10/95
12 October 1995	Wairoa	Three rural schools close after ash fall.	The Wairoa Star, 17/10/95
17 June 1996	Rotorua	Several schools close early and parents asked to collect children with asthma and other respiratory problems.	Daily Post, 19/6/96
18 June 1996	Te Puke	Four schools closed for the day to conserve water supplies.	Bay of Plenty Times, 18/6/96 Daily Post, 19/6/96

During the eruptive episodes special attention was paid to volcanic pollutants by a number of air monitoring programmes operated by regional councils. Particulate matter levels rose above average for brief periods at a number of sites (e.g. Hawke's Bay, Gisborne) but were not regarded as a serious health hazard.

Animals and plants

There was much concern about the potential impact to agriculture at the start of the eruptive episode. As a result of ≤ 5 mm ash fall on the Rangitaiki plains (Taupo) in October 1995 approximately 2000 ewes and lambs (2.5% of the sheep area's population) were killed as a result of eating ash-affected pastures. Autopsies of the dead animals suggest fluorine poisoning or pregnancy toxemia was the cause of death (Gregory & Neall 1996). Three Ayrshire dairy cows died at Atiamuri after the 17-18 June 1996 ash falls (P. Journeaux *pers. comm.*). It was reported that they stopped eating and showed signs of lethargy before dying after swallowing quantities of ash. Toxic levels of fluorine were found in the dead animals' blood. In the Bay of Plenty on 17 June 1996 farmers reported that "*the ash fall stopped stock grazing and most farmers would start feeding out as a result*" (Bay of Plenty Times 18 June

1996).

The Department of Conservation (DOC) reported the death of a number of wild deer in the Kaimanawa Mountains, downwind from Ruapehu, following the two largest October 1995 eruptions (possibly up to 5% of the Sika deer population). Ash in the Whakapapa, Manganuiateao and Tongariro rivers is thought to have affected the 1995 breeding season of the native blue duck and caused their subsequent dispersal due to nutritional stress (Keys 1996). Minor fish deaths were also reported in ash-affected rivers after the October 1995 events but this was insignificant in terms of the total population (Maxwell 1996). Minor disturbance to the 1995 trout-spawning migration was observed, but the Tongariro River fishery has generally remained in good condition.

Minor acid burns were reported on some plants on Ruapehu and the Kaimanawa Mountains but most had recovered by late 1996 (Keys 1996). A major concern at the start of the eruptive episode was the potential impacts on the pipfruit and stone-fruit crops in Hawke's Bay (Ministry of Agriculture and Fisheries *written. comm.*). Fortunately the light ash falls did not create any problems for these crops. There were also concerns about potential impacts on processing and market gardening crops. Major losses (~\$250 000) to cauliflower crops were reported in Gisborne, 250 km downwind, after the 11-12 October 1995 ash fall, but market gardeners were fortunate that many crops had not been planted at the time of the ash falls.

A positive impact of the 1995-1996 Ruapehu ash falls has been to temporarily reduce the sulphur fertilizer requirement for all sheep, beef and dairy farmers within the ash fall area, as well as inducing increased selenium uptake in herbage (Cronin *et al.* 1996).

Water supplies

Contamination of water supplies was a common concern, with the public being advised to disconnect roof-fed water tanks as a precaution. In some cases this proved to be very difficult to accomplish, especially with new enclosed systems. The Department of Conservation disconnected roof-fed water supplies at many of the huts in the Tongariro National Park.

Many communities initiated special or enhanced monitoring of their water supplies due to the potential for ash contamination. In some cases extra supplies were stored. For example, at the Waiouru military base water was stockpiled in jerry cans, rubber bladders and fire engine tanks, and the stream supply was monitored regularly (*New Zealand Herald*, 27 October 1995).

In October 1995 the Rotorua District Council constructed enclosures (costing \$120 000) over

the Rotorua city and Reporoa spring supplies to mitigate the potential of ash contamination. This was to prove valuable in protecting the supply during the 17 June 1996 ash falls. However, Rotorua almost ran out of water when a resident washed ash into a power transformer which exploded just after the ash fall, cutting electricity to water pumps. Residents' efforts at ash clean-up almost drained the supply and the district council imposed a hosing ban until the power supply was restored to the water supply headworks (*Daily Post*, 19 June 1996).

On 17 June 1996 the water supply from the Raymond Dam in the Western Bay of Plenty was disconnected for four hours after the ash falls, while water analysis was carried out (Combined Tauranga and Western Bay of Plenty Councils Civil Defence Organisation *pers. comm.*). The supply feeds Pukehina, Maketu, Pongakawa and Paengaroa and Te Puke. Some areas were without water for several hours (*Bay of Plenty Times*, 18 June 1996) but supplies were fully restored by the following day.

Transportation

Air transportation was the most widely affected transport sector. The Wellington Volcanic Ash Advisory Centre (VAAC) is operated by the Meteorological Service of New Zealand (Metservice) on behalf of the Civil Aviation Authority (CAA) and issued more than 120 volcanic ash advisories in 1995 and more than 90 in 1996 (Metservice 1997). These restricted air-space during eruptive episodes because of drifting ash and the sulphur dioxide haze, resulting in cancellation of many flights and re-routing of others away from the exclusion zones. The restrictions precluded aircraft flying in cloud or at night within these zones due to the inability of aircraft radar to detect ash clouds. Airlines report this caused a major disruption to operations and created additional workload. As the exclusion zones changed constantly regular briefings for pilots were required and the re-routing added extra distance to flights, increasing fuel costs and flight times. This caused additional problems with catering schedules, baggage handling and passengers connecting to other flights. Up to 13 airports were affected at times and this caused flow-on effects well beyond these areas (Table 2.4). The 1996 eruption had the most widespread effect. Mail and courier deliveries were frequently disrupted. Only seven airports received ash falls, with Rotorua Airport receiving the most ash (~1 mm thickness) which required a substantial clean-up operation. At least two minor aircraft ash encounters were reported, a Saab Metroliner en route to Nelson from Wellington (20 June 1996) and an Aztec en route to Takaka from Wellington (21 June 1996), but no serious damage was noted.

TABLE 2.4 Closed or disrupted airports during the 1995-1996 eruption (airports that received ash falls marked by A)

Airport	1995	1996
Auckland		*A
Hamilton	*	*A
Tauranga	*	*A
Whakatane	*	*A
Gisborne	*A	*
Rotorua	*	*A
Napier	*A	*A
Taupo	*	*A
Wanganui	*	*
New Plymouth		*
Palmerston North	*	*
Wellington		*
Nelson		*

During and after ash falls visibility on roads was commonly reduced. Closures of State Highway One, adjacent to the volcano (the Desert Road), occurred on three occasions in 1995: 25 September, 11-12 and 14-15 October. The October 1995 closures were initially due to reduced visibility but both were accompanied by or followed by rain resulting in a slippery ash-sludge. This required removal before safe driving conditions could be restored and the road closures disrupted thousands of travellers, although alternative routes were available. The number of closures was relatively minor compared to the annual disruptions caused by winter snow and ice (Table 2.5). The access roads to the ski fields were also closed for brief periods in 1995 and 1996.

TABLE 2.5 Desert Road closures 1993-1996 and attributed causes of closure (Works Consultancy Services *written comm.*)

Year	Ice and snow	Ash falls
1993	9	-
1994	10	-
1995	12	3
1996	11	-

Rail services were not disrupted by the 1995-1996 eruptions although Tranz Rail placed personnel on duty beside the Tangiwai rail bridge (see Fig. 2.2 for location) to monitor the impact of the Whangaehu lahars during the first week of the eruption in September 1995.

Electricity transmission

Falls of volcanic ash and mud on 25 September 1995 caused shorting on high-voltage electrical power lines (Fig. 2.5) at the base of the volcano (see Fig. 2.2 for location). This caused voltage fluctuations and problems for electrical equipment throughout the North Island. For example, fluctuations in supply tripped the emergency power at Wellington Hospital causing non-essential supplies to be shed. Included in this, by error, was a water pump in a block containing dialysis machines (K. McIntyre, Wellington Hospital *pers. comm.*). Thermal power stations to the north were started to ensure security of the system. Cleaning of 18 towers (and insulators) was undertaken on 27 September 1995 by four crews of four men (Powermark 1995, unpublished, "*Report on volcanic ash contamination*"). The ash was found to be dry and easy to remove. Strain towers were the most affected due to their insulator configurations (i.e. horizontally strung). It was found that subsequent rains (on 26 September 1995) had washed the northern side of towers and insulators. It was concluded that normal rainfall would clean ash from structures, conductors and insulators except the undersides of strain strings. Three strings of insulators were found to have widespread flashover damage but with no electrical problems.

After ash falls electricity generation and supply companies routinely cleaned ash from affected substations. On 17 June 1996 electricity supplies were disrupted in parts of Rotorua city after an explosion at a local substation caused by ash and water settling on a transformer due to a resident's hosing ash from the roof of a neighbouring building (*Daily Post*, 19 June 1996).

Bunnythorpe – Whakamaru A and B Lines, Volcanic Ash

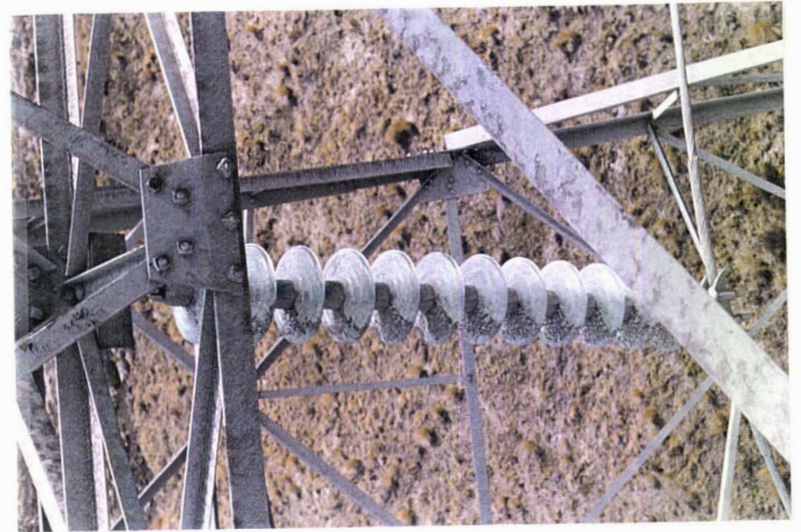


Cleaning using dry cloth, effective but slower

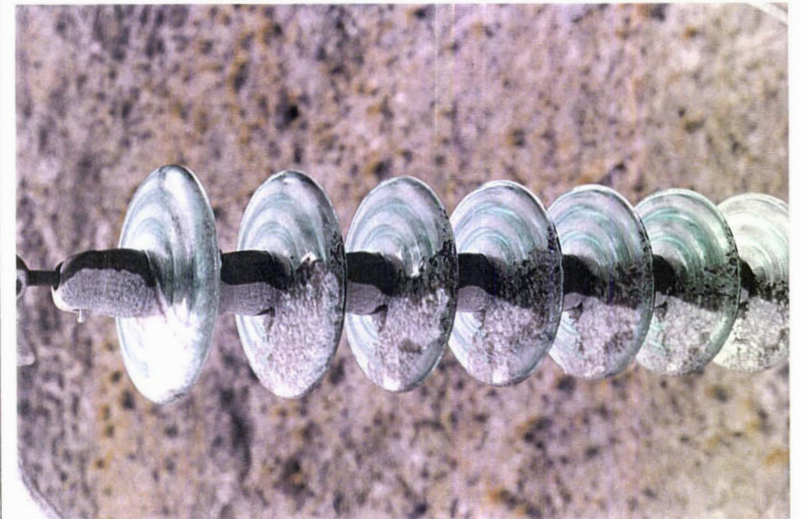


Water blaster (1500psi approx)

Bunnythorpe – Whakamaru A and B Lines, Volcanic Ash



Jumper string and ash on all steelwork



Close up view of jumper string, clean on North side

FIGURE 2.5

Impacts of 25 September 1995 ash falls on high-voltage lines at the base of Ruapehu. (see Fig. 2.2 for location)

Damage to buildings and facilities

In most cases the ash falls were only a nuisance but numerous examples of minor damage have been reported. Many organisations initiated a range of mitigation measures to protect buildings and equipment against damage from ash falls. For example, the Army Museum at Waiouru shut down its air-conditioning units, taped-up doors and other ventilation intakes, and limited access to the building to one entrance (see Chapter 3, Fig. 3.13). The facility was closed for two and half days during the initial week of the eruption.

Air-conditioning units were shut off in many ash affected communities and major problems were reported in a few cases where this was not done (R. Steele, Gisborne District Council *pers. comm.*). Telecom New Zealand reported that over-heating alarms, as far away as Ruatoria, were attributed to volcanic ash (R. Crimp, Telecom *pers comm.*). Some residents in ash-affected communities reported problems removing ash from swimming pools and in several cases damage to pool filters (e.g. *Daily Post*, 19 June 1996).

A small number of insurance claims for damage (~25) were received by the Earthquake Commission. The Earthquake Commission provides cover against damage to house and contents and is subject to a minimum excess of \$200. The Commission's policy did not cover the cost of clean-up operations or long-term damage resulting from a failure to remove ash from buildings. The number of claims (listed in Table 2.6) includes the total number of claim enquiries made after ash falls, although a significant number were not followed-up once the pay-out conditions were known. Claimants are defined as those who received pay-outs. The high value pay-outs were associated with buildings on the volcano's flanks. Two large ski-field claims are still outstanding, estimated at around \$2 million each (see damage description below). Over half of claims paid out were for roof damage (16) resulting from the reaction between ash and galvanised steel and/or paint. Acrylic paint, if it had been applied within the past 3-6 months, was found to be most susceptible to the acidic nature of the ash. Other damage-related pay-outs included:

- * Ash in gutters resulted in their pulling away from the structure (2 cases).
- * Heavy rain after the ash fall resulting in gutters becoming blocked and stormwater overflowing on to hardboard above a verandah area (1 case).
- * Abrasion of the lens of a pair of spectacles (1 case).
- * Abrasion to a bicycle ridden along the Desert Road after an ash fall (1 case).

Other damage reported that did not meet the pay-out criteria included:

- * Damage to clothes left on the line (below excess).
- * Damage to roof gutters caused by clean-up operations.
- * Ash damage to a school's carpets that necessitated cleaning.
- * Ash blockage of down-pipes.
- * Ash blockage of a water pump.

TABLE 2.6 EQC damage claims for the 1995 and 1996 Ruapehu eruption.

	Claims	Open	No. of claimants	Payouts to claimants	No. of Assessors	Payout to Assessors	Total Payouts
1995	29	5	7	\$530311.45	18	\$23680.39	\$553991.84
1996	185	1	18	\$24700.72	51	\$15584.98	\$40285.70
Total	209	6	25	\$555012.17	69	\$39265.37	\$594277.54

Skifields The repeated ash falls and acid rains have caused considerable damage to facilities at Ruapehu's three skifields. The fields undertook a range of mitigation measures to limit damage, including closing lifts, covering motors with plastic, sealing drive stations, removing vehicles from the mountain and disconnecting water supplies. Despite these measures by November 1995 rust damage was severe in places. Further damage resulted from the 1996 eruption.

Galvanised bolts and nuts which attach seating to the double and quadruple chair lifts have all rusted heavily. This results in staining and damage to customers' ski-wear when sitting on the chairs. Grips which attach the chairs' hanger arms to the cables and are heavily galvanised were showing serious surface rusting and had to be removed, cleaned and re-coated. Ski towers showed signs of heavy rusting and loss of paint on the sides of the towers facing the crater; in contrast the downhill or sheltered side of the tower revealed adequate paint coating in most cases.

The ski companies reported they experienced a number of minor problems with lifts. Most of these resulted from electrical malfunctions and breakdowns and on all occasions they are noticing heavy corrosion on the parts that are failing.

Volcanic ash removal

No communities received more than a few millimetres of ash but several were forced or chose

to initiate clean-up operations to remove ash from buildings and streets, notably Rotorua and Wairoa.

On the evening following the 12 October 1995 ash fall the Wairoa cadet unit spent five hours sweeping, scrubbing and washing the town centre to remove the ash in preparation for the official opening of the town's parade (*The Wairoa Star*, 17 October 1995).

Two of Rotorua's sports grounds were badly affected by the 17 June 1996 ash falls. Netball officials cancelled fixtures because of the ash on the courts. Ground staff at Rotorua's hockey headquarters at Smallbone Park spent three days cleaning ash from the playing surface. The cost is estimated at several thousand of dollars; however, had it rained before the work was completed the bill might have been significantly higher (*Daily Post*, 20 June 1996). The Rotorua District Council reported that " *after initial ash fall we began the mammoth task of sweeping and removing ash from the central city footpaths etc*" (Rotorua District Council *written. comm.*). The cost of the clean-up operation was estimated at \$ 53 511 and included cleaning of the CBD, cleaning kerbs and channels in all urban areas and cleaning cesspits in every area.

2.3.3 Social impacts

The impacts of natural hazard events go far beyond the physical effects and may result in a range of social and psychological impacts on affected individuals and communities. Small scale events are often more disruptive than destructive and their social/psychological impacts are often overlooked. High levels of anxiety were present in some individuals during the initial phase of the eruption but such concerns are frequently down-played by local officials. This observation is supported by an empirical study of childhood psychological functioning in three communities adjacent to Ruapehu (Ronan & Johnston 1996; Ronan 1997). The early termination of several hundred jobs in the ski industry and related services have also had an obvious impact on those affected.

The physical evacuation of the public was limited to the ski fields in 1995 (Tukino on 24 September 1995 and Turoa/Whakapapa on 25 September 1995) and ski field staff on 17 June 1996 (Turoa and Whakapapa). Around 25 families of Army personnel in the first response units (who were placed on standby) at Waiouru military camp elected to be evacuated to Linton camp on 25 September 1995. On 25 September 1995 the Ministry of Civil Defence issued a general alert to all people living within a radius of 100 km. A number of locals and visitors also self-evacuated between 23-26 September 1995 from surrounding towns (e.g. Ohakune, Waiouru and Turangi) and others made preparations to do so. In Ohakune, over that period, it was reported that there was no tinned food remaining in the supermarket and

the petrol was sold-out from garages (Keys & Williams 1996).

The impact of the 1995 eruption on public perceptions is discussed further in the two case studies (Whakatane and Hastings) in Chapter 8.

2.3.4 Economic consequences

True estimates of the economic impacts of the Ruapehu eruption are extremely difficult to determine since such events are rare and there are no systems in-place for measuring the economic losses. A number of organisations have reported direct losses, additional unbudgeted expenditure and additional staff time used in response to the eruption but only a few have calculated an actual dollar cost of the eruption to their organisation (Table 2.7). There is a clear reluctance among some organisations to make this calculation, part of the process of re-adjusting to 'normal' operating conditions.

TABLE 2.7 Reported economic losses from the 1995-1996 Ruapehu eruptions

Sector	1995-1996	Reporting organisations
Tourism	\$ 99 200 000	RAL, Turoa Skifield, Ruapehu District Council
Electrical generation	\$ 21 500 000	ECNZ
Central Government	\$ 5 645 692	Metservice, EQC, DOC, MCD, MAF, CAA, Aircorp
Aviation	\$ 2 401 158	Air NZ, Ansett, 4 airports
District Councils	\$ 588 511	Ruapehu, Taupo, Rotorua
Agriculture	\$ 382 500	MAF
Regional Councils	\$ 205 475	Manawatu-Wanganui, Waikato, Taranaki
Total	\$ 129 923 336	

Three skifields on Ruapehu were closed on 25 September 1995, with two briefly reopening for a few days in 1995. In 1996 the eruption severely limited the season (Table 2.8). The closures resulted in the termination of several hundred jobs in the ski industry and related services. The economic losses to the local tourism industry have been estimated to be in the order of \$NZ 100 million (Ruapehu District Council *written comm.*).

TABLE 2.8 Skier numbers and total revenue generated from skiing for 1993-1996.

	1993	1994	1995	1996
Skier numbers	430 000	449 000	340 000 (75 % of 1994)	140 000 (31 % of 1994)
Total revenue generated	\$ 102 million	\$ 107 million	\$ 81 million	\$ 34 million

Some local businesses have capitalized on the eruption with a range of volcanic products and the promotion of their communities as a safe place to "volcano watch" (Fig. 2.6). Despite slight increases in summer visitors, tourism operations report that the gains do not make up for their losses which resulted from the premature termination of the ski season in September 1995 and the limited season of 1996.

The second largest economic cost (~\$21 million) was reported by the Electricity Corporation of New Zealand (ECNZ), resulting from damage to the Rangipo power plant and loss of production (see earlier). The aviation industry reported losses in excess of \$2.5 million but this figure only represents an estimate of lost revenue and does not include an estimate of the economic cost to travellers of disrupted flights. The reported costs to responding government agencies included ~\$5.4 million from central government, ~\$454 000 from district councils and ~\$205 000 from regional councils. Some organisations included staff time and direct expenditure whereas others only reported direct costs (or losses).

The total cost of ~\$130 million represents loss of economic production and services, damage to equipment and expenditure on mitigation and response activities. This estimate is not a comprehensive measure and can only represent a minimum value, not the total cost.



FIGURE 2.6 Examples of impacts of the 1995-1996 Ruapehu eruptions.

- A. Sweatshirts being used as impromptu gas masks to cope with the ash in Gisborne on 12 October 1995.
- B. Ash covered car in Rotorua on 17 June 1996. Many people report minor abrasion damage to paintwork and windscreens
- C. Shop window in Taupo. Some local businesses rapidly adapted to the opportunities supplied by the 1995-1996 eruptions.

2.3.5 Volcanic crisis management

The 1995-1996 eruptions at Ruapehu volcano resulted in an unprecedented response to activity at a New Zealand volcano (Fig. 2.7). A number of organisations had leading roles during the eruption crisis. The Institute of Geological & Nuclear Sciences (GNS) was responsible for monitoring the eruption, setting the "Scientific Alert Level" and providing scientific information to the Ministry of Civil Defence and other organisations. The Ministry of Civil Defence, assisted by a scientific advisory committee, in turn advised the Government and regional and district councils. Management of the land on and close to the volcano was the responsibility of the Department of Conservation (DOC). From the evening of 23 September to the end of the eruptive episode a management group comprising representatives of DOC, GNS, Whakapapa Ski Area, Turoa Ski field, Police, Ministry of Civil Defence and Ruapehu District Council met regularly to consider the hazard to the public and to co-ordinate appropriate responses (Keys & Williams 1996). The Civil Aviation Authority (CAA) and the Met-Service were responsible for monitoring air-space in New Zealand and declaring flight restrictions. Other government organisations involved in specific responses included the Department of Internal Affairs, Ministry of Health and Ministry of Agriculture (MAF). The Army Training Group at Waiouru placed personnel on stand-by during the initial stage of the eruption in September 1995.

At a community level several district councils played significant roles in the dissemination of information and preparing for a potential escalation of activity. In most cases responding district councils were assisted by their respective regional councils.

At no time during the 1995-1996 eruptions was a State of Civil Defence Emergency declared although there was much debate at the initial stage of the eruption (in September 1995) as to whether such a declaration should be made. A declaration would have freed-up additional government funding. The lack of a declaration caused serious initial funding problems for some responding agencies, notably GNS.

A number of responding organisations have subsequently held debriefings to analyse their response to the crisis and identify problems that arose. Some government and public/private organisations have decided to review planning procedures and operations in light of the potential impacts of ash falls and other volcanic hazards.

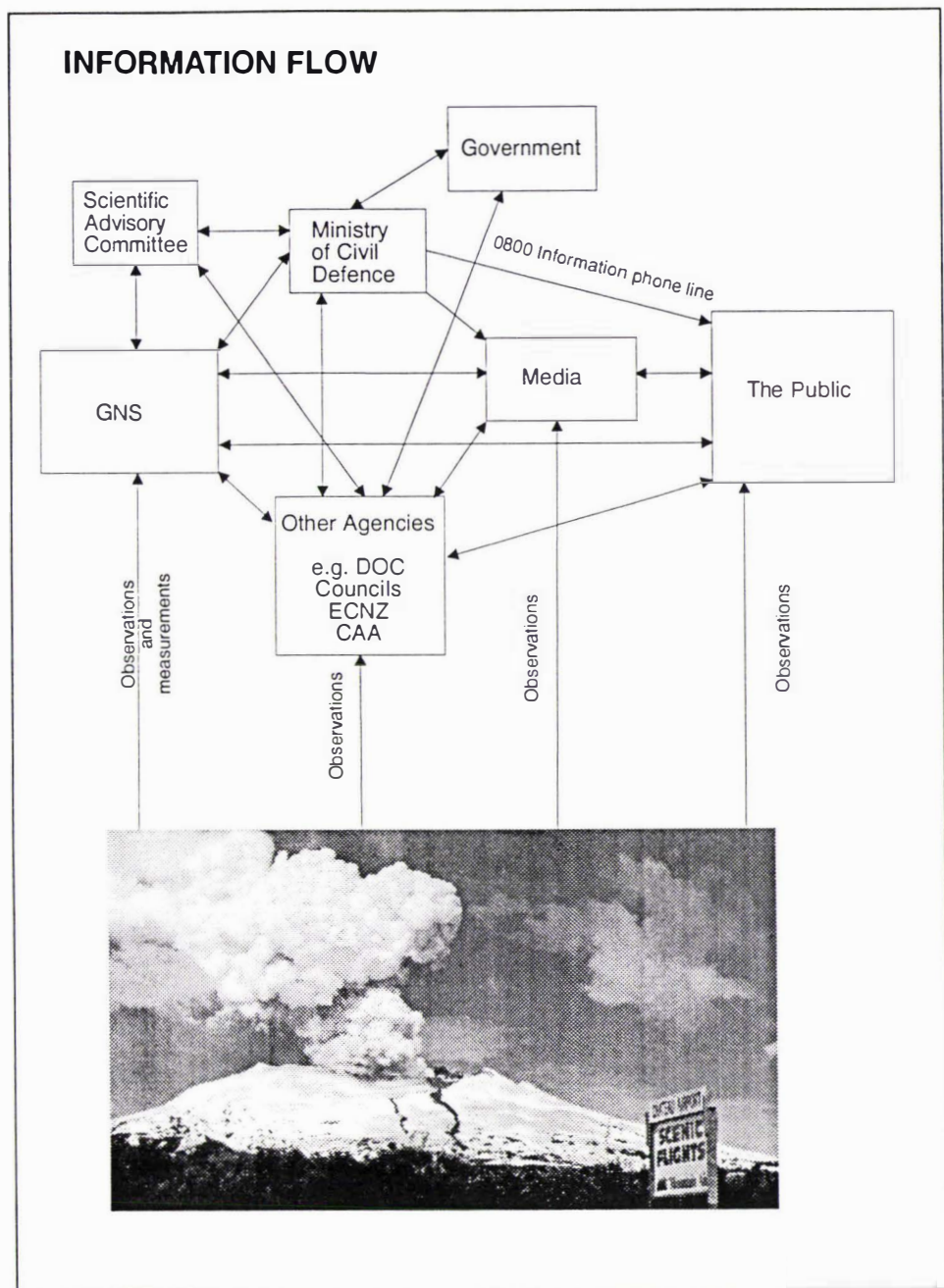


FIGURE 2.7 The flow of information during the 1995-1996 Ruapehu eruptions.

Public information

The 1995-1996 eruptions of Ruapehu received media coverage world-wide. The spectacular yet small eruption on the 23 September 1995 was captured by three "home-video" cameras as well as still photography, and these images were rapidly dispersed to the local and world media. In a number of overseas reports details were grossly inaccurate and this caused some negative impacts on New Zealand tourism (Tourism New Zealand *written comm.*).

Demand for information from responding agencies was enormous and initially it was difficult to respond to this level of interest (Fig. 2.7). Once systems were in place most media organisations reported a satisfactory information flow (Keys & Williams 1996). For the first 10 days of the eruption in September-October 1995 the events received over 300 minutes of television evening news "air-time" (TV1) making it the biggest story in the year (TVNZ *written comm.*). The eruption in 1996 also received considerable coverage in New Zealand and overseas. Information and images of the eruption were also available on the Internet, including a live video feed (e.g. <http://www.stimulus.co.nz>).

The Ministry of Civil Defence provided a public information phone line on the 25 September 1995 initially charging for calls. This was changed the following day to a free-phone number with sponsorship support from NZI Insurance and Telecom New Zealand. During the first week of its operation over 19 000 calls had been received and by end of the year over 34 000 calls had been received. The free-phone information service was again provided in response to the June-August 1996 eruptions. The pattern of calls received was similar in both years with high initial demand, dropping after a week (Fig. 2.8).

At regional and local levels information was disseminated to the public by a number of regional and territorial civil defence organisations. Various media were used including direct radio announcements, newspaper advertisements, mailbox "flyers" and information phonelines.

The 1995 eruption coincided, by chance, with a public awareness campaign *Ruapehu '95* Volcanic Hazard Awareness Week (16-23 October). Numerous activities (talks, field trips, the release of education resources) had been planned throughout the country to raise awareness of volcanic hazards (Johnston & Riley 1996). Organisers obviously took advantage of the eruption to promote the campaign.

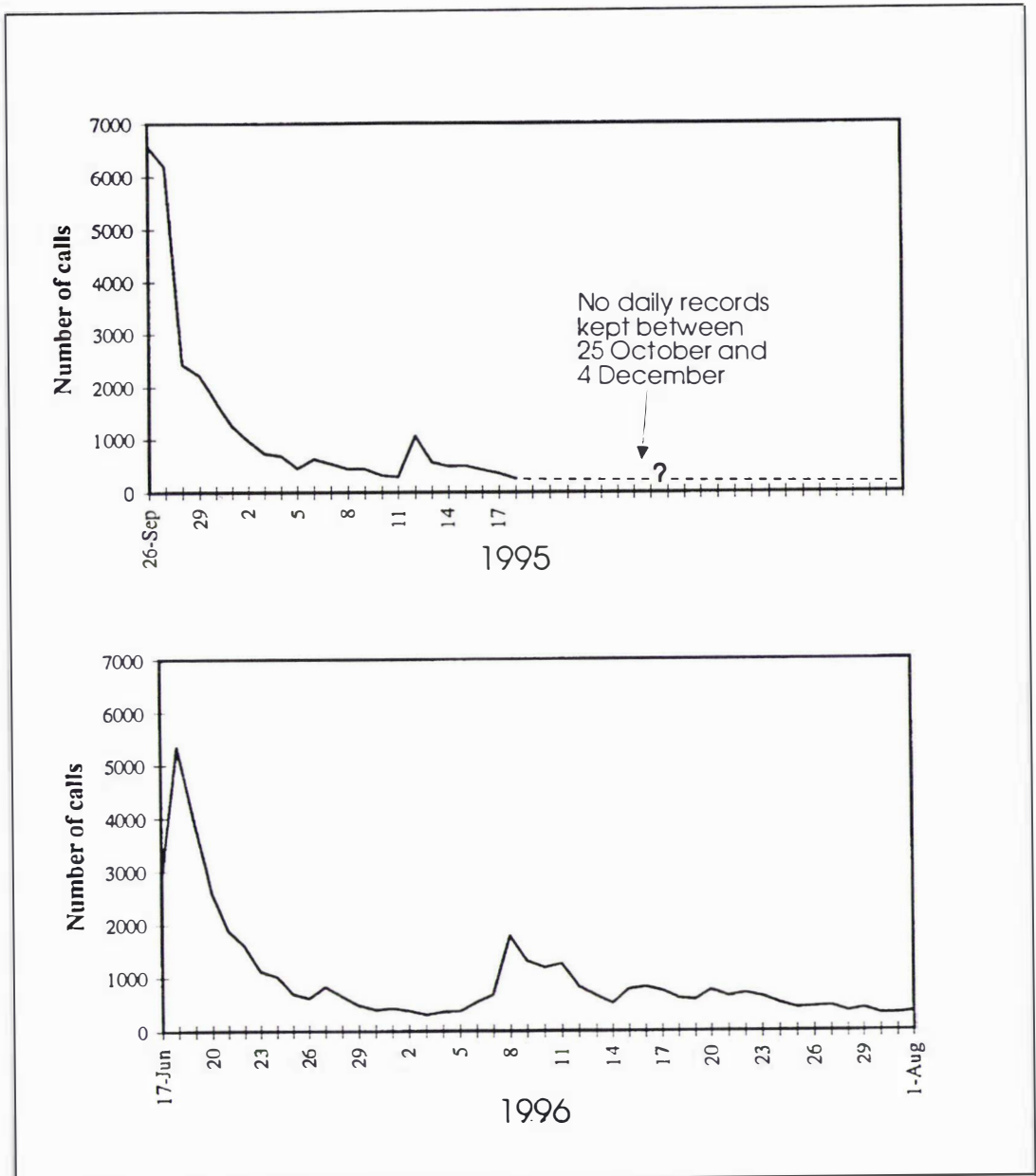


FIGURE 2.8 The number of calls received per day on the Ministry of Civil Defence 0800 information line during the 1995-1996 Ruapehu eruption. The free information phone line was operational from 26 September to 4 December 1995 and 17 June to 6 August 1996. Unfortunately some of the daily call records were deleted, notably between 25 October and 4 December 1995 although the total number of calls received in 1995 is known (34 893).

2.4 DISCUSSION

Over the past 50 years changes in New Zealand's society have increased its vulnerability to eruptions of the size of 1945 (Table 2.9). This was illustrated by the impacts of the 1995-1996 eruptions. Direct comparison of the 1945 and 1995-1996 eruptions is hindered by the lack of detailed measurements and observations of the 1945 event. The 1945 eruption differed from 1995-1996 in that Crater Lake was emptied by the relatively passive emplacement of a lava dome without any recorded lahars. However, both eruptive episodes dispersed ash over much of the North Island. The frequency of ash falls in many communities was greater in 1945 than both 1995 and 1996 combined (Fig. 2.9). The physical effects of these ash falls were similar yet the consequences significantly greater to many sectors in 1995 and 1996.

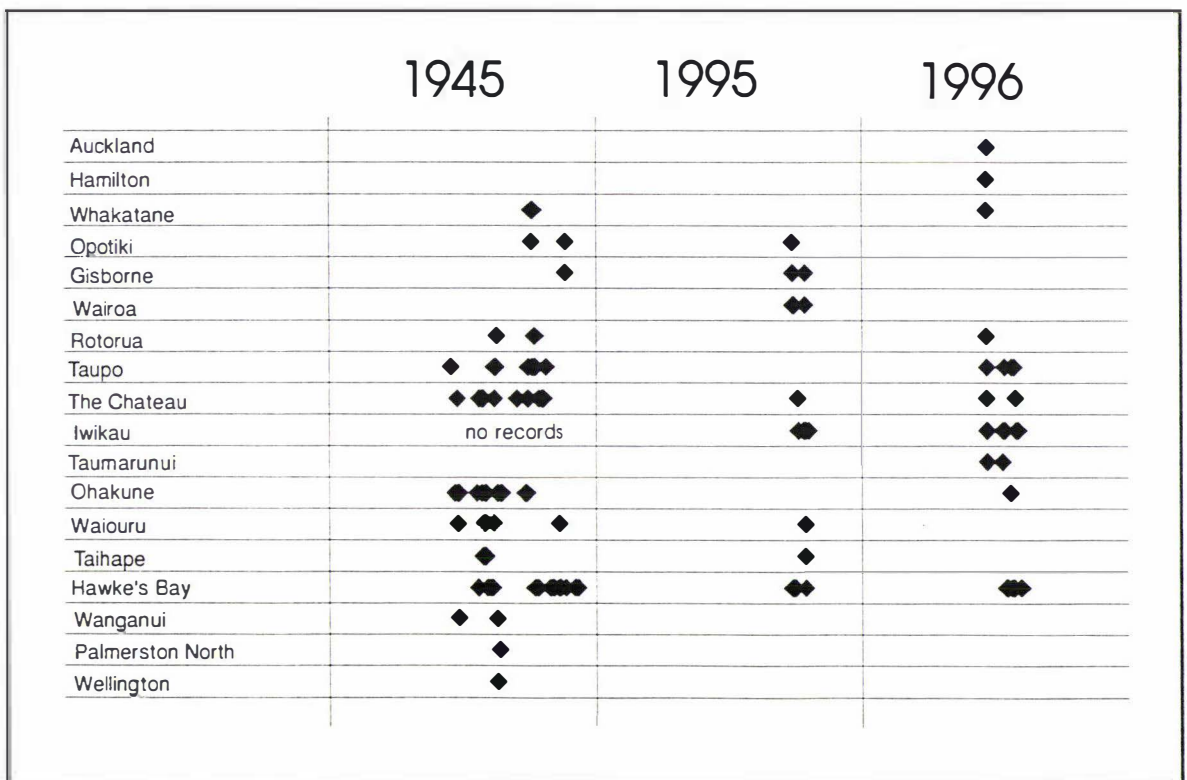


FIGURE 2.9 A comparison of the frequency of ash falls reported from selected North Island communities in 1945, 1995 and 1996, compiled from data presented in Tables 2.1 and 2.2. Each black diamond represents an individual reported ash fall event and each column is for the full year.

New Zealand's population has approximately doubled since 1945. Improvements in transportation and the development of recreational facilities have led to a massive increase in visitor usage of Tongariro National Park. Within the Park three ski fields now operate, with in excess of 450 000 skier days per year (1994) compared to only one field and a few thousand skier days per year in 1945. Ski lifts have increased from zero to 36 over the same period. The 1995 and 1996 eruptions resulted in the closure of all three fields causing the majority of losses to the regional economy.

The Tongariro Power Scheme, built between 1973 and 1983, uses a complex system of canals, tunnels and lakes to collect water from the east, west and south catchments on the flanks of Ruapehu, diverting it northwards for hydro-electric generation. Damage to the electricity sector resulted in the second largest economic impact. Three high-voltage lines pass to within 20 km on the eastern side of the volcano. These were not present in 1945 and were adversely affected by the 1995 eruption.

The use of air transport in New Zealand has undergone rapid growth in the past 50 years. In 1945, scheduled flights were limited to around 61 000 passengers. By 1994 the figure had risen to over 4.5 million per annum. Modern jet aircraft are extremely vulnerable to ash, therefore the Civil Aviation Authority imposed air-space restriction around Ruapehu in 1995 and 1996, disrupting many thousands of travellers. In 1945 the Desert Road, like most provincial roads was unsealed and vehicle speed limits were lower. Road transport has since grown significantly with vehicle numbers increasing over eight times in the past 50 years. At no time in 1945 were roads at the base of Ruapehu closed but there were three ash fall induced closures in 1995.

Progressive legislative development over the past 50 years has resulted in an increasing requirement for public safety and hazard management (e.g. Local Government Act 1974, Civil Defence Act 1983, Resource Management Act 1991 etc), and this was reflected in the organisational response to the 1995-1996 eruptions. At no time in 1945 were access restrictions to the crater area imposed, despite the significant risk to visitors. On at least two occasions in 1945 people were hit by ballistic material. The Department of Conservation now has a responsibility for public safety of visitors to the national park and thus responded accordingly during the 1995-1996 eruptions, imposing a 2 km restriction around the crater. The development of a surveillance capability over the past few decades has been accompanied by an increased responsibility to respond to the information that it generates. The New Zealand Geological Survey had only two geological staff permanently based at the volcano during the peak of activity in August 1945. This compares to over 30 personnel responding during initial stages of the 1995 eruption.

The social and economic impacts of adverse events are determined not only by direct physical consequences but by the interaction of psychological, social, cultural and institutional processes that can amplify and attenuate the public response (Burns *et al.* 1993). Kaspersen *et al.* (1988) refer to this as "social amplification of risk" and this was clearly evident during the 1995-1996 Ruapehu eruption. However, this was not fully appreciated by central government and was reflected by its initial reluctance to provide adequate funding to responding agencies. Much of this "social amplification" was fuelled by the media coverage which brought dramatic images of the eruption to people throughout New Zealand and the world.

TABLE 2.9 Societal changes over the past 50 years (1945-1995).

Measure	1945	1995
New Zealand population	1 702 330 ^a	3 579 900 ^{c (1995)}
Hawke's Bay	49 796 ^a	116 340 ^{d (1991)}
Taupo District	4 248 ^a	30 723 ^{d (1991)}
Ruapehu District	15 320 ^a	18 105 ^{d (1991)}
No. of cars	198 629 ^b	1 647 134 ^{c (1995)}
Cars/head of population	0.12	0.46 ¹⁹⁹⁵
Speed limit (open road)	64 km/h (40 mph)	100 km/h
Domestic air travel - passenger no.	60 968 ^b	4 502 000 ^{e (1995)}
Domestic air flights/head of pop.	0.036	1.3 ¹⁹⁹⁵
Skifields on Ruapehu	1	3
Number of ski lifts	0	36 ¹⁹⁹⁵
Number of skiers	not available	450 000 ^{f (1994)}

a: 1945 census; b: 1945 Yearbook; c: 1996 Yearbook; d: 1991 census; e: Ministry of Transport;

f: Ruapehu District Council .

2.5 SUMMARY

The 1945 eruption of Mount Ruapehu dispersed ash over a wide area of the North Island over a period of several months. Individual ash falls were only a few millimetres thick in communities closest to the volcano (< 50 km) and trace amounts in communities further away. Ash falls were mostly of nuisance value in affected communities, causing minor eye and throat irritations, soiling interiors of houses and damaging paintwork. More significant impacts included crop damage, low wool quality on farms close to the mountain, disruption to skiing, the removal of army vehicles from Waiouru and numerous disruptions to water and electricity supplies.

The 1995-1996 eruptions caused similar physical effects to the 1945 eruption but had considerably greater social and economic impacts. Over the past 50 years the risk has increased significantly due to an increased population, higher visitor usage and a more technologically advanced infrastructure.

CHAPTER 3

THE IMPACT OF HISTORIC ERUPTIONS ON COMMUNITY 'LIFELINES'

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3.1 INTRODUCTION

Numerous types of hazards may result from a volcanic eruption, often simultaneously. The most likely hazards include pyroclastic falls, pyroclastic flows and surges, lava extrusions (flows and domes), lahars, volcanic gases, volcanic earthquakes and atmospheric effects. Unfortunately there are very few quantitative measurements of the impacts of such hazards on communities and their 'lifelines'. However a conceptual model of the likely impacts of a given event can be established, based on direct observations of eruption impacts in conjunction with theoretical analyses. Such models can then be used to estimate effects of various hazards for use in risk analysis and scenarios. To establish the validity of such models, any inconsistencies between the model and estimated effects can be used to refine or expand it with appropriately modified information from observations or theory (Hill 1984). This chapter is intended to examine the impacts of volcanic hazards on community 'lifelines'.

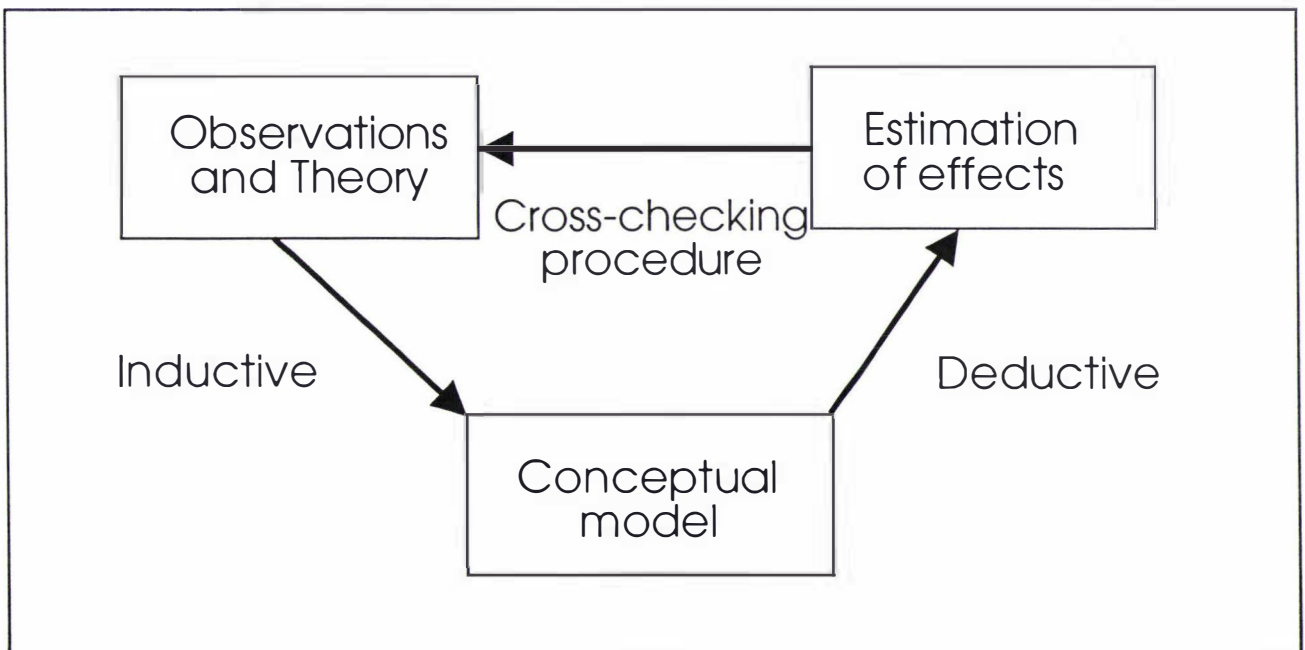


FIGURE 3.1 An approach to estimating the effects of volcanic hazards on community 'lifelines'.

3.2 PYROCLASTIC FALLS

Pyroclastic fall material is produced by three principal processes: (1) degassing of rising magma producing bubble growth and fragmentation; (2) explosive mixing of magma and water; and (3) fragmentation of country rock during rapid expansion of hydrothermal steam and/or hot water (Heiken 1994). Pyroclastic falls have variable impacts with distance from source. Volcanic ash can be deposited hundreds to thousands of kilometres from its source, making it the product most likely to affect the largest area and the greatest number of people. For this reason the impacts of volcanic ash are the main focus of this chapter.

3.2.1 Projectiles

Large fragments (blocks and bombs > 64 mm) follow ballistic trajectories and are here termed projectiles. These fragments rarely land more than 1-2 kilometres from a vent in a brittle or molten state and are capable of starting fires (Blong 1984). The impact of ballistic clasts will cause damage to buildings (including ignition), with the degree of damage dependent on projectile mass, temperature and velocity (Blong 1981, 1984). Projectiles present a high risk of death or injury to people (Baxter 1990). In the 1973 eruption of Heimaey (Iceland) incandescent clasts from 0.1 to 2 m across caused many house fires (Self *et al.* 1974).

3.2.2 Convected air fall

Finer material (ash < 2 mm and lapilli 2-64 mm) is convected upwards in an eruption column (Self & Walker 1994) before settling out downwind to form pyroclastic fall deposits. A community's infrastructure - its 'lifelines' - is vulnerable to disruption and/or damage from pyroclastic falls, with impact severity largely related to fall thickness. Pyroclastic falls will not result in fatalities unless the fall is extremely heavy (Baxter 1990). Falling ash is usually not toxic but it does act as an irritant to the eyes and throat. Deaths and injuries are more likely to result from secondary effects such as roof or veranda collapse, falling branches and accidents associated with poor visibility or poor road conditions.

3.2.3 Properties of ash

Pyroclastic fall deposits are composed of various proportions of vitric, crystal or lithic particles (Fisher & Schmincke 1984). Vitric particles are glass shards or pumice derived from magma (Heiken & Wohletz 1985), while crystals are minerals derived from phenocrysts or microlites developed in the magma. Different minerals reflect the composition of different magmas. The most common minerals are shown in Table 3.1. Lithic particles can be divided into three types: cognate (derived from non-vesicular juvenile magmatic fragments), accessory (derived from co-magmatic volcanic rocks from previous eruptions) or accidental (derived

from basement and therefore of any composition).

TABLE 3.1 Composition of major phenocryst phases in magma (from Thorpe & Brown 1985)

	Basalt	Basaltic andesite	Andesite	Dacite	Rhyolite
plagioclase	**	***	***	***	**
olivine	**	**	*	-	-
pyroxene	**	**	**	*	-
hornblende	*	*	**	**	*
biotite	-	-	*	**	**
alkali feldspar	-	-	*	**	***
quartz	-	-	-	**	***
Fe-Ti oxide	**	**	*	-	-

*** often present. ** frequently present. * rarely present. - absent or rare

Thickness and Particle Size: It is well known that thickness and median grain-size of ash deposits generally decrease exponentially with distance from a volcano (Walker 1971). The distribution of ash (Fig. 3.2) will depend on the initial grain-size distribution of the ejecta (reflecting fragmentation during the eruption), dynamics of the eruption column and the column's interaction with wind (Carey & Sparks 1986, Bursik *et al.* 1992, Sparks *et al.* 1992, Koyaguchi 1994). Pyle (1989) and Fierstein & Nathenson (1992) have shown that pyroclastic fall deposits display an exponential decrease in thickness with the square root of the area enclosed within an isopach contour.

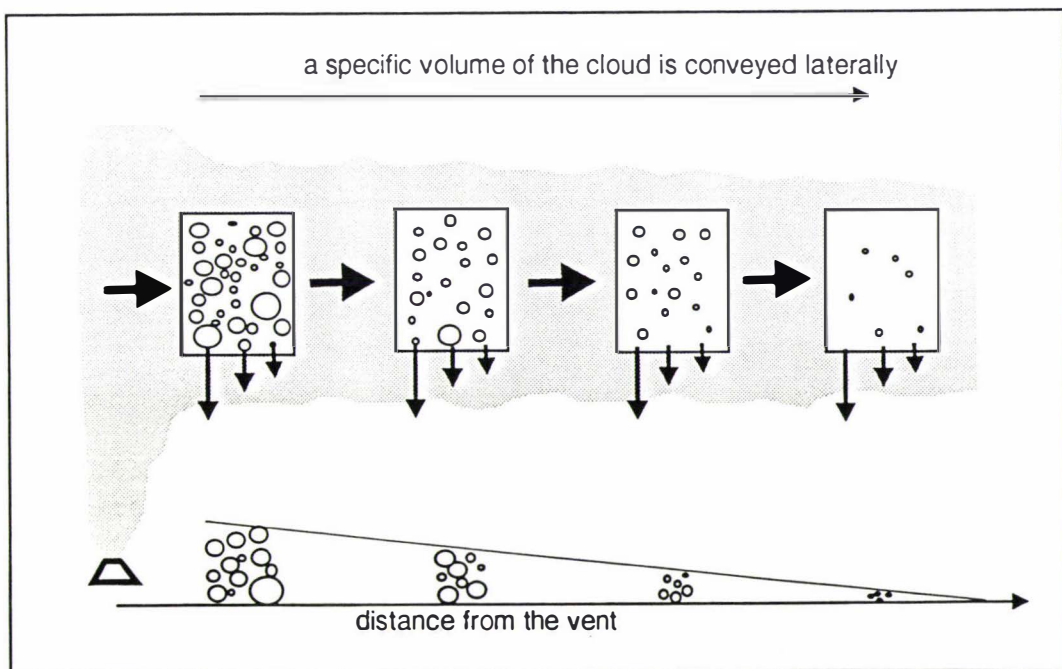


FIGURE 3.2 Schematic illustration of the fall-out of particles from an umbrella eruption cloud showing decreasing thickness and mean grain-size with distance from source.

Density: The density of individual particles may vary from 700-1200 kg m⁻³ for pumice, 2350-2450 kg m⁻³ for glass shards, 2700-3300 kg m⁻³ for crystals and 2600-3200 kg m⁻³ for lithic particles (Shipley & Sarna-Wojcicki 1982). Pumice fragments may form mats of floating material if deposited on water. Since coarser and more dense particles are deposited close to source, fine glass and pumice shards are relatively enriched at distal locations (Fisher & Schmincke 1984).

The bulk density of any pyroclastic fall deposit can be variable, with reported dry bulk densities of newly fallen and slightly compacted deposits ranging from between 500 and 1500 kg m⁻³ (Kienle 1980; Moen & McLucas 1980; Scott & McGimsey 1994). Both increasing and decreasing bulk densities with distance from source have been reported (Scasso *et al.* 1994), but distal ash falls most commonly show slight increases in bulk density with distance from a volcano. Grain-size, composition (proportions of crystal, lithics, glass shards and pumice fragments) and particle shape appear to be the main features controlling bulk density. Less spherical particles (more irregular) will pack relatively poorly resulting in higher porosity and lower bulk densities. Particle aggregation (Gilbert *et al.* 1991) prior to deposition will result in higher particle packing and therefore higher densities.

Abrasiveness: The abrasiveness of volcanic ash is a function of the hardness of the material forming the particles and their shape. Hardness values (on Moh's scale for hardness) for the most common particles are shown in Table 3.2. Ash particles commonly have sharp broken edges (Heiken & Wohletz 1985) which makes them a very abrasive material.

TABLE 3.2 Moh's scale of hardness (mineral hardness from Deer *et al.* 1980).

Scale Number	Mineral	Metal	Minerals in volcanic ash and their hardness (H)
1	---- Talc		
2	---- Gypsum	Aluminium Copper	
3	---- Calcite	Brass	
4	---- Fluorite	Iron	
5	---- Apatite	Steel	volcanic glass, pyroxene, hornblende (H 5-6)
6	---- Orthoclase (Feldspar)		plagioclase, alkali- feldspar (H 6-6.5)
7	---- Quartz		olivine (H 6.5-7) quartz (H 7)
8	---- Topaz		magnetite (H 7.5-8)
9	---- Corundum	Chromium	

Soluble components: Freshly fallen ash grains commonly have surface coatings of soluble components (salts) and/or moisture (Rose 1977). It is these components that make ash mildly corrosive and potentially conductive. These soluble coatings are derived from the interactions in an eruption column between ash particles and aerosols which may be composed of sulphuric and hydrochloric acid droplets with absorbed halide salts (Fig. 3.3). This process is most active close to a volcano (i.e. <50 km), although the amount of available aerosols varies greatly even between eruptions of similar volumes (Bernard & Rose 1990). The release of soluble components (leachates) can also result in changes to local water chemistry and hence quality (refer to 3.2.6).

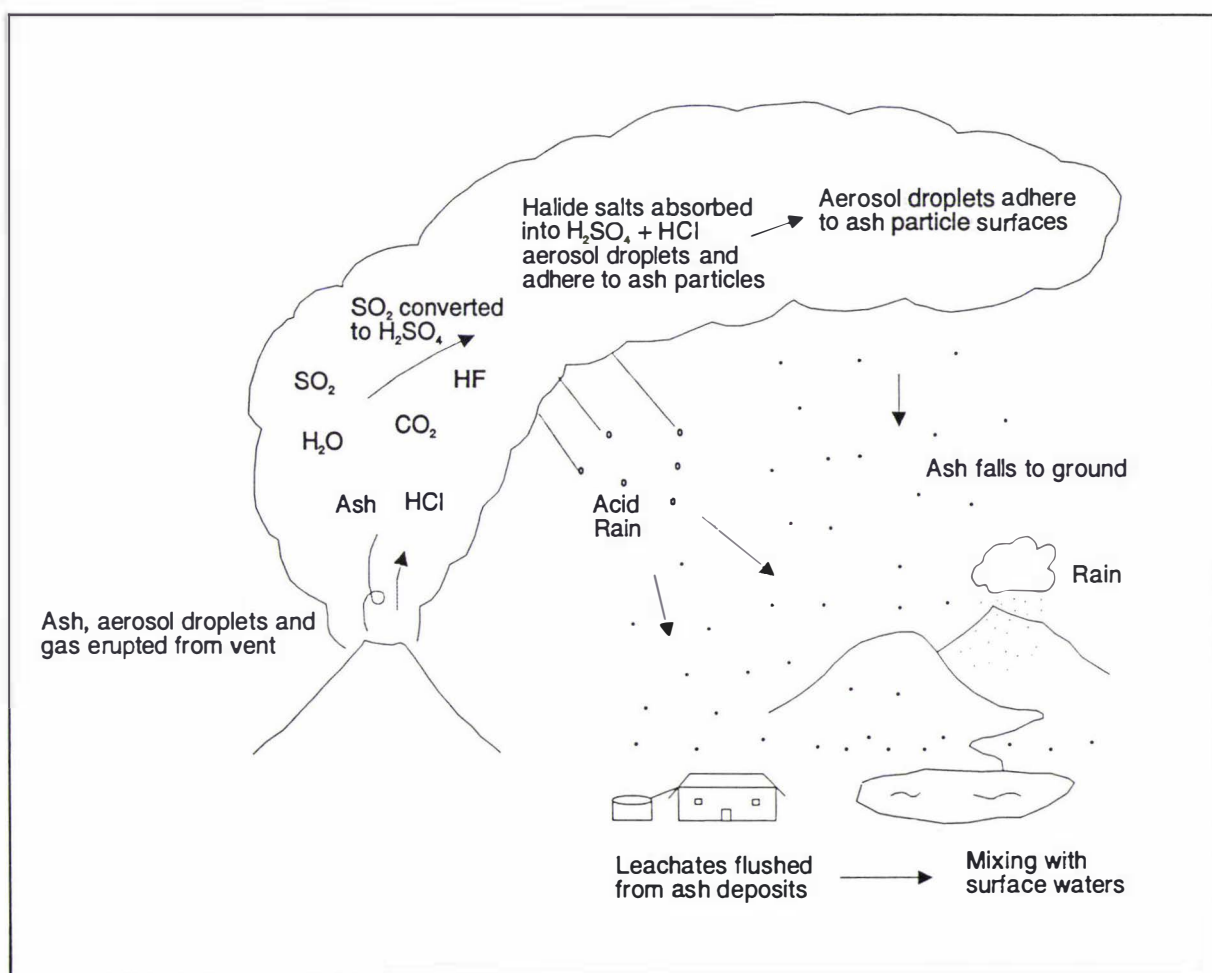


FIGURE 3.3 Volcanic eruptions inject water vapour (H₂O), carbon dioxide (CO₂), sulphur dioxide (SO₂), hydrochloric acid (HCl), hydrofluoric acid (HF) and ash into the atmosphere. HCl and HF will dissolve in water and fall as acid rain whereas most SO₂ is slowly converted to sulphuric acid (H₂SO₄) aerosols. Ash particles may absorb these aerosol droplets onto their surfaces providing an acid leachate after deposition.

3.2.4 Compaction, erosion and redeposition of ash

The bulk density of an ash deposit will increase with time by up to 50% (within a few weeks) and thickness will correspondingly decrease (Waldron 1967; Kienle 1980; Moen & McLucas 1980; Fisher & Schmincke 1984; Scasso *et al.* 1994).

Mount St. Helens' 1980 ash showed initial resistance to wetting and water beaded on its surface (Folsom 1986). However, this resistance lasted for only a few hours in light rain and was eliminated by heavy rain in minutes. After initial wetting, an undisturbed ash layer may remain persistently wet due to the inefficient water drainage from between the angular surfaces of grains. Raindrops impacting on an ash layer contribute to rapid compaction as porosity decreases. Pore space saturation will then occur relatively rapidly during heavy rain. In the 1964 Irazu eruption fine-grained soft, loose ash formed a hard impervious surface crust thought to be a result of precipitation of soluble salts by evaporation (Waldron 1967)

When dry ash falls onto areas without vegetation cover or on paved surfaces it may be reworked by the wind (Foxworthy & Hill 1982; Blong 1984; Folsom 1986; Scasso *et al.* 1994). On moistening by rain, ash usually exhibits cohesive properties that dramatically decrease its reworking potential. The erosion resistance of compacted ash will increase as grains nest more tightly together. Mount St. Helens' 1980 ash was almost completely stripped from slopes of 50° or steeper, with redeposition nearly always local and immediate (Folsom 1986). It is during severe rainstorms that ash is readily eroded from the land surface to be ultimately deposited in streams or rivers. Such events are little different to the behaviour of soils on non-vegetated land during similar severe rainstorms.

Ash on non-paved surfaces will be progressively stabilized by a range of processes. Movement of water through an ash layer is capable of transporting single grains downwards into cracks, root casts, animal burrows and soil macropores below. This process is accelerated by frost action because freezing and thawing helps to desegregate the grains. By these mechanisms the bulk of thin undisturbed fine ash cover may be stabilised to become part of an accreting soil. In parts of eastern Washington State, USA, ash layers up to 100mm thick (from the 1980 eruption of Mount St. Helens) have been incorporated by this process into a silty soil (Folsom 1986).

Chemical changes in the underlying soil can occur as a result of leaching of the aerosols coating individual grains and longer term from unstable glass particles (Cronin *et al.* 1996).

3.2.5 Impacts of volcanic ash on transportation

Transportation networks (e.g. road, rail, air) are extremely vulnerable to volcanic ash falls, being subject to widespread disruptions and damage.

Road: Volcanic ash falling on roads can be extremely disruptive causing reduced visibility, traction problems and damage to vehicles. This may require reduced speed limits to be imposed or even road closures.

Reduced visibility on roads is commonly reported during and after ash falls (see Table 3.3); total darkness may result during heavy ash falls (Blong 1982). During such conditions vehicle headlights are often ineffective [e.g. at Pinatubo 1991 (Bautista & Tadem 1993)] and driving becomes impossible. Dry ash is easily raised in clouds by passing vehicles to become an ongoing hazard for many weeks. Another problem is that ash fall deposits will absorb a considerable amount of water before being washed away. Wet ash can easily turn to mud and cause further problems to vehicle traction, as seen in and around Rabaul after the 1994 eruption (Blong & McKee 1995). Thin ash (<5 mm) will generally be moved to the shoulder of roads by roadway traffic where it tends to remain. Greater thicknesses of ash need to be physically removed. Of note is the comment by Warrick *et al.* (1981) who concluded from experience after the 1980 Mount St Helens eruption that:

"Ash depth had little influence on the initial level of impacts on the transportation systems. On the other hand ash depth had direct influence on the length of recovery time for most transportation systems".

In most cases vehicles can remain operative during ash falls, e.g. Pinatubo 1991 (Rodolfo 1995), Mount Spurr 1992 (Appendix 2), Rabaul 1994 (Finnimore *et al.* 1995) and Ruapehu 1995-1996 (Chapter 2) providing they are adequately maintained. Fine dry ash can clog air-filters which causes vehicles to overheat because of over-enrichment of the fuel/air ratio (Warrick *et al.* 1981). This was the main cause of vehicle strandings in heavy ash fall areas after the 18 May 1980 Mount St. Helens eruption (Schuster 1981). Other problems noted after the Mount St. Helens ash falls were fouled ignition points and the gap in spark plugs welding together.

Ash entering a car engine causes wear on most moving parts, reducing their life. In most cases severe damage can result from excessive use in an ash-rich environment. A number of ash-affected communities report keeping damage to a minimum by initiating active preventative maintenance programmes (i.e. changing oil, oil filters, air-filters etc). The ash can also act as an abrasive, damaging vehicle brakes, exterior fittings, paintwork and windows. Corrosion of paintwork and exterior fittings may also result where ash is in contact

with vehicle bodies (for the reasons outlined in 3.2.9).

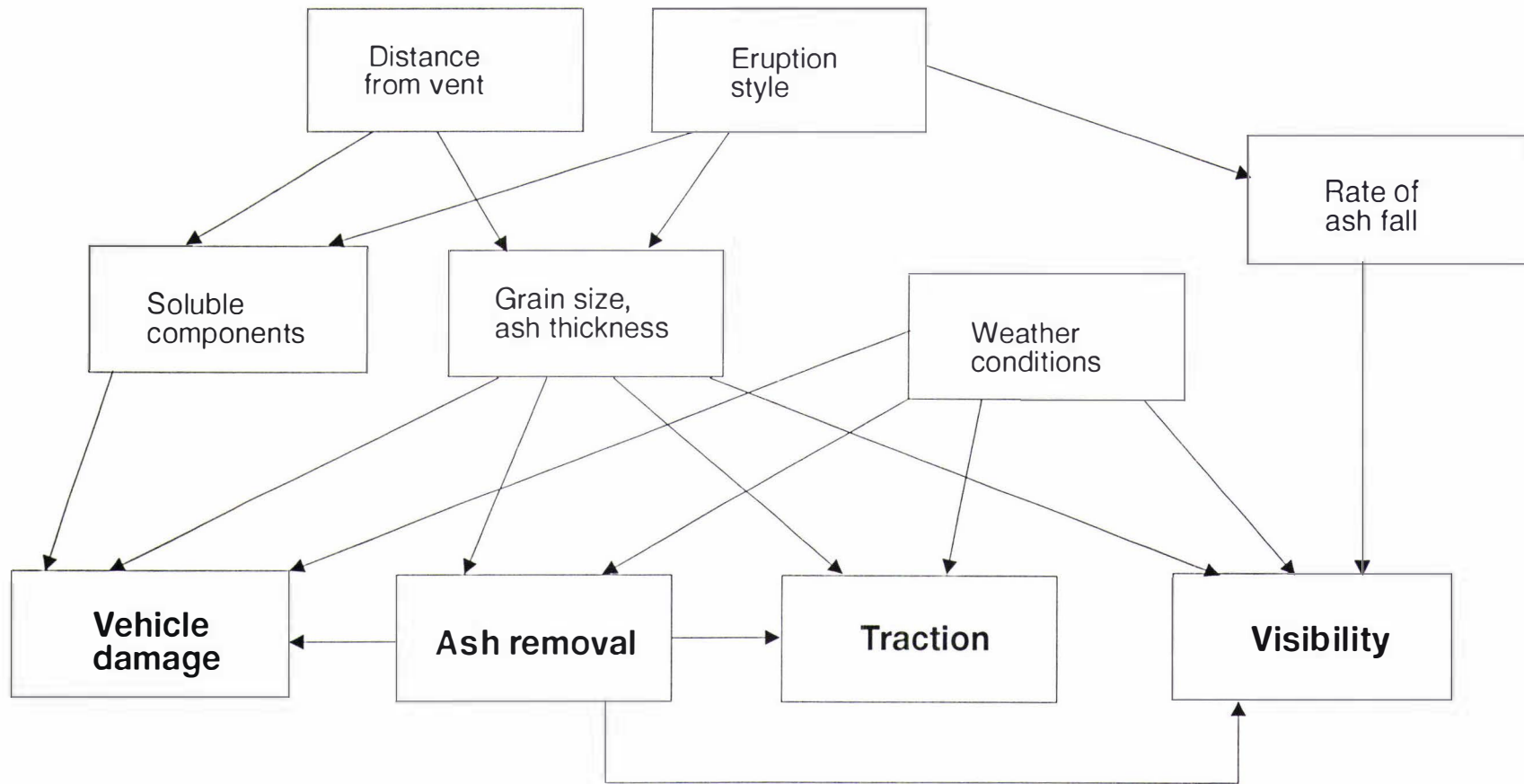
TABLE 3.3 Examples of ash fall impacts on road transport in 6 selected eruptions.

Volcano and year	Road closures	Reduced visibility	Vehicle damage	Traction problems	Reference
Hudson 1991		*	*		Bitschene 1995
Mt St Helens 1980	*	*	*		Blong 1984, Warrick <i>et al.</i> 1981 Schuster 1981
Pinatubo 1991		*	*		Bautista & Tadem 1993, Rodolfo 1995
Rabaul 1937 1994	* *	 *	* *	* *	Johnson & Threlfall 1985 Blong & McKee 1995, Finnimore <i>et al.</i> 1995
Ruapehu 1945 1995	 *	 * *	* *	 *	Johnston & Neall 1995 Houghton <i>et al.</i> 1996
Unzen 1990-1992		*			Yanagi <i>et al.</i> 1992

Secondary problems consequent upon road closure may include loss of access for emergency services, stranding of travellers, disruption to food and emergency water supplies and economic impacts on businesses. Where roads remain open, speed restrictions may need to be introduced to ensure motorists' safety with reduced visibility. After the 1980 Mount St Helens eruption travel was curtailed in ash-affected areas for three reasons: 1) people chose to stay home due to fear of the effects of ash, and were either advised to or were required to clean-up ash from their properties; 2) people experienced difficulty in travel due to reduced visibility and/or clogging of car air-filters; and 3) activities at destinations were unavailable (Dueker *et al.* 1980)

The relationships of factors affecting the impacts of volcanic ash on road transport is presented in Figure 3.4.

Figure 3.4 Factors affecting the impact of volcanic ash on road transport



Mitigation measures for vehicles: Damage to vehicles operating in ash-rich environments can be reduced by using a number of mitigation techniques. From the experience gained during the 1980 Mount St. Helens eruptions, F.E.M.A. (1984) produced the following recommendations for ash removal and protection of vehicles (Table 3.4).

TABLE 3.4 Suggested mitigation measures for the protection of vehicles (from F.E.M.A. 1984).

1)	<i>Avoid driving in heavy ash conditions unless absolutely required. The more dense the dust, the more urgent the requirement should be for driving.</i>
2)	<i>When required to drive in dense dust keep speed below 35 mph or lower. Do not follow too close to car ahead. Use headlights on low beam.</i>
3)	<i>Change oil often. In very dense dust change at 50-100 mile intervals. In light dust conditions change oil at 500-1000 mile intervals. Lubricate all chassis components at each oil change.</i>
4)	<i>Clean air filters by back-flushing filter paper with compressed air (30 psi). Caution: Blow element from inside (clean side) to outside (dirty side). DO NOT strike filters against anything. Air clean only. If unsure, have a qualified mechanic perform the air filter service. Inspect filters for dents or torn paper. Clean the inside of filters and the filter cover with damp cloth before reinstalling filter. Reinstall filter in housing and tighten on cover very tight, approximately one full turn with pliers after tightening. Do not exceed one full turn with pliers or you may damage the system.</i>
5)	<i>DO NOT install hose from carburettor air intake (air clean) to inside of car. Outside dust and ash will be drawn into vehicle.</i>
6)	<i>Wrapping air cleaner element with a silk stocking or cheese cloth is of questionable value. It will not improve air cleaner filtration and may actually prove serious if not installed correctly. Rags, or any other intended filtering material, should not be placed over the carburettor inlet inside the air cleaner element; serious damage to the engine and/or loss of vehicle control may result.</i>
7)	<i>Cover passenger compartment vent inlet (located at base of wind-shield and usually under hood) with thick, loosely woven felt-type material to filter air into vehicles. With vent filter in place, keep heater blower high. Blower will slightly pressurize inside of vehicle and keep dust from entering through body gaps or holes. If a vent filter is NOT installed, keep air conditioner and heater blowers off.</i>
8)	<i>Have service garage clean wheel brake assemblies every 50-100 miles for very severe road conditions, or every 200-500 miles for heavy dust conditions.</i>
9)	<i>Have service garage clean alternators winding with compressed air after heavy accumulation or every 500 to 1000 miles or after severe dust exposure.</i>
10)	<i>Wash engine compartment with garden hose or steam cleaner. Be sure to seal off air intakes and electrical components before cleaning.</i>
11)	<i>Commercial truck filters can be installed to increase the filtering capacity of the cleaner. However, this is expensive and should only be attempted by trained garage mechanics or experienced personnel. This would be beneficial for vehicles operating continuously in extreme dust conditions.</i>
12)	<i>Air filter restriction gauges can be installed by qualified mechanics. The gauge will tell you when your air filter requires servicing in order to avoid over-servicing.</i>

Ash removal from roads: Ash will need to be removed from urban areas even after a fall of only a few millimetres. A number of factors will influence the removal method employed, the ease with which ash can be removed and the cost of any clean-up operation. These include ash thickness, grain-size and availability of equipment. Removal of ash from roads was undertaken by a number of public works departments after the 1980 Mount St. Helens eruption. Few, if any, of these organisations had developed plans for ash-removal prior to the eruption and little knowledge was available on how to undertake this (Saarinen & Sell 1985). A range of methods were tried during initial clean-up operations (Hoff 1980; Markesino 1981; Novak & Zais 1981) before the best method was found. This was to sprinkle the ash with water, blade it to the side or middle of the road for pick-up by belt or front-end loaders and then use power-brooms or more water to remove the remainder (Table 3.5) (see Appendix 3 for examples). Prior to ash removal, dust retardants have been used to control wind blown ash with "Coherex", an emulsion of petroleum resins used successfully for this purpose in Oregon after the 1980 Mount St. Helens eruption (Public Works 1980).

TABLE 3.5 Suggested ash removal methods for roads (from F.E.M.A. 1984).

- * *Notify bordering property owners to move ash from roofs and the rest of their property to the street, away from the gutters, to prevent the need for more than one ash removal project and to avoid storm sewer blockages.*
- * *Encourage and monitor block efforts and volunteer work.*
- * *Before beginning cleanup activities, build small dike (using sandbags or other methods) around catch basin inlets to screen ash.*
- * *To keep ash out of storm drains, hand sweep the dry ash outwards from the gutters about two feet or so. (Volunteer teams can provide important assistance in this area.)*
- * *Moisten the ash using a sprinkling system. Avoid moistening it too much, for it will become unmanageable. Due to its fineness, ash powder when saturated can retain large amounts of water and weigh up to 80 pounds per cubic foot. (Wet sawdust or wood-chips have been used to help reduce the dust, but these methods are not as effective as only wetting ash.)*
- * *Use motor patrol graders to blade the ash. Collect, load and transfer the ash to trucks to be hauled to dump sites.*
- * *For a thorough cleaning of paved roads with storm sewers, use power brooms on the dampened residue.*
- * *To remove the remaining ash on paved roads without storm sewers, flush the roads with water.*
- * *As soon after the street cleanup as possible, remove ash deposits from catch basin inlets with vacuum trucks or machines with jet rodding and vacuum systems. Delaying the cleanup allows time for the ash to crust and cake, making it harder to remove. Further, the ash density impairs the self-cleaning function of the sewer's grade, creating the potential for plugging the sewer.*

Paved or Oiled Roads That Have No Curbs or Sewers

- * *Sprinkle ash with water and blade it onto the shoulders or into the ditches. Then load and remove the ash. Remove the residue by sweeping or flushing it, if necessary. Where gravel shoulders exist, replace lost gravel so as not to lose the integrity of the roadway.*

Gravel Roads

- * *Blade the ash into ditches, being careful to avoid unnecessary loss of surface materials.*
- * *If the existing right-of-way is wide enough, spread the ash along the back slopes outside the ditch. (Note that much of the ash may become integrated into roadside vegetation and that the ash in these areas will blow for some time during windstorms.)*
- * *Remove ash blocking the drainage in ditches and culverts, and transport it to a disposal site. A considerable amount of ash will remain on the roadbed surfacing, creating a serious visibility problem for traffic. Nothing can be reasonably done to eliminate it totally, but it will decrease with time.*
- * *On the roadbed, place a thin layer of rock consisting of graded material 5/8 inch to 0 in size and crushed to standard specification. This layer can be added and processed into the existing surface to achieve the binding effect that will stabilize the surface under traffic. (While this expensive method will not provide total dust control, it is, nevertheless, the most suitable method available for achieving visibility levels so that traffic operations can be restored.)*

Railways: Rail transportation is less vulnerable to volcanic ash than road, with disruptions mainly caused by poor visibility and breathing problems for train crews. Trains will also stir up fallen ash which can affect residents close to railway tracks. Fine ash enters engines causing increased wear on all moving parts. Light rain on fallen ash may also lead to short-circuiting of signal equipment.

Blong (1984) describes a number of examples of disruption to rail services. The 18 May 1980 eruption of Mount St Helens severely disrupted rail services in eastern Washington (Warrick *et al.* 1981) where in areas receiving ash, train crews reported almost zero visibility resulting in train services being suspended. Operations resumed within 24 hours of the end of the ash fall. Speed restrictions were then emplaced for the following nine days to combat the raising of dust clouds. Rain several days after the eruption caused numerous short-circuits of track signals.

Air transport: Air transportation is extremely vulnerable to volcanic ash (Casadevall 1993; Miller 1994; Zinser 1994). Severe impacts can result from aircraft-ash encounters, as temperatures reach 3000°C in modern jet engines - enough to melt ash. Over 90 ash encounters have been reported world-wide in the period 1960-1996, with eight aircraft having lost in-flight jet engine power over that period (Casadevall 1997). Luckily, to date, none have crashed as a consequence of such encounters. The aircraft repair cost resulting from the December 1989 aircraft-ash encounter off Alaska involving a Boeing 747-400 aircraft, is estimated in excess of \$US80 million (Tuck *et al.* 1992). Drifting volcanic ash can affect large volumes of air-space, commonly resulting in aircraft exclusion since ash cannot be detected by aircraft radar. This was the main cause of flight disruptions during the 1995-1996 Ruapehu eruptions (see Chapter 2). With world-wide air traffic planned to double over the next decade and with future aircraft being bigger and with fewer engines the vulnerability will continue to increase.

Even minor ash falls on airports may render them inoperative, with damage to both aircraft and facilities (Labadie 1994). Tyler and Reynertson (1981) give details of the clean-up operation at Fairchild Airforce Base, USA after ash falls from Mount St Helens in 1980. Water was used to wet the ash; graders and snowploughs then worked the ash for loaders to pick it up. It was then hauled to a central location where it was buried using landfill techniques. It was noted that around buildings the wind blowing ash from roof tops constantly contaminated previously cleaned areas. Other examples of ash-affected airports are given by Casadevall (1993). Table 3.6 summarises the key findings of a 1993 workshop on the impacts of volcanic ash on airport facilities.

TABLE 3.6 Key findings of a 1993 workshop on the "Impacts of volcanic ash on airport facilities", Seattle, Washington, April 1993 (Casadevall 1993)

1. *Have a plan and make sure the plan is practised and staff are trained.*
2. *Water-water-water; any system that can provide water, especially under pressure is valuable.*
3. *Move ash only once (plan ahead!); ash is not snow, it won't melt and disappear!*
4. *From trucks to brooms, have the right equipment on hand.*
5. *Get airplanes away from the airfield before ash starts to fall.*
6. *Do not start cleanup until ash fall is over (except when threatened by overloading of roofs).*
7. *In conditions of light ash fall, aircraft are not badly affected: they can land and take off, but should exercise proper care and procedures such as tow-in/tow-out from ramp area.*
8. *Ash can be slippery when wet; aircraft and ground vehicles should watch out!*
9. *Protect people working on roofs, on aircraft wings, and during poor visibility!*
10. *Be innovative with your solutions!*

Conclusions: Ash falls have the potential to cause severe and widespread disruption to transportation links over wide areas and between countries. Aviation is the most widely affected transport sector due to closures of air-space and airports. Ash falls reduce visibility on roads and damage vehicles. Falls of only a few millimetres frequently require time-consuming and expensive removal operations before roads and airports can re-open. Rail is commonly the least disrupted transport system.

3.2.6 Impacts of volcanic ash on water supplies

Contamination of water supplies can take a number of forms resulting from physical and chemical changes in water quality. The most common contamination problem results from the suspension of ash in water (turbidity). Limits for potable water quality are easily exceeded by suspended ash. High turbidity often interferes with disinfecting processes at water treatment plants.

Freshly fallen ash readily releases soluble components (leachates) resulting in changes to local water chemistry. Leachates are sourced from the surface coatings of soluble components on individual ash grains and in the longer term from the release of soluble elements and compounds from within grains (minerals or solid solutions in glass). The flushing of soluble components from surfaces of ash particles is the main initial source of leachates. The most common leachates are Cl, SO₄, Na, Ca, K, Mg, and F (Smith *et al.* 1982). Other elements reported but in lower concentrations include Mn, Zn, Ba, Se, Br, B, Al, Si, Cd, Pb, As, Cu and Fe. Most of these elements and compounds are naturally present in ground and surface water but become hazardous above threshold concentrations. Finer ash is able to carry more soluble ions than coarser ash because of its larger surface area. This is significant because it is smaller particles that travel greater distances from the vent and often extend over very wide areas.

The potential for chemical contamination of water supplies or pollution of rivers and lakes depends on the ratio between the volume of water and amount of leachate delivered (Table 3.7).

TABLE 3.7 The relative vulnerability to volcanic ash contamination of different types of water supplies.

Type	River/ stream	Reservoir	Groundwater	Roof-fed/ water troughs
chemical	low-medium	low-medium	low	high
pH	low-high*	low-high*	low	high
turbidity	high	medium-high	low	high

* depends on the ash thickness and water volume ratio.

The release of Cl⁻ and SO₄²⁻ ions from water soluble salts in volcanic ash will lower the pH of water, possibly beyond the acceptable safe limits for potable water supply. Changes in pH of surface and groundwater will however be strongly influenced by the buffering effect of soils (Hausenbuiller 1978).

Physical impacts can result from damage to filters at intake structures and/or treatment plants,

greater susceptibility to wear of plant and interference with electrical equipment or supply. Other indirect problems can result from increased water demand for clean-up operations by residents of communities affected by ash fall.

Historic examples of potable water supply contamination: Contamination of water supplies has been reported after a number of historic eruptions (Table 3.8). The most common problems were the result of unacceptable pH and turbidity levels (Blong 1984; Collins 1978; Le Guern *et al.* 1980; Wilcox 1959), but hazardous chemical changes have been reported in a few cases (Blong 1984; Collins 1978; Oskarsson 1980; Thorarinsson 1979). Excess fluorine is recognised as the most hazardous circumstance.

TABLE 3.8 Reported examples of contaminated potable water supplies.

Volcano, year	Chemical	Turbidity	pH	Reference
Ruapehu				
1945		*		Chapter 2
1969	*	*	*	Collins 1978
1995-1996		*		Chapter 2
Mt Spurr				
1953		*	*	Wilcox 1959
Mt St Helens				
1980		*	*	Blong 1984, Warrick <i>et al.</i> 1981
Hekla				
1947	*			Thorarinsson 1979
1970	*			Oskarsson 1980
Soufriere				
1976-1977			*	Le Guern <i>et al.</i> 1980

Mitigation measures - stream, river, lake and reservoir supplies: In the first instance water supply intakes should be closed before turbidity and acidity levels become excessive; regular monitoring will indicate when the supply can be resumed. High turbidity levels are manageable if water-treatment filters are cleaned or replaced frequently but they may be blocked if levels become excessive. Where turbidity is high precautionary warnings to "boil water" should be issued. This is because the suspended ash may have decreased the effectiveness of any disinfection or flocculation process. As the fine ash can remain in suspension for long periods (days to weeks) a coagulation-flocculating agent may need to be added. Alum is found to be the best agent (Hindin 1982). To reduce the physical damage to plant, equipment and pumps should be covered when there is an impending eruption and the ash removed before continuing operations.

Mitigation measures - water tanks and troughs: As well as turbidity and acidity problems, bodies of water close to an erupting volcano with low volume-to-catchment-area ratios may be subject to chemical contamination by hazardous leachates, notably fluorine. Households with roof water supply should immediately disconnect down pipes when ash falls occur. Where ash has collected on a roof and down pipes were not disconnected, the tank water should not be used until water quality tests have been undertaken. If ash is found to be non-toxic but turbidity is still high, then water should be boiled before use. If testing is unavailable it would be advisable to drain and flush the tank and refill with uncontaminated water. Farm water troughs are highly vulnerable to contamination and would most probably need to be emptied and refilled after ash falls.

Conclusion: Contamination of open water supplies is possible even from relatively small ash falls. Both turbidity and acidity will usually return to normal levels within a few hours to days unless ash falls are prolonged. Adverse affects on covered water supplies are minimal. Hazardous changes in water chemistry are rare, except close to a volcano where small volumes of water (such as roof-fed water tanks, stock water troughs and shallow surface water bodies) can be contaminated by ash leaching to levels that exceed guidelines for potable water. Levels of contaminants in streams, rivers and lakes may also be elevated for short periods. Observations of historic eruptions show that concentrations of hazardous leachates in ash decrease with distance from the vent, and few examples of serious chemical contamination of potable water supplies exist. Excess fluorine is recognised as the most hazardous potential circumstance.

3.2.7 Impacts of volcanic ash on sewage and stormwater systems

Sewage and stormwater systems are vulnerable to damage from volcanic ash falls, because ash blocks pipes, damages pumps and other machinery and interferes with sewage treatment processes (White *et al.* 1980; Day & Fisher 1980; F.E.M.A. 1984; Schuster 1981; Warrick *et al.* 1981; Blong 1984; A.I.D.A.B. 1994). Table 3.9 gives examples of serious problems. When ash falls on impervious surfaces, such as roads, roofs and other paved areas, it is easily washed into stormwater systems by rain, or during clean-up operations. It may also enter the sewage system via illegal connections, manholes, gully traps or inter-connections to a stormwater system. Since the mean grain-size and density of ash particles decreases with distance from an erupting volcano, it is at more distal localities where fine ash enters the system more easily. The density of ash is usually too high for it to be held in suspension by most water velocities in the sewer or stormwater systems; thus ash deposits will tend to collect rapidly and easily in sediment traps and cesspits. Very fine ash (or pumice) may remain in suspension and be transported to sewage treatment plants depending on pipe size, fluid pressure and velocity. Where pipes become blocked local flooding results. Sewage pumps may also be damaged by ash-laden sewage or they may fail if ash impacts on their electricity supply system. This may result in banking up of sewage in urban areas. To remove ash from sewage and stormwater systems is a time-consuming and costly exercise (Fig. 3.5) (refer to Chapter 2 and Appendix 3 for examples). The factors that interact in these situations are presented in Figure 3.6.

Sewage Treatment Plants: Ash-laden sewage may enter a treatment plant overloading solid removal equipment at both the pretreatment and primary treatment stages. Milliscreens, mechanical grit/sludge removal mechanisms, comminutors and other equipment may become damaged. Ash falling directly into sedimentation tanks will add to the volume of material which has to be removed. Low density pumice and finer pumice shards may float on the surface of ponds. Ash entering secondary treatment facilities, such as oxidation ponds or biofilters, will tend to reduce or halt the oxidation process until the ash settles out or is removed. Ash may affect the acidity or toxicity level of effluent to such an extent that bacterial growth may be damaged or lost. If there is plant failure and/or deliberate shutdown untreated sewage may have to be released into waterways. A summary structure of factors affecting the impact of volcanic ash on sewage treatment plants is presented in Figure 3.7.

TABLE 3.9 Examples of ash-affected urban stormwater and sewage systems.

Volcano, year, affected town	Ash thickness (mm)	Impact	Reference
Mt St Helens - 1980			
Moses Lake	25	Stormwater blocked, sewage system rendered inoperative, damage to plant.	Schuster 1981
Yakima	10	Stormwater blocked, sewage system rendered inoperative, damage to plant.	Schuster 1981
Spokane	5	Stormwater filled with ash, sewage plant received ash but remained operative.	Schuster 1981
Ellensburg	3	Stormwater system overloaded in a number of places but city employees kept the system open using high-pressure water jet sewer cleaners.	Warrick <i>et al.</i> 1981
Mt Spurr - 1992			
Anchorage	3	Ash settled in stormwater system and caused some local flooding during the spring thaw.	Appendix 3
Rabaul - 1994			
Rabaul	up to 1000	System totally blocked but generally undamaged.	A.I.D.A.B. 1994
Ruapehu - 1996			
Rotorua	1	Small amount of ash removed from stormwater but no major problems reported.	Chapter 2

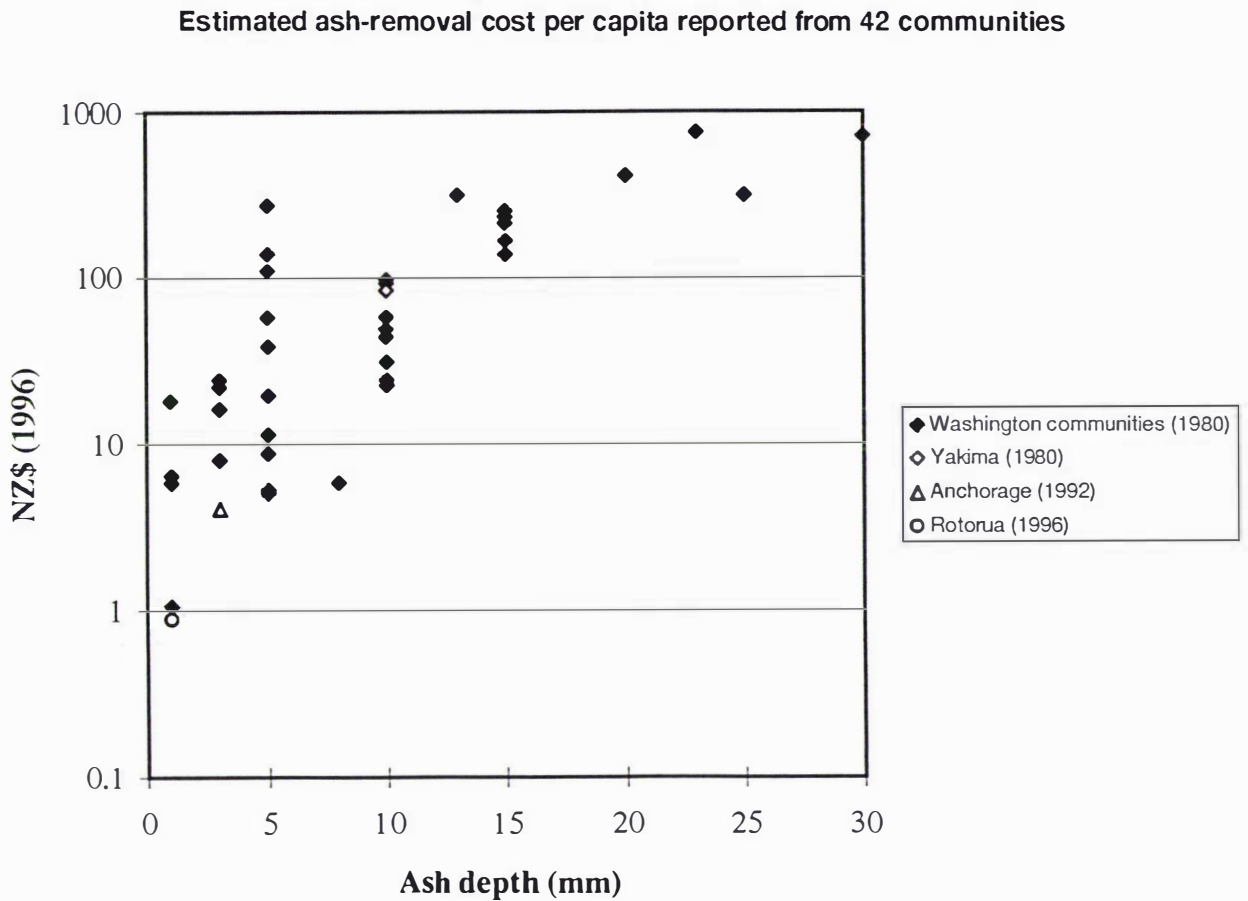
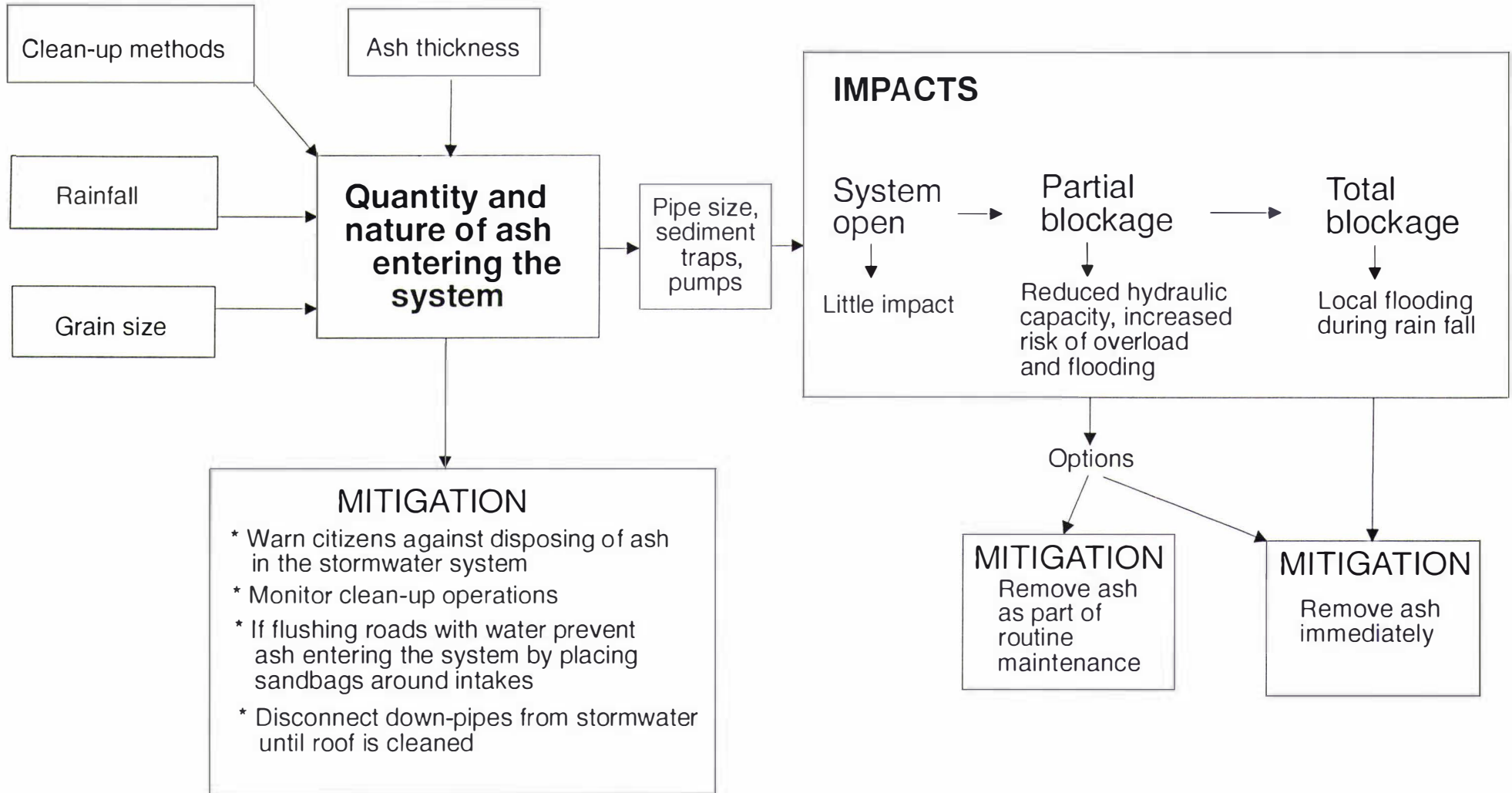


FIGURE 3.5 The estimated ash-removal cost per capita versus ash depth reported from 42 communities (includes removal from road and sewage/stormwater systems). The 1980 ash clean-up in Yakima and other Washington communities resulted from the 18 May 1980 eruption of Mount St Helens (reported by Warrick *et al.* 1981). The 1992 Anchorage ash clean-up was a consequence of the 18 August 1992 eruption of Mt Spurr and the 1996 ash clean-up in Rotorua was a result of the 17 June 1996 eruption of Ruapehu. See Chapter 2 and Appendix 3 for further details. The costs have been adjusted to 1996 values by using the U.S. consumer price index and converted at \$1NZ = \$0.7US.

Figure 3.6

Factors affecting the impact of volcanic ash falls on stormwater systems



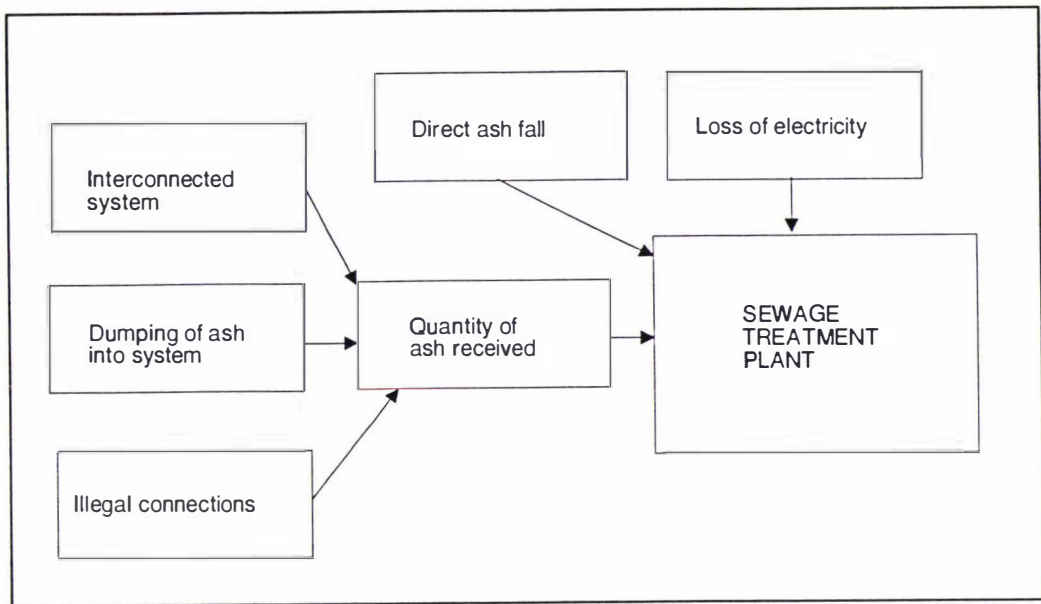


FIGURE 3.7 A summary structure of factors affecting the impact of volcanic ash on sewage treatment plants.

Mitigation measures for sewage and storm water systems: The blockage of sewer and stormwater pipes is a major problem created by ash falls. It is therefore of prime importance to limit the amount of ash in the initial sections of such systems. F.E.M.A. (1984) has recommended a number of measures which can reduce this ash entering input and these are listed in Table 3.10.

TABLE 3.10 Suggested methods for the protection of sewage and stormwater systems from volcanic ash (from F.E.M.A. 1984)

- 1) *Have local ordinances in effect banning connections of downpipes and roof drains to the sewer.*
- 2) *Warn citizens against disposing ash down manhole of both sewer and stormwater systems.*
- 3) *When hosing streets, place sand bags around or over manhole covers or avoid covers entirely, since the vent holes and the areas between the cover and the rings allow passage of ash.*
- 4) *When washing streets, parking areas, roofs, use a weir (sandbags) in each manhole and stormwater intake to trap the ash.*
- 5) *Instruct the public how to protect storm water systems*
- 6) *When possible, disconnect downpipes from the stormwater system until roof clearing is complete.*
- 7) *Instruct citizens where to deposit ash cleared from property.*
- 8) *Closely monitor the cleanup activities of privately owned parking areas.*
- 9) *Use dry methods, like hand sweeping, prior to flush cleaning when clearing streets and parking areas served by a free discharging or dry well stormwater system.*
- 10) *Sweep the ash outwards from the gutters about two feet or so.*

Note: Shallow deposits of ash in the stormwater or sewerage system will not reduce the hydraulic capacity of the pipes by a significant amount; thus expenditure of time and money in these circumstances to clean lines may not be warranted.

For protection of sewage treatment plants F.E.M.A. (1984) and White *et al.* (1980) recommend the precautions in Table 3.11 be taken.

TABLE 3.11 Suggested methods for protection of sewage treatment plants from volcanic ash (from F.E.M.A. 1984).

1)	<i>Temporarily cover all equipment (e.g. mechanical, biofilters), including ventilation intakes, that might be directly exposed to the ash fall before or during the ash falls.</i>
2)	<i>Shut down all equipment not absolutely necessary.</i>
3)	<i>Where possible, place sandbags or other devices at the entrance channel to the plant to trap ash. This procedure will require frequent attention due to normal settleable solids present in sanitary sewage.</i>
4)	<i>Consider removing or bypassing the comminutor during the initial heavy flows of ash into the plant.</i>
5)	<i>Frequently check the primary clarifiers to prevent (a) damage to the sludge collection mechanism and/or the digesters sludge pumps and (b) the transference of ash to the digester. Depending on the type of mixing employed in the digester, further damage may occur in the sludge transfer pumps.</i>
6)	<i>To clear ash from individual sections of the treatment facility, bypass individual units, or in extreme instances, make a complete plant bypass to a holding pond or lagoon.</i>

Conclusion: Ash falls can cause severe damage to sewage and stormwater systems. Ash is easily washed from impervious surfaces such as roads, carparks and buildings into them. The most effective mitigation measure is to reduce the input of ash in the first place. Sewage treatment plants can be severely affected by either ash falling directly on the plant or by the receipt of ash-laden sewage. Bypassing and/or shutting down parts of a plant may need to be considered to reduce the likelihood of damage.

3.2.8 Impacts of volcanic ash on electrical distribution systems

Volcanic ash can cause many different problems to electrical distribution systems (Table 3.12). Most commonly these are: (1) supply outages resulting from insulator flashover; (2) controlled outages during ash cleaning; and (3) line breakage. Investigations on these effects have been reported by Nellis & Hendrix (1980), Stember & Batiste (1981), Sarkinen & Wiitala (1981), Blong (1984) and Heiken *et al.* (1995). The factors affecting flashover potential of insulators are primarily ash conductivity, ash adherence and insulator dimensions (Figure 3.8) which are here discussed in turn.

TABLE 3.12 Examples of electricity outages resulting from ash falls.

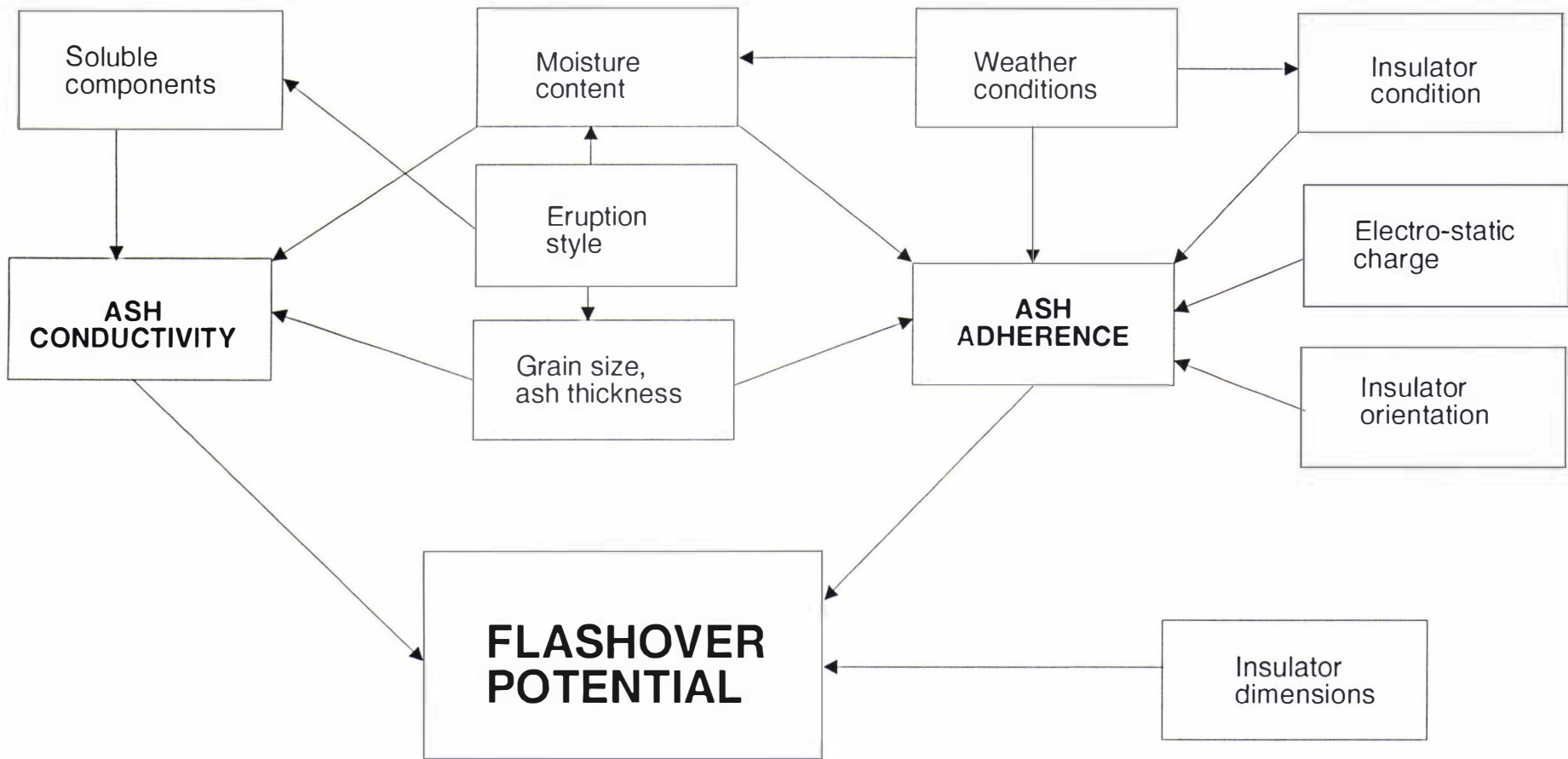
Volcano - year	Impact	Reference
Mt St Helens 1980	insulator flashovers in areas receiving > 5 mm of ash, in conjunction with rain.	Nellis & Hendrix 1980 Blong 1984
Redoubt 1989	insulator flashovers in areas receiving ash, in conjunction with rain.	Tuck <i>et al.</i> 1992
Rabaul 1994	wire and crossarms damaged by collapsing buildings and tree breakage	A.I.D.A.B. 1994 Blong & McKee 1995
Ruapehu 1995	insulator flashovers on high voltage lines receiving moist ash	Chapter 2
1996	flashover at substation due to water (from clean-up operations) settling on ash covered insulators	Chapter 2

Ash conductivity: Dry volcanic ash is not conductive enough to cause insulator flashover problems. However, if insulating surfaces are completely coated in ash, the presence of moisture in association with soluble ash coatings can be critical factors in initiating insulator flashovers. Moisture may be derived from the atmosphere, in the form of rain (during or after the ash fall), or from the eruption plume itself. The soluble coatings are derived from aerosols in the eruptive column (refer to 3.2.3). With time rain will dilute the soluble components.

Ash adherence: Weather conditions at the time of ash fall influence how ash adheres to insulating surfaces. Dry ash generally tends to rest on horizontal or gently sloping surfaces but causes no immediate electrical problems. In contrast wet ash sticks to all exposed surfaces. In experiments reported by Nellis and Hendrix (1980) heavy rain washed off about 66% of ash from insulators, whereas light rain removed little ash.

Figure 3.8

Factors affecting flashover potential due to volcanic ash



Tests also examined the effects of wind and showed that winds of up to 55 km/hr removed 95% of dry ash. The type, condition and orientation of insulators has also been found to influence the adherence of ash. Epoxy insulators are more vulnerable to flashovers than porcelain insulators due to increased ash adherence (Heiken *et al.* 1995). Nellis and Hendrix's (1980) experiments also showed that if insulators were wet prior to ash falls, adherence was enhanced. Especially significant was the ability for ash to accumulate on the underside of wet insulators.

Insulation that has 30% or more of its creepage distance either clean or dry has a low probability of initiating insulator flashovers. Since lower voltage insulators have smaller weather-sheds they are more prone to becoming completely covered with ash and water, and therefore are more vulnerable to flashovers than higher voltage insulators (Nellis & Hendrix 1980). Substation insulators are more susceptible to flashovers than line insulators because of their distinct shape and orientation.

Other problems encountered in ash falls include:

- * Ash contamination on insulators and conductors increases corona activity which in turn causes increase in audible noise (around 10-15 dB) and radio interference (Nellis & Hendrix 1980).
- * Volcanic ash is a contaminant which abrades and clogs mechanically moving parts. Precautionary measures may be needed to service and maintain substation equipment after ash falls.
- * Saturated volcanic ash on ground surfaces has the potential to be hazardous due to its conductivity (Nellis & Hendrix 1980).
- * Wet ash-laden tree limbs may fall on distribution lines (e.g. in Rabaul in 1994 (A.I.D.A.B. 1994)).

The consequences of loss of electricity supply are widespread, and many other public utilities (e.g. water supply pumps, radio and telecommunication facilities) may be inoperative for the duration of the power loss unless local backup power supplies (batteries and generators) are available.

Mitigation measures for electricity supply: Ash that falls dry on dry surfaces is easily cleaned by air blasting or brushing. Ash that falls wet or is wetted before cleaning is not easily removed without high pressure water or hand cleaning. Immediate ash removal seems the best mitigation option to prevent widespread outages. The washing of insulators should start

from the bottom up to minimise the chance of wet reworked ash forming a sufficient cover to induce flashover. If possible de-ionised water should be used. Mitigation recommendations by F.E.M.A. (1984) are summarised in Table 3.13.

TABLE 3.13 Suggested methods for the protection of electricity supplies (from F.E.M.A. 1984).

*	<i>Immediately after an ash fall, dispatch personnel to the substations to dust, sweep, and blow ash from electrical equipment. Prompt and adequate maintenance of the mechanical and electrical systems is essential.</i>
*	<i>Shut down all electrical systems before any attempt is made to clean or service them. Throw the main circuit breakers, not just the nearest switches.</i>
*	<i>Remove dry ash immediately from the most sensitive systems by blowing it off using air pressure of 30 psi or less, to avoid a sandblasting effect. Avoid rubbing or brushing equipment, as that will damage many surfaces. Be careful not to blow the ash to other places that should be kept clean. Vacuum ash when possible and change filter bags often.</i>
*	<i>Clean electrical components such as small motors and light bulbs, as they will generate excess heat when blanketed with dust. The excess heat can cause fires and short term operating life.</i>
*	<i>The ash should be vacuumed or blown off as described above.</i>
*	<i>Avoid saturating electrical components when hosing dust off. Many of these systems can handle rain and moisture, but not the effect of water jets from hoses.</i>
*	<i>Check for trees heavily loaded with ash near power lines because the added weight can cause limbs to fall on power lines.</i>
*	<i>Check and keep insulators clean. A moderate wind, while the ash is still dry, will clean most insulators on outdoor distribution lines and equipment. Light rain, which does not wash the ash away, is harmful and can cause flashovers and short circuits. Ash that has hardened may require special cleaning methods such as hand cleaning or water jetting.</i>
*	<i>Protect backup and auxiliary units to avoid starting problems when they are activated.</i>
*	<i>Maintain protection and cleaning programmes continuously until the threat of windblown ash is over.</i>

Conclusions: Falls of volcanic ash can cause the widespread loss of electricity leading to a number of public utilities being inoperative for the duration of the power loss. Weather conditions will influence the extent to which falling ash adheres to insulating surfaces, with outages mainly occurring if the ash is wet (i.e. conductive). Finer ash has a higher conductive potential. Lower voltage systems are more vulnerable than higher voltage systems due to smaller weather sheds on insulators. Immediate ash removal is the best mitigation option to prevent widespread outages.

3.2.9 Impacts of volcanic ash on buildings and building services

Volcanic ash damage to buildings and building services may happen in several different ways. Effects principally can be subdivided into (1) overloading roof strength causing collapse, and (2) less catastrophic building damage such as soiling interiors, interrupting services (electrical and mechanical) and damage to exterior materials. These effects depend upon the thickness of ash, its mass and chemical reactivity, the building's roof form, construction and orientation,

and the spacing of other buildings nearby.

Ash loading: Building failure or damage may result from ash loading on roofs, and against walls or foundations (Blong 1981, 1984; Bitschene 1995; Blong & McKee 1995; Johnson & Threlfall 1985; Spence *et al.* 1996). The loading on a building is given by the equation:

$$L = \frac{dpg}{1000} \quad (3.1)$$

where

- L is volcanic ash load (pressure in kPa)
- d is ash depth (m)
- p is ash density (kg m^{-3})
- and g is the gravitational acceleration (9.8 m s^{-2}).

Compaction increases the density of an ash cover but not its weight. Loading caused by ash depends on its thickness, density and whether it is dry or wet. Densities range from about 500 kg m^{-3} for dry uncompacted ash to more than 2000 kg m^{-3} for a compacted very wet ash (Fig. 3.9). There are strong similarities to problems with loading by snow but the effects of ash accumulation are much more severe (Table 3.14). New Zealand building codes (New Zealand Standard 4203) make allowances for snow, ice and rain water load but not loading by volcanic ash. The snow loading codes will afford some protection against ash but this is highly dependent on the location of structures because snow load levels vary with altitude and geographic position. As seen in Figure 3.10 the northern half of the North Island is not subject to snow loading codes.

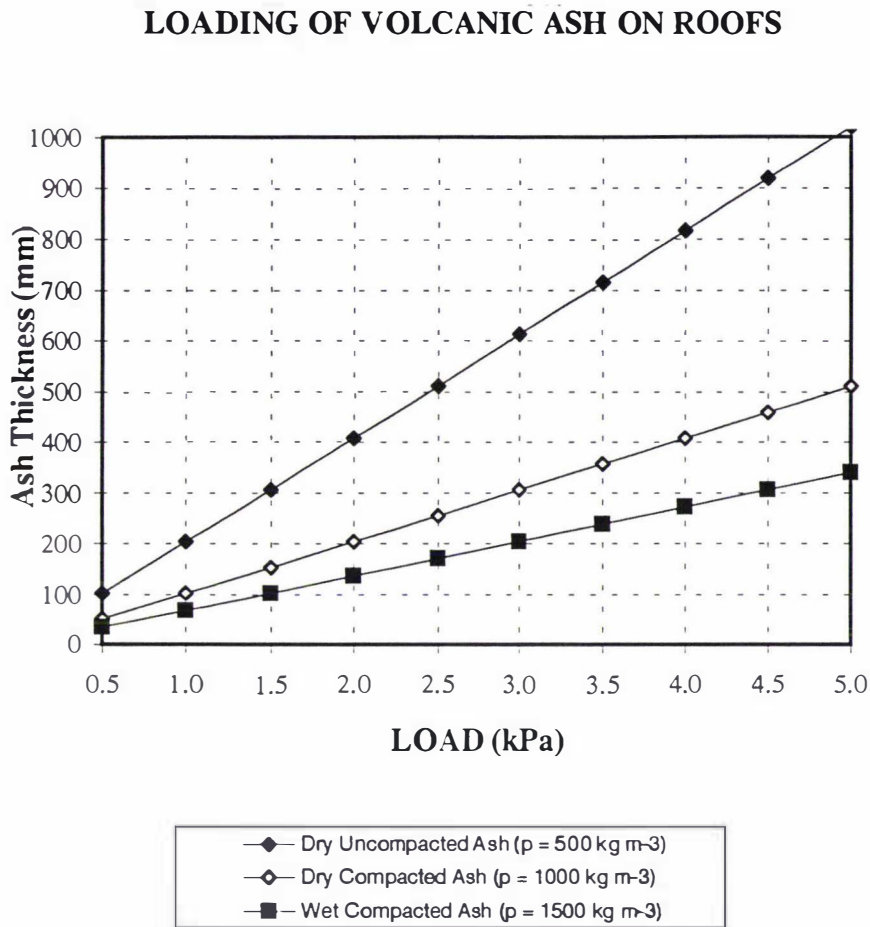


FIGURE 3.9 Loading of tephra on a roof for (a) wet compacted ash, and (b) dry uncompacted ash. The uncompacted ash is assumed to have a density of 500 kg m^{-3} . The wet ash is assumed in this example to have a dry (compacted) density of 1000 kg m^{-3} and a saturation of 50% water by volume and therefore a wet density of 1500 kg m^{-3} .

TABLE 3.14 Comparison in loading of 10 centimetres (100 mm) of snow with volcanic ash.

Type	Load
new snow ($50 - 70 \text{ kg m}^{-3}$) ¹	0.05-0.07 kPa
damp new snow ($100 - 200 \text{ kg m}^{-3}$) ¹	0.1-0.2 kPa
settled snow ($200 - 300 \text{ kg m}^{-3}$) ¹	0.2-0.3 kPa
dry uncompacted ash ($500 - 1300 \text{ kg m}^{-3}$)	0.5-1.3 kPa
wet compacted ash ($1000 - 2000 \text{ kg m}^{-3}$)	1.0-2.0 kPa

¹ Density measures for snow from Fitzharris *et al.* (1992)

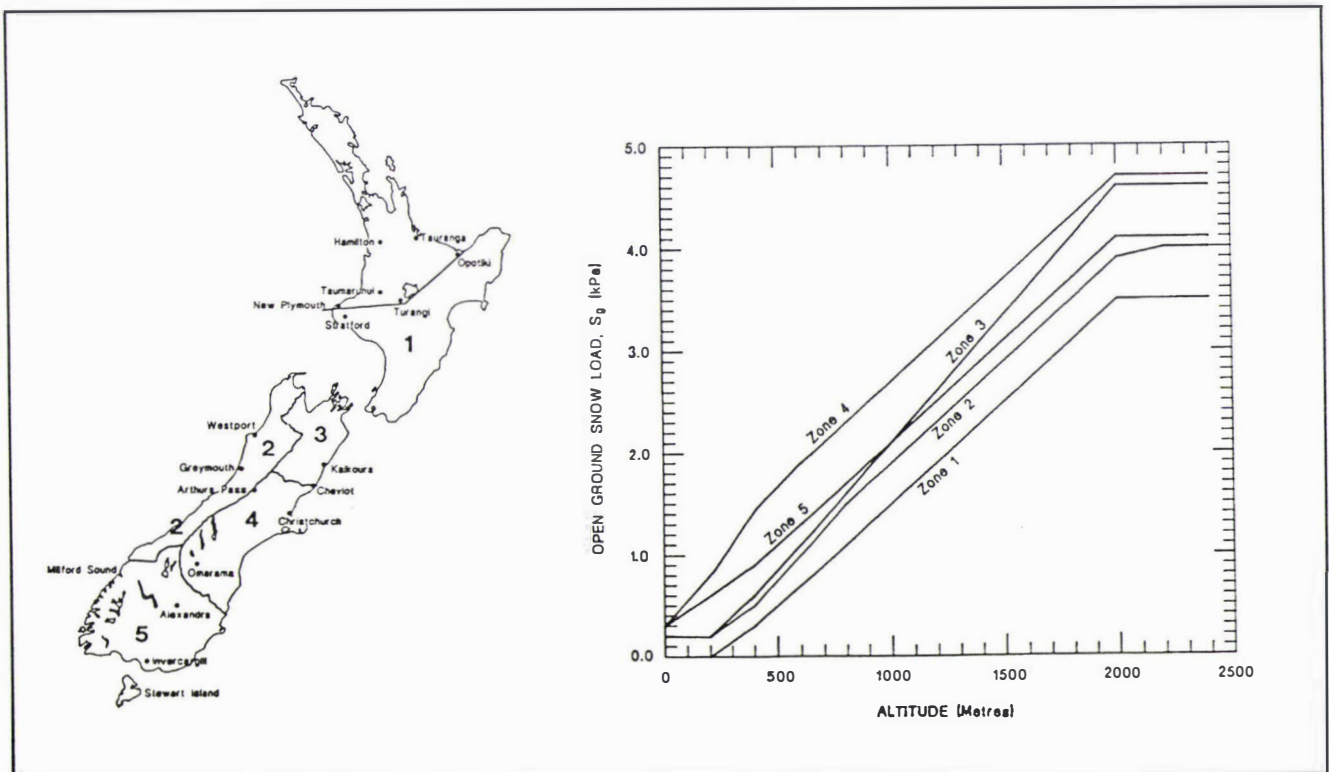


FIGURE 3.10

New Zealand Standard for open ground snow loads, S_g for snow zones (right) (modified from New Zealand Standard 4203:1992).

Blong (1984) gives several examples of roof collapse under ash falls. In most cases where ash fell to a thickness <100 mm only a portion of buildings suffered roof collapse and/or damage whereas at >100 mm thickness more widespread collapses begin to occur. Blong & McKee (1995) describe the damage to buildings during the 1994 Rabaul eruption.

"The damage sustained by roofs under the load of volcanic ash is undoubtedly a function of many key factors including ash thickness, ash bulk density, the moisture content of the ash, extent to which ash drifts (creating unbalanced dynamic loads), roof span and support systems, construction materials, roof slope and age and maintenance of the building."

However, they do not assess the relative importance of these factors. A summary of their Rabaul observations is shown in Table 3.15

TABLE 3.15 The effect of various ash loads on buildings in Rabaul (from Blong & McKee (1995))

Ash thickness ¹	Estimated load ²	Observed damage to roofs
<100 mm	1.5-2.0 kPa	Roofs and guttering generally remained intact
<200 mm	3.0-4.0 kPa	80-90% of roofs remained intact with little apparent damage. Sagging or partial collapse occurred in some buildings
<300 mm	4.5-6.0 kPa	More than 50 % of roofs did not collapse
500-600 mm	7.5-12.0 kPa	More than 50% of roofs collapsed.
>600 mm	9.0-12.0 kPa	It is doubtful that buildings survived without significant damage even when the roof remained relatively intact

¹ Ash fell wet; ² Using equation 3.1 and assuming ash density of 1500 to 2000 kg m⁻³

Rodolfo (1995) describes numerous roof collapses including warehouses and wide-span roofed buildings at a United States Navy base in the town of Olongapo in the Philippines that received 150 mm from the 1991 eruption of Pinatubo. A survey of building damage in the nearby town of Castillejos concluded that roofs failed because the ash load was greater than the vertical load-carrying capacity of their supporting structure. (Spence *et al.* 1996). Wide-span roofed buildings suffered more damage than short-span domestic scale construction.

Pitch angle is also a critical parameter to the vulnerability of roof collapse. Ash can obviously slide off steeply pitched roofs. Even moderate pitches can be less susceptible to

collapse than flat ones. This has been observed in many instances from ash-affected buildings. During the heavy ash falls on the town of Vestmannaeyjar, Iceland, in 1973, houses with roofs sloping at $>20^\circ$ suffered little damage from ash loading (Williams & Moore 1973). Following the 1991 Pinatubo eruption Nairn (1991b) noted that pitched roofed residential houses at Clark Air Base did not collapse whereas wide-span gently curved roofed aircraft hangars did (Fig. 3.11). Following the 1994 Rabaul eruption Blong and McKee (1995) concluded that under the same load:

"it seems clear that buildings with steep roofs survived better than those with gentle pitches.....a hotel where ash loads had been considered in the design of the steeply pitched roof, survived largely intact".

Obstructions such as parapets, roof tanks or solar panels may cause accumulation of ash. In fact roof guttering is one of the most susceptible parts of a house to damage (Blong 1984, Blong & McKee 1995) and, especially after rain, the gutters may fill with ash and collapse.

**FIGURE 3.11**

A comparison of the damage caused to buildings receiving ~ 150 mm of ash and lapilli from the 1991 Pinatubo eruption. Photo A shows a collapsed wide-span gently curved roofed aircraft hangar and B relatively undamaged residential houses, both at Clark Air Base (photos by I. Nairn).

Damage to exterior materials: The soluble components in volcanic ash can lead to premature ageing and weakening of cladding and other building materials (Table 3.16). Most metal roofing used in New Zealand is hot-dipped zinc or zinc/aluminium coated (galvanised) steel, sometimes with an additional paint cover. Zinc has a high resistance to atmospheric corrosion due to the development of an insoluble basic carbonate film that protects the surface. However, sulphurous and sulphuric acids are extremely corrosive to almost all metals (Bradford 1992). These acids ionise to H^+ ions and electrode processes occur on the corroding metal surface (Fig. 3.12). Although rain can initially release the acidic soluble components from the ash, it will with time wash these contaminants away and actually reduce corrosion. Unwashed areas such as under eaves, unlined soffits, spouting, overhangs, sheltered walls and the upper parts of garage doors may be especially vulnerable to corrosion if ash infiltration occurs. This is because these areas seldom receive the benefit of rain-washing yet they are subject to condensation.

The 1995-1996 Ruapehu eruptions deposited a few millimetres of ash on several North Island towns causing minor damage to a small number of roofs. This resulted from a reaction between the ash and galvanised steel and/or paint (see Chapter 2). Acrylic paint applied within the past 3-6 months was found to be particularly susceptible to corrosion by this ash.

Metal corrosion resulting from ash falls has been studied by Matsumoto *et al.* (1988) during eruptions of Sakurajima volcano in Japan. They found that corrosion strongly correlated with the concentration of soluble components in the ash and concentrations of SO_2 and fluorine compounds in the atmosphere. The degree and rate of metal deterioration decreased in order from aluminium, steel, galvanised steel and copper to stainless steel.

TABLE 3.16 Examples of ash-fall induced corrosion of roofs.

Volcano, year	Corrosion reported	Reference
Hudson 1991	ash and acid rain damage to paint on roofs.	Bitschene 1995
Mount St. Helens 1980	rusting of galvanised iron roofing.	Blong 1984
	isolated incidents of corrosion to tools and vehicles.	Stember & Batiste 1981
Sakurajima 1987-1988	corrosion of metal roofing material	Matsumoto <i>et al.</i> 1988
Rabaul 1994	significant rusting of corrugated iron and sheet steel roofs	Blong & McKee 1995
Ruapehu		
1969	deterioration of roof paintwork	Traill 1978
1995-1996	minor damage to roofs, resulting from the reaction between ash and galvanised steel and/or paint	Chapter 2

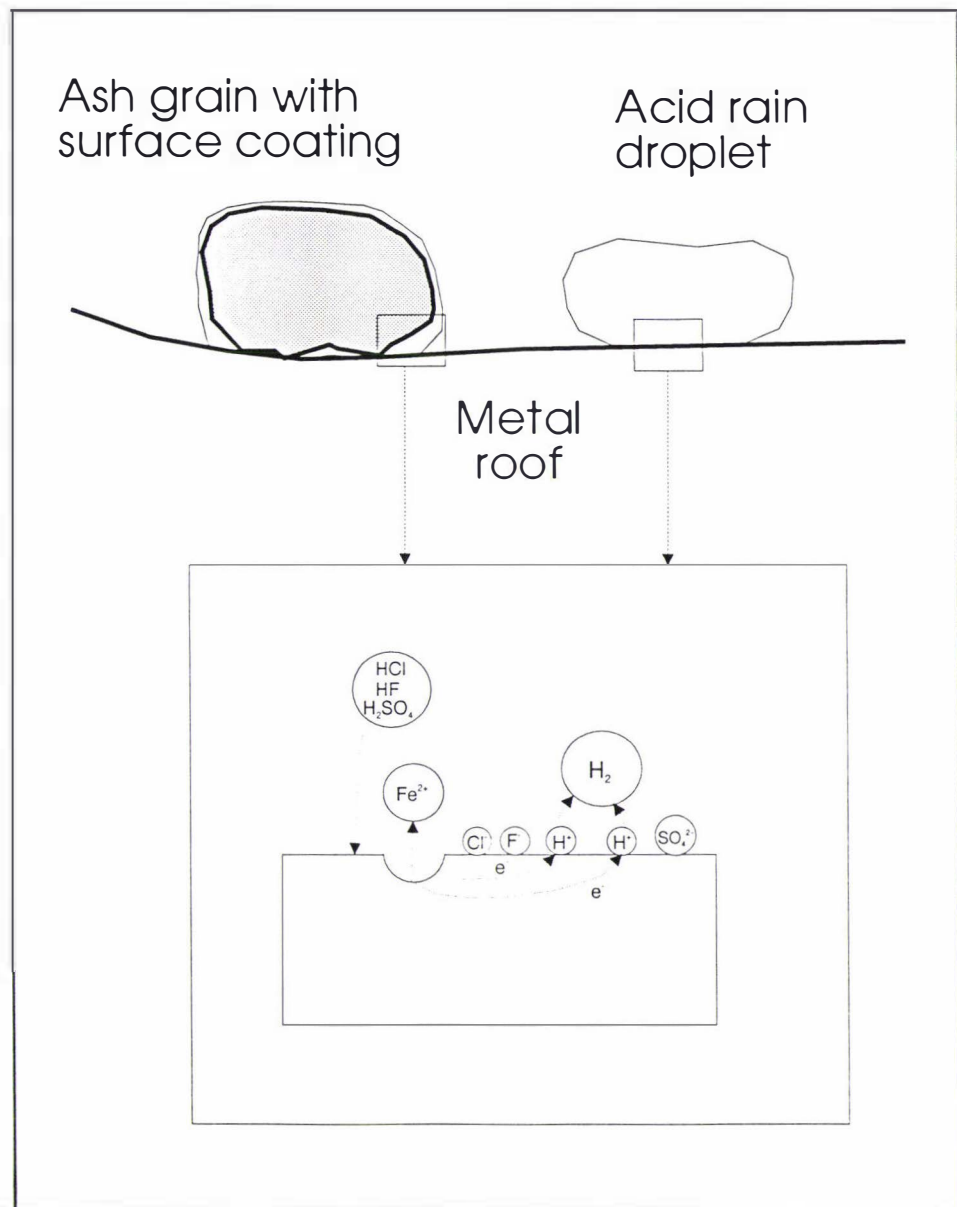


FIGURE 3.12

Corrosion of metal roofs by volcanic ash and acid rain droplets, showing the anode and cathode processes for corrosion of metal by acids. The acids (+ water) act as the electrolyte in contact with both the anode and the cathode to provide a path for ionic conduction. The metal roof acts as both the cathode and the anode.

Soiling interiors: Ash can enter a building by a number of routes ranging from open doors and windows to small gaps between roofing iron or tiles and even gaps around closed doors and windows (Blong 1984; Deguchi 1988). Even small amounts of ash entering buildings can result in a considerable amount of time spent on its removal (Dillman & Roberts 1982). Fine ash easily penetrates carpets and abrades them.

A survey of damage from repeated ash falls from Sakurajima volcano (Japan) on the cities of Kagoshima and Taramizu found the finer the ash the easier it can penetrate buildings (Deguchi 1988). Ash that had built up in gaps promoted capillarity thus drawing in water and causing wicking to the roof lining and resultant leaks. Leaking also occurred as a result of rusting of nails caused by corrosion. Ash on outer walls and windows leads to soiling especially when combined with rain.

Damage to services: The highly abrasive and mildly corrosive nature of ash is a threat to mechanical and electrical appliances (Table 3.17). Air-conditioning units are vulnerable to ash damage and filter blockage especially if intakes are horizontal surfaces (Figure 3.12), although severe damage is commonly avoided by shutting-down systems. Penetration of ash into the electrical system can lead to short-circuiting and fires. Blong (1984) reviews the impacts of the 1980 Mount St. Helens eruption and notes that "*electrical problems were the most common sources of failure in equipment in urban areas*", caused by shorting of switch points. However, there have been no formal attempts to estimate damage-ratios. Computers and computing systems are also vulnerable to ash damage. In many cases damage can be avoided by sensible mitigative action.

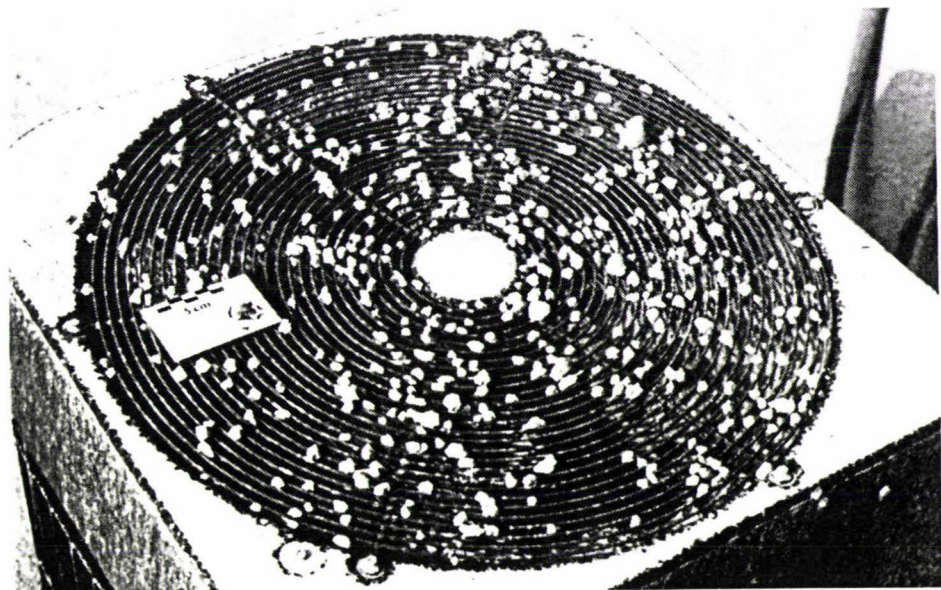


FIGURE 3.13

Ash and lapilli covered air-conditioning unit from a house at Clark Air Base, Philippines after the 1991 eruption. The finer ash has been washed through the grill onto the four blades beneath. Photo: V. Neall.

TABLE 3.17 Examples of ash-induced damage to services.

Volcano, year	Reported damage	Reference
Air-conditioning units		
Mount St. Helens, 1980	Slight damage reported following 18 May ash falls.	Blong 1984
Mt Spurr, 1991	Major problems with telephone exchange air-intakes.	Appendix 2
Ruapehu 1995-1996	Ash-blocked units reported.	Chapter 2
Computers		
Mount St. Helens, 1980	Damage to automatic bank tellers noted.	Blong 1984
	Computer-related failures reported. Ash particularly harmful to disk drives.	Blong 1984

Mitigation measures for buildings: Since building collapse usually requires ash thicknesses in excess of 100 to 300 mm, an area affected will usually be limited to within a few kilometres or tens of kilometres of the volcano (except in the case of very large rhyolite eruptions). Limitations on the building of permanent structures in such areas is a low cost mitigative measure. Building codes recommending the use of steeper roof pitches, particularly for important public buildings such as schools, hospitals, police and fire stations is another option and this has been proposed for the towns of Rabaul and Kokopo, Papua New Guinea, following the 1994 eruption (Blong 1996).

A number of researchers have raised the question of whether roofs should be kept clear of ash during ash falls (Blong 1984; Rodolfo 1995; Spence *et al.* 1996). In most New Zealand situations it is reasonable to expect that if a community was exposed to ash falls >100 mm it would be evacuated before the climactic phase of the eruption (except possibly in the case of a very large rhyolite eruption from Taupo or Okataina). Those exposed to ash falls >100 mm should seek shelter in pitched roof buildings or at least avoid wide-span flat roof structures. Active clearing of roofs may prevent collapse but this must be weighed against the risk of personal injury working in a dark, ash-rich environment. Clearing any ash from a roof should be done with extreme care because injuries are commonly reported (e.g. Blong 1984; Appendix 3). People may slip from roofs and fall from ladders or through weak roofs while clearing ash. After an ash fall buildings which have received in excess of 100 to 300 mm of ash and that have not collapsed still run a high risk of load damage so ash should be removed immediately. Figure 3.14 summarises some mitigation options available.

Distal ash falls: During any volcanic eruption the largest areas affected are those subjected to light to moderate ash falls (millimetres to a few centimetres). Mitigative actions for distal ash falls have two basic purposes: 1) preventing or limiting ash entering systems or enclosures; and 2) effective and efficient removal of ash to prevent or reduce damage. The most effective method to prevent ash-induced damage is to shut down, close off and/or seal off buildings and equipment until the ash is removed from the immediate environment (Fig. 3.14). In many cases this is not practical or acceptable because some mitigative procedures can cause additional problems or may be counter-productive. No one technique is the solution to all situations and a range of measures will often provide the best results. Constant monitoring of ash effects and mitigative procedures is desirable to achieve the most effective balance between operational requirements and the level of damage limitation.

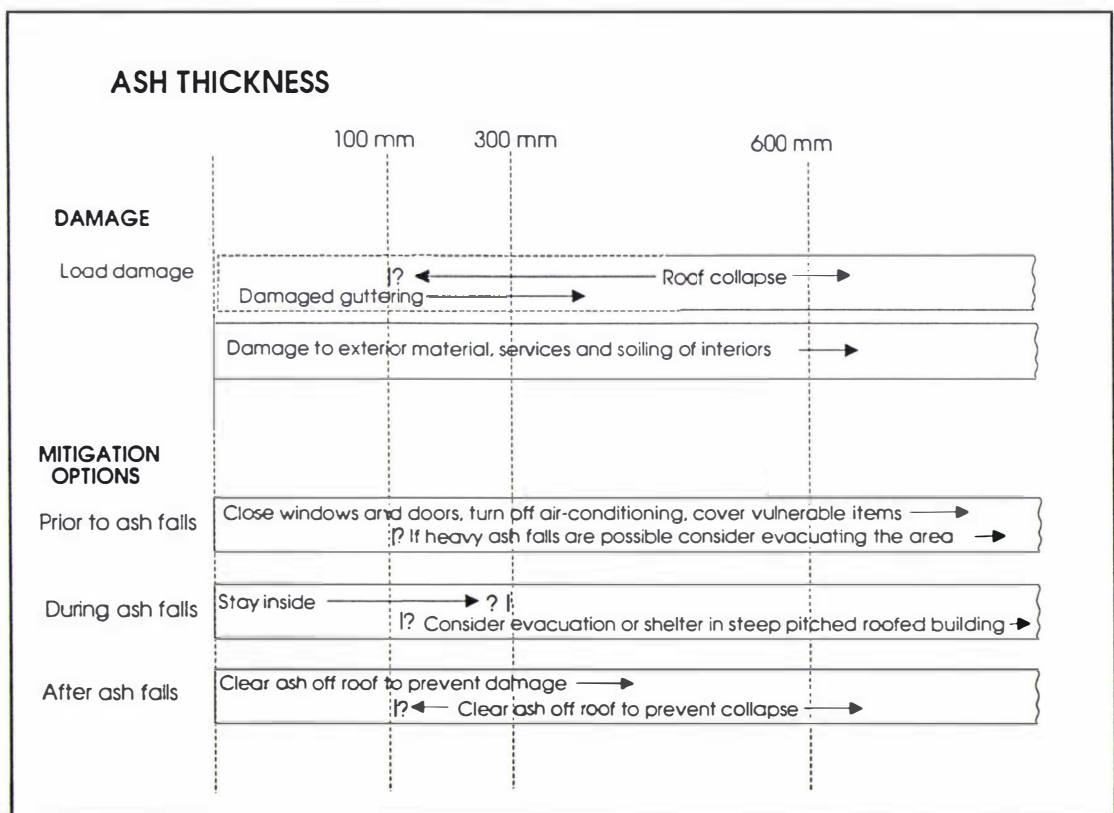


FIGURE 3.14

Mitigation options for buildings subject to ash falls.



FIGURE 3.15 Examples of simple ash fall mitigation measures used at the Army Museum, Waiouru from September to November 1995, as a result of the Ruapehu eruption.

A. Entry was restricted to one point and those entering were instructed to wipe their feet upon entering. B. Air-vents located on the roof of the building were covered by canvas and tape. C. Roller doors sealed by using cloth

and tape.

The following tables (3.18-3.20) are a list of general guidelines proposed by Labadie (1983) for removing and controlling volcanic ash in buildings, heating/cooling systems and computer services.

TABLE 3.18 Essential elements in the management of volcanic ash in buildings (from Labadie 1983).

<p>Mitigation techniques:</p> <ul style="list-style-type: none"> - <i>Establish a written procedure; train personnel.</i> - <i>Stockpile disposal containers, mops, brooms, shovels, pails, industrial vacuum cleaners, plastic bags, and sheets.</i> - <i>Stock filters and filter materials.</i> - <i>Remove dust from roofs and entry ways prior to re-activating machinery.</i> - <i>Keep roof drains, storm drains, gutters, etc, clear of clogging ash. It is best to sweep dust from roofs and not flush with water; roof drains clog very easily.</i> - <i>Make a written record of all steps taken to secure the building, so these steps can be retraced for start-up procedures, or if problems arise.</i> - <i>Use a damp mop to clean hard floors.</i> - <i>Use a water-type industrial vacuum cleaner, if possible, for cleaning rugs and cloth furniture.</i> - <i>Use damp, disposable cloths to dust furniture, window sills.</i> - <i>Restrict building access to the most protected entrance. Admit only authorised personnel.</i> - <i>Close and seal all unnecessary outside openings, including air intakes and vents.</i> - <i>Shut down all unnecessary building operations and equipment.</i> - <i>Establish decontamination rooms for personnel entering the building. Require personnel to brush down clothing and shoes prior to entering the building and to vacuum off clothing immediately upon entering the building, or to bring a change of clothing and shoes for use while in the building.</i> - <i>If outside air intake is required, monitor air intake filters at regular intervals, and change as required. Remove dust from area of outside-air intakes.</i> - <i>Maintain a relatively clean environment throughout the entire building. Damp-mop floors, wipe off machinery and furniture at least once a day.</i>

TABLE 3.19 Suggested mitigation techniques for heating/cooling systems (from Labadie 1983).

- *Close external air intakes; use internal circulation only; this will create positive pressure inside building.*
- *Control access, seal doors.*
- *Establish decontamination rooms for entering personnel; provide vacuum cleaners, shoe covers, disposable caps.*
- *Stockpile cleaning supplies, duct tape, disposal containers.*
- *Use extra (and heavier) filters for external air intakes.*
- *Clean dust away from external intakes; restrict vehicle and foot traffic near intakes.*
- *Install intake hoods that extend farther above ground.*
- *Install pre-filters.*
- *Add sand filters to cooling towers.*
- *Cover cooling towers.*
- *Clean coils, radiators, etc, with compressed air and/or water.*
- *Add cooling coils to un-interruptible power supply to reduce temperature of incoming air by 10° (increases cooling capacity).*
- *Add back-flushed filters to cooler sumps.*
- *Install alarm circuit to warn of excessive pressure differential across filters; filters that get too clogged can break open.*
- *Change from open, drip-proof type motors to totally enclosed, fan-type motors.*
- *Reduce staff to minimum required.*
- *Close and seal unused rooms; turn off unused equipment.*
- *Shutdown air handling system to prevent damage to chillers, fans, pumps, etc.*

TABLE 3.20 Suggested mitigation techniques for computer systems (from Labadie 1983).

- *Best tactic for ash mitigation is prevention. Clean and condition surrounding air to keep ash out of equipment.*
- *Cotton mat filters (used in clean rooms) were found to be best for filtering particles, but they reduce the air flow. A solution is to use larger fans to maintain required air flow. Rack-mounted equipment can be modified to add a larger fan; smaller instruments or components with a built-in fan would require design change to increase fan capacity.*
- *Use fluted filters as a compromise; increases surface area but reduces air flow by only about 20%.*
- *Digital integrated circuits can vary 5-10% in performance (depending on type of circuit) and still be acceptable. It is difficult to generalize about other equipment (e.g. high-voltage power supplies).*
- *Humidifying ambient air (e.g. wet down carpets) will help to control ash re-entrainment.*
- *Ash on equipment can be blown out with compressed air. If the air is too dry, static discharge could damage sensitive components (e.g. MOS integrated circuits). If the air is too damp, the ash will stick. Relative humidity of 25-30% is best for compressed air.*
- *Cleaning with a pressurized water-detergent mix and a hot water rinse is quite effective. However, this process requires at least partial disassembly.*
- *Ash on digital circuits won't cause much of a problem because of the low voltages involved. High voltage or high-impedance circuits are very vulnerable to leakage caused by semi-conductive ash. Ash that is acidic is conductive as well as corrosive.*
- *Ash should be blown or brushed away from power supplies and CRTs (especially high-voltage leads, capacitors).*
- *Ash may have high static charge and be hard to dislodge; requires brushing to dislodge.*
- *Accelerate filter change; use pre-filters.*
- *Change to absolute filters; will keep out particles down to 1 micron.*
- *Keep computer power on to operate filtration, but don't run (especially disk drives).*
- *Maintain "room-within-a-room" configuration; restrict access; re-circulate air; accelerate cleaning of area.*

Ash removal from buildings: Sweeping dry ash from roofs can create secondary ash clouds which may slow the cleanup process (Dillman & Roberts 1982). Wetting ash can form a cohesive "glue-like" material, which is not easy to remove and adds weight to the deposit. The best method for removal is to lightly damp the ash and then sweep it. Highest priority should be given to removing ash from roofs for four reasons (F.E.M.A. 1984).

- i) *It is a prerequisite to reactivate ventilating and air-handling systems.*
- ii) *It is fruitless to clear ground level areas and find it recovered by windblown ash from roofs above.*
- iii) *Rapid removal may prevent the possibility of catastrophic roof collapse.*
- iv) *Ash removal from public buildings will enhance morale and confidence of the public if they observe rapid cleanup and prompt functioning of local buildings.*

From the experience gained from the Mount St Helens eruption F.E.M.A. (1984) has produced detailed recommendations for ash removal: Tables 3.21-3.22.

TABLE 3.21 Suggested ash removal methods for buildings (from F.E.M.A. 1984).

*	<i>Promptly notify building owners to remove ash from roofs in a timely manner to prevent streets from being repetitively cleaned.</i>
*	<i>Inform public of effective methods for (1) removing ash from roofs and property and preparing it for pick-up by emergency crews and (2) organizing neighbourhood cleanup activities.</i>
*	<i>Caution residents against flushing ash into sewers.</i>
*	<i>Remove ash dry and before the first rain. Dampen ash with a light spray of water to reduce billowing. (Do not use large amounts of water which will cause the ash to cake).</i>
*	<i>Make sure that the ash cleanup is supervised by knowledgeable building maintenance personnel to prevent unnecessary damage to roof material and surfaces.</i>
*	<i>Use protective measures when removing ash from roofs. Walking on roofs and using tools and small equipment can cause breaks and punctures if the roof is dry and brittle. The full force of water from fire hoses will break lap shingles or tear lap roofing.</i>
*	<i>Do not flush ash into drains and down-spout, for it can clog the small-sized pipes. Ash flushed into dry wells can seal them, rendering them inoperative.</i>
*	<i>Thoroughly remove all traces of ash near intakes of ventilation systems.</i>
*	<i>To protect sewer lines, disconnect down drains at ground level until cleanup is complete.</i>
*	<i>To prevent or reduce the accelerated deterioration of roof coatings by mildly acidic property of ash, clean and/or protect the roof surfaces accordingly. Metallic roof surfaces, particularly older galvanized roofs which are pitted, and lower gauge galvanized roofs are most susceptible to increased deterioration from the properties of ash.</i>
*	<i>On flat roofs, hand sweep ash into windrows and transport it by wheelbarrow to an edge dump. Use proper protection such as planking, mats, plywood sheets, and pliable footwear to prevent unnecessary damage from impact and abrasion. Hoppers with a funnel pip suspended above a loading truck can be used to collect the ash. To remove final dry residue or thin layer of ash, use air pressures with regulation. Note that small vacuum equipment is not practical because of the abrasiveness of the ash.</i>
*	<i>On steep shingle roofs, place dams in the troughs to prevent the ash from reaching the down drains. Then hose down the ash and clear it from the eave troughs. This operation must be performed with care to avoid deforming the gutters and tearing them loose.</i>
*	<i>On low slope bitumastic mopped roofs, where there is only a thin ash layer or small residue, flush the ash with water. A gain too much pressure from high pressure hoses can damage roof materials.</i>
*	<i>To avoid clogging the inlets to roof drains, encircle the roof inlet with a fabricated ring made from heavy sheet metal about four inches wide and two feet in diameter. This serves as a dam allowing water to spill over the top, while the ash settles in the surrounding roof depression. Later, when dry, the ash can be removed manually.</i>

TABLE 3.21 (contin.) Suggested ash removal methods for buildings (from F.E.M.A. 1984).

<i>Building Exteriors</i>	
*	<i>Sills, ledges, parapets, and wall surfaces - usually these building features will not warrant extra cleanup efforts or expenditure if the primary functioning of the building is not impaired.</i>
*	<i>Air-handling and air conditioning mechanisms.</i>
	<i>- Shut down systems prior to or during the initial deposition of the ash. Simultaneously, check all public buildings to make sure windows are closed, air conditioners are off, and that all unnecessary outside openings, including air intakes, are closed and sealed. These initial activities will help prevent or reduce the introduction of ash to building interiors and air-handling systems.</i>
*	<i>To restart air-handling systems:</i>
	<i>- Clean the roof-mounted intakes and the roof area adjacent to intakes.</i>
	<i>- Clean or replace filters.</i>
	<i>- Inspect, clean or lubricate moving portions of the mechanism, following prescribed routine maintenance.</i>
<i>Building Interiors</i>	
*	<i>Restrict building access to the most protected entrance.</i>
*	<i>Instruct building managers to educate occupants in preventing ash entrainment into the building.</i>
*	<i>Have building managers establish an entry room or zone where personnel are required to brush or vacuum clothing and shoes or make clothing changes, if appropriate.</i>
*	<i>Establish any necessary, extra cleaning procedures to protect the interior environment.</i>
*	<i>To substantially reduce the need for extensive maintenance of equipment, place coverings over office machines as standard procedures.</i>
*	<i>Carefully monitor vacuum cleaners to assure that filters and ash bags are changed when necessary.</i>

TABLE 3.22 Suggested ash removal within households (from F.E.M.A. 1980).

<i>Household surfaces should be vacuumed to remove as much ash as possible.</i>	
-	<i>After vacuuming carpets and upholstery may be cleaned with a detergent shampoo. Avoid excess rubbing action because the sharp ash particles may cut textile fibres.</i>
-	<i>Glass, porcelain enamel and acrylic surfaces may be scratched if wiped too vigorously. Use a detergent soaked cloth or sponge and dab rather than wipe.</i>
-	<i>High-shine wood finishes will be dulled by the fine grit. Vacuum surfaces and then blot with a cloth treated to pick up ash. A tack cloth used by furniture refinishers should work well</i>
-	<i>Ash-coated fabrics should be rinsed under running water and then washed carefully.</i>
<i>Remember: Soiled clothing will require extra detergent. Wash small loads of clothing, using plenty of water so the clothes will have room to move freely in the water. Do not mix heavily soiled clothes with garments that are lightly soiled. Be sure clothes are free of ash before putting them in an automatic dryer. Ash may scratch the inner surface of the dryer.</i>	
<i>During the next few months, filters must be replaced often. Air conditioner and furnace filters need careful attention. Clean refrigerator air intakes. Clean any surface that may blow air and recirculate the ash. Stove fans and vents should be cleaned thoroughly.</i>	

3.2.10 Impacts of volcanic ash on communications

Communications can be severely disrupted around an erupting volcano. Such disruptions may result from interference to radio waves due to atmospheric conditions, overloading of telephone systems due to increased demand, direct damage to communications facilities, and indirect impacts resulting from disruption to electricity supplies or transportation of operations or maintenance workers.

Large quantities of electrically-charged ash can be generated in an eruption column (Anderson *et al.* 1965; Gilbert *et al.* 1991; Gilbert & Lane 1994). These cause interference to radio waves. For days following the 1912 Katmai eruption radio communications were inoperative on Kodiak Island, 160 km from the vent (Erskine 1962). During the 1963 Surtsey eruption clicks of radio static were observed by a passing ship (Anderson *et al.* 1965). Problems with radio communications around Pinatubo in 1991 were possibly due to electromagnetic disturbances from the fine volcanic ash (Rodolfo 1995). However, there are also numerous examples of radio and telephone communications continuing to function around an erupting volcano and in areas receiving ash falls (e.g. Mount St. Helens 1980, Pinatubo 1991 and Ruapehu 1995-1996.). Rodolfo (1995) reports "*surprisingly, the telephones continued to work...*" in the Philippines after 150 mm of ash fell from the 1991 Pinatubo eruption.

During most natural disasters telephone and radio communications are susceptible to overloading by public and emergency services use. Overloaded telephone systems were recorded in communities receiving ash during the 1953 Mt Spurr eruption (Wilcox 1959) and the 1980 Mount St Helens eruption (Dillman *et al.* 1982). Response organisations report frequent overloading of their telephone lines even in cases where the general system remains operative (e.g. during eruptions of Mount Spurr 1992 and Ruapehu 1995-1995; see Chapter 2 and Appendix 3)

Most modern telephone exchanges require air-conditioning units to keep electronic switching gear below critical temperatures. Exchanges with external air-conditioning units are thus vulnerable to over-heating if these units fail or are switched off (due to ash falls), even if the exchange itself is sealed. Some exchanges are specially sealed to keep out corrosive geothermal gases such as H₂S (eg. in Taupo and Rotorua). However, any ash entering telephone exchanges can cause abrasion, corrosion and /or conductivity damage to electrical and mechanical systems.

Mitigation measures for communications systems: From the experience gained from the Mount St Helens eruption Labadie (1983) produced recommendations for mitigating the effects of volcanic ash on communications systems (Table 3.23). The most serious problems resulted from the conductive and abrasive properties of ash.

TABLE 3.23 Suggested mitigation techniques for communications systems (from Labadie 1983).

Mitigation techniques	
-	<i>Teflon insulators on communications antennas were covered with dust and shorted out. Very difficult to clean as residue would adhere. Replacement with ceramic insulators required.</i>
-	<i>Plastic switches and push-buttons (especially those with self-cleaning contacts) abrade quickly. Necessary to replace.</i>
-	<i>Seal up repeater stations and other installations; shut air intakes; internal air circulation and leakage should be sufficient for cooling.</i>
-	<i>Blow out or vacuum out radio equipment; brush off.</i>
-	<i>Seal equipment that is not already watertight. Smaller units have low-power consumption and do not generate much heat.</i>
-	<i>Magnetic particles that stick to relay cores should be blown off.</i>
-	<i>Keep moisture out of equipment.</i>
-	<i>Clean equipment daily: increase use of filter paper.</i>
-	<i>Clean out microwave dishes, feed horns, wave guides. Install covers; plastic tarp will do in an emergency.</i>

Communications are a vital part of everyday life and critical in any emergency. Radio, TV and telephone communications are extremely vulnerable to disruption during a volcanic ash fall and may fail completely in eruption-affected areas. Thus loss of communications makes disaster management extremely difficult under and following eruption conditions.

3.2.11 Impacts of volcanic ash on gas supplies

To date literature searches have failed to locate any reports of adverse impacts on gas supply systems by volcanic ash. Most gas pipes are located below ground and thus protected from the direct effects of ash falls. Above-ground pumping stations, pressure reduction facilities, pipeline bridge crossings and gas meters at consumer sites may be vulnerable to ash damage as described previously.

3.2.12 Ash removal and disposal

The fall of a few millimetres of ash on an urban community will result in the need for disposal of large quantities of material. Ash disposal should be done in a way that minimises ongoing public health problems and is cost-effective. Ash dumps may need to be covered to prevent remobilisation of the ash by wind. Two examples are presented in Appendix 3. Methods of stabilizing ash dumps include covering with topsoil or hydraulic seeding. Ash is generally a good fill, it has a good bearing strength, mixes well with soil and will support vegetation if fertilized (F.E.M.A. 1984).

3.3 PYROCLASTIC FLOWS AND SURGES

The collapse of an eruption column into an outwardly moving expanding cloud of ejecta and gas produces pyroclastic flows and/or surges (Sparks 1976). Flows and surges often travel at speeds up to 200 km/h and cause total destruction in the areas they cover. Surges are more dilute, turbulent and widespread in their effects. Flows are more concentrated and are topographically controlled. Flows and surges from magmatic eruptions are usually very hot (several hundred °C) and can start fires. Dry surges tend to sandblast objects with a mixture of ash and superheated gas and steam. The ash-laden wind causes varying degrees of damage to structures depending on its temperature, duration and the amount of solid material it is carrying. The area affected by pyroclastic flows and surges may vary considerably (Fig. 3.16).

Surges can also result from the interaction of magma with surface/ground water or saturated sediments (White 1996). Surges from phreatomagmatic eruptions are often wet, containing both steam and water. They are more dense than dry surges and tend to decelerate more rapidly and deposit sticky wet ash. This wet ash will often cause the collapse of structures it buries due to loading as described in the previous section (pyroclastic fall). A wet surge deposit will have a density between 1300-2000 kg/m³. In the Tarawera eruption of 1886, surges from Rotomahana travelled more than 6 km from source and overwhelmed the Maori village at Te Ariki, burying it under several metres of wet ejecta (Nairn 1979; Keam 1988). In the 1966 eruption of Taal (Moore *et al.* 1966; Moore 1967), surges sandblasted trees as far

as 6km from the vent but there was no evidence of charring or burning. This damage is summarised in Table 3.23.

TABLE 3.24 Surge damage produced by the 1965 eruption of Taal, Philippines (from Moore 1967)

Distance from vent	Impact
0.5-1.0 km	All trees and stumps removed
1.0-1.25 km	Trees remain but strongly sand blasted. Little or no coating of mud.
1.25-6 km	Blast recorded by mud coatings, stripping of bark of trees, breakage of bamboo, deroofing of houses, stripping of palm tree fronds on the blast side and faint scarring of small bushes.

People caught in the direct path of pyroclastic flows and surges are most unlikely to survive; any survivors will probably receive severe injuries (Baxter 1990). Buildings offer some protection on the surge periphery, but will not guarantee survival because the building may be destroyed or severely damaged. The best protection is to evacuate the near-vent area prior to eruption. Buildings near the vent will be totally obliterated, with the possible ignition of combustible material. Structures near the margins of the surge may be less damaged as the surge velocity decreases, but damage will still be caused by clast impact. Pyroclastic surges can destroy or severely damage any infrastructural facilities. Where pyroclastic flows and surges enter reservoirs, large amounts of eruptive material can be deposited in the water, leading to contamination of the supply and reduced storage capacity. Flows and surges will cut and/or remove power lines in affected areas. Buried cables and gas pipelines have a much better chance of survival.

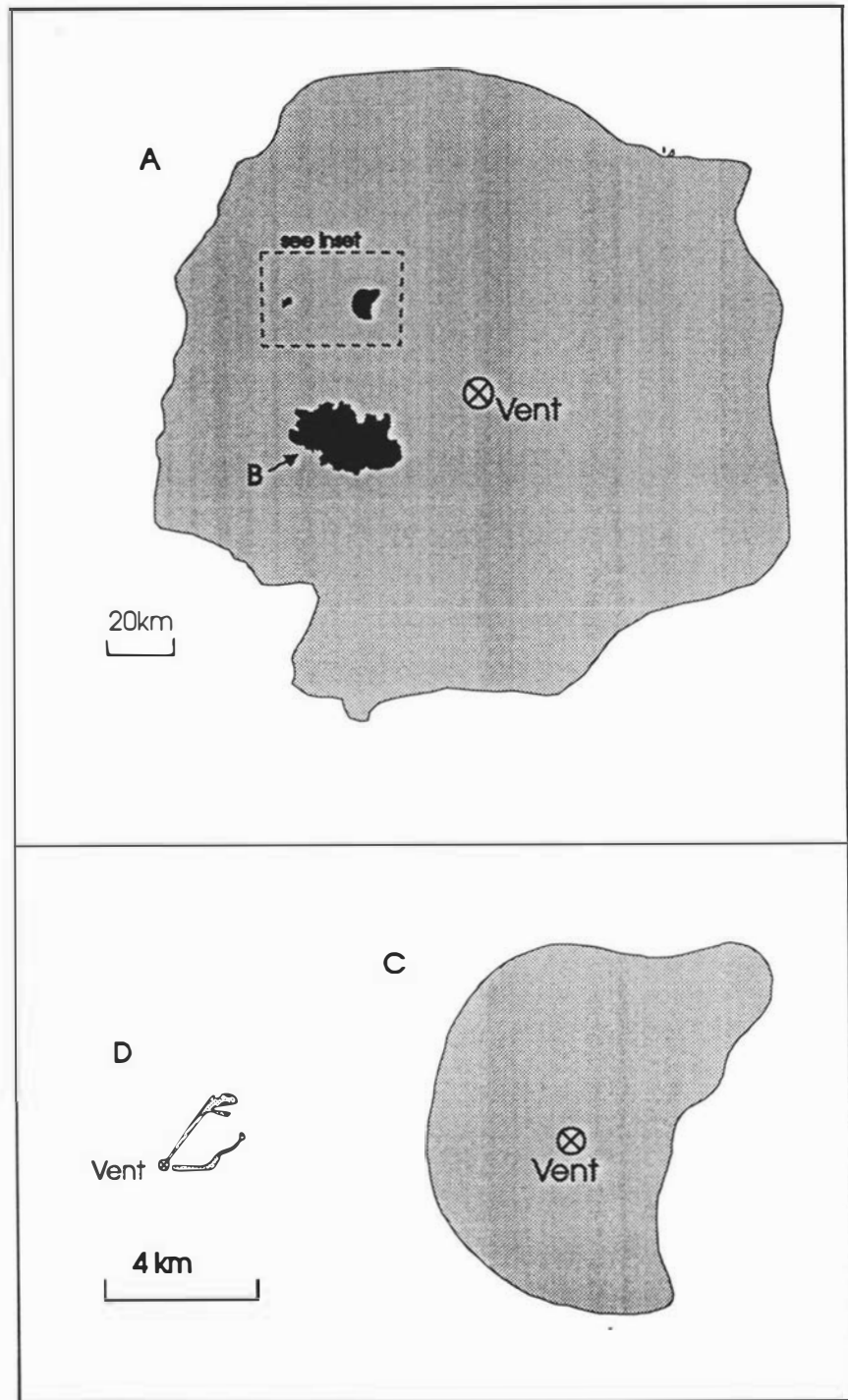


FIGURE 3.16 An example of the area of destruction covered by pyroclastic surges and flows.

- A The area covered by the 1800 years B.P. Taupo ignimbrite (from Wilson & Walker 1985).
- B The area covered by the 1980 Mount St. Helens blast deposit (from Hoblitt *et al.* 1981).
- C The area covered by the 1965 Taal base surge deposit (from Moore 1967).
- D The area covered by the 1975 Ngauruhoe pyroclastic flows (from Nairn & Self 1978).

3.4 LAVA FLOWS

Lava flows are streams of molten rock that flow downslope from a volcano. The distance they travel depends on the viscosity of the lava, output rates, volume erupted, steepness of the slope, topography and obstructions in the flow path (Walker 1973; Cas & Wright 1987). The areal extent affected by lava flows varies considerably (Fig. 3.16). Basalt flows have low viscosity and have been recorded at more than 160 km from the source volcano but usually only flow 5-10 km. Basaltic eruptions produce both pahoehoe and a'a lava flows. Both flow types will flow at right angles to the contour but only pahoehoe are sensitive to local perturbations, especially in areas with slopes less than 5° (Trusdell 1995). Andesite flows are more viscous and rarely travel more than 5 km. Dacite and rhyolite lavas have high viscosity and typically form thick stubby flows or domes.

Shallow slopes may slow the progress of lava flows whereas steeper slopes will accelerate them. Lava flows seldom threaten human life because of their slow rate of movement. However, if the steep fronts of flows become unstable they can collapse unexpectedly, causing small pyroclastic flows or new lobes of lava (Blong 1984, Baxter 1990).

Lava flows may cause extreme damage to buildings and other infrastructure, resulting from burial, ignition and/or excessive forces causing structural collapse. Blong (1984) describes a number of examples of damage from lava flows. Thick slow-moving a'a flows exert larger stresses on structures than more fluid pahoehoe flows. In numerous cases flows have been diverted by resistant structures. When a flow meets an obstruction its orientation to the structure will influence the flow's behaviour. Structures perpendicular to flows have a higher risk of collapse. Inflation of pahoehoe flows may cause flows to overtop structures that initially halted their advance (Hon *et al.* 1994).

The ignition of flammable materials is a common consequence of lava flow inundation. Some masonry buildings survive, but most structures are ignited and gutted by fire.

Diversion of lava flows: A number of methods have been used in attempts to divert lava flows (Blong 1984). In Hawaii authorities used barriers to contain advancing flows in 1955 and 1960 and water jets in 1960 and 1983. It was found that hosing water could locally check flows for long enough to remove contents from buildings, but eventually flows continued their advance. The US military resorted to bombing in attempts to break levees in 1935, 1942 and 1975-1976. During the eruption of Heimaey (1973), in Iceland, sea water was pumped onto flows to stem their advance (Williams & Moore 1973). The effectiveness of these methods is debatable. The first unqualified success was in 1992 on Mount Etna where explosives were used to open a lava-tube cutting the supply to the flow front (Barberi *et al.* 1993).

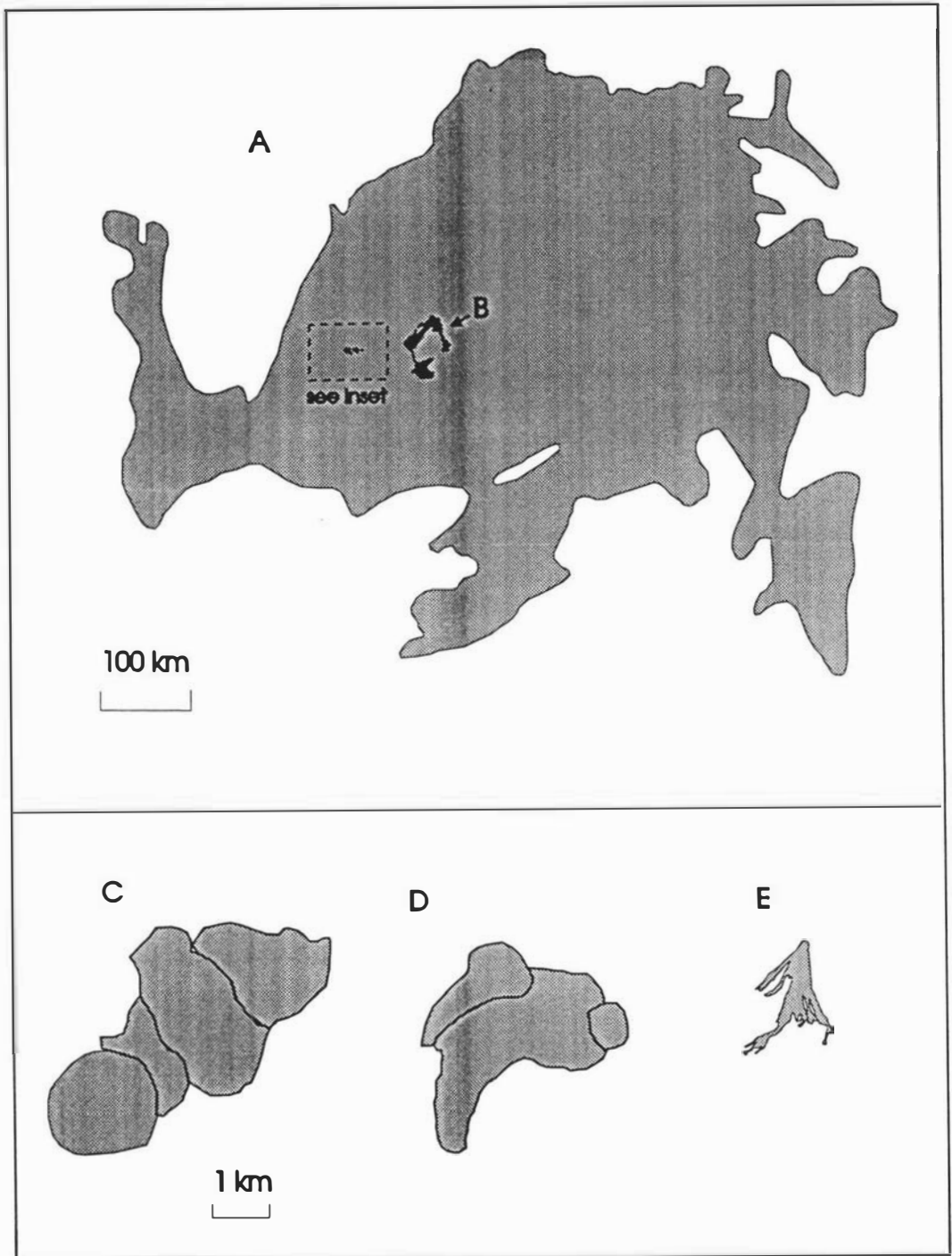


FIGURE 3.17 An example of the range of areas covered by lava flows.

- A. The distribution of the Columbia River flood basalt (modified from Swanson *et al.* 1975).
- B. The distribution of the 1783 Laki basalt flow (modified from Thorarinsson 1969).
- C. The distribution of rhyolite domes at Tarawera (modified from Nairn 1989).
- D. The distribution of dacitic domes from Santiaguito (modified from Rose *et al.* 1977).
- E. The distribution of the 1954 Ngauruhoe andesite lava flows (modified from Gregg 1960).

3.5 VOLCANIC GASES

Volcanic gases consist predominantly of steam (H_2O), followed in abundance by carbon dioxide (CO_2) and compounds of chlorine and sulphur (Giggenbach 1996). Minor amounts of carbon monoxide, fluorine and other compounds are also released. Concentrations of gases will dilute rapidly away from a volcano and pose little threat to people more than a few kilometres from the active vent. When sulphur dioxide (SO_2) is released it reacts with oxygen, water and sunlight to form aerosols (droplets and tiny particles) of sulphuric acid and other sulphur oxide species (Rose 1977; Sutton & Elias 1993, Zhao *et al.* 1995). This mixture often produces an atmospheric haze known as volcanic smog or "vog". The composition of the volcanic gases can irritate humans' and animals' eyes and respiration. The same compounds can cause corrosion of metals. Heavier-than-air gases (i.e carbon dioxide) can also collect in depressions and suffocate people and animals [e.g. on the Dieng volcanic plateau, Indonesia in 1979 (Le Guern *et al.* 1982) and Lake Nyos, Cameroon in 1986 (Kusakabe *et al.* 1989)]. Gases can also be released when lava reaches the ocean and vaporises seawater. A series of chemical reactions can produce an aerosol mixture of hydrochloric acid (HCl) and seawater, which is termed lava haze or "laze" in Hawaii (Gerlach *et al.* 1989; Sutton & Elias 1993), which is potentially harmful to people and is corrosive. However, concentrations decrease sharply with distance from source.

3.6 VOLCANIC EARTHQUAKES AND GROUND DEFORMATION

Earthquakes precede and accompany most volcanic eruptions. They are generated by the movement of magma, the formation of cracks in rocks through which the magma moves, gas explosions in the conduit and readjustment of the volcanic edifice to magmatic pressures. Volcanic earthquakes rarely exceed magnitude 5 (Richter scale), and are usually much less damaging than the associated eruptions (Latter 1981). Damage is usually limited to a relatively small area around the volcano, but buildings within this zone may be subject to shaking damage. Many earthquakes occur at or near volcanoes without associated eruptions and seismic building codes in New Zealand are in place to protect structures against such earthquake damage. Ground deformation may also cause damage to structures and pipelines near vent, often associated with earthquakes. Commencement of the 1957 eruption of Capelinhos in the Azores was followed several months later by a seismic crisis and ground deformation that destroyed over 500 houses (Machado *et al.* 1962). Widespread building damage occurred following ground deformation associated with the 1977 Usu eruption in Japan (Blong 1984).

3.7 ATMOSPHERIC EFFECTS

Volcanic eruptions often produce an array of atmospheric effects. Atmospheric shockwaves have been recorded from many historic volcanic explosions (Table 3.24), where they have produced overpressures sufficient to break windows and knock people down (Blong 1984; Cordoba 1997).

TABLE 3.25 Examples of damage caused by shockwaves
(from Blong 1984; Cordoba 1997)

Volcano and year	Damage
Vulcano, 1888-1890	Broken windows 10 km from volcano
Stromboli, 1907	Nearly every window on the island broken
Asama, 1958	Damaged houses within 15 km
Sakurajima, 1977	Broken windows at 3 km from crater
Galeras (historic accounts)	Broken windows 9 km from vent, people knocked down at 13 km).

Lightning strikes are commonly generated as a result of electrically charged ash in a convecting eruption column (Table 3.25) and can cause both injuries to people and damage to facilities (Anderson *et al.* 1965; Gilbert *et al.* 1991; Gilbert & Lane 1994). Since telecommunications equipment is commonly situated on high ground it is particularly vulnerable if located near the volcano.

TABLE 3.26 Historical examples of eruption-induced lightning strikes.

Volcano and year	Observation	Reference
Tarawera, 1886	Probable forest fires started by lightning.	Keam 1988
Soufrière, 1902	Lightning strikes killed animals and damaged buildings up to 4 km from the vent.	Blong 1984
Kilauea, 1924	Lightning strikes 8 km from the vent destroying 21 consecutive power poles.	Blong 1984
Rabaul, 1937	Lightning strikes hit trees and houses and may have resulted in the loss of several lives.	Johnson & Threlfall 1985
Paricutin, 1943	Three people killed by lightning believed to be caused by the eruption.	Luhr & Simkin 1993
Surtsey, 1963	Spectacular lightning displays within the ash plume.	Thorarinsson 1965
Soufrière, 1979	Strikes 9 km from the volcano.	Shepherd <i>et al.</i> 1979
Hudson, 1991	Lightning-strike damage to communication equipment was reported.	Bitschene 1995
Rabaul, 1994	One person killed by lightning.	Blong & McKee 1995

3.8 LAHARS

Lahars are mudflows formed by mixing of volcanic particles and water (Smith & Fritz 1989). They can be generated by the collapse or overtopping of a volcanic barrier impounding a lake or river, or simply heavy rain washing unconsolidated volcanic material from slopes, or directly from pyroclastic flows or debris avalanches (Neall 1996). Lahars have densities greater than normal river flows and travel at greater velocities; therefore they are more energetic and are highly erosive to river banks.

People caught in the path of a lahar have a high risk of death from severe crush injuries, drowning or asphyxiation (Baxter 1990). Depending on their densities and flow velocities, lahars may destroy structures, or bury them in situ. People have survived lahars by climbing onto the roofs of houses which have remained intact despite inundation and even transportation by the lahar. Two of the best examples of this devastating impact were seen as a consequence of the 1985 Nevado del Ruiz (Voight 1990) and 1991 Pinatubo (Rodolfo 1995) eruptions.

3.9 DEBRIS AVALANCHES

A debris avalanche is a sudden and rapid movement of rock and associated materials due to gravity (Siebert 1984). Flowage can be either in a wet or dry state or mixed. If the avalanche contains a large amount of water it may continue to flow downslope as a lahar once the larger blocks have settled out. Debris avalanches usually occur at large over-steepened volcanoes and are one of the most hazardous of volcanic events. Failure of a portion of a volcanic cone may result from one or more causes, including intrusion of magma, earthquake shaking, and gradual weakening due to hydrothermal alteration or heavy rain which may saturate and weaken parts of the cone. The debris avalanche at Mount St. Helens in 1980 is the best recorded historical example and resulted from magma intrusion coupled with earthquake shaking (Voight *et al.* 1981). Debris avalanches can travel considerable distances (>100 km) from a summit area.

Debris avalanches destroy everything in their path. They can occur with little or no warning and can travel at high speeds. Prior evacuation is the only safe option for areas that might be affected if an avalanche is anticipated.

CHAPTER 4

INTRODUCTION TO 'LIFELINES' ANALYSIS

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4.1 INTRODUCTION

A community's infrastructure provides services, utilities and linkages which allow society to function. The term 'lifelines' is commonly used for this infrastructure and is defined by Platt (1991) as:

"systems or networks which provide for the circulation of people, goods, services and information, upon which health, safety, comfort and economic activity depends".

Lifelines are the means whereby a community supports its day to day activities and include mechanisms used to respond to emergencies. During and after an eruption from the active volcanoes of the central North Island 'lifelines' are vulnerable to disruption and/or damage from a range of volcanic hazards (as described in Chapters 2 and 3). These systems are often large, complex and interdependent. Failure of one system (or part of it) causes repercussions in other systems and therefore increases a community's vulnerability further. A community's 'lifelines' are also vulnerable to other natural hazards and the ability to respond and recover has frequently been highlighted [e.g. hurricanes (Nigg 1990), earthquakes (Nigg 1995a; Nigg & Tierney 1995; Tierney 1994,1995) and floods (Tierney 1995)].

4.2 'LIFELINES' VULNERABILITY ANALYSIS

In recent years several New Zealand projects have been initiated to address the issue of the vulnerability of 'lifelines' to natural hazards. The Wellington Earthquake Lifelines Study (Hopkins *et al.* 1993) examines the impacts of a major earthquake on the engineering lifeline services (water, drainage, electricity, transportation etc.) in the Wellington region. The Christchurch Engineering Lifelines Study (Christchurch Engineering Lifelines Project 1994) extended the range of hazards considered to include earthquakes, snow and wind storms, flooding and tsunamis. Both studies used a similar methodology, following the steps shown in Figure 4.1. A key feature of both projects was the wide involvement of engineers and managers from utility organisations, including local authorities, and private and public companies. Neither study considered volcanic hazards. Potential impacts of volcanic eruptions on 'lifelines' in New Zealand have only been addressed in a limited way for the Auckland Volcanic Field (Allen 1992, Johnston *et al.* 1997), Okataina Volcanic Centre (Johnston & Nairn 1993; Nairn 1995) and Egmont volcano (Patterson 1987).

4.2.1 Scope

Many types of volcanic hazards have the potential to impact on 'lifelines' (see Chapter 3). Since volcanic ash falls have more potential to affect communities in New Zealand than other volcanic hazards, they are the main focus of the 'lifelines' study. Other hazard types will be

considered in the scenarios presented in Chapters 6 and 7.

The following lifelines considered in this study are:

- * Transport - air, road and rail
- * Electricity
- * Water supply
- * Sewerage and stormwater
- * Communications
- * Gas supply.

Due to the size and complexity of certain systems not all components of each will be considered. Rather, the selection of system components is intended to be representative of the broad system types that make up the system. Risk assessments have been undertaken at two levels: firstly the general vulnerability of the system and its components to volcanic ash falls, and secondly, the vulnerability of the system to the impacts of an eruption scenario.

4.2.2 Methodology

The vulnerability assessments in this study follow the path outlined in Figure 4.1 and have been adapted from the Christchurch and Wellington 'Lifelines' studies. The first step is to define what elements of a system are at risk from the hazards identified. To do this each system and its components are mapped two ways. Geographic maps show the location of key components of a system and system maps show the interrelationships between components in a schematic way (Fig. 4.2).

As most infrequent natural phenomena, such as volcanic eruptions and earthquakes, are extremely complex and rarely follow the precise pattern of previous events, pure quantitative assessments (such as that applied to engineering risk) are not always practical (Helm 1996a). In order to make semi-quantitative assessments, individual components may be assessed on a vulnerability chart (Table 4.1 & 4.2). The vulnerability chart was modified from those used in 'lifelines' studies of Wellington (Centre for Advanced Engineering 1991) and Tasmania (Lunn 1996). The analysis process has five stages.

- i) **Importance** Each component of a system is assessed for its importance to the system (ranked from 1 to 5).
- ii) **Vulnerability** Each system is separated into components and their vulnerability to ash fall is assessed. Components may become inoperative due to disruption from interdependent services or as a result of mitigation actions

but may not necessarily be damaged. It is therefore important to separate the vulnerability of a component to becoming inoperative from its vulnerability to being physically damaged. The impacts of ash falls on structures and equipment depend largely on the ash's thickness. Since the vulnerability of certain system components increases with increasing ash thickness four categories are here assessed: a) <5 mm, b) 5-20 mm, c) 20-100 mm, d) >100 mm. Other variables such as rainfall during and after ash falls will affect vulnerability.

- iii) **Interdependence** This can be assessed using an interdependence matrix (Table 4.3). Dependency is ranked from 0 to 3. By adding the rows a measure of importance can be calculated; adding the columns gives a measure of total dependency. The sum of dependency and importance is referred to as the priority factor.
- iv) **Backup or redundancy** Does the component or system have back-ups and/or is there redundancy in the system?
- v) **Impact of damage** Impact or consequence of the damage and/or failure and the ability of the system to function is assessed.

High impact	The element is vital and its continued unavailability would cause substantial impact on ability of the system to operate.
Moderate impact	The element is important and its continued unavailability would cause an impact on ability of the system to operate if it remained inoperative for greater than 24 hours.
Low impact	The element is non-essential but its failure may reduce the efficiency of the system. Its continued unavailability would cause an impact on ability of the system to operate if it remained inoperative for greater than a week.
No impact	The system can function for an extended time without this element.

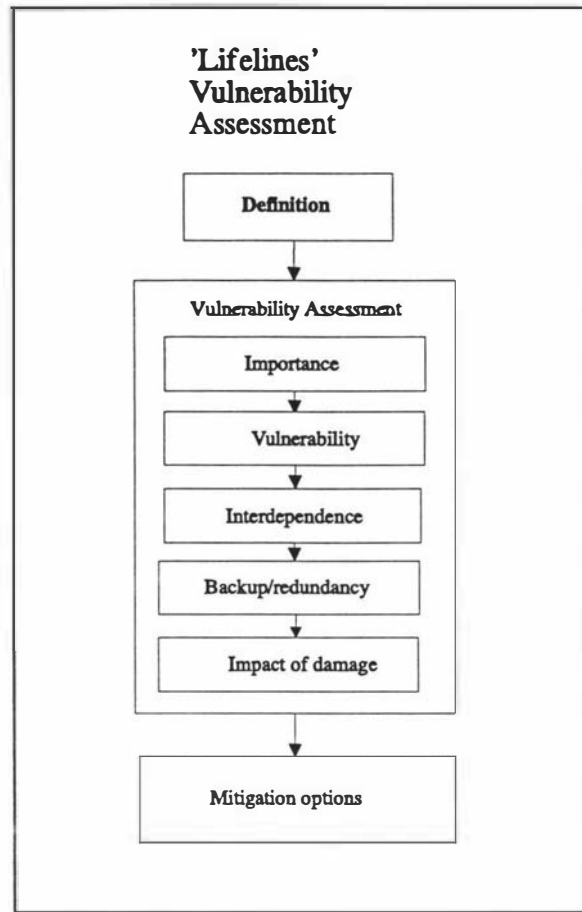


FIGURE 4.1 Flow path for 'lifelines' vulnerability assessment.

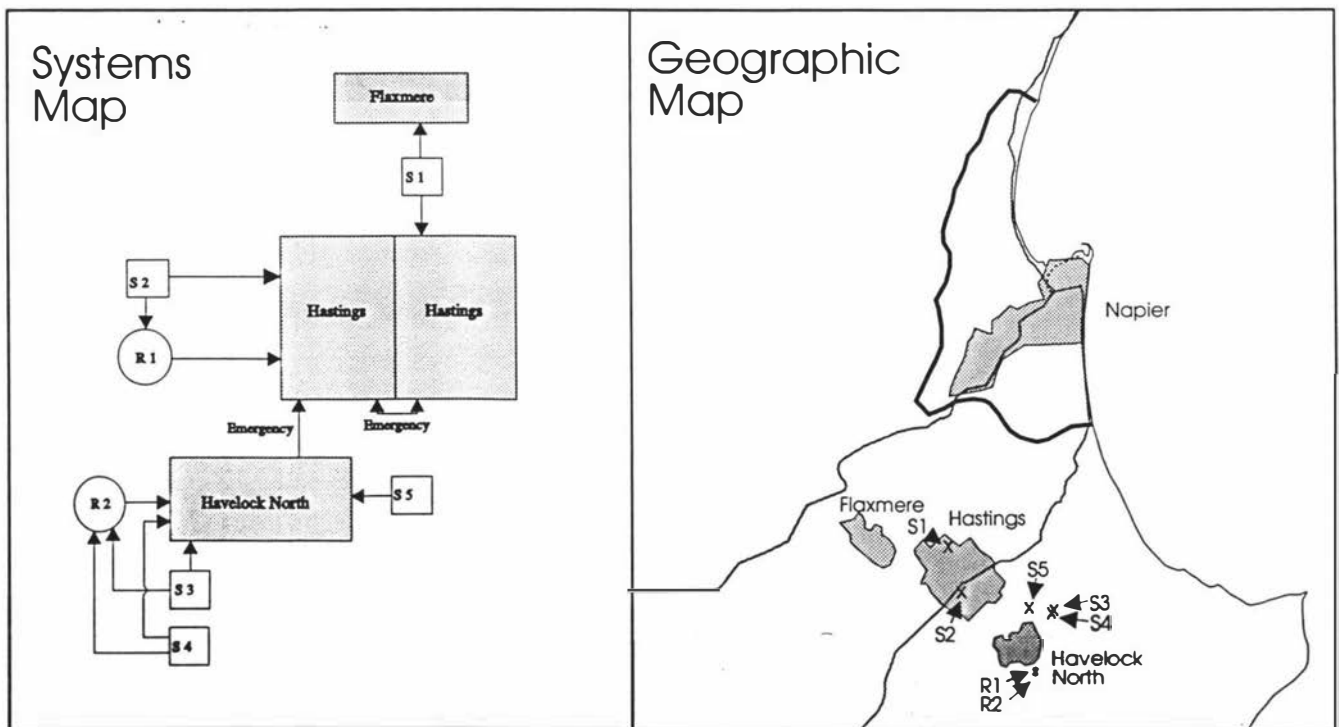


FIGURE 4.2 Examples of systems and geographic maps (e.g. Hastings water supply (from Chapter 6)).

TABLE 4.1 VULNERABILITY CHART KEY**Importance**

Scale from 1 to 5 assessing the importance of the component to the operation of the system. The support % includes the operation of back-up systems. Scale 1 to 5.

1	supports <10 % of the system
2	supports 10-25 % of the system
3	supports 25-50 % of the system
4	supports 50-75 % of the system
5	supports 75-100 % of the system

Ash Condition

The condition of the ash: dry, wet, acidity, grainsize.

Vulnerability**Inoperative**

Each component assessed for its likelihood of becoming inoperative in each ash thickness category. Scale 0 to 3.

0	Not susceptible to being rendered inoperative
1	Low likelihood of being rendered inoperative
2	Moderate likelihood of being rendered inoperative
3	High likelihood of being rendered inoperative

Damage

Each component assessed for its likelihood of being damaged in each ash thickness category. Scale 0 to 3.

i) Discrete components

0	Not susceptible to damage
1	Low likelihood of damage
2	Moderate likelihood of damage
3	High likelihood of damage

ii) System Segments

0	Not susceptible to damage
1	Low likelihood of damage
2	Moderate likelihood of damage
3	High likelihood of damage

Interdependence

The dependency on other components or systems to be operational. Scale 0 to 3

0	No dependency
1	Low dependency
2	Moderate dependency
3	Total dependency

Backup or redundancy

Does the component or system have back-up systems and/or is there redundancy in the system?

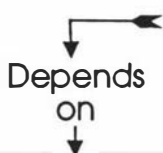
Impacts of damage

The consequence of a component being damaged. Scale 0 to 3.

0	No impact
1	Low impact
2	Moderate Impact
3	High Impact

TABLE 4.3 Interdependence matrix (i.e. for Hastings 'lifelines', see Chapter 6).

Hastings

 Depends on	Water Supply	Gas Supply	Sewerage	Storm Water	Mains Electricity	Standby Electricity	VHF Radio	Telephones	Roads	Rail	Air transport	Fuel Supply	Fire Fighting	Air-conditioning	Total Importance
	Water Supply	*	1	*	*	*	*	*	*	*	*	*	*	3	2
Gas Supply	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0
Sewerage	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0
Storm Water	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0
Mains Electricity	2	1	2	2	*	*	2	3	*	1	3	2	*	3	21
Standby Electricity	3	1	3	3	*	*	1	3	*	*	3	2	*	2	21
VHF Radio	3	3	3	2	3	*	*	2	2	2	3	*	3	*	26
Telephones	2	1	1	*	1	1	2	*	*	1	1	1	2	*	13
Roads	2	2	2	2	3	2	1	2	*	2	3	2	3	1	27
Rail	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0
Air Transport	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0
Fuel Supply	3	1	1	1	*	3	1	2	3	2	3		3	*	23
Fire Fighting	*	*	*	*	*	*	*	*	*	*	2	1		*	3
Air-conditioning Equipment	*	*	*	*	2	2	*	3	*	*	2	*	*	*	9
Equipment	3	3	3	2	3	3	3	3	3	3	3	2	3	3	40
Total Dependence	18	12	16	12	12	11	10	18	8	11	23	10	17	11	
Priority Factor	24	12	16	12	33	32	36	31	35	11	23	33	20	20	

Note: 3 = High Dependence
 2 = Moderate Dependence
 1 = Low Dependence
 * = No Dependence

Priority Factor = Importance + Dependence

4.2.3 Mitigation measures

Once the vulnerability of a system has been assessed and vulnerable elements identified, mitigation strategies can be developed. Three types of approaches can be used:

- * Policy and management measures that reduce the likelihood of damage and/or failure.
- * Engineering design measures that reduce the vulnerability.
- * Preparedness and response planning to deal with the consequences of the event.

Mitigation options should be evaluated in terms of the risk reduction and the benefits or opportunities created. In selecting any appropriate option or options the cost of implementation must be balanced against the benefits derived from it (Fig 4.3). A more detailed discussion of this point is presented in Chapter 9.

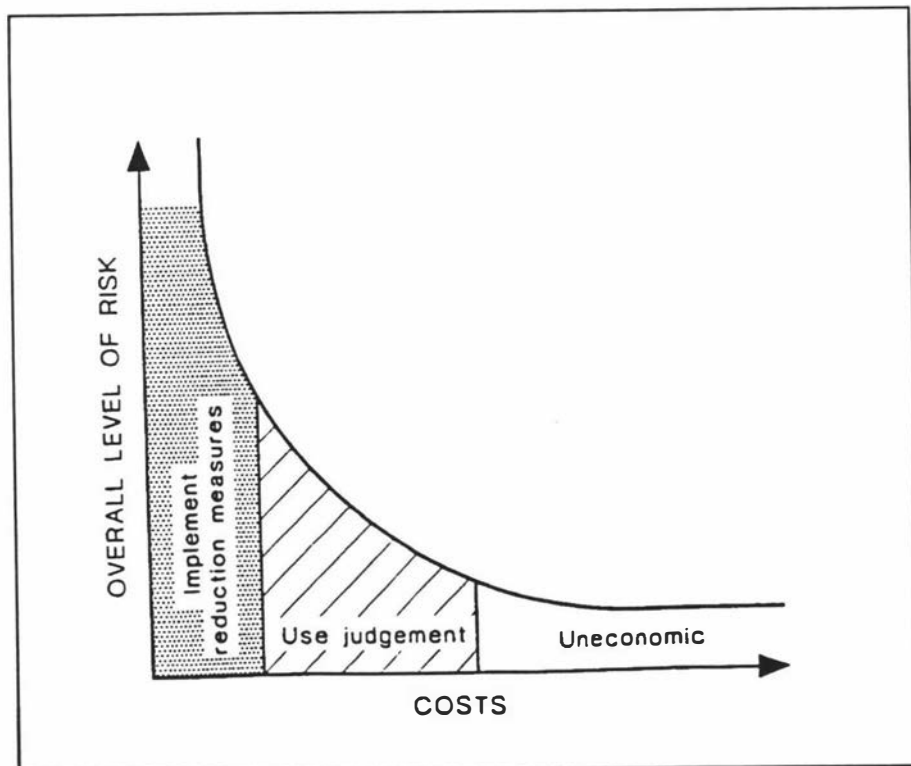


FIGURE 4.3 Cost of risk reduction measures (from Australian/New Zealand Standard 1995).

4.3 SCENARIOS

A scenario is an imagined sequence of future events. It is a useful and powerful tool in hazard management and can be applied to a range of natural hazards [e.g. floods (Erickson 1975), earthquakes (Centre for Advanced Engineering 1991) and volcanic eruptions (Blong & Aislabie 1988; Johnston & Naim 1993)]. Scenarios provide a way of considering a range of events that are possible but have not yet occurred. They do not attempt to test a hypothesis but examine what would happen if a given hypothesis or set of hypotheses were to hold true under a set of variable conditions. They attempt to set up a logical sequence of events from a given starting point and allow a range of possibilities to be considered.

The utility of the scenario methodology is outlined by Erickson (1975) who highlights the following functions:

- a) As a tool for thinking about complex problems that have uncertain outcomes by linking individual elements of a dynamic system.
- b) Reducing random outcomes by producing results that help structure existing information into a coherent whole.
- c) Using it as a preliminary sorting procedure for identifying a range of problems that may be subsequently examined by more quantitative analytical procedures.
- d) Providing a tool for decision makers, since a scenario's function is to anticipate changes in the future, which often depend on decisions made in the present.
- e) Providing educational and community value to end-users as scenarios are intentionally dramatic and literal in style;

Erickson (1975) defines two types of scenarios: exploratory and normative. Exploratory scenarios focus on the processes of change in a system whereas normative scenarios have a pre-determined outcome and explore alternative paths used to reach this outcome.

This study is intended to provide a way of illustrating the types of impacts that might realistically be expected from a volcanic eruption on two New Zealand communities. A simple exploratory approach has been adopted with two linked scenarios for each community (Fig. 4.4). Firstly, an eruption scenario has been created to provide the conditions that affect each community. An impact scenario is then developed, combining a vulnerability analysis of each community's key 'lifelines' and an assessment of the physical and social impacts that would result from the eruption scenario. Effects of volcanic eruptions can be considered in three groupings (Table 4.4): (i) primary effects resulting from the occurrence of the hazard and exposure to it; (ii) secondary effects resulting from instant or direct outcomes of primary effects; (iii) high-order effects that result as flow-on consequences of earlier effects. Chapters 6 and 7 develop two eruption scenarios: 1) a 0.1 km³ andesitic eruption of Ruapehu composite

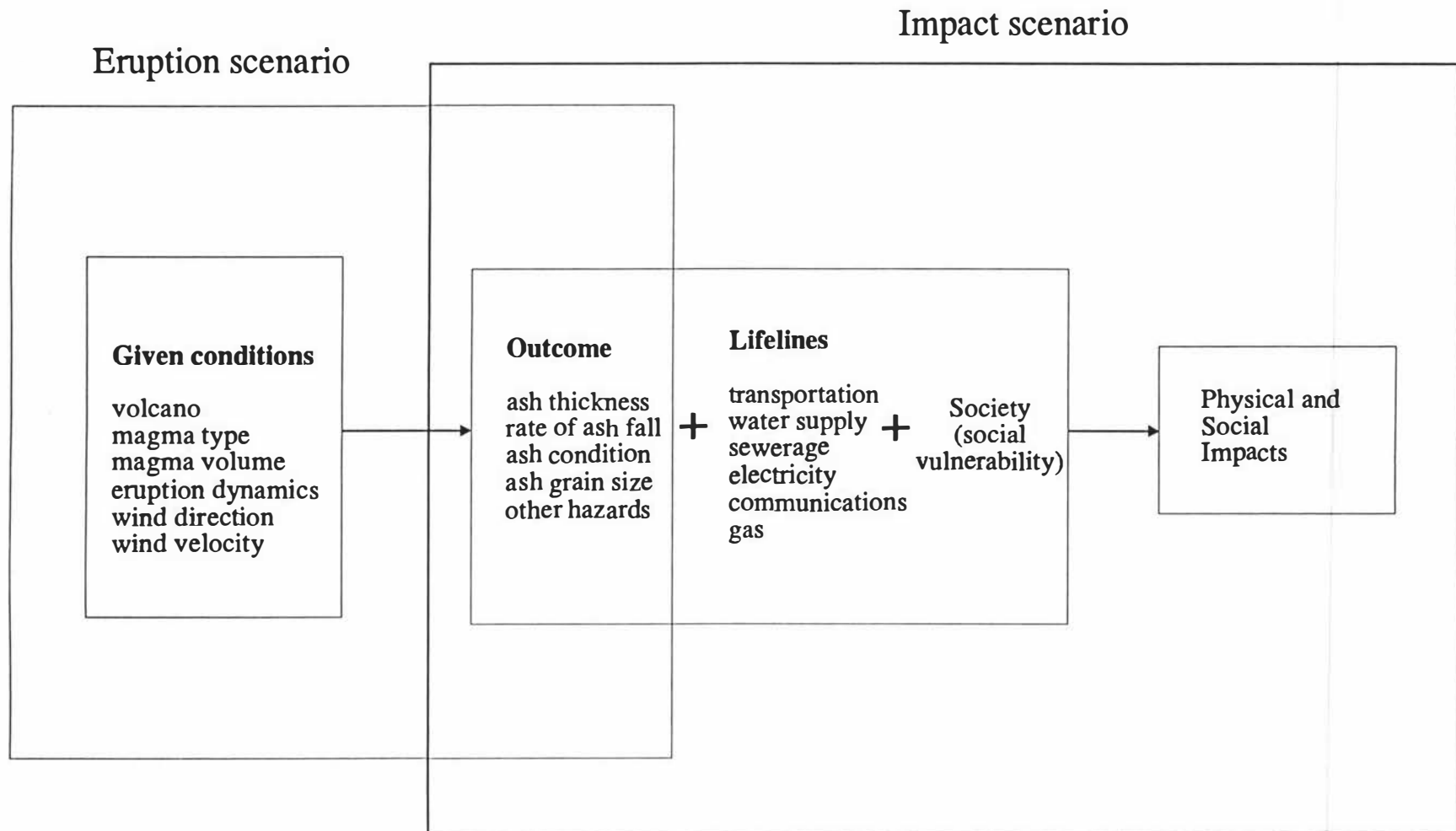
volcano during a northwesterly wind affecting Hastings District; and 2) a 4 km³ rhyolitic eruption from the Okataina caldera during a westerly wind affecting Whakatane District.

TABLE 4.4 Possible effects of volcanic eruptions

Primary effects		Secondary effects		Higher order effects	
1.	Death and injury to people and/or evacuation	1.	Evacuation and/or homelessness	1.	Unemployment
2.	Psychological trauma and anxiety	2.	Disruption to 'lifelines'	2.	Loss of personal, business and industry income
2.	Death and injury to livestock and domestic animals and/or evacuation	2.	Slowdowns or closure of business and industry	3.	Depletion of personal and business savings and/or capital
4.	Implementation of mitigation measures e.g. removal of assets, shut-down of services	4.	Financial expenditure for mitigation measures, clean-up operations, repair and replacement of damaged utilities, buildings and contents, by central and local government, business, communities and individuals.	3.	Diversion of investment capital into recovery
3.	Damage to structures and their contents			4.	Alteration of land and property values
4.	Damage to utilities	5.	Insurance payouts to policy holders.	5.	Alteration of population growth and migration
5.	Damage to transport systems (e.g road, vehicles, airports).			6.	Increased tax burdens to finance response and recovery
6.	Damage to crops, forests, etc			7.	Alteration in socio-economic viability
7.	Changes to the landscape, river flows etc.				

(modified from "Taxonomy of Natural Hazard Effects" by Petak & Atkisson (1982)).

FIGURE 4.4 Scenario Development



CHAPTER 5

MODELLING ASH DISTRIBUTION

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5.1 INTRODUCTION

In the following chapters (6 and 7) two eruption scenarios are developed: 1) a 0.1 km³ andesitic eruption of Ruapehu composite volcano during a northwesterly wind affecting Hastings District; 2) a 4 km³ rhyolitic eruption from the Okataina caldera during a westerly wind affecting Whakatane District. The choice of scenarios is designed to illustrate the contrast between a disruptive moderate-sized eruption from a cone volcano (Ruapehu) and the destructive impacts of a large caldera eruption (Okataina). Modelling of the distribution of ash in the two eruption scenarios detailed in Chapters 6 and 7 has been based on the use of the program ASHFALL. The program calculates ash thickness for a given eruption column and prevailing wind conditions (Hurst 1994). The program was developed by T. Hurst from the Institute of Geological & Nuclear Sciences based on work by G. Macedonio, M. Pareschi and P. Armienti of the University of Pisa (Armienti *et al.* 1988; Macedonio *et al.* 1988, 1990).

The program starts with a rising column of a certain total weight of ash reaching an altitude of neutral buoyancy (Z_{buoy}). Above this point the rising column loses momentum and velocity decreases to zero at the top of the column. The ash distribution with height ($V'(z)$), is assumed to follow the Suzuki distribution (given a total volume (V) and height of the column (Z)) such that:

$$V'(z) = kV(1-z/Z)e^{-A(1-z/Z)} \quad (5.1)$$

where V is total volume,
 z is the height of the column,
and k is a constant of integration,
a function of the Suzuki constant
(A).

The Suzuki constant A defines the relationship between Z and Z_{buoy} and is typically around 5 (Macedonio *et al.* 1988). The program calculates the trajectory of all clasts with similar settling velocities. The horizontal position of clasts will change with each vertical step and once they reach the ground their distribution is calculated based on the rate of horizontal movement and the time they left the column. A grid file is generated once all particles have reached the ground.

5.2 PROGRAM PARAMETERS

The ash distribution generated by the ASHFALL program depends on both volcanic and meteorological factors. Input information is read from two files, the "volcano" file containing

initial setup information and eruption parameters, and the "wind" file, giving wind direction and velocity.

The "volcano" file contains:

- 1) Eruption column position and height
- 2) Total erupted mass
- 3) Fraction of ash of different sizes (and hence settling velocities).

The "wind" file contains:

- 1) Wind direction and velocity at each level between ground level and the top of the column, and variation of this with time and space.

5.3 SCENARIO PARAMETERS

For the two scenarios considered in Chapters 6 and 7 the following conditions were built into the models.

Eruption column position and height

Scenario 1	Grid reference:	T20 312 105 (refer to Chapter 6 for justification)
	Column height:	12 km
Scenario 2	Grid reference:	V16 144 346 (refer to Chapter 7 for justification)
	Column height:	25 km

Total erupted mass

Scenario 1	0.1 km ³	(refer to Chapter 6 for justification)
Scenario 2	4 km ³	(refer to Chapter 7 for justification)

Fraction of ash of different sizes (and hence settling velocities)

The settling velocity of ash particles increases with particle size and density and their relationship is shown in Figure 5.1. The fraction of ash in each category relates to the initial size distribution of ash in the column. The ash size distributions used in both scenarios are shown in Figures 5.2 and 5.3. The Scenario 1 distribution has been proposed by T. Hurst (*pers. comm.*) and was used for modelling ash fall predictions by the Institute of Geological

& Nuclear Sciences during the 1995 and 1996 Ruapehu eruption. The Scenario 2 distribution is that proposed by Macedonio *et al.* (1990), based on deposits of the eruption of Vesuvius A.D. 79.

Wind direction and velocity.

Variations in upper atmosphere wind directions for Auckland Airport are shown in Figure 5.4 and have been used as the nearest point of available data. A northwest wind has been chosen for the Ruapehu scenario (1) in order to disperse ash directly over Hastings city. Wind from the westerly sector is statistically the most likely to occur during an eruption, and this is assumed for the Okataina scenario (2). However, slight variations in direction with height are commonly observed in measured wind profiles and have been used in the models to produce a more realistic ash distribution. Wind velocities for both directions are based on longer-term averages from the Auckland airport data set. Three velocity profiles are calculated representing the velocity that wind blows at or below 20%, 50% and 90% of the time (Table 5.1).

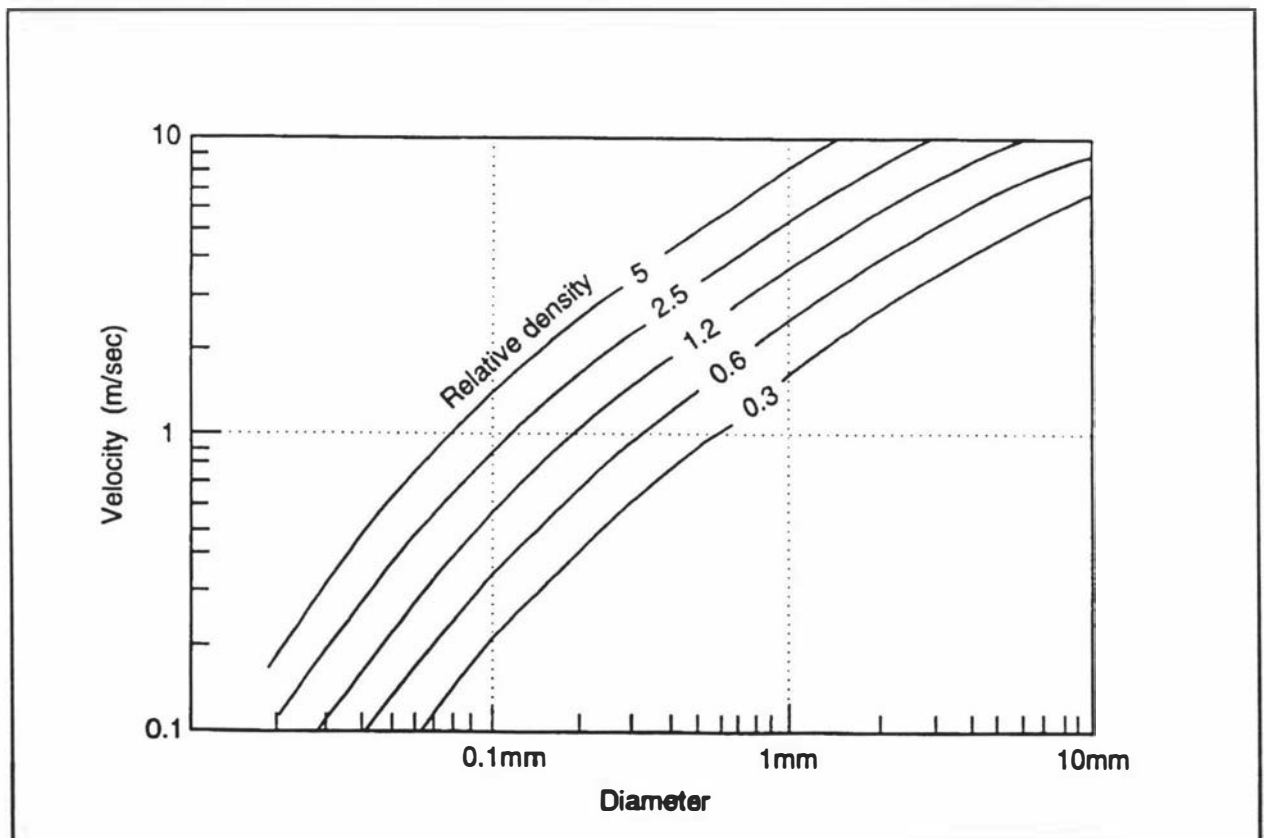


FIGURE 5.1 Settling (terminal) velocities of volcanic ash of various sizes based on modelling by Walker *et al.*(1971).

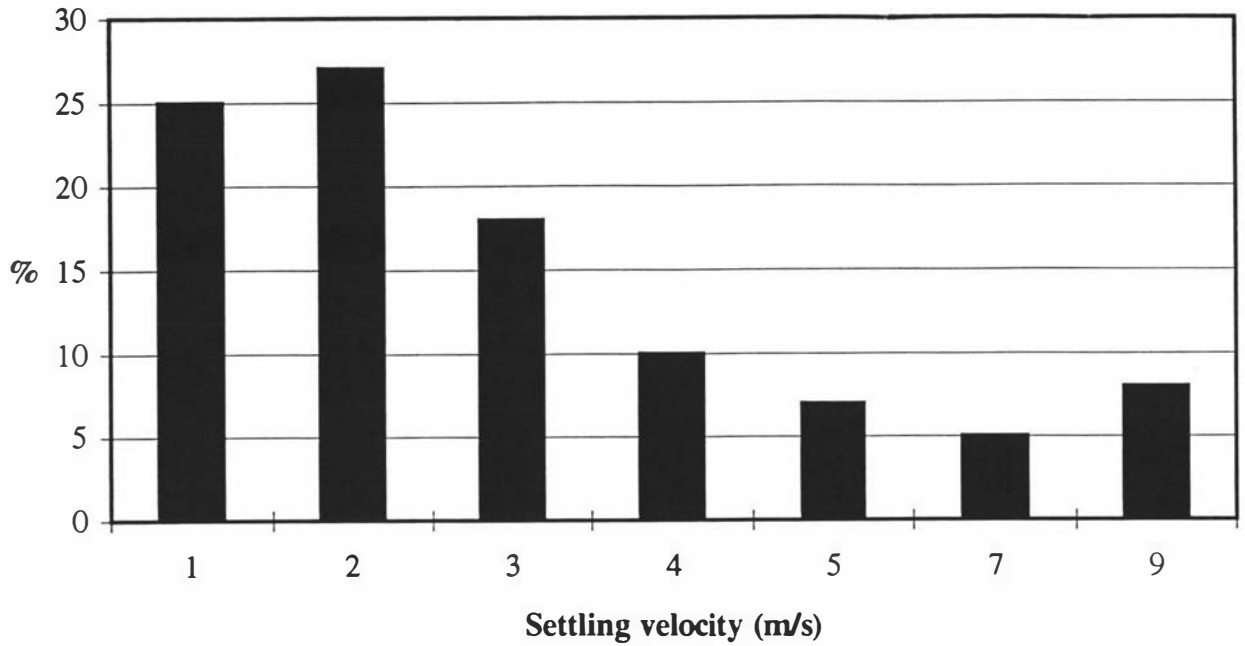


FIGURE 5.2 Distribution of ash in terms of settling velocities for Scenario 1 eruption (data from T. Hurst *pers. comm.*)

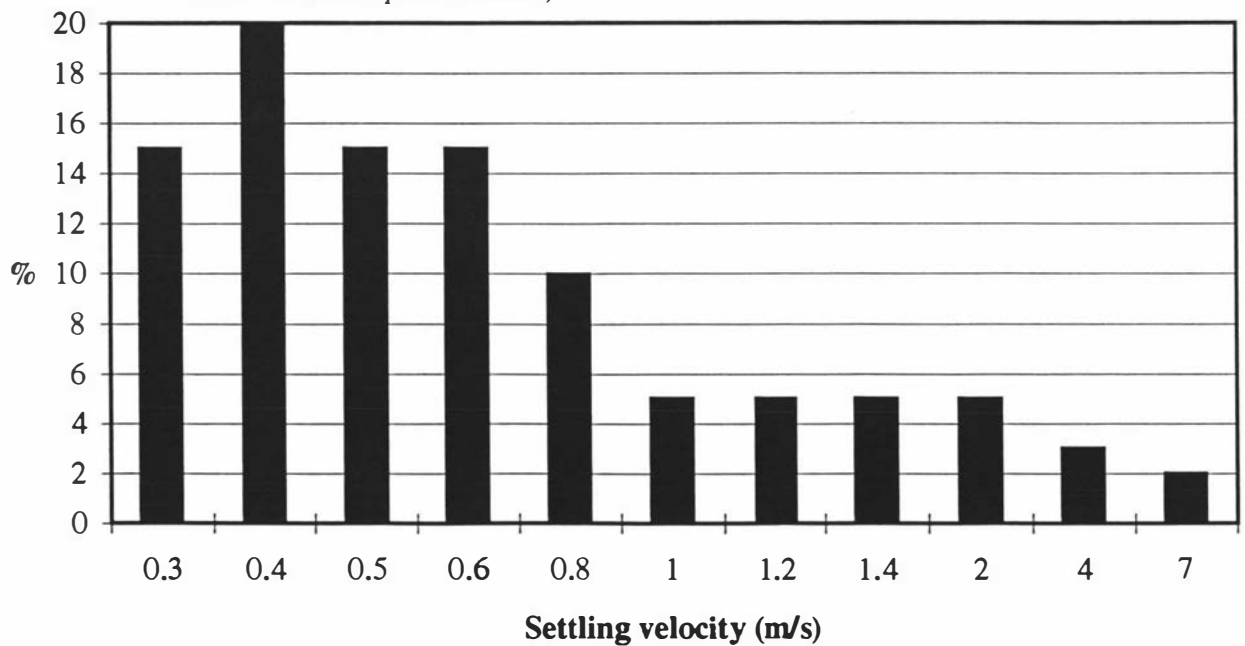


FIGURE 5.3 Distribution of ash in terms of settling velocities for Scenario 2 eruption (data from Macedonio *et al.* 1990)

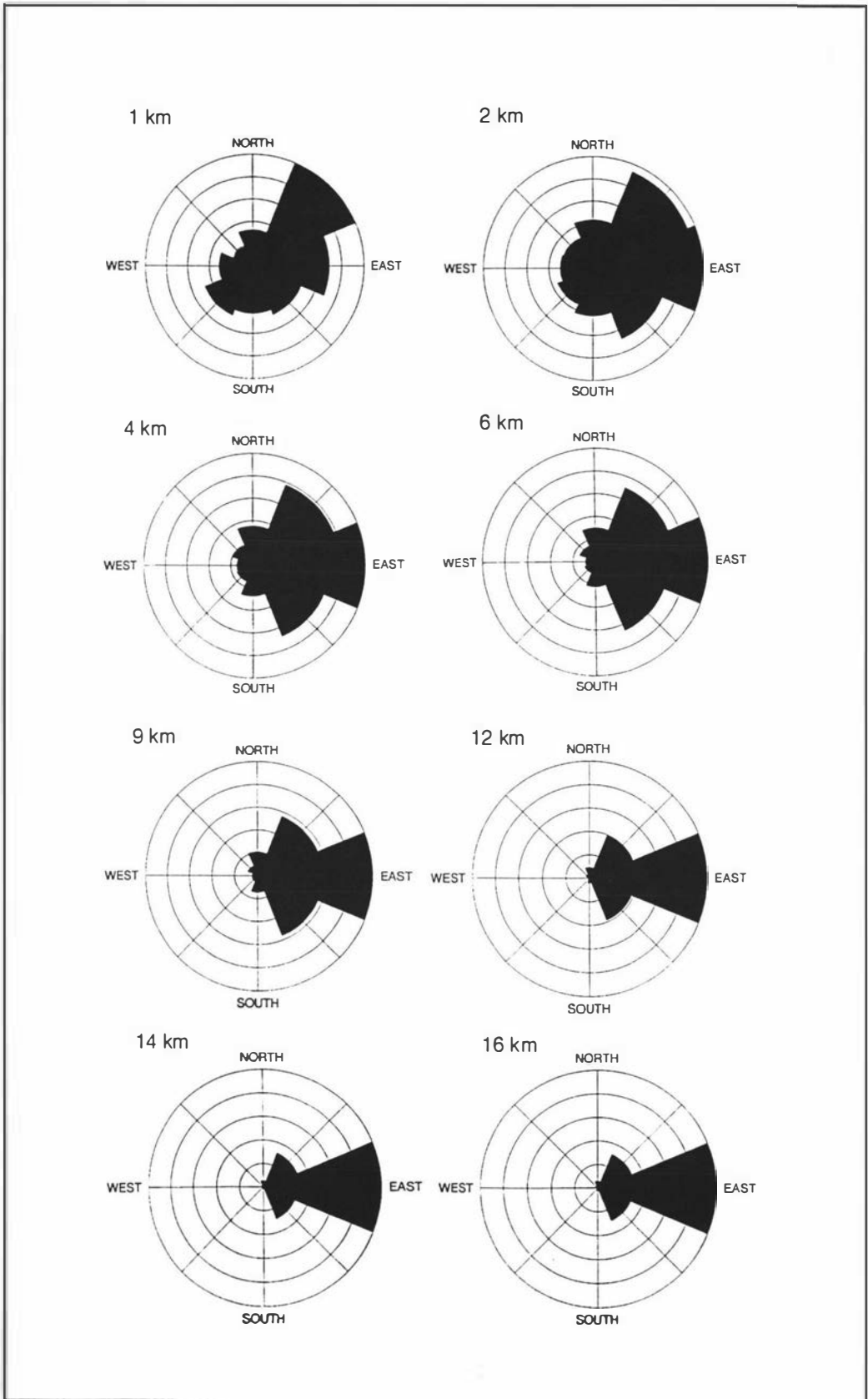


FIGURE 5.4 The frequency of wind directions at various heights above Auckland Airport derived from 1966 to 1979 data.

TABLE 5.1 Wind velocity (ms^{-1}) profiles above Auckland Airport for specific directions (northwest and west) giving the velocity that wind blows at or below 20 %, 50% and 90 % of the time, derived from 1966 to 1979 data.

A Northwest

Altitude (m)	20%	50%	90%
1000	5	9	19
1500	5	10	20
2000	6	11	21
3000	6	12	23
4300	7	13	25
5500	7	15	29
7200	9	17	34
9200	11	21	40
10400	13	23	42
12000	12	21	39
13600	11	18	34
16300	5	12	23

B West

Altitude (m)	20%	50%	90%
1000	5	9	17
1500	6	10	18
2000	6	11	19
3000	6	12	22
4300	7	13	24
5500	9	16	29
7200	11	19	36
9200	14	24	42
10400	16	27	49
12000	17	28	49
13600	15	24	40
16300	10	16	28

5.4 ASHFALL OUTPUTS

The following figures (5.5 and 5.6) show isopach maps produced using a constant "volcano" file and three different "wind" files for each scenario. The light wind generated isopachs are used (Fig 5.5a and Fig. 5.6a) for the two eruption scenarios, presented in the following chapters (6 and 7).

5.5 DISCUSSION

The distribution of ash is highly dependent on wind direction. Long-term upper atmosphere wind data has been obtained from the New Zealand MetService for three sites in New Zealand (Whenuapai 1956-1966, Auckland Airport 1966-1983 and Ohakea 1956-1983). Winds at higher altitudes are far more uniform than at lower levels. It is these high level winds which have the greatest control on widespread ash distribution. There is little variation in character of the upper-level winds at the three sites because of the small difference in latitude between them, therefore, any of the three data sets can be used. However, the models do not fully consider the seasonal variations of tropospheric winds (i.e. >20 km) as shown in Figure 5.7. Any portion of an eruption column greater than 18-20 km in summer will be predominantly affected by the easterly wind direction but as ash falls below this height the dominant westerly conditions prevail. This will have no affect on Scenario 1, as the column height is below this altitude, but will potentially affect the dispersal of ash in Scenario 2.

Even though winds from a non-westerly direction occur only for a small proportion of the time, the distribution of ash during such times cannot be ignored. A community on the side of a volcano towards which the wind blows only 1% of the time has only a 1% probability that a single discrete random eruption will drop ash on it. If the eruptive episode consists of multiple eruptive events, the probability that ash will fall on the community (i.e. $p [x \geq 1]$) is considerably higher, as shown in the equation.

$$\begin{aligned} p [x \geq 1] &= 1 - p [x = 0] && (5.2) \\ &= 1 - (1 - w) ^ n \end{aligned}$$

where x = number of ash fall events
 w = wind frequency
 n = number of eruptive events

If, for example, an eruptive episode has 100 discrete ash producing events, there is a 63% probability that one or more of the eruptions will disperse ash in the 1% wind direction, assuming the events are randomly distributed. Therefore, using the wind frequency data to estimate the likelihood of an ash fall occurring, without considering the cumulative frequency probability that results from multiple eruptive events, may lead to a dramatic underestimation of the true likelihood of ash fall at a certain location.

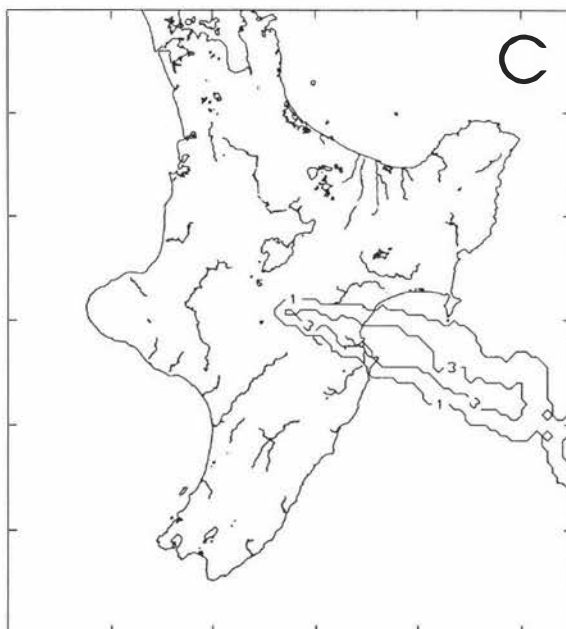
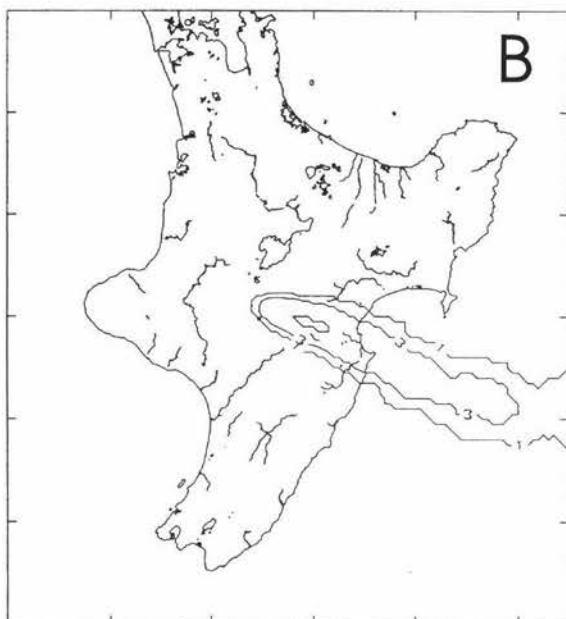
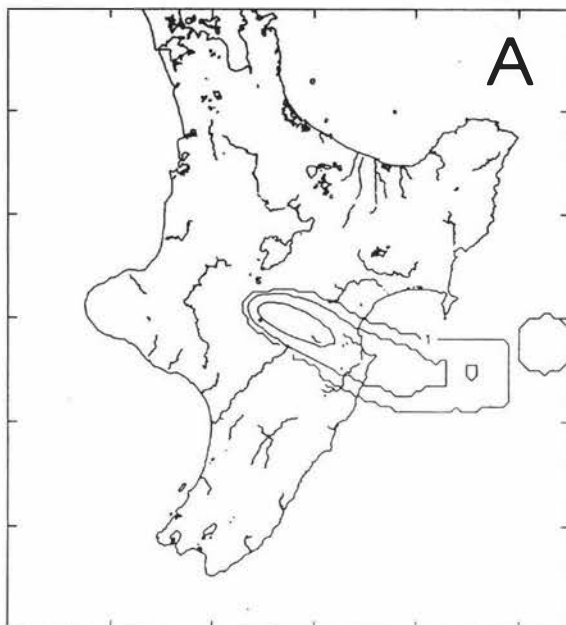


FIGURE 5.5

Three ASHFALL models for a 0.1 km³ Ruapehu eruption scenario

Wind Profiles

A	0 hr.		3 hr.		9 hr.	
	v.	dir.	v.	dir.	v.	dir.
2000	5	250	5	290	11	195
4000	7	290	8	295	10	220
6000	9	290	8	300	13	250
8000	13	295	11	295	8	260
10000	12	295	12	295	11	250
12000	11	295	12	280	16	260

B	0 hr.		3 hr.		9 hr.	
	v.	dir.	v.	dir.	v.	dir.
2000	9	250	9	290	11	195
4000	12	290	12	295	10	220
6000	15	290	15	300	13	250
8000	17	295	17	295	08	260
10000	20	295	20	295	11	250
12000	22	295	22	280	16	260

C	0 hr.		3 hr.		9 hr.	
	v.	dir.	v.	dir.	v.	dir.
2000	19	250	19	290	11	195
4000	23	290	23	295	10	220
6000	29	290	29	300	13	250
8000	24	295	34	295	08	260
10000	40	295	40	295	11	250
12000	40	295	40	280	16	260

KEY

alt. = altitude in metres
 v. = wind velocity in ms⁻¹
 dir. = wind direction in degrees
 contours at: 1, 3 and 10 mm

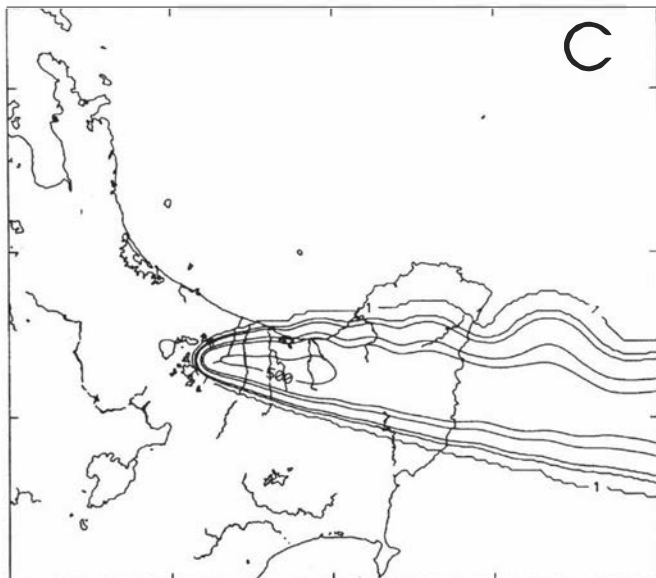
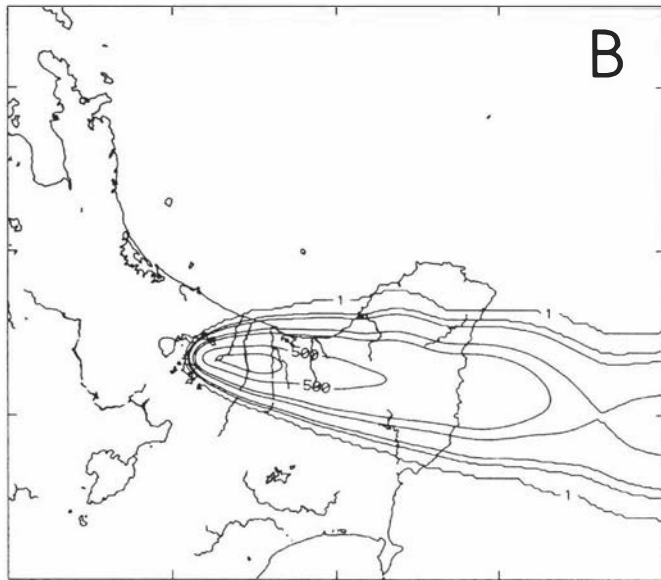
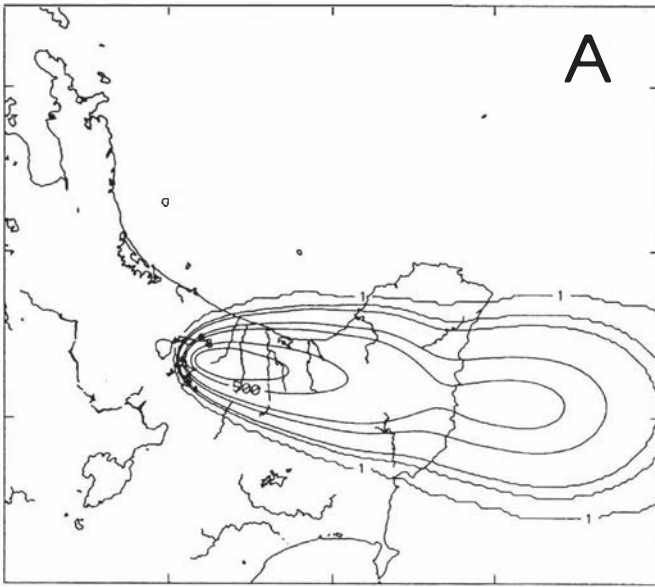


FIGURE 5.6

Three ASHFALL models for a 4km³ Okataina eruption scenario

Wind Profiles

A	0 hr.		24 hr.	
	alt.	v. dir.	v.	dir.
2000	6	270	9	255
4000	7	270	11	285
6000	9	270	12	300
8000	12	270	13	315
10000	15	290	14	310
12000	17	280	16	280
14000	14	280	17	280
16000	10	270	20	270
18000	10	270	20	260
20000	8	280	20	270
22000	8	260	20	260
24000	8	270	25	270
26000	9	260	20	270
28000	8	250	15	260
30000	8	270	15	260

B	0 hr.		24 hr.	
	alt.	v. dir.	v.	dir.
2000	11	270	9	255
4000	13	270	11	285
6000	17	270	12	300
8000	21	290	13	315
10000	26	290	14	310
12000	28	280	16	280
14000	23	280	17	280
16000	17	270	20	270
18000	15	270	20	260
20000	15	280	20	270
22000	15	260	20	260
24000	10	270	25	270
26000	10	260	20	270
28000	10	250	15	260
30000	10	270	15	260

C	0 hr.		24 hr.	
	alt.	v. dir.	v.	dir.
2000	19	270	9	255
4000	23	270	11	285
6000	31	270	12	300
8000	38	270	13	315
10000	48	290	14	310
12000	49	280	16	280
14000	39	280	17	280
16000	29	270	20	270
18000	27	270	20	260
20000	25	280	20	270
22000	25	260	20	260
24000	20	270	25	270
26000	20	260	20	270
28000	20	250	15	260
30000	20	270	15	260

KEY

alt. = altitude in metres
 v. = wind velocity in ms⁻¹
 dir. = wind direction in degrees
 contours at: 1, 5, 10, 50, 100 and 500 mm

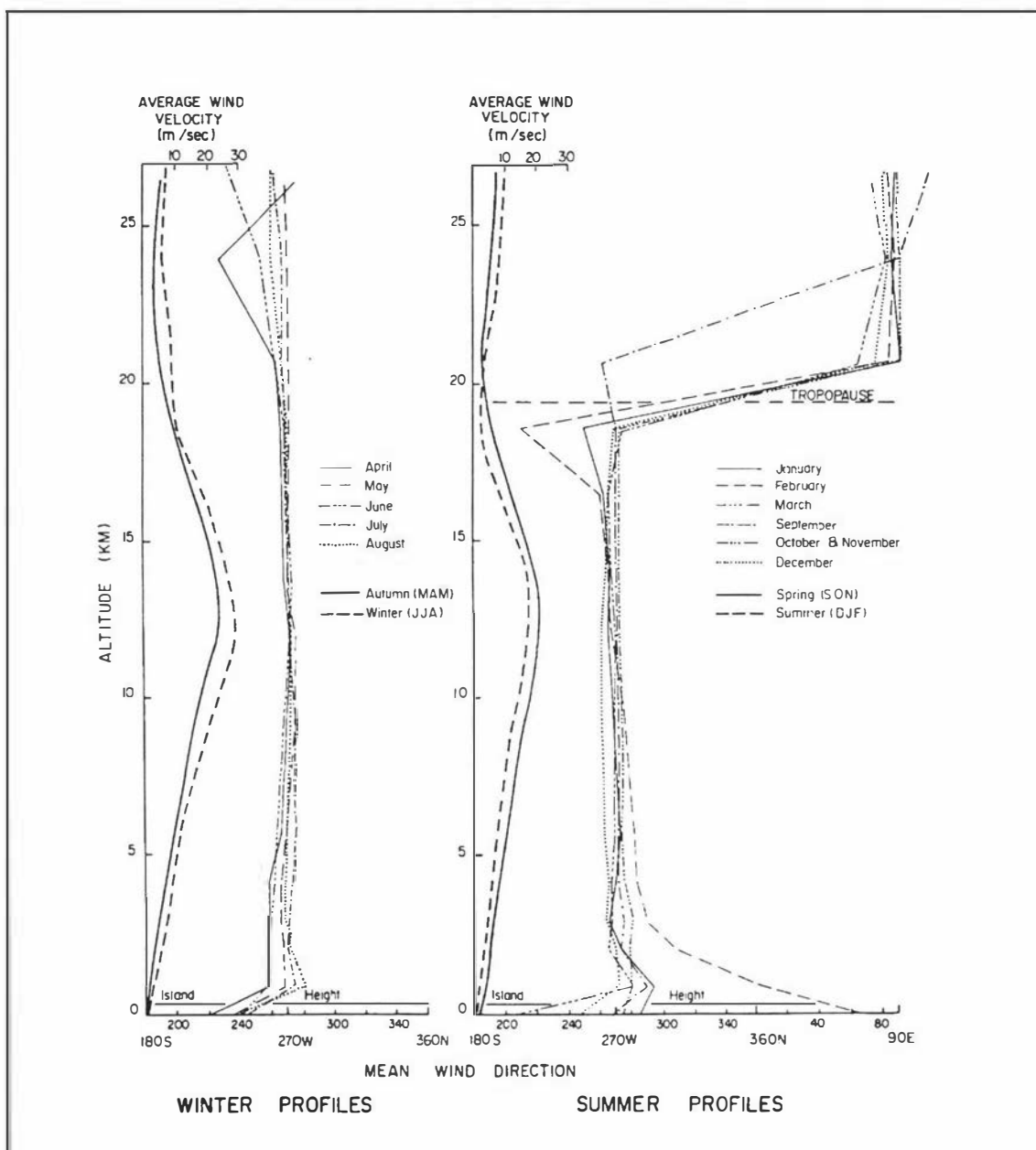


FIGURE 5.7 Monthly average wind velocities and wind directions for the upper air at Whenuapai, from 1956 to 1966 (diagram from Buck 1985, data from De Lisle 1969).

CHAPTER 6

SCENARIO ONE - ERUPTION FROM THE RUAPEHU VOLCANO

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6.1 INTRODUCTION

This chapter examines the impacts on the Hastings District of a 0.1 km³ andesitic eruption scenario from the Ruapehu volcano.

6.2 VOLCANIC HISTORY OF RUAPEHU VOLCANO

Ruapehu is an active composite volcano, erupting predominantly andesite magma. It forms the highest peak (2797m a.s.l.) in the North Island and is one of New Zealand's most active volcanoes. Recorded activity dates back 120 years, beginning with the 1861 eruption. Prehistoric activity dates back over 250 Ka (Hackett 1985) with at least four cone-building episodes. The most recent episode forms the andesitic to dacitic Whakapapa Formation from 15 000 years to the present. Evidence for past activity includes strombolian explosive eruptions, eruption of block lava flows, sub-plinian eruptions with or without the generation of small pyroclastic flows and cone-collapse generating debris avalanches and lahars (Hackett & Houghton 1989).

Donoghue (1991) has examined the tephrostratigraphy of the past c. 22 600 years on the southern and eastern ring plain which reveals a complex history of multiple small eruptions. At least 60 ash and lapilli layers were deposited between 22 000 and 10 000 years B.P. The largest is represented by the Okapata Tephra dated between 13 000 and 10 000 years B.P. with an estimated volume of $2 \times 10^8 \text{m}^3$ (0.2 km³) (Topping 1973). These tephra-depositing eruptions have a recurrence interval of approximately 200 years. Few tephra appear to have been erupted between 10 000 and 1800 years B.P. The youngest sequence is that of the Tufa Trig Formation erupted between 1800 years B.P. and the present, consisting of 18 recognisable andesite tephra units (Donoghue 1991). The largest unit (Tf5) has an estimated volume of $\sim 10^8 \text{m}^3$. The preserved tephra suggest a recurrence interval of approximately 100 years.

Historic phreatic and phreatomagmatic eruptions have been smaller, in the range from 10^4 - 10^7m^3 with intervals between eruptive episodes frequently as low as 1-3 years (Houghton *et al.* 1987). Historic magmatic eruptions are limited to the 1945, 1995 and 1996 eruptions, and a possible event in 1861. No recognisable deposits of the 1945 eruptions are preserved although considerable ash was ejected. The impacts of the 1945, 1995 and 1996 eruptions and the distribution of their tephra is discussed in more detail in Chapter 2 and Appendices 1 & 2. These eruptions highlight the problem of estimating the frequency of past eruptions from the tephra record since preservation of deposits is commonly lacking for eruptions that are below a certain size. Hackett and Houghton (1989) suggest that dome growth at Ruapehu is also underestimated as the preservation potential for dome products is exceedingly low.

An extensive ring plain has formed around Ruapehu from rapid reworking of pyroclastics and detritus from the flanks of the volcano by lahars, streams and slope wash. With the low preservation potential of primary pyroclastics on the cone the sedimentary record on the ring plains is an important means of deciphering the past history of the volcano (Palmer 1991). Detailed studies of Ruapehu laharic deposits have been undertaken by Palmer (1991) on the northwest ring plain, Donoghue (1991) on the southwest ring plain, Hodgson (1993) in the Whangaehu River valley and Cronin (1997) on the northeast ring plain. The younger lahar deposits are collectively mapped as the Onetapu Formation, post-dating c. 1830 years B.P. Hodgson (1993) recognises 17 units, three correlating with large historic lahars. A total of 21 historic lahars of all sizes have been recorded in the valley prior to 1995. Early eruptions through Crater Lake in 1995 generated lahars down the Whangaehu, Whakapapaiti, Wahianoa and Mangaturuturu rivers, with over 90% of the volume of the lahar material flowing down the Whangaehu River in 35 lahars (Cronin *et al.* 1997).

6.3 SCENARIO ERUPTION PARAMETERS

In the design of eruption scenarios a number of assumptions need to be made. An important assumption is that future eruptions will be analogues of past eruptions. This is not always the case. However, since the aim of this scenario is to consider the impacts on Hastings city of a large eruption from Ruapehu, it is assumed in this scenario that the volcano behaves in a style typical of andesite cone volcanoes and mirrors as much as possible its past activity. The eruption of andesitic magma from a cone volcano can range in style from the extrusion of lava flows and domes to explosive sub-plinian to plinian eruptions producing columns to heights of 10 to 25 km. A plinian eruption of 10^8m^3 (0.1 km^3) is considered in this scenario, equivalent to the largest Ruapehu eruption in the past ~ 2000 years (i.e. the Tufa Trig unit Tf5 of Donoghue *et al.* (1995)).

The precursory sequence used follows the same pattern observed prior to the September 1995 eruption. The initial eruption consists of phreatomagmatic explosions through Crater Lake, followed by a dry sub-plinian eruption once the lake is removed. The eruption ends with the growth of a lava dome, in part based on the 1989-1990 Redoubt eruptive episodes (Brantley 1990). A chronology of the eruption scenario is given in the following section.

The thickness of the pyroclastic fall deposits at any one point is related to the total volume of magma which is erupted in the column, the eruption column height, the distance from the vent and the wind direction and velocity (Self & Walker 1994). In modelling ash fall distribution for the scenario the ASHFALL program (Hurst 1994) was used, as discussed in Chapter 5. The wind direction above Ruapehu is variable. Predominant directions are westerly; however, a northwest wind has been chosen for this scenario in order to disperse ash directly over Hastings city (Fig. 6.1).

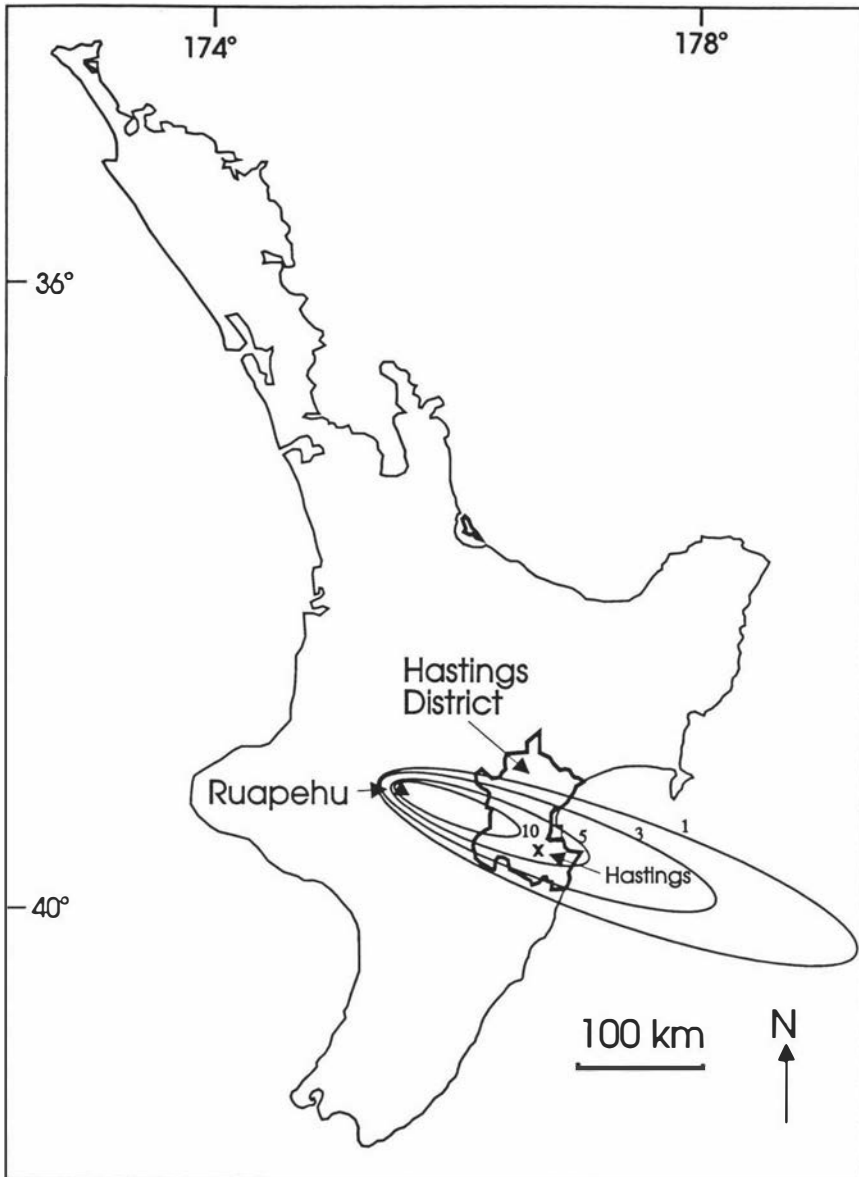


FIGURE 6.1 The distribution of 0.1 km^3 of ash from the eruption scenario.

6.4 CHRONOLOGY OF THE SCENARIO ERUPTION

- 10 months Lake temperature 15°C. Heating cycle begins.
- 9 months Small phreatic eruptions. Lake temperature 48°C. Low seismicity. **Scientific Alert Level raised to 2***.
- 8 months Small phreatic events continue. Lake 51.4°C. Level of tremor increased slightly.
- 7 months Lake temperature 45.5°C.
- 6 months Lake temperature approaching 35°C. Tremor declined during the past month.
- 5 months Lake temperature rises to >47°C. Increase in volcanic tremor and acoustic noise.
- 4 months Minor phreatic eruptions. Temperature falls late in month.
- 90 days Intense volcanic tremor lasting c. 12 hours.
- 87 days Phreatic eruption from Crater Lake. destroying monitoring equipment on the lake shore.
- 83 days Explosive phreatic eruption accompanied by volcanic eruptions.
- 80 to- 12 days Lake continues to cool. **Scientific Alert Level reduced to 1** on -12 days.
- 7 days Explosive eruption with significant lahar down Whangaehu River. small lahar down Mangaturuturu. **Scientific Alert level raised to 2.**
- 5 days Eruption produces lahar down Whangaehu River. Temperature of the lake 48°C. New scoria bombs on lake margins. voluminous lake outflow.
- 3 days Large discrete explosive eruption. Large blocks thrown 1 km. plume to 10-12 km. lahars down three major valleys. **Scientific Alert Level raised to 3.**
- 2 days Small sporadic explosions producing steam rich plumes. Effects confined to crater area.
- 1 day Weak to moderate tremor until 1500 h then continuous tremor and explosions for over four hours. Ash column to 7000 m. Sustained expulsion of water from eruptions in the Crater Lake create a continuous multi-peaking lahar in the Whangaehu River over the next six hours. **Scientific Alert Level raised to 4.**
- Eruption From midnight frequency of volcanic tremor increases. Eruption pulse commences around 3 am with the appearance of an ash-rich eruption cloud. Voluminous vertical eruption column is generated. Ash-laden column grows rapidly and rises to 12 000 m in 10 minutes. A steady column remains for 6 hours before waning and is replaced by a less voluminous column of white ash-laden steam. The ash-laden cloud from the first eruption is quickly carried by the strong northwesterly winds to the southeast. Total volume of material ejected is 0.1 km³. **Scientific Alert Level raised to 5.**
- + 8 hours A second eruption pulse commences with the appearance of a dark ash-rich eruption cloud. About 1 min after the start of the pulse a vertical eruption column begins to form rapidly again to a height of 12 000 m. Total volume of material ejected is 0.01 km³.
- + 1 to 5 days Fluctuating low to moderate tremor. Continuous low-level emission of ash and steam.
- + 1 week Lava dome begins to grow within the crater. Numerous steam explosions occur sending small ash-laden column to 5-8 km. **Scientific Alert Level lowered to 4.**
- + 3 weeks Activity peaks again as dome is blown apart. Voluminous eruption column rises to 12 km. Ash is deposited to the northeast over the Wairoa and Gisborne districts. Second dome begins to grow within 24 hours of the eruptive episode.
- + 4 months Second eruption destroys dome. Ash-laden column rises to 12 km and is carried to the north over Taupo and Rotorua. No new dome appears.
- + 5 months Activity appears to have ceased. **Scientific Alert Level lowered to 3.**

* See Chapter 9, Table 9.2 for description of the Science Alert Levels

6.5 IMPACTS ON THE 'LIFELINES' OF HASTINGS DISTRICT

6.5.1 Setting

The Hastings District is situated in the Hawke's Bay Region. The district is predominantly rural hill country but with large urban areas of Hastings, Flaxmere and Havelock North located on the Heretaunga Plains. Three major river systems, the Mohaka, Ngaruroro and Tukituki flow through the district.

The Hastings climate is influenced largely by the westerly airstreams crossing the North Island. Lower level winds over the district are modified by local topography but upper atmosphere winds are far more likely to blow from a westerly to southwesterly direction. Weather systems that bring rain to the district are irregular, causing a highly variable rainfall pattern. There is a normal seasonal variation, with greater rainfall in winter and least in spring and early summer (Thompson 1987). Rainfalls are also influenced by topography, with over 2400 mm per year on the highest parts of the central ranges to the west. Temperatures vary more than many other parts of the country because the district is subject to warm foehn winds from the west.

The Hastings District has a population of 66 280 (census 1996, provisional results), concentrated in the Heretaunga Plains (90%; Table 6.1). The three main urban areas account for 73 % of the district's total population. A number of rural service and coastal settlements are also located on the plains along with the neighbouring city of Napier (outside the district boundary).

TABLE 6.1 Population of Hastings District (1991 census)

	Urban	Rural
Hastings	27 201	----
Flaxmere	10 173	----
Havelock North	9 120	----
Heretaunga Plains	----	10 947
Outlying district	---	6 561

The Heretaunga Plains contain rich fertile soils and combined with a "Mediterranean" climate create conditions favourable for intensive horticulture. The district is New Zealand's largest producer of apples, pears and peaches and second largest producer of grapes and wine. Forestry is becoming of increasing importance, with processing at the Whirinaki mill. Much of the district's produce is exported through the port at Napier. Hastings city has developed

as a significant food processing, manufacturing and commercial centre. Tourism plays an increasingly important part in the district's economy.

6.5.2 Scenario impact on Hastings city

The following section discusses the impacts of the eruption scenario on Hastings District. A semi-quantitative ash fall vulnerability assessment of selected 'lifelines' has been undertaken. Vulnerability charts are presented with each scenario impacts assessment.

- 9 to 1 months The continued activity at Ruapehu gets frequent mention in both local and national papers, as well as an occasional item on the TV news. Hastings District Civil Defence hold several volcanic contingency planning meetings to review their district volcanic contingency plan. A basic response procedure has been developed and is shown below (Fig 6.2).

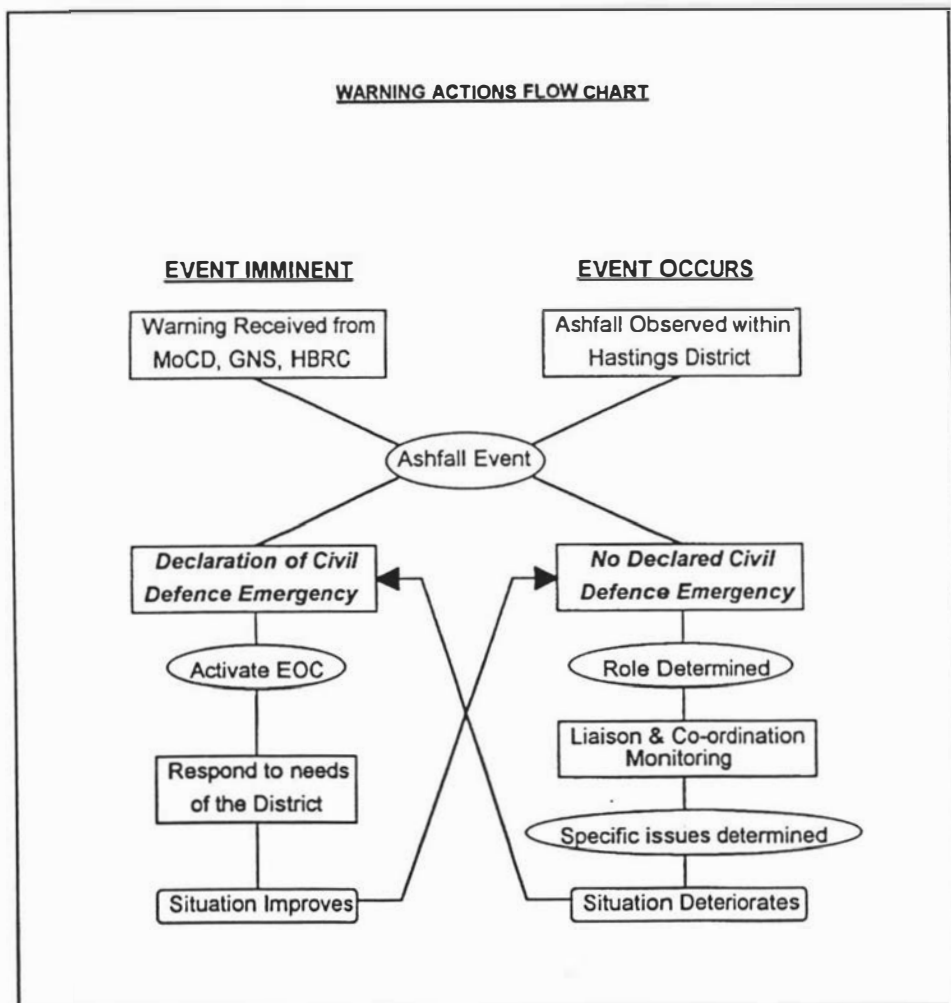


FIGURE 6.2 Basic response plan developed by Hastings District Council Civil Defence (Hastings District Council 1995)

- 3 days
Within ten minutes of the large explosive event local radio stations carry the story. The District CD Officer moves to CD Headquarters (HQ) and makes contact with the local CD Controller, warden posts and Ministry of Civil Defence. The CD HQ is put on stand-by and warden posts set up collecting stations for ash falls. A very light ash fall is detected at some sites. Within two hours the CD HQ receives an Institute of Geological & Nuclear Sciences (GNS) Science Alert Bulletin via the Ministry of Civil Defence.

- 2 days
The eruption receives major coverage in both local and national media. The local Civil Defence committee meets to discuss contingency arrangements. The CD HQ remains on stand-by.

- 1 day
Civil Defence receives ash fall prediction from GNS that shows Hastings city directly down wind of the volcano during at least the next 24 hours. The CD HQ remains on stand-by.

- Eruption day
At about 5 am, two hours after the start of the main eruption, ash begins to fall on the urban areas of Flaxmere, Hastings and Havelock North. Hastings police on patrol are among the first to notice the ash falls and contact Police regional HQ, who in turn notify the District CD Officer. The Civil Defence staff report to the CD HQ within fifteen minutes but by now falls of fine sand-sized ash are clearly visible on smooth surfaces. CD staff seek confirmation from the Ministry of Civil Defence that a major eruption is in progress at Ruapehu. By 5.20 am local radio stations are broadcasting public information notices, advising people to remain inside and suggesting appropriate measures to deal with the ash. The vast majority of residents are unaware of the events that are unfolding at this stage. Darkness persists over Hastings well past the time of normal sunrise. At 6 am a regional state of civil defence emergency is declared and the Hastings district and Hawke's Bay region CD HQs are fully activated. The city receives ash at a rate of about 1 to 2 mm/hour over the next six hours. All schools and most businesses instruct students and/or staff to remain home. With a forecast of rain showers in the evening and during the following days, residents are instructed to conserve water and prepare for potential electricity outages. Telephone services are cut to many parts of the district but are restored by the evening. At midday the city is still cloaked in darkness as ash continues to fall. During the next hour light returns slowly, as the sky begins to clear. The city is covered with

around 10 mm of fine sand-sized grey ash. Ash is easily raised by the wind and passing vehicles. Visibility is limited by large quantities of airborne particles.

Impacts on selected 'lifelines' are discussed in more detail in the following sections.

- + 1 Day Light rain falls over the region as a front crosses Hawke's Bay, accompanied by four hours of scattered showers causing isolated electricity outages for brief periods. The CD HQ is overwhelmed by requests for information on the health effects of ash and how to remove it from properties. At times the telephone system over the entire district is overloaded. The local radio and newspapers provide information on how to cope with the ash falls. Ash clean-up operations are well under way by the end of the first day following ash fall.
- + 3 Days Heavy rainfalls across the entire region cause some problems with ash-blocked drains but rain improves the air quality in ash-affected areas.
- + 4 Days Schools reopen, with many using students and other volunteers to clean ash from buildings and playgrounds.
- + 7 Days The CD Controller allows the Regional Civil Defence Emergency to expire without seeking an extension. Clean-up operations continue in ash-affected areas.

TABLE 6.2 Summary of scenario 1 parameters

Given Conditions	Scenario 1	Outcome for Hastings city	
Volcano:	Ruapehu	Ash thickness:	5-10 mm
Magma type:	andesite	Rate of ash fall:	1 mm/hour
Magma volume:	0.1km ³	Ash condition:	mildly acidic, initially dry, wet after 24 hours
Precursors:	10 months	Ash grain-size:	fine sand-sized mean
Eruption dynamics:	sub-plinian		
Wind direction:	northwest		
Weather:	fine on eruption day followed by rain within 24 hours		

6.5.3 ROAD TRANSPORTATION

Road transport is the most important transport sector in the district with a well developed arterial roading system fed by a network of collector roads and streets. State Highway 2 passes through the district and links Gisborne to the north and central Hawke's Bay to the south. State Highway 30 also provides access to the south and State Highway 5 links the district to Taupo to the northwest (Fig. 6.3). All state highways are controlled and funded by Transit New Zealand with the remaining roads under the auspices of the Hastings District Council. An ash fall vulnerability assessment is summarised in the vulnerability chart presented in Table 6.3.

Impact of the scenario eruption

During and after the ash falls reduced visibility on roads would be experienced over large areas of the district. During the peak of ash fall near-zero visibility would reduce road transportation to a virtual standstill and Civil Defence would urge people to stay home or indoors and above all not to drive, except in an emergency. Civil Defence warden posts and local residents may need to provide shelter for stranded motorists. Road blocks would be established early on the first morning to prevent vehicles entering ash-affected parts of the district, and remain in force for several days. All public transport would be cancelled in ash affected areas for at least three days stranding many travellers.

After the ash falls end the dry fine ash would be readily raised in billowing clouds by passing vehicles and presents an ongoing hazard. Speed restrictions may be introduced to ensure traffic safety on roads in reduced visibility, and to reduce dust problems in adjacent communities. These will remain in force until roads are cleared of ash. Any subsequent rain will cause the fine ash to turn to mud, creating vehicle traction problems but it will also act as an ash stabiliser. After rain the surface of ash deposits quickly dries out and ash will again be easily raised by wind or moving traffic.

Thin ash deposits (<5 mm) will generally be moved to the shoulder or middle of roads by traffic, but will remain there. Greater thicknesses of ash need to be physically removed from road surfaces. The Hastings District Council and Transit New Zealand (through contractors) would immediately mobilise roading staff as the magnitude of the problem rapidly becomes apparent. Contractors would need to be hired from within the district and beyond but a shortage of specific equipment such as graders, loaders and water trucks will limit the pace of clean-up operations. Priority would be given to state highways and urban roads. The central business area of Hastings city may be closed to traffic for a few days to help speed up ash removal. In most urban areas, community groups will take a leading role in coordinating residents who volunteer to help in the ash clean-up. With most businesses and

all schools closed for a few days, most residents will be available to help clear ash from their properties and neighbourhood streets.

Ash entering vehicle engines and transmissions will cause wear on moving parts, reducing their life. In most cases severe damage only results from excessive vehicle use in the ash-affected areas so enhanced maintenance programmes for all vehicles working in the ash-rich environment is advisable. Most private vehicle owners will follow the advice of authorities in limiting vehicle use during the first few days after the eruption. Dulling of paintwork may be common among car owners whose vehicles were exposed to the ash, along with abrasion damage to paint and windscreens.

6.5.4 RAIL TRANSPORTATION

Rail services in Hastings district are part of the Palmerston North-Gisborne line (Fig. 6.3). Services operate daily with freight the main user. Passenger services operate only south to Wellington. Rail transport is the least important transport sector in the district. An ash fall vulnerability assessment is summarised in the vulnerability chart presented in Table 6.3.

Impact of the scenario eruption

Rail transport is affected in a similar manner to road transport. Rail services through the Hawke's Bay will be suspended early on the morning of the ash falls but may resume within 24 hours. In the following days problems with ash clouds stirred up by train passage will restrict operating speeds due to problems with operators' vision and breathing. Light rain following the ash fall may lead to minor short-circuiting of electrically-operated signal equipment but equipment should be checked and cleared within a few days. Rail will be the least affected transport sector.

6.5.5 AIR TRANSPORTATION

Hawke's Bay airport (outside Napier city) is the only commercial airport serving the district with daily scheduled flights, by both Air New Zealand and Ansett New Zealand (Fig. 6.3). A commercial airfield is located at Bridge Pa. An ash fall vulnerability assessment is summarised in the vulnerability chart presented in Table 6.3.

Impact of the scenario eruption

Aviation is the most vulnerable transport sector, with even small amounts of ash closing airspace and airports. Hawke's Bay airport and the airstrip at Bridge Pa will be closed immediately on deposition of ash. The airport will be closed for several days although an ash

clean-up will be immediately initiated but hampered by lack of equipment. The ash falls present a corrosion hazard to all exposed aircraft, airport communication and electronic facilities.

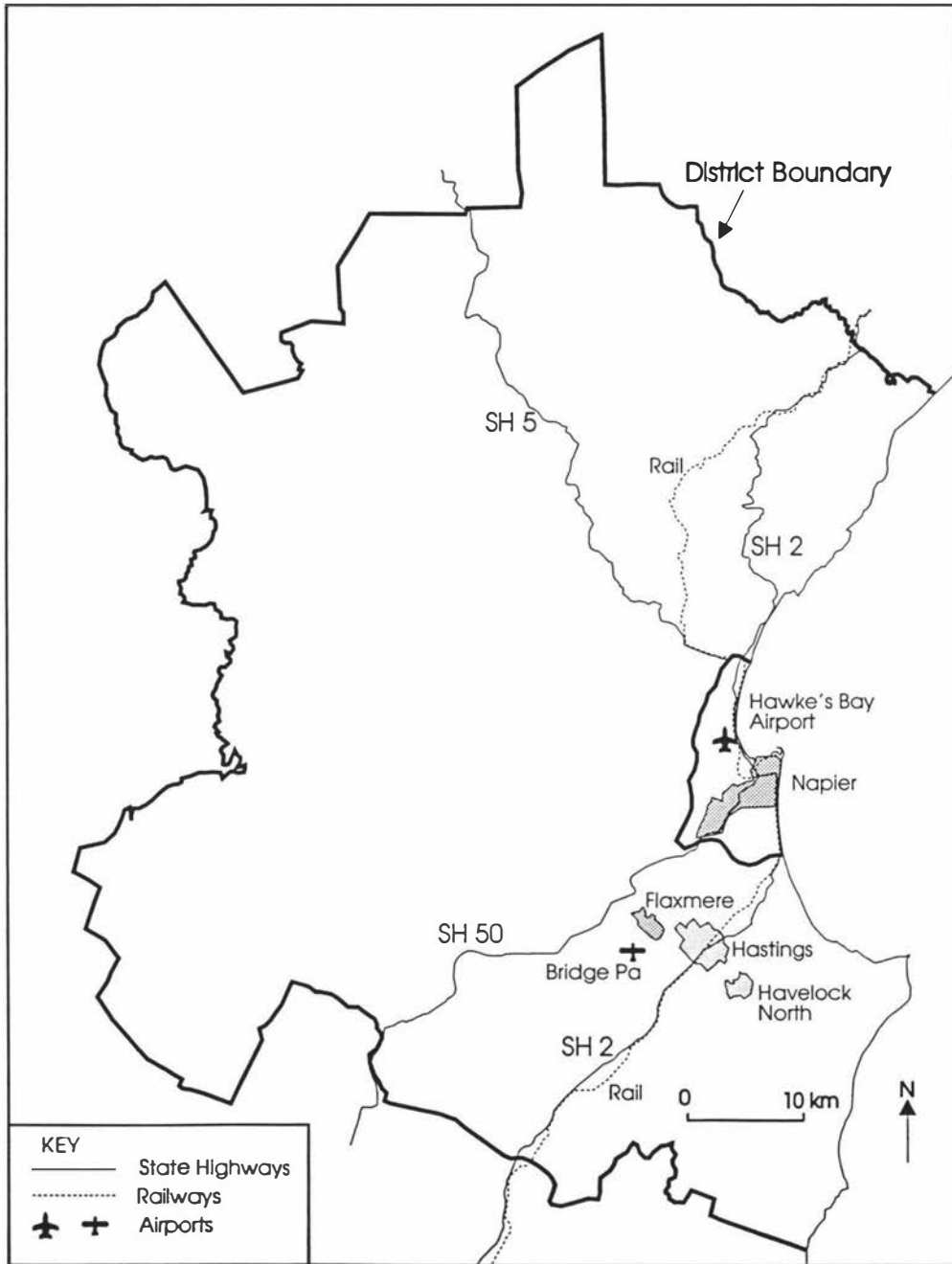


FIGURE 6.3 Main transportation routes and airport locations in the Hastings district.

TABLE 6.3 HASTINGS TRANSPORTATION VULNERABILITY CHART

* See Chapter 4, Table 4.1 for vulnerability chart key

Component	Importance	Ash condition	Vulnerability to direct ash falls								Interdependence		Backup or redundancy	Impact of being damaged						
			Becoming inoperative				Damage				Element	Reliance		During ash falls	Immed. after	Period following	Return to normal			
			< 5 mm	5-20 mm	20-100 mm	> 100 mm	< 5 mm	5-20 mm	20-100 mm	> 100 mm										
AIR (a)	1	wet dry	3 3	3 3	3 3	3 3	1-2 1-2	2-3 2-3	3 3	3 3	airports require electricity, VHF radio, radar	{ all 3	altern. modes of transport	1	2	3	3			
Airspace		n/a	3	3	3	3	0	0	0	0										
Airports and aircraft (a,b)		wet dry	3 3	3 3	3 3	3 3	2 1	2 2	3 3	3 3										
ROAD (a)	5	wet dry	1-2 1-2	2-3 2-3	2-3 2-3	3 3	1 1	2 2	3 3	3 3	all aircraft, vehicles and locomotives require fuel	{ 3		3	3	3	3			
Vehicles (b)		wet dry	1 1-2	2-3 2-3	2-3 2-3	3 3	2 1	2 2	2 2	2 2										
Roads (a)		wet dry	1-2 1-2	2-3 2-3	2-3 2-3	3 3	1 1	2 2	3 3	3 3										
RAIL (a)	1	wet dry	1-2 1-2	2-3 2	2-3 2-3	3 3	1 1	2 2	3 3	3 3	needs electricity	3		1	2	3	3			
Tracks and signals (a)		wet dry	1-2 1-2	2-3 2	2-3 2	3 3	2 1	2 2	3 3	3 3										
Locomotives (b)		wet dry	1-2 1-2	2 2	2 2	3 3	2 1	2 2	2 2	2 2										

- a. damage includes cost of clean-up operations.
- b. damage assessment assumes exposure to direct ash fall but the item is not used.

6.5.6 ELECTRICITY SUPPLY AND RETICULATION

Most electricity used in the Hastings district is produced by 'ECNZ' and 'CONTACT' generating facilities located outside the district, and distributed by the national grid operated by TransPower (Fig. 6.4). High voltage lines feed into a number of the district's substations (Figs. 6.4a & 6.5) and then on to local substations for distribution to customers (Fig 6.4c). The system configuration and voltage step-down is shown schematically in Figure 6.4b. Hawke's Bay Electricity maintains the local distribution systems. The ECNZ's Whirinaki gas-turbine peak load station is the only generation plant in the district and for economic reasons is only used occasionally. An ash fall vulnerability assessment is summarised in the vulnerability chart presented in Table 6.4.

Impacts of the scenario eruption

The falls of volcanic ash may disrupt electricity supply over wide areas in several ways. Staff from both Hawke's Bay Power and TransPower will begin to remove ash deposits from substation transformer insulators and other substation equipment immediately after an ash fall, knowing that damp or wet ash coatings on insulators induce flashovers. These clean-up operations may be hampered by difficulties in staff driving to substation sites. Some short-lived power outages may occur as loads are shifted off various substations during the cleaning. Light rainfalls will induce several flashovers, whereas heavy rain will clear ash from insulators, transformers and lines. Most ash fall-induced power outages will be of short duration. The consequences of loss of electricity supply can be widespread, and many public utilities (e.g. water supply pumps, radio and telecommunication facilities) will be inoperative for brief periods unless local backup power supplies (batteries and generators) are available. Many standby generators may not operate in the ash-rich environment. No major problems would be expected in this scenario beyond the first two days after the ash falls but substations and transformer cleaning will continue for over a week.

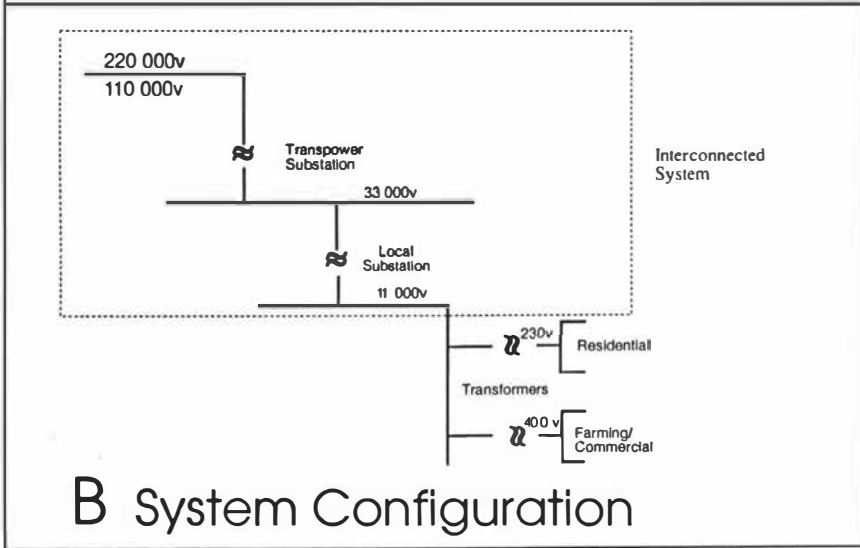
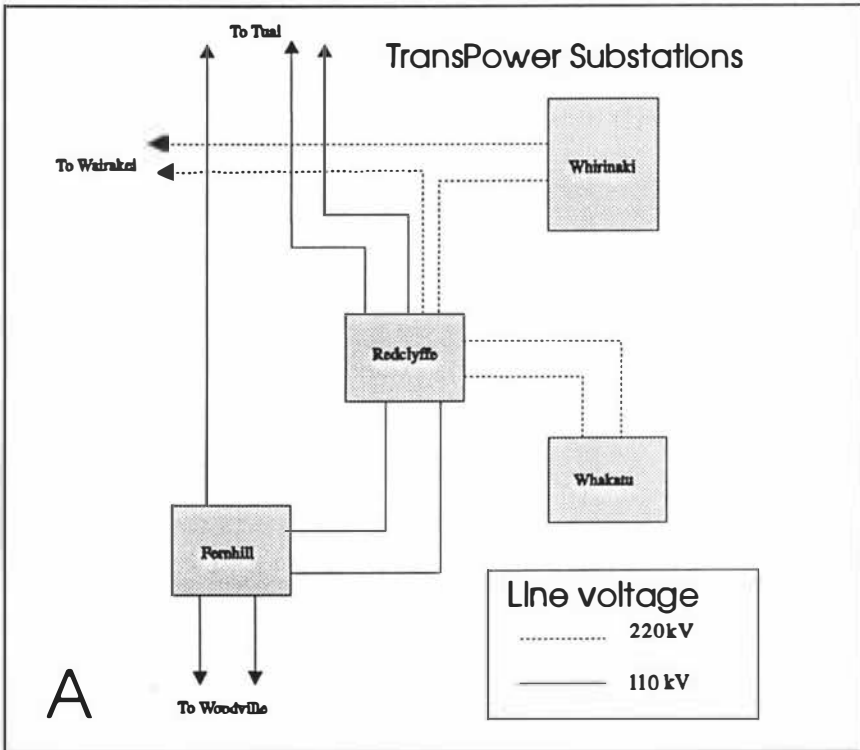
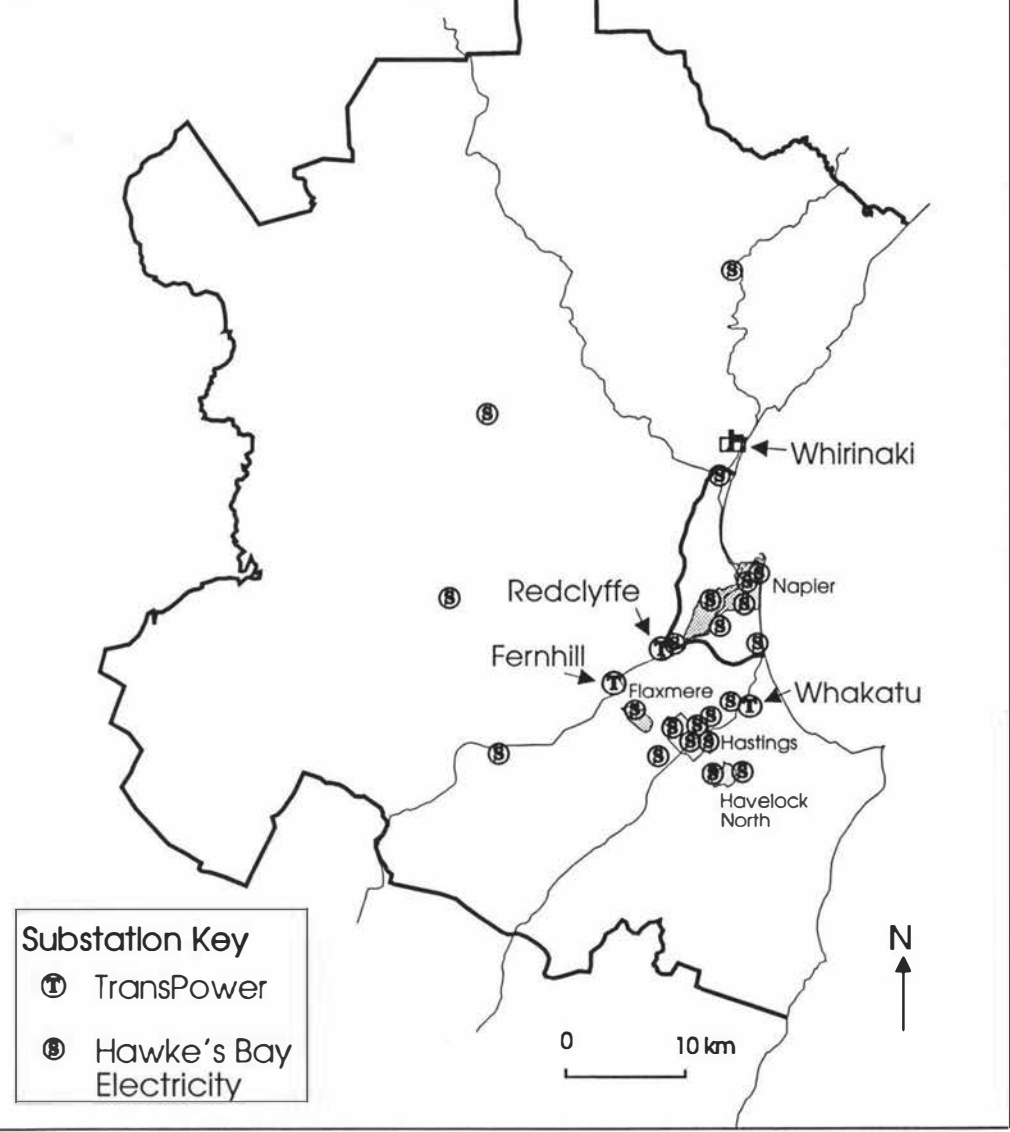


FIGURE 6.4
C Location Map



Substation Key

- Ⓣ TransPower
- ⓑ Hawke's Bay Electricity

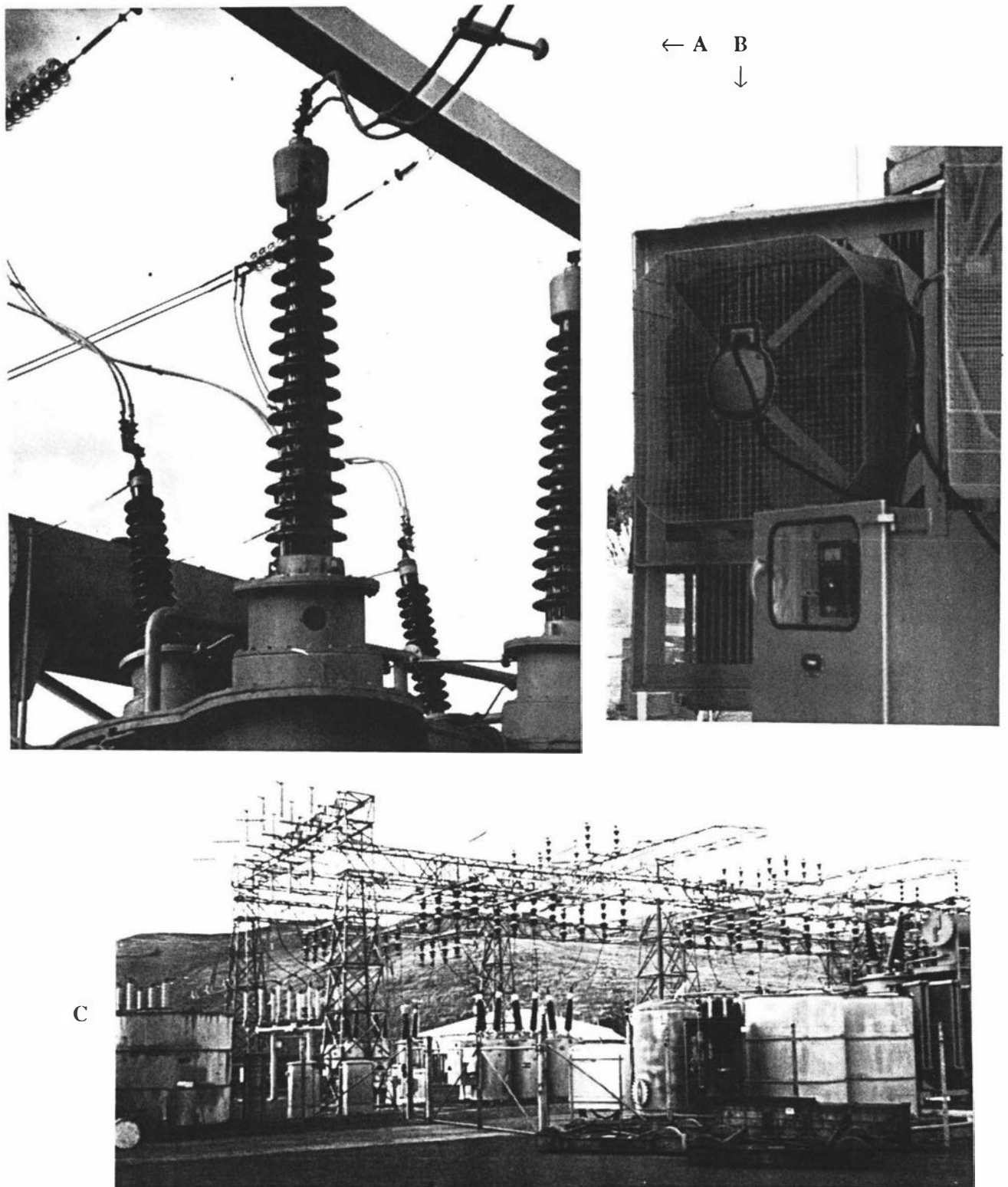


FIGURE 6.6 Example: Redclyffe substation (33 kV \rightarrow 11 kV).

- A. Transformer bushings. Flashover will occur if wet ash covers the insulator surface.
- B. Transformer cooling fans: vulnerable to ash abrasion damage if operated in an ash-rich environment.
- C. General view of Redclyffe substation

TABLE 6.4 HAWKE'S BAY ELECTRICITY VULNERABILITY CHART

* See Chapter 4, Table 4.1 for vulnerability chart key

Component	Importance	Ash condition	Vulnerability to direct ash falls								Interdependence		Backup or redundancy	Impact of being damaged			
			Becoming Inoperative				Damage				Element	Reliance		During ash falls	Immed. after	Period following	Return to normal
			< 5 mm	5-20 mm	20-100 mm	> 100 mm	< 5 mm	5-20 mm	20-100 mm	> 100 mm							
TransPower substations	5																
Fernhill	3	{wet	2	3	3	3	2	3	3	3	outside supply	2-3	altern. supply routes	3	3	3	3
Redclyffe	3	{dry	1	2	2	3	1	2	3								
Whakatu	3																
Hastings Electricity substations	5	wet dry	3 1	3 2	3 2	3 3	2 1	3 2	3 3	3 3	TransPower supply	3	none	3	3	3	3
ECNZ Whirinaki	1	wet dry	3 3	3 3	3 3	3 3	2 1	3 2	3 2	3 3	Fuel	3	none	1	1	1	1

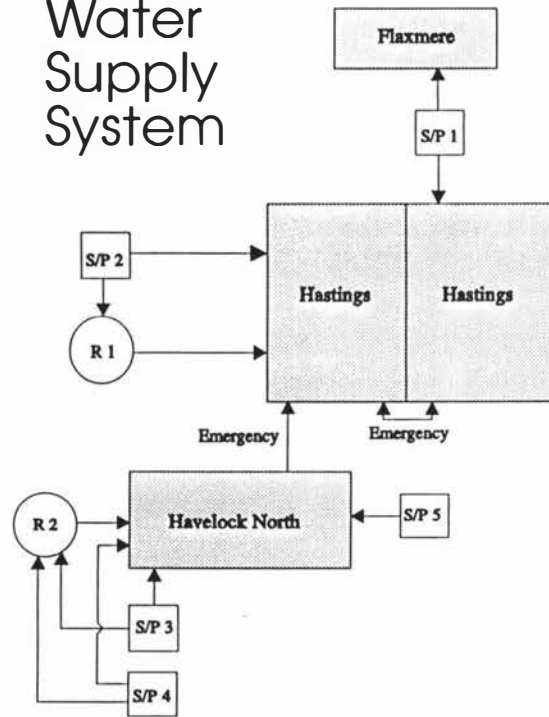
6.5.7 WATER SUPPLY

Water for Hastings, Flaxmere and Havelock North is obtained from several artesian wells and is pumped directly into the reticulation system and through feeder and delivery mains to closed concrete reservoirs on the hills behind Havelock North. The system is shown in Figure 6.6. Water pumped from the aquifer system is free of bacteria so no major treatment is required but CaCO_3 is added along with fluoride. The two main pumping stations have back-up diesel generators and all pumping stations and reservoirs are remotely controlled from Lindstan Place control station (Fig 6.7 & 6.8). An ash fall vulnerability assessment is summarised in the vulnerability chart presented in Table 6.5.

Impacts of the scenario eruption

The aquifer source of Hastings' water supply protects it from direct ash contamination. However, since electrical pumps are required to pump the wells there will be some concern about possible loss of electricity supply. Water levels in reservoirs should be kept as high as possible on advice of ash fall warnings to maximise the buffer effect that they afford the system in the case of a long duration ash-induced power outage. Minor electricity outages will stop all pump stations, briefly cutting the flow of water to the reservoirs. Back-up generators at Lindhurst Road and Lindstan Place will need to be switched to manual over-ride to prevent their use in the ash-rich, potentially damaging environment. After ash falls have stopped, water usage is expected to increase as residents begin to clean ash from their properties. Predicting a severe water shortage in the days after an ash fall, the council would be advised to introduce a range of water conservation measures to avoid reservoir depletion. These may take the form of specific time allocations for individuals' hose usage. With only limited power outages predicted in the scenario and strict enforcement of water conservation measures, major water shortages should be averted. Water usage could be expected to return to pre-ash fall levels within days to weeks despite continued ash clean-up operations.

A Water Supply System



B Sewage System

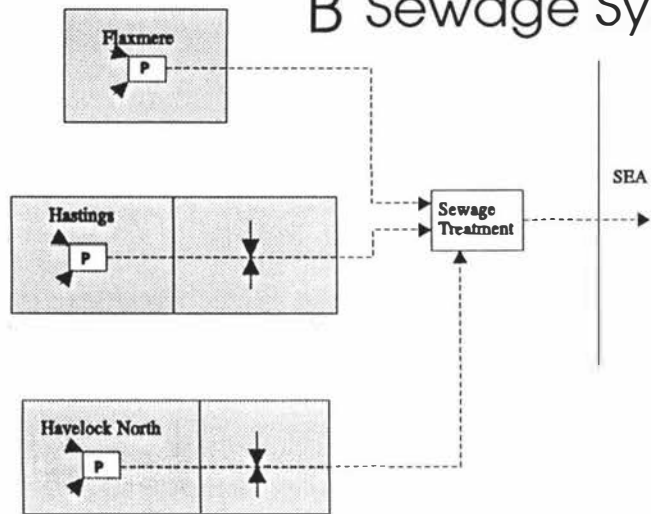
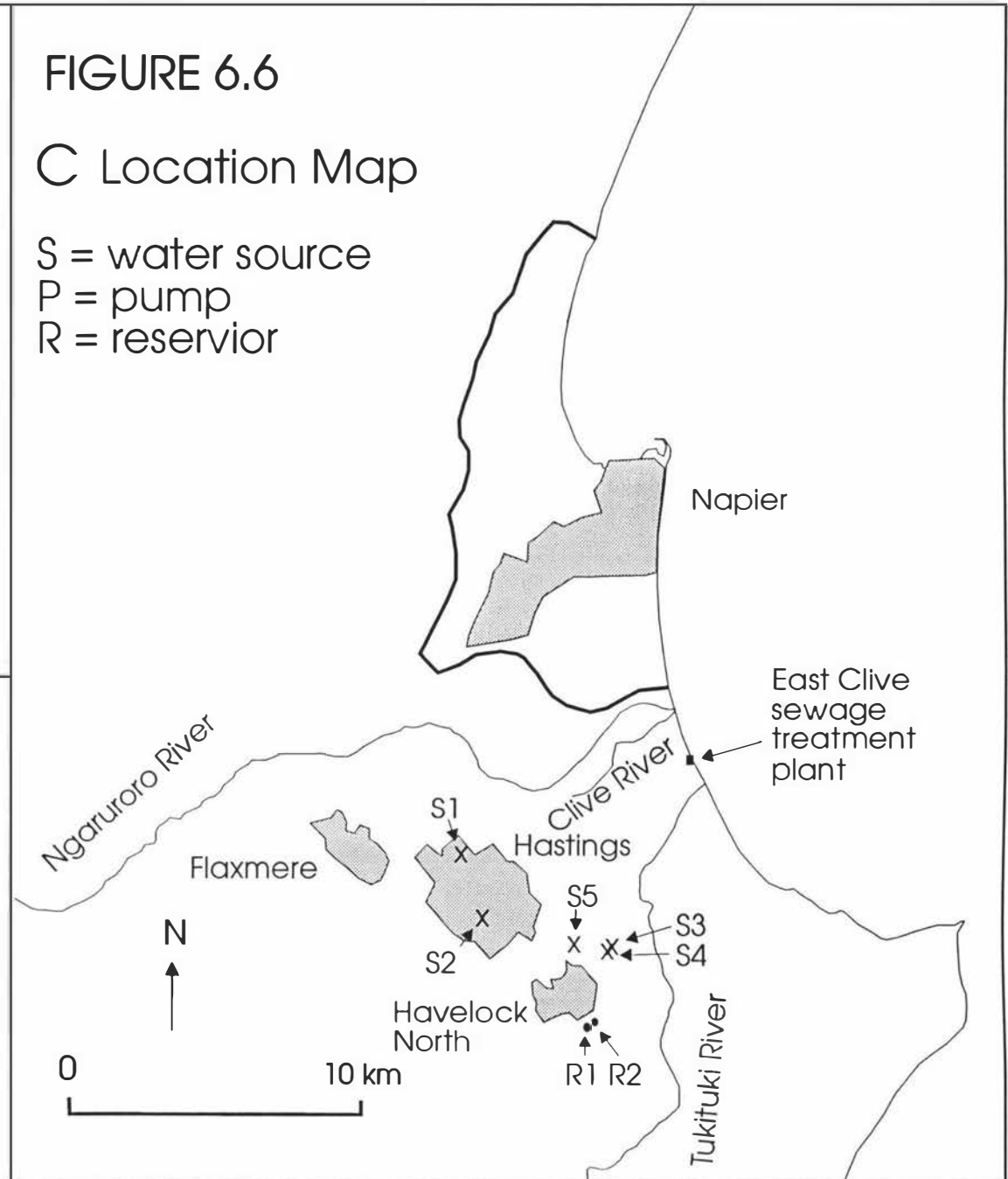


FIGURE 6.6

C Location Map

S = water source
 P = pump
 R = reservoir



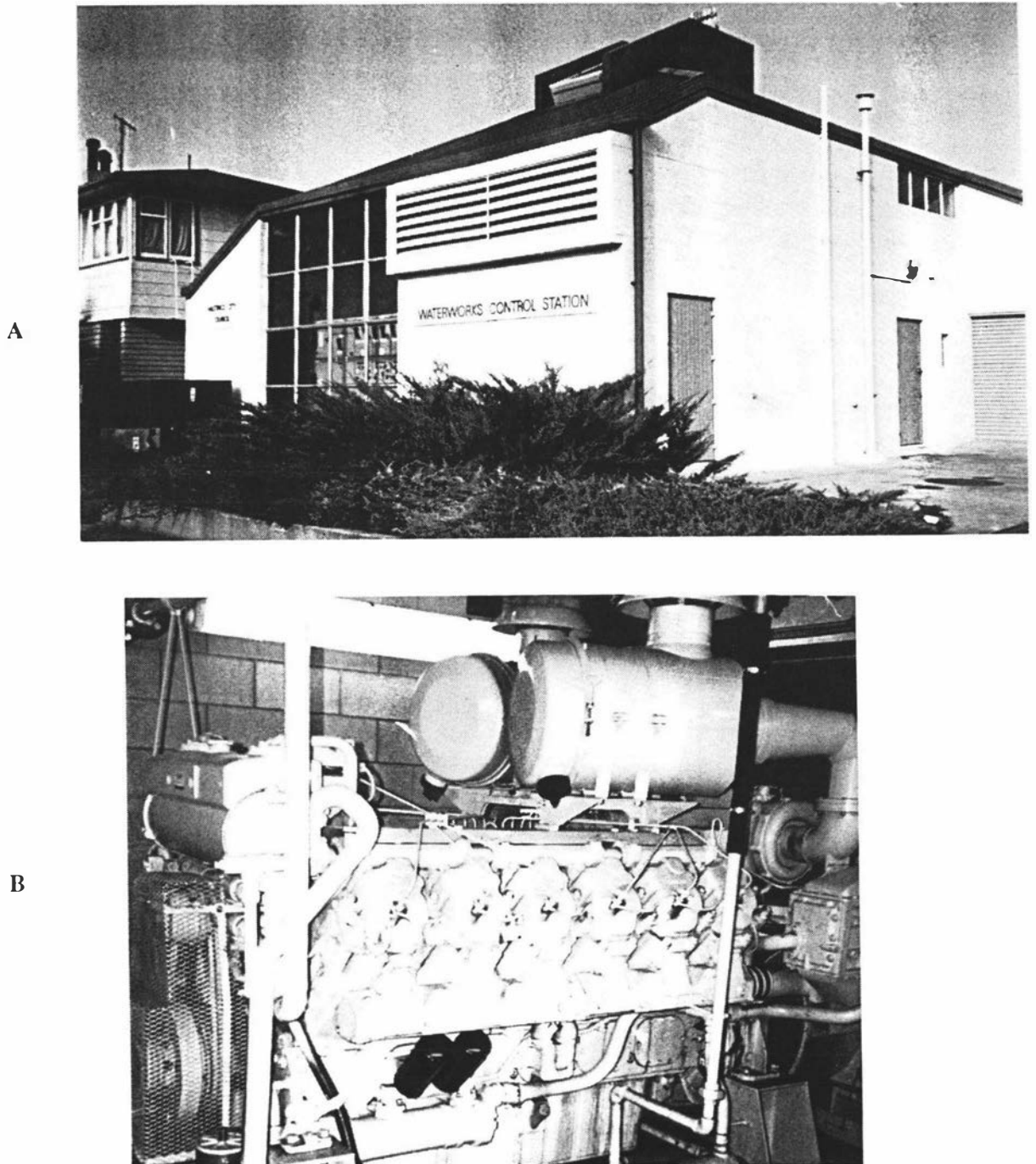


FIGURE 6.7 Examples of Hastings water supply system.

- A. Lindstan Place pumping station (S2 in Fig. 6.6). A sealed control/switching room is located behind the front windows.
- B. Back-up generator at Lindstan Place pumping station. Only mesh covers the air intake of the generator room.

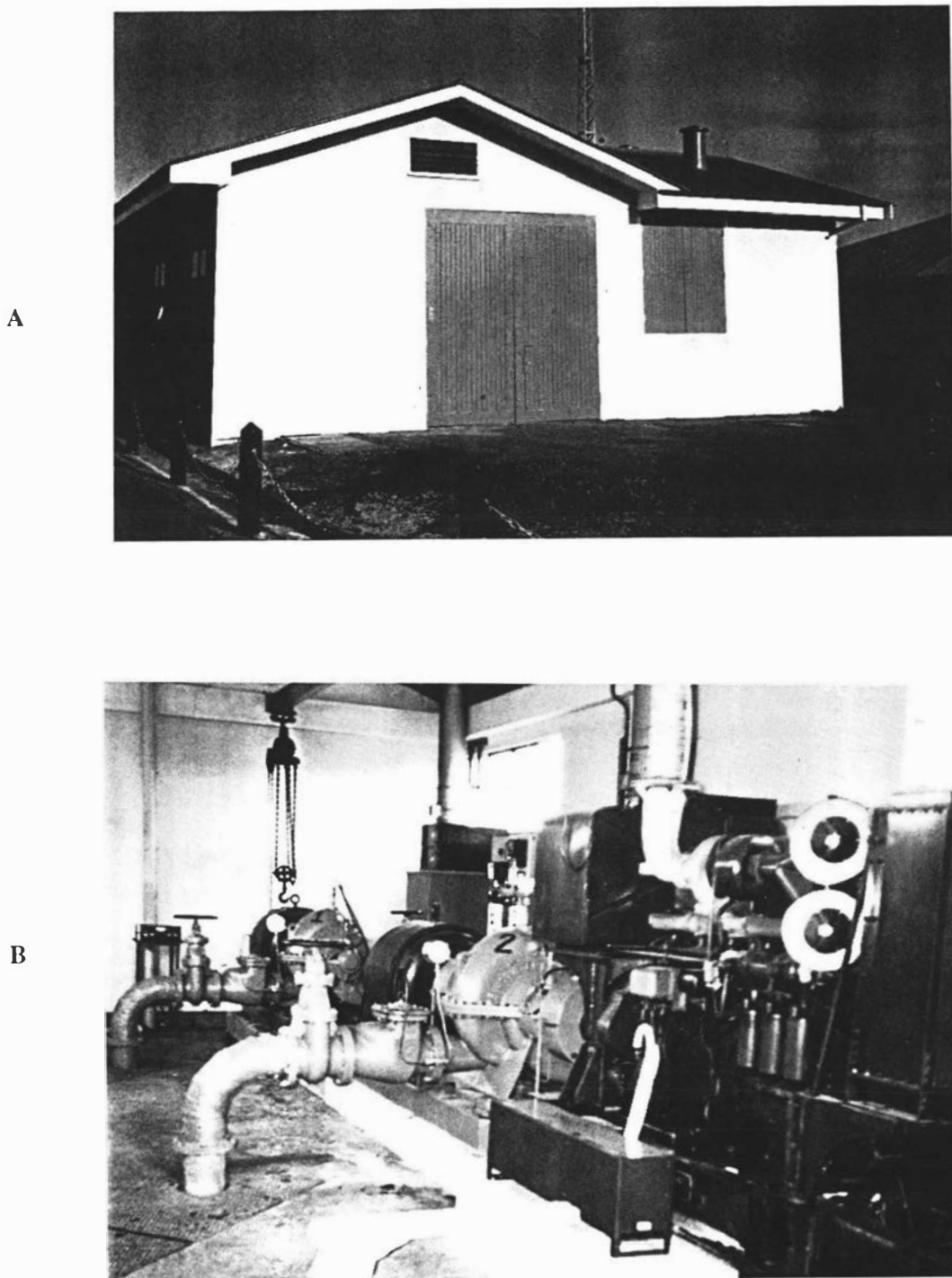


FIGURE 6.8 Examples of Hastings water supply system

- A. Lindhurst Road pumping station (S 1 in Fig. 6.6).
- B. Lindhurst Road pumping station. Two electric pumps from bores feeding Flaxmere and eastern Hastings. Back-up generator (foreground) cannot be run without the doors (photo A) of the plant building being open.

TABLE 6.5a HASTINGS - HAVELOCK NORTH - FLAXMERE WATER SUPPLY VULNERABILITY CHART

* See Chapter 4, Table 4.1 for vulnerability chart key

Component	Importance	Vulnerability to direct ash falls								Backup or redundancy	Impact of being damaged			
		Becoming Inoperative				Damage					During ash falls	Immed. after	Period following	Return to normal
		< 5 mm	5-20 mm	20-100 mm	> 100 mm	< 5 mm	5-20 mm	20-100 mm	> 100 mm					
Source														
S 1 Lindhurst Road	3	0	0	0	0	1	1	1	1	none	1	2	3	3
S 2 Lindstan Place	3	0	0	0	0	1	1	1	1	none	1	2	3	3
S 3 Havelock North	2	0	0	0	0	1	1	1	1	none	1	2	3	3
S 4 Havelock North	2	0	0	0	0	1	1	1	1	none	1	2	3	3
S 5 Havelock North	1	0	0	0	0	1	1	1	1	none	1	2	3	3

TABLE 6.5b HASTINGS - HAVELOCK NORTH - FLAXMERE WATER SUPPLY VULNERABILITY CHART

* See Chapter 4, Table 4.1 for vulnerability chart key

Component	Importance	Vulnerability to direct ash falls								Interdependence		Backup or redundancy	Impact of being damaged			
		Becoming Inoperative				Damage				Element	Reliance		During ash falls	Immed. after	Period following	Return to normal
		< 5 mm	5-20 mm	20-100 mm	> 100 mm	< 5 mm	5-20 mm	20-100 mm	> 100 mm							
Pumps																
P 1 Lindhurst Road	3	1	1	1	1	1	1	1	1	needs electricity VHF telemetry	3 2	back-up generator	1	2	3	3
P 2 Lindstan Place	3	1	1	1	1	1	1	1	1	needs electricity VIIF telemetry	3 2	back-up generator	1	2	3	3
P 3 Havelock North	2	1	1	1	1	1	1	1	1	needs electricity VIIF telemetry	3 2	none	1	2	3	3
P 4 Havelock North	2	1	1	1	1	1	1	1	1	needs electricity VIIF telemetry	3 2	none	1	2	3	3
P 5 Havelock North	1	1	1	1	1	1	1	1	1	needs electricity VIIF telemetry	3 2	none	1	2	3	3
Reservoir																
R1 Hastings	4	0	1	1	2	0	0	1	2	needs water VIIF telemetry	3 2	up to 24 hours supply when full	3	3	3	3
R 2 Havelock North	3	0	1	1	2	0	0	1	2	needs water VIIF telemetry	3 2	up to 24 hours supply when full	3	3	3	3

6.5.8 WASTEWATER RETICULATION AND TREATMENT

The wastewater system for Hastings, Havelock North and Flaxmere consists of a network of pipes and electric pumping stations which are remotely controlled but none having back-up power supplies (Fig. 6.6). Sewerage and stormwater are separate systems. Sewage is pumped and gravity fed to East Clive (Hastings is half pumped and half gravity fed to East Clive plant, Havelock North two thirds pumped and Flaxmere is all pumped) (Fig. 6.9). Stormwater is also both pumped and gravity fed, discharging in the Clive, Ngaruroro and Tukituki rivers.

East Clive sewage plant (Fig. 6.10) has three lines into a 1 mm aperture milliscreening plant. Sewage is then passed through an open grit setting chamber and pumped 2.6 km out to sea. The plant has three electrical pumps although only two are needed and one is on standby. There are two electricity feeds into the station. A back-up generator can operate the plant at half capacity.

An ash fall vulnerability assessment of the wastewater system is summarised in the vulnerability chart presented in Table 6.6.

Impacts of the scenario eruptions

Ash falls will cause serious problems to Hastings sewage and stormwater systems. Ash which falls on roads, roofs, and other impervious areas, is easily washed into the stormwater system by rain, or during cleanup operations. The city is fortunate to have separate systems; however, a small but significant amount of ash may enter the sewage system via illegal connections, manholes and gully traps. The density of ash is too high for a significant amount to remain in suspension so ash will readily accumulate, blocking pipes or reducing their transportational capacity. This will cause surface ponding of stormwater after rain. Finer ash that remains in suspension in the sewage system may be transported to the sewage treatment plant. Sewage and stormwater pumps may also receive some abrasion damage by ash-laden sewage. Milliscreens at the East Clive treatment plant will be rapidly abraded. If there are deliberate shut downs of the plant to avoid damage then release of untreated sewage will result.

Blocked pipes can be cleared by normal maintenance procedures within a few weeks. The key to minimising problems will be to limit the amount of ash entering the system by rapid ash removal from roads and providing residents with methods of disposing of ash from their own properties.

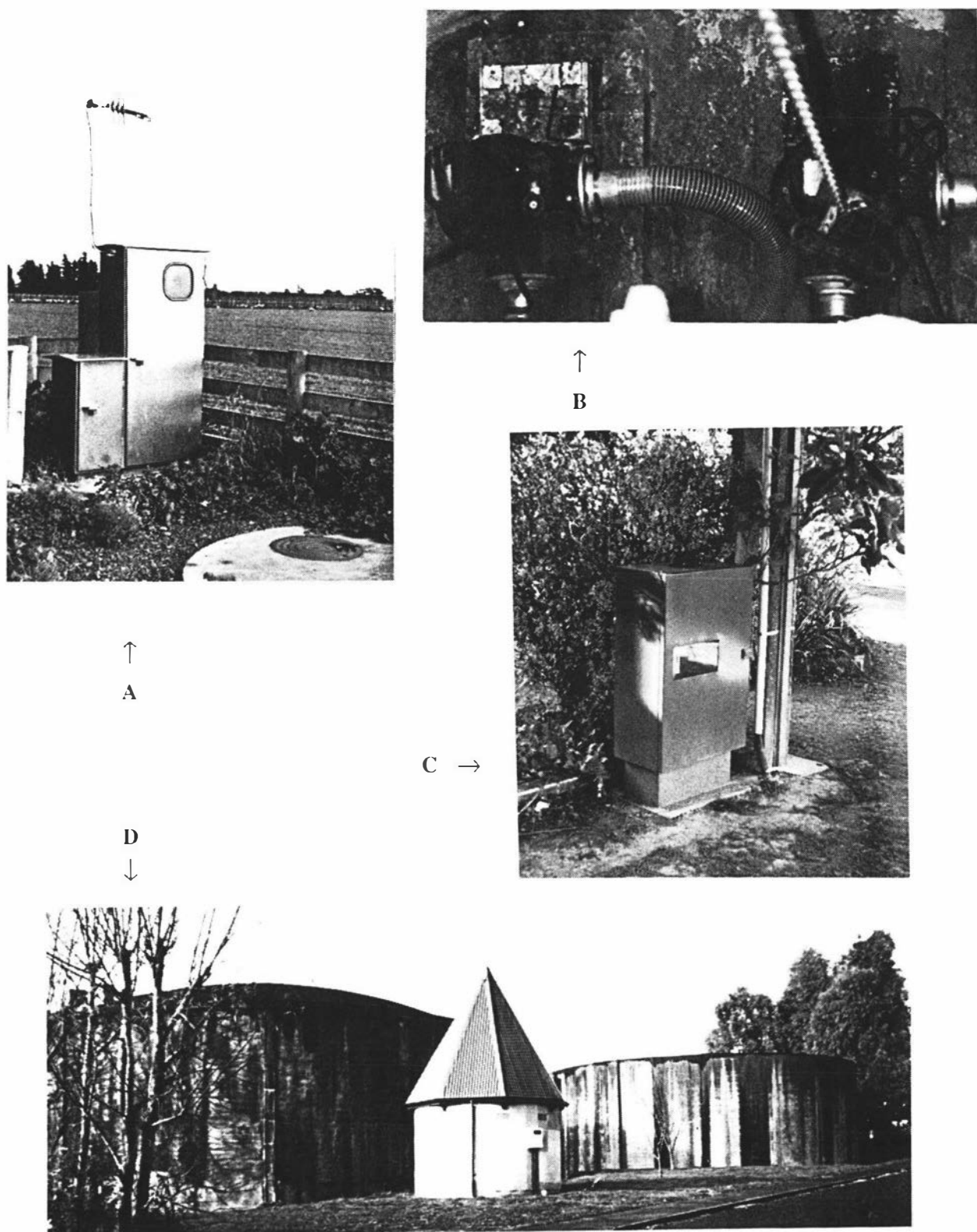


FIGURE 6.9 Hastings water and wastewater systems.

- A. Havelock North water pumping station (S 3 in Fig. 6.6). Pumps are located under the concrete pad and remotely controlled.
- B. Closeup view of a Hastings sewage pump.
- C. The power supply and control unit for a Hastings sewage pump. Pumps are located underground and remotely controlled.
- D. Havelock North reservoirs (R 2 in Fig. 6.6).

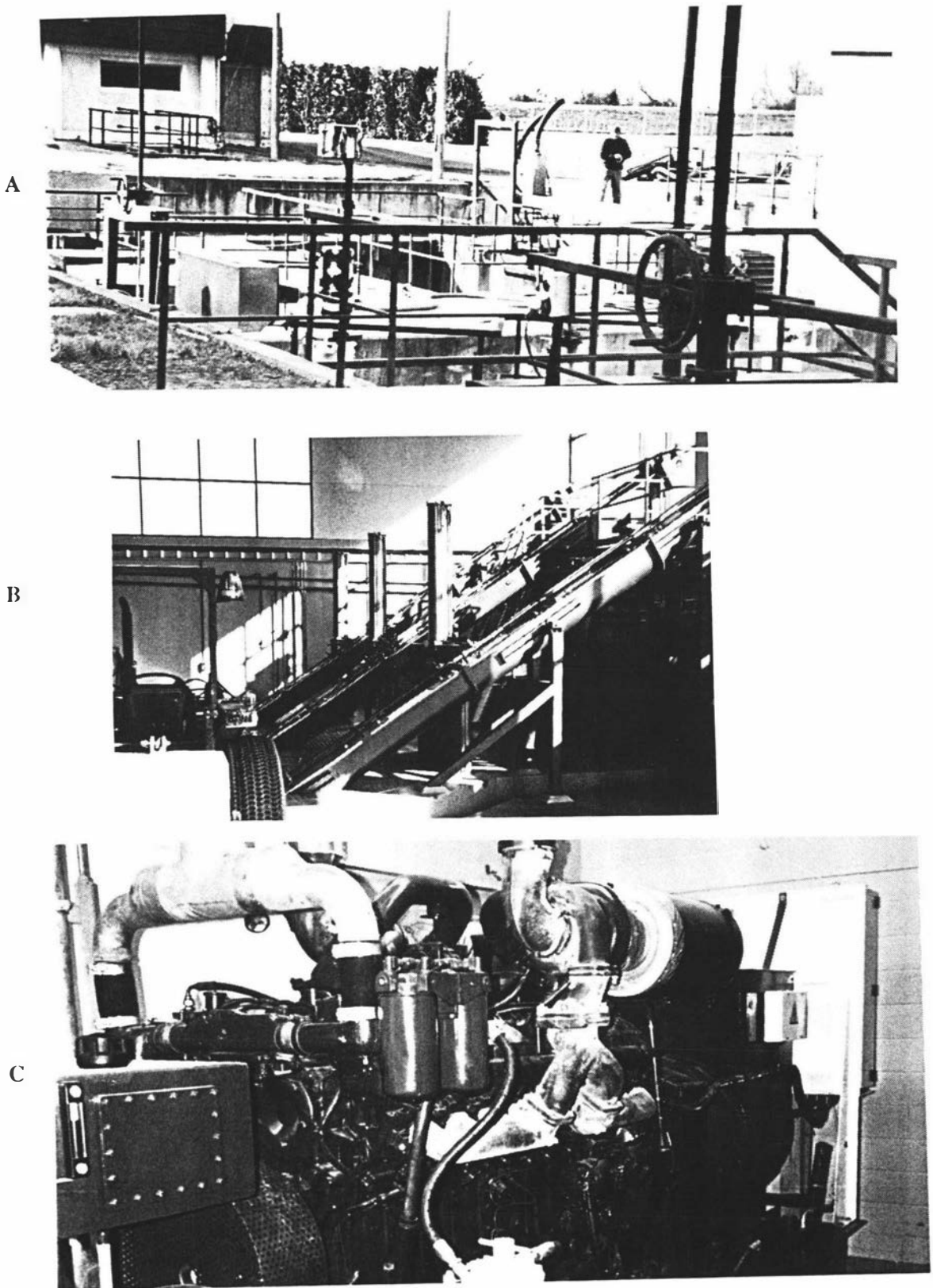


FIGURE 6.10 East Clive sewage treatment plant (see Fig 6.6 for location).

- A. Sewage passes through grit settling chamber open to the atmosphere (and ash falls).
- B. Solids removal equipment at the milliscreening plant.
- C. Back-up generator for the electric sewage pumps which can operate the plant at half capacity.

TABLE 6.6 HASTINGS - HAVELOCK NORTH - FLAXMERE SEWAGE SYSTEM VULNERABILITY CHART

* See Chapter 4, Table 4.1 for vulnerability chart key

Component	Importance	Vulnerability to direct ash falls								Interdependence		Backup or redundancy	Impact of being damaged				
		Becoming Inoperative				Damage				Element	Reliance		During ash falls	Immed. after	Period following	Return to normal	
		< 5 mm	5-20 mm	20-100 mm	> 100 mm	< 5 mm	5-20 mm	20-100 mm	> 100 mm								
Sewage pumps	3-4	1	1-2	2	2	1	1	1	2	needs electricity VHF telemetry	3 2	none none	1	3	3	3	
Sewage mains	5	1	1-2	2	2	1	2	3	2	needs electricity	3	none	1	3	3	3	
Eastclive sewage treatment plant	5	2	2	3	3	2	3	3	3	needs electricity	3	none	2-3	3	3	3	
Screening plant	5	2	2	3	3	1	2	2	2	needs electricity	3	back-up generator	2-3	3	3	3	
Grit settling chamber	5	1	2	3	3	2	3	3	3				2-3	3	3	3	
Outflow pumps	5	2	2	3	3	2	2	2	2	needs electricity	3	back-up generator	2-3	3	3	3	

6.5.9 COMMUNICATIONS

The Hawke's Bay Telecom network provides local and external telephone links in the region. Local lines are connected to local telephone exchanges which are in turn linked to microwave repeater radio stations (nodal points) by underground copper or fibre cables (Fig. 6.11). The microwave radio stations transmit and receive calls to and from neighbouring stations (Fig. 6.12). A number of microwave stations are also the sites of VHF and cellular telephone stations. Fibre cables also connect with exchanges outside the district. An ash fall vulnerability assessment is summarised in the vulnerability chart presented in Table 6.7.

Impacts of the scenario

Communications may become severely disrupted as a result of the scenario eruption principally by overloading of telecommunication systems due to increased demand. In addition, most of Hawke's Bay's telephone exchanges require air-conditioning units to keep electronic switching gear below certain critical temperatures and these may be switched off due to the falling ash, even though exchanges are sealed. This will result in overheating of the exchange and shut down within half an hour to prevent costly damage. Where special filters have been fitted no problems will be encountered. Indirect impacts may also result from disruption to electricity supplies and transportation difficulties, preventing staff accessing telecommunication sites. Battery powered backup systems can enable continued operation of exchanges during loss of electricity supply; however, generators that rely on external air intakes will need to be switched off to prevent clogging of their filters. This will result in partial depletion of battery capacity after a few hours demand.

The periodic loss of communications will make disaster management extremely difficult during and after an eruption. However, Civil Defence VHF radio networks should continue to operate throughout the emergency along with radio and television broadcasts. These will be fully utilised by Civil Defence and other emergency organisations to disseminate information and public warnings.

A Location Map

District Boundary

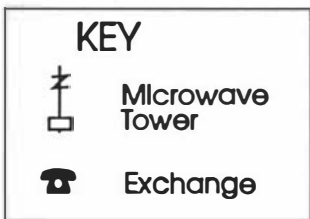
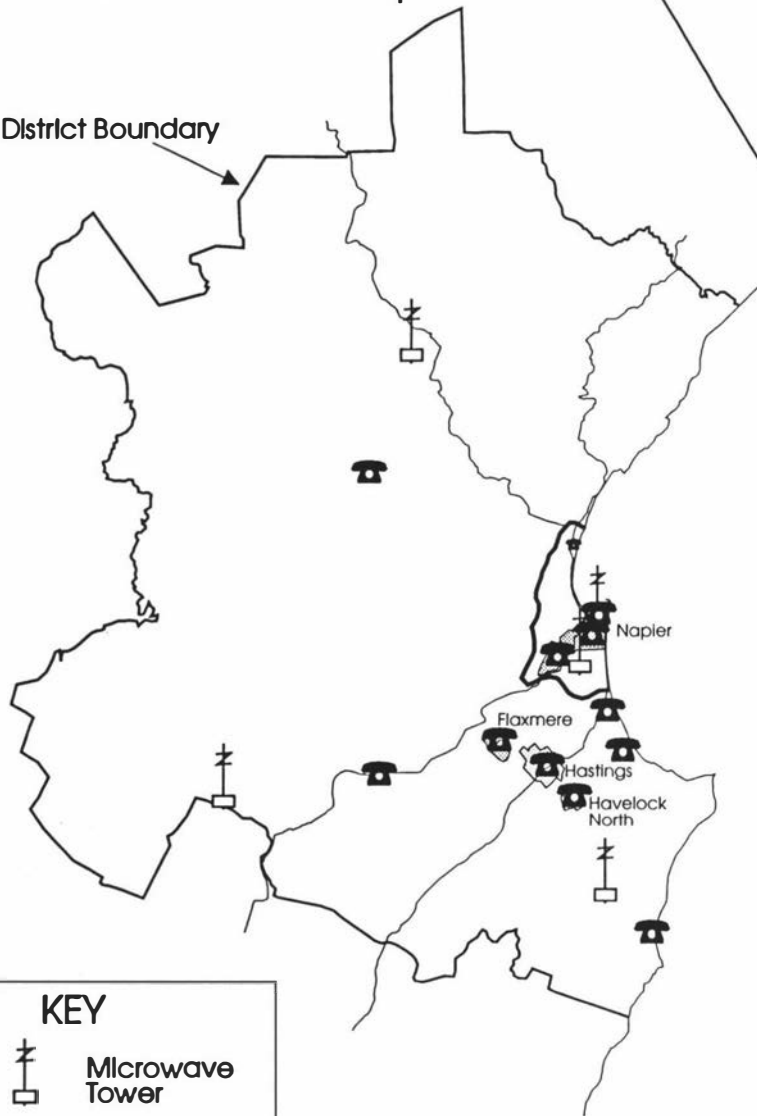
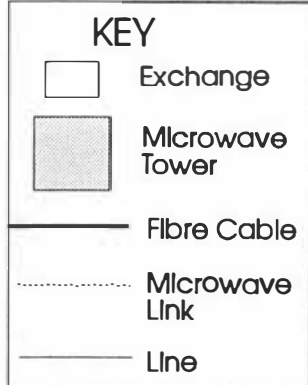
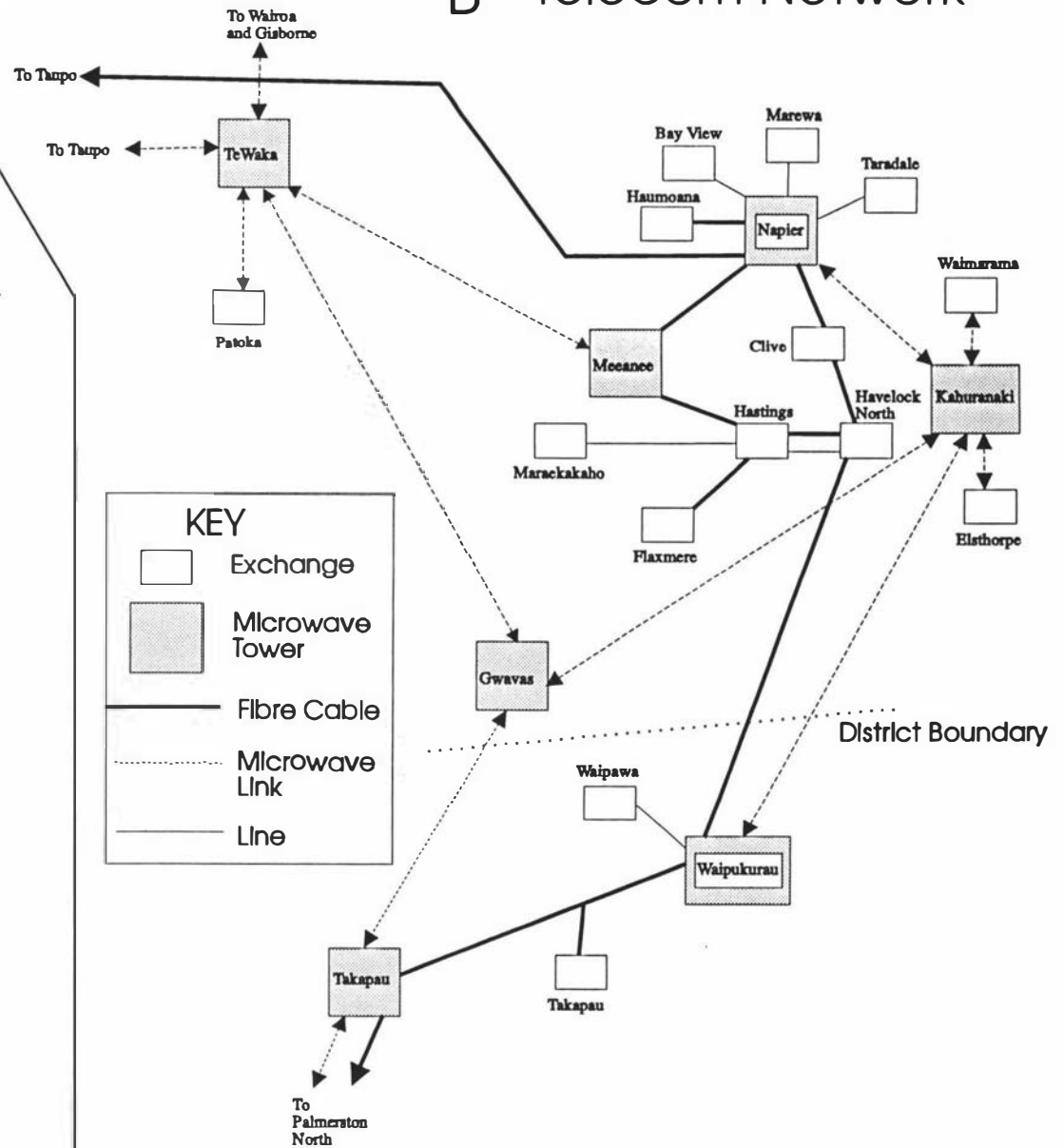
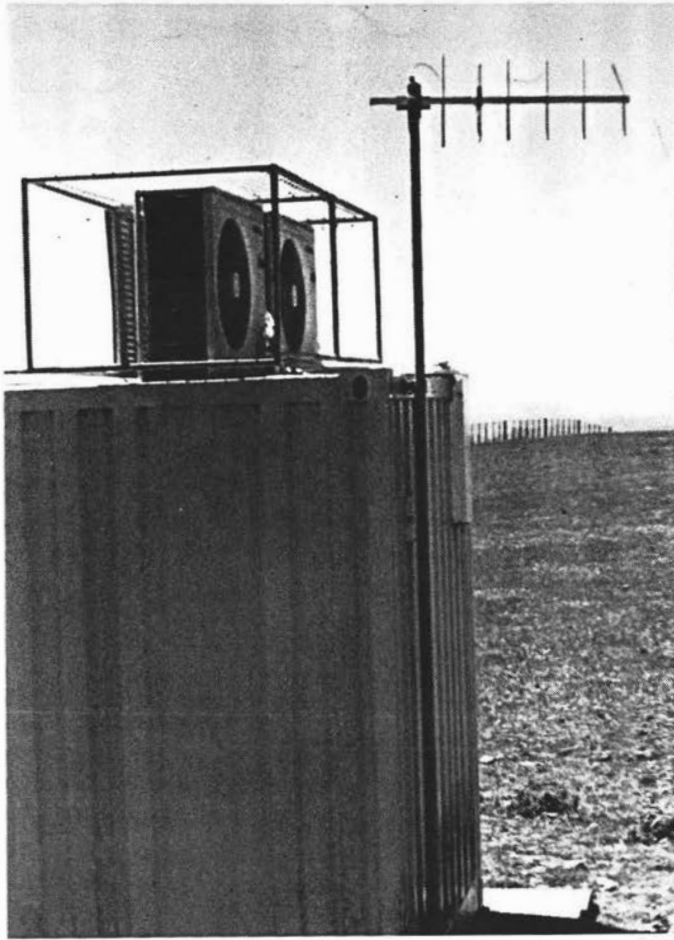


FIGURE 6.11

B Telecom Network





← A



B →

FIGURE 6.12

Examples of Telecom's Hawke's Bay facilities.

- A. Paging equipment cabinet with air-conditioning unit on top, highly vulnerable to ash falls.
- B. Te Waka microwave tower.

TABLE 6.7 HAWKE'S BAY TELECOM NETWORK VULNERABILITY CHART

* See Chapter 4, Table 4.1 for vulnerability chart key

Component	Importance	Vulnerability to direct ash falls								Interdependence		Backup or redundancy	Impact of being damaged				
		Becoming Inoperative				Damage				Element	Reliance		During ash falls	Immed. after	Period following	Return to normal	
		< 5 mm	5-20 mm	20-100 mm	> 100 mm	< 5 mm	5-20 mm	20-100 mm	> 100 mm								
Exchanges (a)	5	3	3	3	3	1	2	2	2	needs electricity and cooling	3 3	back-up generator/ batteries none	2	3	3	3	
Air-con. units (b)	4	3	3	3	3	2	2	3	3	needs electricity	3	none	3	3	3	3	
Microwave towers	3	1	1	2	3	1	1	2	3	needs electricity			2	3	3	3	
Lines	4	1	1	2	2-3	1	1	2	3				2	3	3	3	
Cables	3	0	0	0	0	0	0	0	0				2	3	3	3	

a. assumes external air-conditioning.

b. damage assessment assumes exposure to direct ash fall but the item is not used.

6.5.10 GAS SUPPLY AND RETICULATION

Natural gas is piped from the Maui gas field to Hawke's Bay by the Natural Gas Corporation. The pipes are usually buried to more than 0.9 m depth. Automatic shutdown equipment at points along the pipeline is designed to cut off the gas supply if the pipe is ruptured. Gas pressure is reduced for local supply by Enerco Gas Ltd. Above-ground structures in the district are limited to a "sales gate", which links the transmission pipeline to the local distribution system (see Fig. 7.16 for details).

Impacts of the scenario

Gas supply systems have a low likelihood of disruption from ash falls as facilities are well sealed. Metering equipment does require mains electricity but has back-up battery supplies. No major problems with the system are expected in this scenario.

6.6 INTERDEPENDENCE OF 'LIFELINES'

It is well known from 'lifelines' studies, including the scenario presented in this chapter, that independence of 'lifelines' has implications for the vulnerability of individual components. Damage or disruption of one can have major impacts on many others. Interdependence can be illustrated in a tabular form as shown in Table 6.8. As systems are often complex no particular precision can be claimed in the numbers given but the table highlights the links between 'lifelines' in the period following an ash fall in Hastings.

TABLE 6.8 Interdependence of selected 'lifelines' in Hastings within 24 hours of an ash fall greater than 5 mm.

Depends on	Water Supply	Gas Supply	Sewerage	Storm Water	Mains Electricity	Standby Electricity	VHF Radio	Telephones	Roads	Rail	Air transport	Fuel Supply	Fire Fighting	Air-conditioning	Total Importance
	Water Supply	*	1	*	*	*	*	*	*	*	*	*	*	3	2
Gas Supply	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0
Sewerage	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0
Storm Water	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0
Mains Electricity	2	1	2	2	*	2	3	*	1	3	2	*	3	21	
Standby Electricity	3	1	3	3	*	1	3	*	*	3	2	*	2	21	
VHF Radio	3	3	3	2	3	*	2	2	2	3	*	3	*	26	
Telephones	2	1	1	*	1	1	2	*	1	1	1	2	*	13	
Roads	2	2	2	2	3	2	1	2	2	3	2	3	1	27	
Rail	*	*	*	*	*	*	*	*	*	*	*	*	*	0	
Air Transport	*	*	*	*	*	*	*	*	*	*	*	*	*	0	
Fuel Supply	3	1	1	1	*	3	1	2	3	2	3	3	*	23	
Fire Fighting	*	*	*	*	*	*	*	*	*	*	2	1	*	3	
Air-conditioning Equipment	*	*	*	*	2	2	*	3	*	*	2	*	*	9	
Equipment	3	3	3	2	3	3	3	3	3	3	3	2	3	40	
Total Dependence	18	12	16	12	12	11	10	18	8	11	23	10	17	11	
Priority Factor	24	12	16	12	33	32	36	31	35	11	23	33	20	20	

Note: 3 = High Dependence
 2 = Moderate Dependence
 1 = Low Dependence
 * = No Dependence

Priority Factor = Importance + Dependence

Analysis of the table confirms many of the conclusions reached in the previous sections:

- * Specific vulnerable items of equipment are of paramount importance in the operation of most 'lifelines' and should be protected (if possible) against ash falls.
- * Roads are the most important transport sector in relation to other 'lifelines' and in terms of public use. Access to many utilities to remove ash and/or protect them often requires the use of roads at the very time they are affected by ash falls. Despite their importance they have a low dependence on other 'lifelines'.
- * Many 'lifelines' rely on VHF links for both telemetry and communications but they are unlikely to be affected by ash falls.
- * Fuel supplies are important for standby electricity generation, and road, rail and air transportation, but most utilities will have access to sufficient supplies after an ash fall. Supplies have a moderate to low dependence on other 'lifelines'.
- * Electricity supplies are important for the operation of many 'lifelines' and are vulnerable during and after ash falls. Back-up electricity may not necessarily be available after an ash fall. Electricity supplies have only a moderate dependence on other 'lifelines'.
- * Telephone systems have a moderate importance to other 'lifelines' but are highly dependent on electricity supplies and air-conditioning.
- * Air-conditioning units are important to a few lifelines, notably telephones, and are dependent on electricity and water.
- * Water supplies are required by a few 'lifelines' but since supply systems are relatively robust in Hastings, short-term problems should be minimal. However, water supplies have a high dependence on other 'lifelines', notably electricity supplies. Increased demand may strain the system.
- * Fire-fighting is required by few 'lifelines' but is dependent on a number, notably water supplies and road transport.
- * Stormwater, sewerage, rail, gas supplies and air transport are not required by most 'lifelines' but are highly dependent on others.

In Table 6.8 the priority factor is a combination of importance and dependence. However, it does not directly measure the vulnerability of the 'lifeline' to ash falls. For example, VHF radio has the highest rating but is one of the least vulnerable 'lifelines'. The table is also limited in that it does not indicate the consequence of the failure of certain 'lifelines' to society in general. Sewerage and storm water both have low priority factors but are highly vulnerable to ash falls and their failure will have major societal impacts.

Buildings, whether they are residential, business, or critical facilities (hospitals, fire and police stations, civil defence facilities, schools etc), are extremely vulnerable to disruptions of 'lifelines' which provide the services that allow them to operate. Electricity is required for

lighting, ventilation, boilers, water heating, refrigerators/freezers, kitchens, medical services, lifts and security. Water supply is required for satisfactory operation of hot and cold water systems, fire hoses and sprinklers, kitchens and laboratories. Communication facilities are critical for the operation of emergency management organisations, and usually require continued electricity supply.

An assessment of the vulnerability of 'lifelines' must therefore consider the physical vulnerability of the particular 'lifeline', its dependence on other 'lifelines', the flow-on effects that its disruption may have and the societal demands placed on that 'lifeline' after an event. Failure to consider all these aspects is illustrated by the example presented in Appendix 3 of Anchorage, Alaska following the 1992 Mount Spurr eruption, when a light ash fall caused major water shortages. A vulnerability assessment of the water supply system and subsequent contingency planning had failed to anticipate increased water usage following such an event and appropriate measures were not taken once an ash fall warning was received (see Appendix 3 for details).

6.7 PUBLIC HEALTH ISSUES

Public health concerns have followed many ash falls both in New Zealand and overseas. Fresh ash acts as an irritant on the upper and lower respiratory tracts and eyes but is usually non-toxic. Respiratory problems will result from the inhalation of fine ash, but will be more acute in patients with existing respiratory disorders. Eye problems will include foreign material in eyes, corneal abrasion and conjunctivitis. During ash fall people are advised to stay indoors. Where it is necessary to move outside protective filter masks are recommended. No major health problems would be expected as a consequence of this scenario although a general increase in the level of anxiety may be experienced. This is not evenly distributed across the community with certain groups more vulnerable than others (e.g. elderly, those with existing respiratory disorders). A number of accidents are expected where people fall from ladders and roofs during ash cleaning.

6.8 SOCIOECONOMIC CONSEQUENCES

True estimates of the economic impacts of this scenario eruption are extremely difficult to determine. Economic impacts may include direct and indirect losses, additional unbudgeted expenditure and additional staff time used in response to the ash falls. In this scenario the recovery process will be spontaneous, immediate and rapid. The speed of recovery will have a major influence on the overall economic consequences but some losses will be unavoidable.

6.8.1 Agriculture and horticulture

Of major concern to the regional economy during the 1995-1996 Ruapehu eruption were potential impacts of ash falls to the local agricultural and horticultural industry. It has been established that the time of year will have a major affect on the vulnerability of animals and crops and therefore the level of impact to the regional economy.

Ash of 5-10 mm is unlikely to immediately kill animals except in certain circumstances. Ash will deter stock from eating pasture but most grazing animals will survive. Provision of supplementary feed may be necessary. Fluorine aerosols attached to fine ash pose the most significant threat to animal well being (Gregory & Neall 1996). As a result of ≤ 5 mm ash fall on the Rangitaiki Plains (near Taupo) during the 1995 Ruapehu eruption, approximately 2000 ewes and lambs (2.5% of the area's sheep population) were killed either by fluorosis or from starvation (pregnancy toxemia). This occurred during spring lambing when feed was short, placing additional stress on animals. Ash falls during such periods of the year will increase animal vulnerability. Ash falls may also damage wool quality of affected sheep and goats, and have the greatest impact immediately prior to shearing. Minor stock losses are possible in this scenario but most farmers should be able to take prudent mitigative measures to limit the impact.

Damage to crops is highly dependent on the stage of crop development. The period between November and April will have the greatest impact (Table 6.9). Ash falls on leafy vegetable crops (e.g. cabbage, broccoli, lettuce etc) may cause serious damage with crops unmarketable. Large losses are possible. Crop losses are likely to affect only one growing season but the economic impacts may affect farmers for years to come. Small amounts of ash may improve soils through textural modifications and provision of nutrients. A positive impact of the 1995-1996 Ruapehu ash falls has been to temporarily reduce the sulphur fertilizer requirement for all sheep, beef and dairy farms within the ash fall area as well as inducing increased selenium uptake in herbage (Cronin *et al.* 1996).

TABLE 6.9 Periods of high crop risk from ash falls (M.A.F. 1995 *written comm.*)

Periods when crops are most at risk

Pea: from emergence until end of flowering.

Squash: during the initial stages of growth and flowering.

Tomatoes: during seed emergence and flowering stages.

Sweetcorn: during the early stages of growth.

Pipfruit has three danger periods:

- blossom where severely acidic ash (pH less than 3) could burn plant tissue and result in poor pollination;
- 6 to 8 weeks after blossoming, when the skin of fruit is particularly sensitive; and
- later stages of development when fruit is prone to cosmetic blemishing.

Stonefruit is also susceptible at the same times as pipfruit, except that the early fruit development period is 4-6 weeks after blossoming, when sensitive fruit skins could be damaged, and show russet or deformation in severe cases.

Kiwifruit is also at risk at, and 6-8 weeks after, blossom. There would also be a problem at harvest time. As kiwi fruit cannot be washed prior to packing, the hairy nature of the fruit would make ash removal very difficult.

Grapes have three main periods when damage could occur:

- Flowering, when acidic ash could burn plant tissue, reduce pollination and reduce bunch fill;
- Fruit development, where ash deposits would block sunlight and reduce quality; and
- Harvest, where ash deposits would be a contaminant, with the extra acidity of the ash possibly having a significant impact on wine quality. Ash would have to be removed prior to harvesting by washing and allowing bunches to dry.

Peas			<u>End of flowering</u>						<u>Emergence</u>	
Squash			<u>Initial stages of growth and flowering</u>							
Tomatoes			<u>Flowering stages</u>							
Sweetcorn			<u>Early stages of growth</u>							
Pipfruit		<u>Blossom</u>		<u>After blossoming</u>		<u>Later stages of development</u>				
Stonefruit	<u>Blossom</u>			<u>Cosmetic effects</u>						
Kiwifruit		<u>Blossom</u>						<u>Harvest</u>		
Grape		<u>Flowering</u>		<u>Fruit development</u>		<u>Harvest</u>				
	September	October	November	December	January	February	March	April	May	June

6.8.2 Business and industry

The scenario eruption may disrupt business activity in several ways through: 1) forced closure due to 'lifeline' disruptions; 2) reduced business activity; 3) contaminated merchandise; 4) minor building damage; 5) employee absenteeism. Most impacts should abate within a few days to a week but some negative economic impacts would be experienced. Any major economic impacts to the rural economy will have flow-on effects to all other sectors. Tourism may be a sector moderately impacted, as people are put off visiting the ash-affected areas. Some businesses will benefit from the eruption, particularly those supplying automotive spare parts and equipment required for cleaning ash. Contractors with equipment needed for street cleaning will enjoy positive benefits from the eruption in the form of additional work. As the scenario eruption will affect other parts of the North Island a range of external impacts may have flow-on effects into the district. For example, during the entire eruptive episode aviation will be severely affected throughout the North Island.

6.8.3 Individuals

Individual economic exposure to the eruption will vary considerably. For the majority of residents of the district the eruption will represent a short term disruption to their daily life (brief electricity outages, water restrictions, school closures etc). Most people will be required to undertake ash cleaning of their properties and many will become involved in neighbourhood clean-up efforts. In most cases only minor property damage will occur. The Earthquake Commission provides insurance cover for damage to property and contents but considers the cost of cleaning to be a reasonable mitigation requirement and the responsibility of the property owner. During the 1995-1996 Ruapehu eruptions a number of claims were rejected where damage resulted from the failure of the property owner to remove the ash. However, this policy may present problems for those who are unable to remove ash themselves (e.g. elderly or disabled people) and do not have the resource to pay for the work to be done. Reduced employment opportunities will affect certain individuals, especially those dependent on the agricultural and food harvesting industries.

6.8.4 Local government

The Hastings District Council will carry a high proportion of the costs of the eruption. The single biggest cost to the council will be the ash clean-up, in the vicinity of several million dollars using the estimates of ash-removal cost per capita from past eruptions (see Fig. 3.5). The council will need to take a proactive role in dealing with ash removal: coordinating clean-up operations, managing both contractors and volunteers and providing public information on the removal and disposal of the ash. Contingency planning can identify ash disposal sites and these can be rapidly brought into service. Double handling of ash should be avoided to

reduce costs and clean-up time.

6.8.5 Central government

A number of organisations will have leading roles during such an eruption crisis. The Institute of Geological & Nuclear Sciences (GNS) would be responsible for monitoring the eruption, setting the "Scientific Alert Level" and providing scientific information to the Ministry of Civil Defence and other organisations. The Ministry of Civil Defence, assisted by a scientific advisory committee, in turn would advise Government, regional and district councils. The Airways Corporation and the Met-Service would be responsible for monitoring air-space and declaring flight restrictions. Other government organisations would be involved in specific responses including the Department of Internal Affairs, Department of Social Welfare, Ministry of Health and Ministry of Agriculture (MAF).

The cost of the provision of these services will be substantially greater than those experienced during the 1995-1996 Ruapehu eruptions due to the greater magnitude of the event.

6.9 CONCLUSIONS

The scenario will have disruptive short term impacts on Hastings district. During the ash falls all forms of transport will be affected. The fallen ash will present an on-going hazard but most transport systems will be operational within a few days. Electricity supplies may be disrupted if ash becomes wet (i.e. conductive) but most outages would be for a short duration. Telephone exchanges are vulnerable to over-heating if air-conditioning systems are disrupted. Ash entering sewage and stormwater systems would cause severe problems. The recovery process will be spontaneous, immediate and rapid as individuals, businesses and other organisations attempt to limit socioeconomic impacts. The removal of ash from buildings, roads, sewerage and stormwater will be an expensive and time-consuming process. The social and economic impacts of the ash falls on Hastings district are not determined only by direct physical consequences. Demand for information on all aspects of the emergency will be high during the initial stages, as individuals and organisations deal with the relatively "unknown" problems associated with a major ash fall.

CHAPTER 7

SCENARIO TWO - ERUPTION FROM THE OKATAINA VOLCANIC CENTRE

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7.1 INTRODUCTION

This chapter examines the impacts of a 4 km³ rhyolitic eruption scenario from Okataina Volcanic Centre on the Whakatane District. The scale of many of the physical impacts described in the previous chapter (6) will be amplified and a range of additional effects result from this larger magnitude event.

7.2 VOLCANIC HISTORY OF THE OKATAINA VOLCANIC CENTRE

The Okataina Volcanic Centre (OVC) is situated east of Rotorua city (Fig 7.1). It includes the large volcanic dome complexes of Haroharo and Tarawera plus the smaller Okareka complex, all of which have grown within the Haroharo Caldera (Nairn 1981, 1991a). Other smaller vent complexes occur outside the caldera, notably the Rotoma rhyolite complex, and the Rotokawau-Rotoatua alignment of basaltic vents.

Little is known about the early eruptions of the Okataina Volcanic Centre but at least three caldera-forming pyroclastic eruptions occurred during the period 350 000 to 60 000 years B.P.. These formed extensive ignimbrite sheets surrounding the centre and erupted in total over 500 km³ of material. Each of these eruptions devastated most of the central North Island. They were followed by a series of eight smaller eruptions between 60 000 and 24 000 years B.P. which also affected much of the central North Island. A detailed history of the past 21 000 years has been established (Nairn 1981, 1991a) during which 11 distinct eruptive episodes occurred (see Table 7.1) and the dome complexes of Tarawera and Haroharo were constructed. The eruptions that built Mount Tarawera commenced 18 000 years B.P., and further rhyolite eruptions occurred at 15 000, 11 000 and 700 years ago. In 1886 the most recent and smallest eruption occurred, with basalt scoria erupted from Mount Tarawera and phreatomagmatic deposits from Lake Rotomahana. The eruption resulted in over 100 deaths, caused by pyroclastic surges and tephra fall from the Rotomahana vents (Nairn 1979; Kean 1988). Tephra deposited at the outlet to Lake Tarawera acted as a barrier blocking the outflow (White *et al.* 1997). On 1 November 1904, at a time of high rainfall, the lake overtopped this barrier and flooded down the Tarawera River, with the lake level falling 1 m in one day. More of the tephra barrier was carried away on 4 November when the lake level fell by about 3.3 m. The resulting flood triggered an episode of rapid erosion and sedimentation on the coastal plain. Haroharo (Fig 7.1) has a rather similar history to Tarawera, with activity commencing at 21 000 years B.P. and further rhyolitic eruptions at 9000, 7500 and 5000 years B.P. Eruptions occurred at Rotoma (Fig. 7.1) at 9000 years B.P. and Okareka at 21 000 and 13 500 years B.P. Basalt was erupted from the Rotokawau-Rotoatua vent lineation at 3400 B.P. (Beanland & Houghton 1991).

TABLE 7.1 Volumes, types (B = basalt, R = rhyolite), ages and quiescent intervals between eruptions at Okataina Volcanic Centre during the past 21 000 years (modified from Nairn 1991a and Nairn 1992a).

Eruption	Vent area	Magma Volume (km ³)	Eruption Type	Age (B.P.)	Quiescence (Years)
Tarawera	Tarawera/Rotomahana	1	B	110 (1886 A.D.)	700
Kaharoa	Tarawera	5	R	700	2800
Rotokawau	Rotokawau	0.5	B	3500	1500
Whakatane	Haroharo	13	R	5000	2500
Mamaku	Haroharo	18	R	7500	1500
Rotoma	Rotoma/Haroharo	8	R	9000	2000
Waiohau	Tarawera	11	R	11 000	2500
Rotorua	Okareka	4	R	13 500	1500
Rerewhakaaitu	Tarawera	5	R	15 000	3000
Okareka	Tarawera	8	B/R	?18 000	?3000
Te Rere	Haroharo/Okareka	13	R	21 000	3000

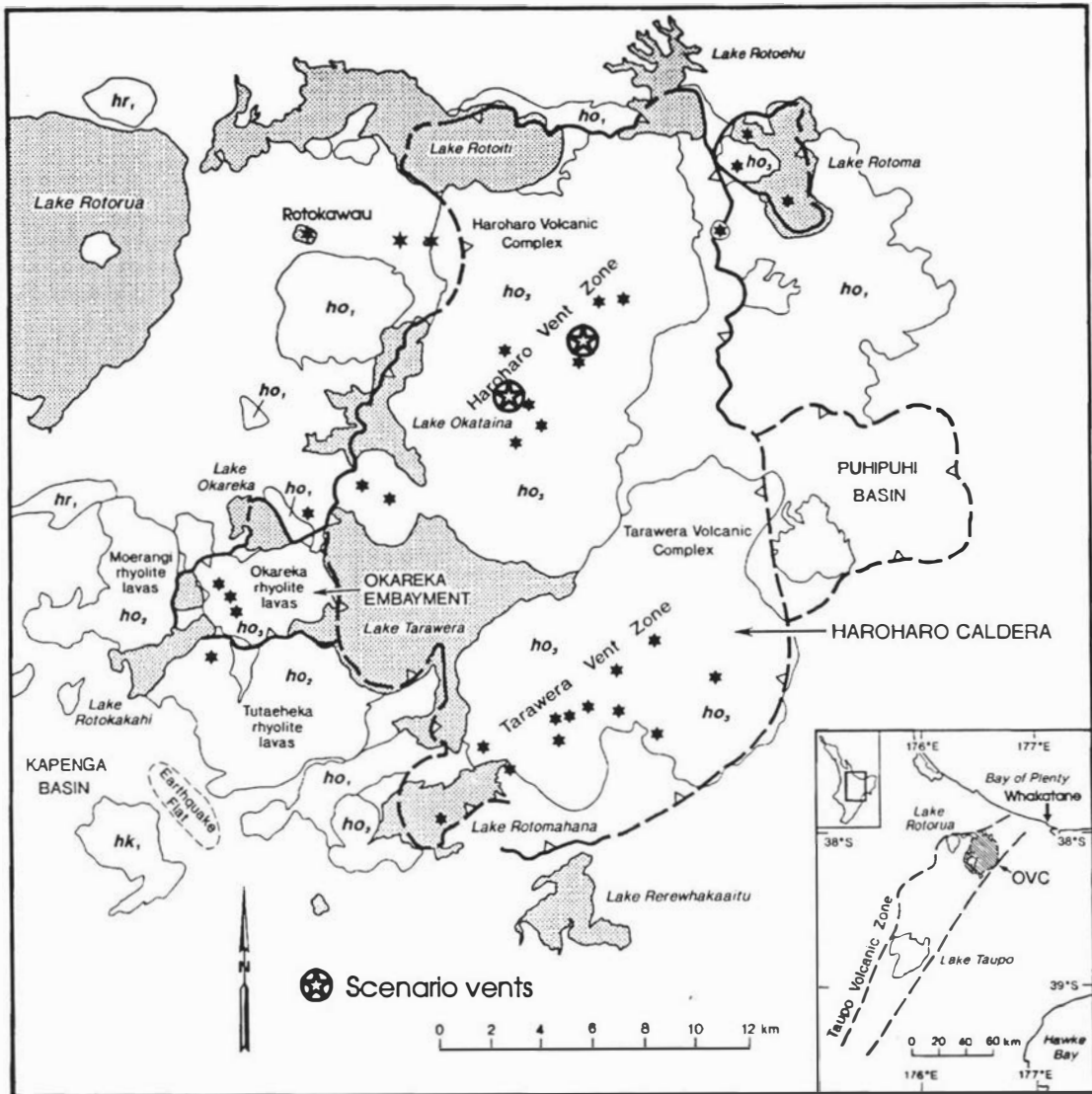


FIGURE 7.1

Map of the Okataina Volcanic Centre (OVC) and scenario vents (modified from Nairn 1992a). Small stars mark post-21 000 yr B.P. vent locations which define two northeast-trending vent zones through Haroharo and Tarawera respectively. Oldest rhyolites are ho_1 , hr_1 and hk_1 ; intermediate age rhyolites are ho_2 ; intracaldera rhyolites (all <21 000 yr B.P.) are ho_3 . Inset shows the position of the OVC in the Taupo Volcanic Zone.

7.3 SCENARIO ERUPTION PARAMETERS

The eruption of rhyolitic magma is often characterised by extremely explosive plinian eruptions which disperse pyroclastic material over a wide area that can be $>100\,000\text{ km}^2$ (Walker 1981). There has been no historic rhyolitic eruption affecting a modern society on which to base this scenario. The 1991 eruption of Pinatubo, although dacitic in composition, provides one of the best models for the sequence of events leading to a rhyolitic eruption from Okataina Volcanic Centre (Nairn 1992b). Past rhyolitic eruptions from Okataina and the 1991 Pinatubo eruption both produced plinian eruption columns, pyroclastic flows, lahars and widespread pyroclastic fall deposits.

The thickness of a pyroclastic fall deposit any one point is related to the total volume of magma which is erupted, the eruption column height, the distance from the vent and the wind velocity (Self & Walker 1994). In modelling ash fall distribution for this scenario the ASHFALL program (Hurst 1994) has been used as discussed in Chapter 5. Wind direction in the Bay of Plenty is variable but the predominant one is from the west and it is this direction that has been chosen for this scenario.

During the eruption the plinian eruption column may undergo partial or total collapse to generate pyroclastic flows, consisting of laterally moving mixtures of gas, ash and pumice at high temperatures (300 to 800°C) (Cas & Wright 1987). These flows move outwards over the ground surface at speeds which can reach 200 ms^{-1} and are often channelised in valleys.

There is evidence for lahars being produced as a consequence of most eruptions from the Okataina Volcanic Centre (White *et al.* 1997). Lahars can be generated by the collapse or overtopping of a volcanic barrier impounding a lake or river, or by heavy rain eroding unconsolidated volcanic material from slopes, or directly from pyroclastic flows (Neall 1996).

At the Okataina Volcanic Centre, evidence from past eruptions suggests that a rhyolite eruptive episode may last for months to years, or even longer. Caldera volcanoes can also undergo long periods of unrest (seismicity, deformation, release of volcanic gases etc) before an eruption (see Chapter 9, Table 9.1 for examples). An initial eruptive phase may be followed by periods of days or weeks of quiescence before activity recommences. The total thickness of pyroclastic material deposited during an eruptive episode is typically the result of a number of eruptive phases, each lasting hours to days, that have occurred over several months or years. Isopach maps of tephra deposited by past eruption episodes may represent the cumulative amount of ash from a series of eruptive phases which may not necessarily represent the amount of ash that falls on a daily basis.

The final phase of a rhyolitic eruption is often the non-explosive extrusion of degassed magma to form lava domes and flows (Fink 1993). There are many examples of these at the

Okataina Volcanic Centre (Nairn 1991a).

7.4 CHRONOLOGY OF THE SCENARIO ERUPTION

The chronology of the scenario is modified from that of a scenario used by Johnston & Nairn (1993). It is detailed as follows:

-18 to -12 months	An increased level of seismicity is recorded within the OVC, with a change to swarms of 3-5 weeks duration. All events are high frequency (HF) tectonic earthquakes. Scientific Alert level 1 declared* at -16 months.
-12 to - 6 months	Seismicity returns to normal levels. Scientific Alert Level reduced to 0.
-6 to -3 months	A series of earthquake swarms occurs within the OVC at 2-3 week intervals. Scientific Alert Level 1 declared. Each swarm contains 50 to 100 HF events between Magnitude 2 and 4. Largest event is Mag. 4.1. No deformation is recorded.
-45 Days	A Mag. 4.9 earthquake occurs 10 km below Haroharo.
-44 Days	4 HF events between Mag. 3 and 4.
-43 to -41 Days	Further aftershocks occur, but seismic activity is declining.
-35 Days	Seismicity resumes with a swarm of 11 HF events > Mag. 3-4.
-34 Days	Seismicity increases to 65 events in a day, with the first long period (LF) earthquakes recorded. Scientific Alert level 2 declared.
-33 Days	48 HF events (8 felt).
-32 Days	23 HF events (6 felt).
-31 Days	Seismicity decreases to 10 HF events (none felt).
-30 to -26 Days	Low frequency tremor recorded, no earthquakes.
-25 to -21 Days	Mostly quiet. A few earthquakes felt.
-20 Days	A major earthquake swarm occurs with 112 HF events (Mag. 2-4), largest 4.1. Minor cracking is found on a fault trace at Haroharo. 8 LF earthquakes are recorded.
-19 Days	Seismicity continues. 5 long period earthquakes.
-18 Days	Minor tilt recorded on Haroharo
-17 Days	Volcanic tremor recorded lasting 30-60 sec. 35 earthquakes recorded.
-16 Days	42 events recorded. Average 3 per hour.
-15 Days	Uplift 5cm in past 7 days at north base of Haroharo dome. 35 events recorded.
-14 Days	Uplift recorded on tiltmeters. 42 events. 8 tremor episodes.
-13 Days	Increases in temperature and outflow of warm springs on Haroharo. 5cm of uplift in the past 2 days. 44 events and 6 tremor episodes.
-12 Days	Dead and dying vegetation reported around the summit of Haroharo. The smell of SO ₂ noted in the air. 32 HF events, 8 tremor episodes.
-11 Days	45 HF events and 18 LF.
-10 Days	SO ₂ confirmed from the Haroharo area. 50 HF events, 4 LF.
-9 Days	Uplift continues. 43 HF events, 6 LF.

* See Chapter 9, Table 9.2 for description of the Scientific Alert Levels

-8 Days	52 HF, 9 LF. Cumulative uplift of 128 mm in past 35 days.
-7 Days	70 HF, 8 LF events. Ground cracking reported.
-6 Days	185 HF events, 20 LF.
-5 Days	A small explosion forms a NE-trending vent near Pukerimu cone. A fissure 80 m long and 3-8 m wide is emitting steam plumes to 300 m. Blocks up to 1 m across are thrown out to 50 m and fine ash falls up to 3 km downwind. Seismicity increases dramatically with 434 recorded events. Scientific Alert Level 3 declared.
-4 to -2 Days	Small eruptions continue, with minor ash falls downwind. Tilt meters continue to measure inflation. Seismicity continues at high level with many periods of volcanic tremor. SO ₂ outputs increase.
- 1 Days	Seismic activity intensifies. Harmonic tremor becomes more or less consistent. Moderate-sized eruptions begin with ash column rising to 10 km. Scientific Alert Level 4 declared.

Climactic Eruption

An eruption earthquake of Mag. 4.6 is recorded. A small steam and ash column rises to 1 km above the Pukerimu vent followed within 10 minutes by the onset of major explosions. The initial eruptions are phreatomagmatic, generating pyroclastic surges and flows which extend out to 4 km from the vent, accompanied by ash and pumice falls to 15 km downwind. The eruption column rises to 10 km high. As the eruption grows the vent area widens and a clear conduit is established to the magma body. The eruption enters a plinian phase after 30 minutes with the eruption column rising to 40 km high. **Scientific Alert Level 5 declared.** Heavy falls of ash and pumice commence within 20 km radially from the vent, and extend to 70 km downwind, causing total darkness apart from weak illumination by frequent lightning flashes. Severe ground shaking affects much of the Bay of Plenty during the climactic eruptive phase, up to intensity MM VI (Modified Mercalli). Numerous pyroclastic flows are generated. Flows travel north to enter Lake Rotoiti where they generate large waves on the lake surface and send water surges down the Kaituna River. Other flows reach lakes Okataina and Tarawera where they cause similar effects. After 6 hours a second vent opens on Haroharo dome, forming a second plinian eruption column. The columns merge above a height of 1 km. Tephra is falling across the entire Bay of Plenty region, and beyond to the east coast and offshore, causing total darkness in this area apart from frequent lightning.

The initial plinian phase ends after 12 hours, declining to a small eruption column rising to 5 km above the Haroharo dome vent. Lahars are generated in the Tarawera valley and flow to the sea along the Tarawera River, inundating areas adjacent to the river. Flooding occurs on the western Rangitaiki Plains.

The eruption episode continues for the next three months with the growth and explosive destruction of rhyolitic lava domes which build a tuff cone formed at the Pukerimu vent. The six largest explosive events throw metre-sized ballistic blocks up to 3-4 km from the vent, produce small pyroclastic flows and send ash over a large area of the region. Large lahars flow down the Tarawera River valley after each heavy rainfall in the catchment area. Secondary explosions are generated in the thick pyroclastic flow deposits which choke the Tarawera River valley, and infill the main stream valleys draining off the Haroharo complex. These explosions occur at irregular intervals as groundwater percolates into the still very hot pyroclastic flow deposits. The explosions generate small secondary pyroclastic flows and ash columns which rise to 10 km, showering fine ash over downwind areas. Small lahars, derived from redeposited air fall ash and pumice, flow down all the streams draining north from lakes Rotoehu and Rotoma.

After three months the primary explosive eruptions stop and a large rhyolitic dome commences to grow in the vent area. The dome stops growing after 12 months. Lahars and floods continue to flow down the Tarawera River for years after the eruption.

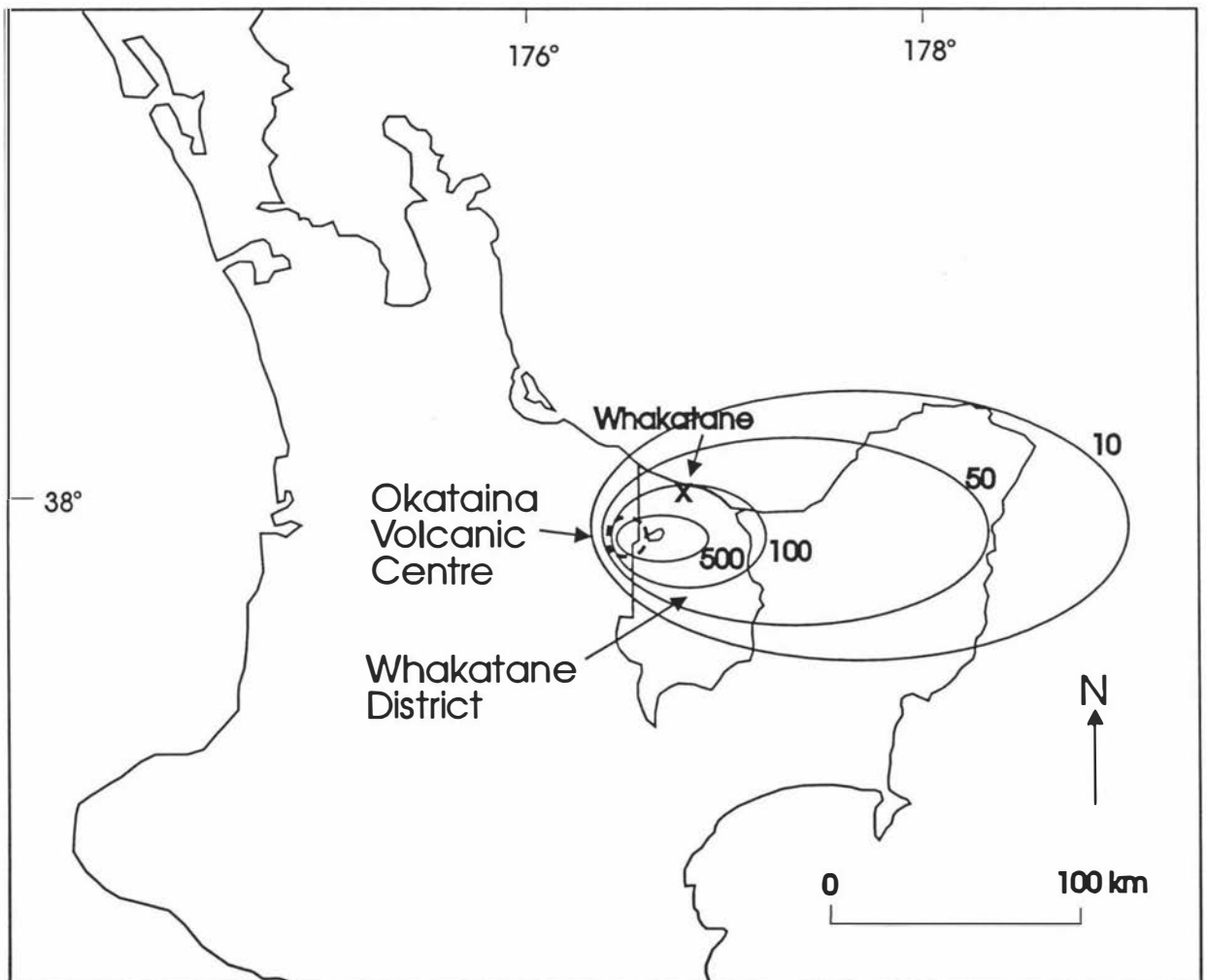


FIGURE 7.2

An isopach map showing the distribution of tephra from the scenario eruption (isopachs in millimetres).

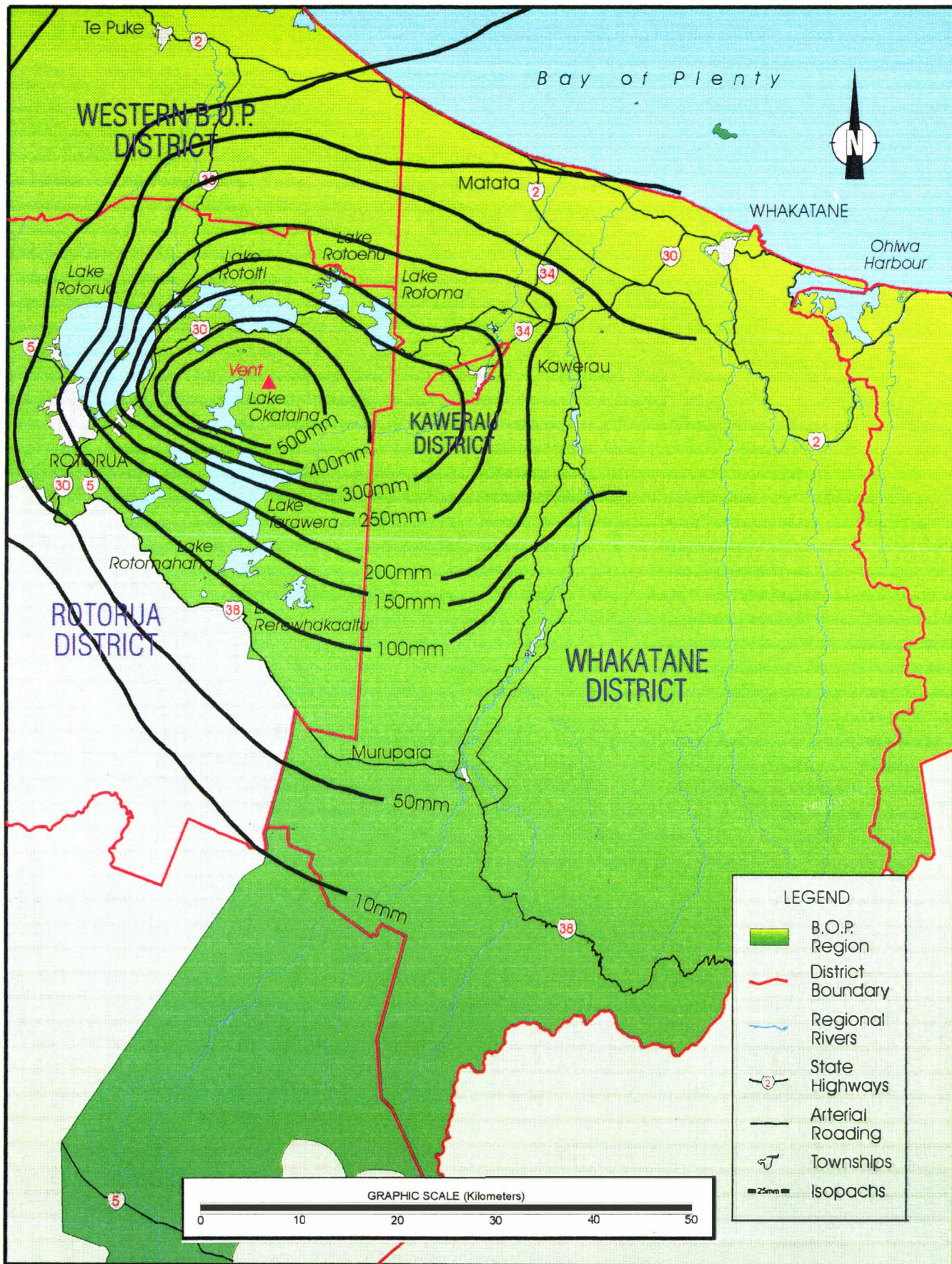


FIGURE 7.3

The distribution of pyroclastic fall deposits from the 1991 eruption of Mount Pinatubo, Philippines, superimposed on the Okataina Volcanic Centre. The open-ended isopachs represent Philippines' coastline, with no data available beyond this.

7.5 IMPACTS ON THE 'LIFELINES' OF WHAKATANE DISTRICT

7.5.1 Setting

The Whakatane District is situated in the Bay of Plenty region and has a roughly rectangular shape. The district has a 52 km long coastal boundary running from Otamarakau in the west to the mouth of Ohiwa Harbour in the east. The remaining boundaries follow a range of roads, rivers, ranges and tenure patterns, not always following the landscape. The district contains the Rangitaiki and Galatea plains and upland areas of the Taupo Volcanic Zone to the west and Urewera ranges to the east. The small district of Kawerau is located within the Whakatane District boundaries. Three major river systems, the Tarawera, Rangitaiki and Whakatane, drain the upland areas of the district, all flowing in a generally northerly direction.

The Whakatane district is partly sheltered from prevailing westerly winds by the high central North Island. Lower level winds over the district are modified by local topography but upper atmosphere winds are far more likely to blow from a westerly to southwesterly direction. The pattern of rainfall distribution over the district largely reflects exposure to the main rain-bearing northeast winds. The highest rainfalls occur in the months May to August and the lowest in November to February. The east and southeast areas have a wide seasonal range of rainfall. Rainfall exceeding 0.1 mm per day occurs on average about 131 days per year (Quayle 1984). Rainfalls are also influenced by topography with over 4500 mm per year on the highest parts of the eastern ranges.

The Whakatane District has a population of 33 125 and Kawerau District 7 829 (census 1996, provisional results). The urban areas account for 74% of the combined districts' population.

TABLE 7.2 Population of urban areas in the Whakatane District (from 1991 census)

Urban Area	Population
Whakatane/Ohope	15 618
Kawerau	8 136
Murupara	2 325
Edgecumbe	1 782
Taneatua	852
Matata	612
Te Teko	606

Horticulture, agriculture, forestry and associated processing are the major industries in the district. The fertile Rangitaiki and Galatea plains support intense agricultural and horticultural

use. Upland areas are extensively planted in exotic pines. Bay Milk operates a milk processing plant at Edgecumbe, producing milk products for local and export markets. The Tasman mill in Kawerau produces around 370 000 tonnes of pulp and paper per year, the majority for the export market. The mill employs 1400 staff. Other mills in the district include the Caxton Pulp and Paper Mill in Kawerau, producing pulp and tissue, and the Whakatane Board Mills, producing paper boards. Tourism also plays a small but increasingly important part in the district's economy.

7.5.2 Scenario impact on Whakatane town

The following section discusses the impacts of the eruption scenario on Whakatane District. A semi-quantitative ash fall vulnerability assessment of selected 'lifelines' has been undertaken and vulnerability charts are presented with each scenario impact assessment.

18-16 months	The local and national newspapers carry numerous stories about earthquake swarms at Okataina.
-16 months	The declaration of Scientific Alert Level 1 receives considerable local and national coverage, however national interest rapidly drops off. The regional and local civil defence committees meet to review the provisions of their contingency planning. The regional council convenes a meeting of senior management from local government in the Bay of Plenty to be briefed by Institute of Geological & Nuclear Sciences (GNS) staff on the nature of the unrest at the Okataina Volcanic Centre.
-12 months	The return to Scientific Alert Level 0 receives brief coverage in national and local media.
-6 months	The declaration of Scientific Alert Level 1 receives national and local media coverage but less than it did 10 months ago. The regional and local civil defence committees meet to discuss their response.
-34 Days	The declaration of Scientific Alert Level 2 receives massive local and national coverage. Public information notices are placed in all local newspapers, explaining the significance of the alert status and advice on what actions should be taken and by whom. A pre-emptive declaration of regional civil defence emergency is put in place and regional civil defence HQ in Whakatane is activated. A red zone, with restricted access, is established within a 10 km

radius of the Haroharo vent line. State Highway 30 between Lake Rotoma and Lake Rotoiti remains open although passing within the 10 km zone.

-33 to -6 Days

Large numbers of people decide to leave the district over the next few weeks. Some families send children to stay with relatives outside the region. School rolls drop dramatically. Retailers report a down-turn in sales.

-5 Days

Scientific Alert Level 3 is declared. A formal evacuation of people from rest-homes, hospitals and other institutions begins and a total evacuation of the red zone. State Highway 30 is closed to all traffic between Lake Rotoiti and a point just north of Kawerau. A light fall of ash covers Whakatane.

- 1 Day

Scientific Alert Level 4 is declared. The weather forecasts predict a west to southwest wind direction over the next 24 hours. Full evacuation of the high-risk parts of the district is ordered, including Whakatane town. A small number of people resist relocation. The regional civil defence headquarters is relocated to Hamilton.

Climactic eruption

The morning dawns clear but a steam and ash column is visible from Whakatane. By 9 am detonations can be heard in the town. A large number of vehicles leave the town, as residents continue to heed the evacuation order. The majority of vehicles head towards Tauranga but some move to Opotiki and Gisborne. By 9.30 am a large plinian eruption column is visible to the southwest and a dark ash-cloud fills the sky. By 10.00 am the sky darkens and ash and lapilli begin to fall in Whakatane. Within ten minutes total darkness engulfs the town. Heavy ash falls make travel extremely hazardous. The sky is filled with numerous lightning bolts and frequent small earthquakes are felt. Remaining residents seek shelter inside. Ash accumulates at a rate of 2 cm/hour for the next ten hours. Light rain accompanies the ash fall from late afternoon, adding to roof loading. By nightfall a large number of wide-span buildings have collapsed. Most residential houses receive only minor roof damage, commonly losing gutters. Many house verandas collapse.

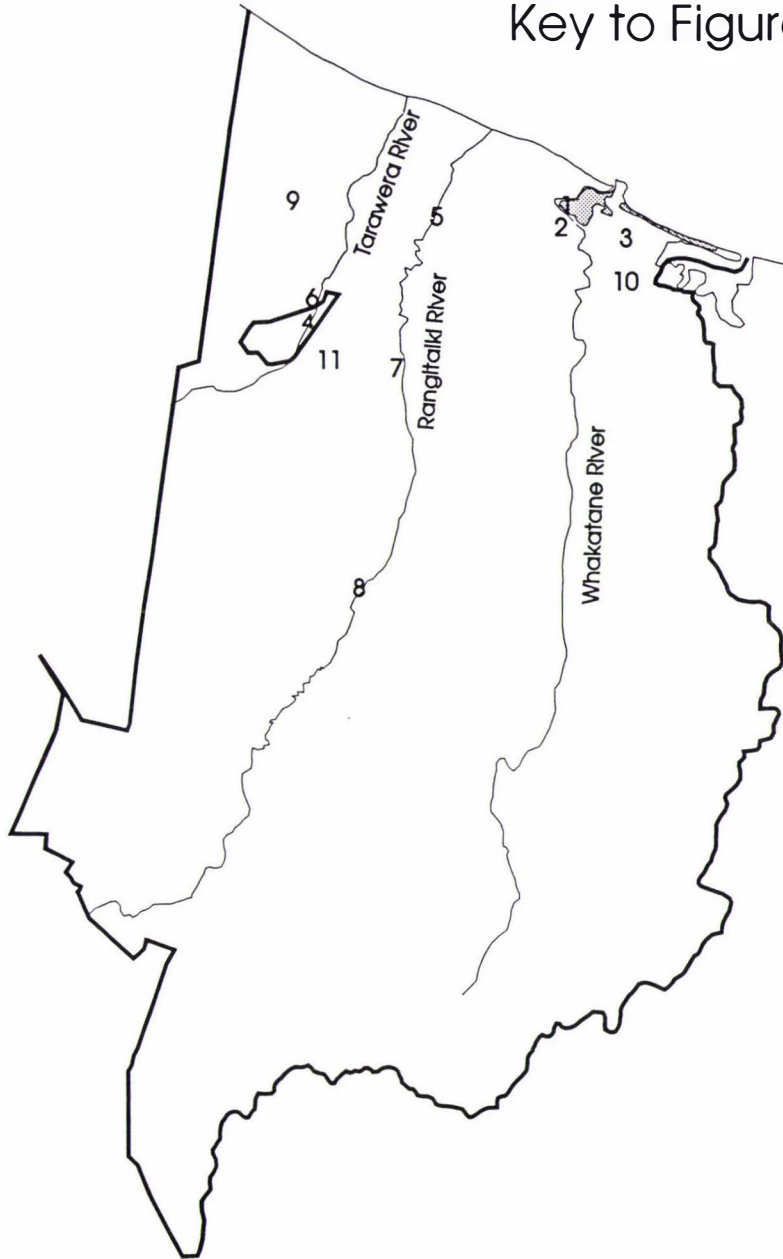
Impacts on selected 'lifelines' are discussed in the following sections.

- + 1 to 30 Days Heavy rain falls cause further flat roofs and verandas to collapse. Ash is washed from steep slopes, flowing through the town of Whakatane. Lahars down the Tarawera River will wash out road and rail bridges and cut transport links from day four of the eruption. Continued lahars prevent the re-establishment of these links for at least twelve months, effectively dividing the northern part of the district in two (Fig. 7.4).
- 0 to + 3 months Several light ash falls cover Whakatane town over the ensuing 3 months, depositing over 20 mm of new ash.

TABLE 7.3 Summary of Scenario 2 parameters

Given Conditions	Scenario 2	Outcome for Whakatane	
Volcano:	Okataina Volcanic Centre	Ash thickness:	200 mm
Magma type:	Rhyolite	Rate of ash fall:	20 mm/hour
Magma volume:	4 km ³	Ash condition:	Mildly acidic, initially dry, wet after 24 hours.
Precursors:	18 months	Other hazards:	Lahars down Tarawera River, lightning, ground-shaking
Eruption dynamics:	Plinian		
Wind direction:	West		

Key to Figure 7.4



Substations

- 1 Whakatane
- 2 Station Road
- 3 Ohope
- 4 Kawerau
- 5 Edgecumbe

Electricity generation

- 6 Kawerau
- 7 Matahina
- 8 Anawhina

Microwave towers

- 9 Manawahe
- 10 Pukehoko
- 11 Mt. Edgecumbe

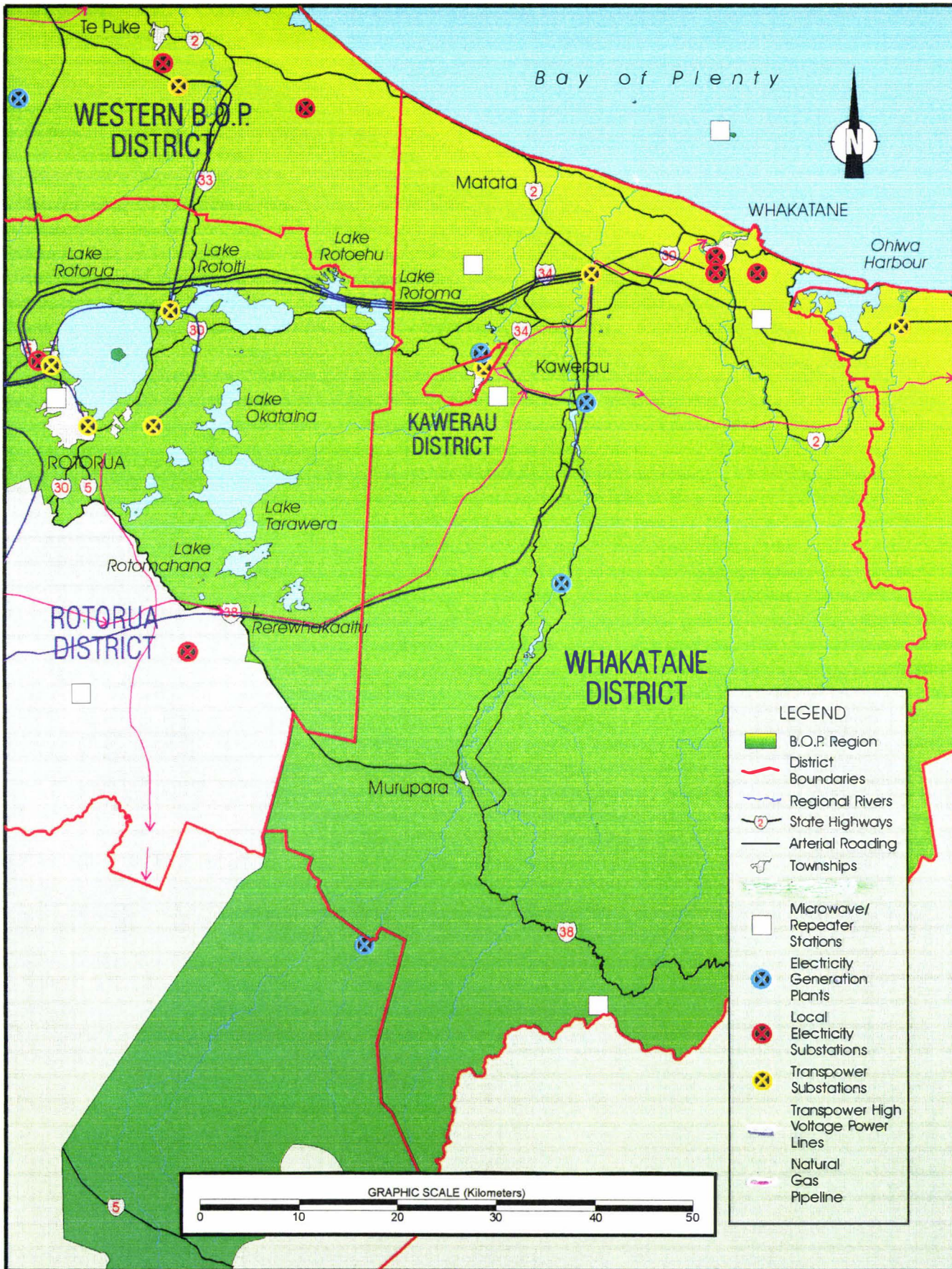


FIGURE 7.4 Major 'lifelines' in the Whakatane District.

7.5.3 ROAD TRANSPORTATION

The Whakatane District has a well developed arterial roading system, fed by a network of collector roads and streets. There is approximately 831 km of district roads of which 286 km (34%) are unsealed. All urban centres are connected by state highways, controlled and funded by Transit New Zealand. The remaining roads are controlled and funded by the Whakatane District Council. The state and privately owned forests in the district are served by a network of roads generally not available to the public. An ash fall vulnerability assessment is summarised in the vulnerability chart presented in Table 7.4

Impacts of the scenario eruption

Reduced visibility on roads is experienced over wide areas during and after ash falls. From the onset of ash fall total darkness prevails over most of the district, lasting for the entire first day of the climactic eruption. Light rain will turn ash to mud causing vehicle traction problems and making driving extremely hazardous in the dark, slippery conditions. The thick (>100 mm) ash deposits will block many of the district's roads, especially where ash is reworked from steep slopes onto roads. Blocked drains result in further damage to roads as rain causes surface flooding and over-flowing drains erode road surfaces. Ash deposits will need to be physically removed from road surfaces over much of the district before roads can be used. Lahars down the Tarawera River will wash out road bridges and cut transport links from day four of the eruption and continued lahars will prevent the re-establishment of this link for at least twelve months effectively dividing the northern part of the district in two (Fig. 7.5).

Fine weather over the following week will dry the ash, which is readily raised in billowing clouds by passing vehicles or by the wind. Where ash-covered roads remain open, speed restrictions need to be introduced, to ensure traffic safety and to reduce dust problems in adjacent communities. Ash entering vehicle engines and transmissions will cause wear on moving parts, reducing their life.

Major problems will arise as a consequence of road closures, including lack of access for emergency services and stranding of remaining travellers and residents. The clean-up of roads would be beyond the current resources of the district council and Transit New Zealand, which reserves only 5% of its annual budget for emergency work (Gibbon 1992). If resources are delivered from other areas of Transit New Zealand's budget, it would make a heavy impact on their programme over the rest of the country. Even if resources are available, re-establishing road links will be hindered by lack of personnel and equipment and on-going hazards (lahars, reworking of ash and minor ash falls).

7.5.4 RAIL TRANSPORTATION

The railway system serving Whakatane District comprises a number of lines (Fig. 7.5). The East Coast main trunk railway (ECMT) extends eastwards from Tauranga through Te Puke to Kawerau. The Murupara branch railway extends southward from Kawerau to Murupara and another branch line joins the ECMT south of Matata, servicing Edgecumbe, Taneatua and the Whakatane Board Mills. The main commodities carried by rail include logs, wood pulp, paper and paperboard, dairy products, fertiliser and steel. No passenger services operate in the district. An ash fall vulnerability assessment is summarised in the vulnerability chart presented in Table 7.4.

Impacts of the scenario eruption

Rail lines and rail transportation will be affected in a similar manner to road transportation. Heavy ash falls block rail lines and light rain may lead to extensive short-circuiting of electrically-operated signal equipment. Lahars down the Tarawera River will wash out rail bridges and sever the rail transport link from day four of the eruption. Continued lahars will deposit sediment over sections of the Matata - Kawerau line and prevent the re-establishment of the link for at least twelve months. Numerous slips, caused by reworked ash, will block the Murupara branch line and will need to be removed before the line can be reopened.

7.5.5 AIR TRANSPORTATION

Whakatane is the only commercial airport in the district with daily scheduled flights by both Air New Zealand and Ansett New Zealand. Other airfields are located at Kawerau and Galatea (Fig 7.5). An ash fall vulnerability assessment is summarised in the vulnerability chart presented in Table 7.4.

Impact of the scenario eruption

Air transportation is particularly vulnerable to volcanic eruptions. All airports would be closed by even minor ash falls, and large airspace exclusion zones would be established to avoid actual (or suspected) ash clouds which can cause failure of aircraft engines in flight. From the onset of eruptive activity disruptions to air services will begin as air-space restrictions around the volcano are imposed. Whakatane and Galatea will be covered by over 200 mm of ash and Kawerau by over 500 mm, preventing use of and damaging any remaining aircraft and other facilities. Expensive and time-consuming ash removal operations will be required to return the airports to normal service. The recovery of all three airports will depend on the provision of resources, and may be given a lower priority than other rehabilitation work.

7.5.6 PORT FACILITIES

The Whakatane River mouth and Ohiwa harbour (Port Ohope) provide safe harbouring and are used by a small number of fishing boats and charter operators, as well as recreational users.

Impact of the scenario eruption

Both ports will be affected by over 200 mm of ash fall, covering and damaging any remaining vessels. The Whakatane River will also be affected by high river turbidity, rafts of floating pumice and pumiceous sediment transported from its hinterland. Silting up of the river mouth will reduce its capacity, increase the risk of flooding and hinder boat access. This will be an ongoing problem for years, especially after periods of heavy rain. As road access becomes severely restricted in the district and the Whakatane River affected by sediment, Port Ohope will provide an option for post-eruption access to the eastern part of the district.

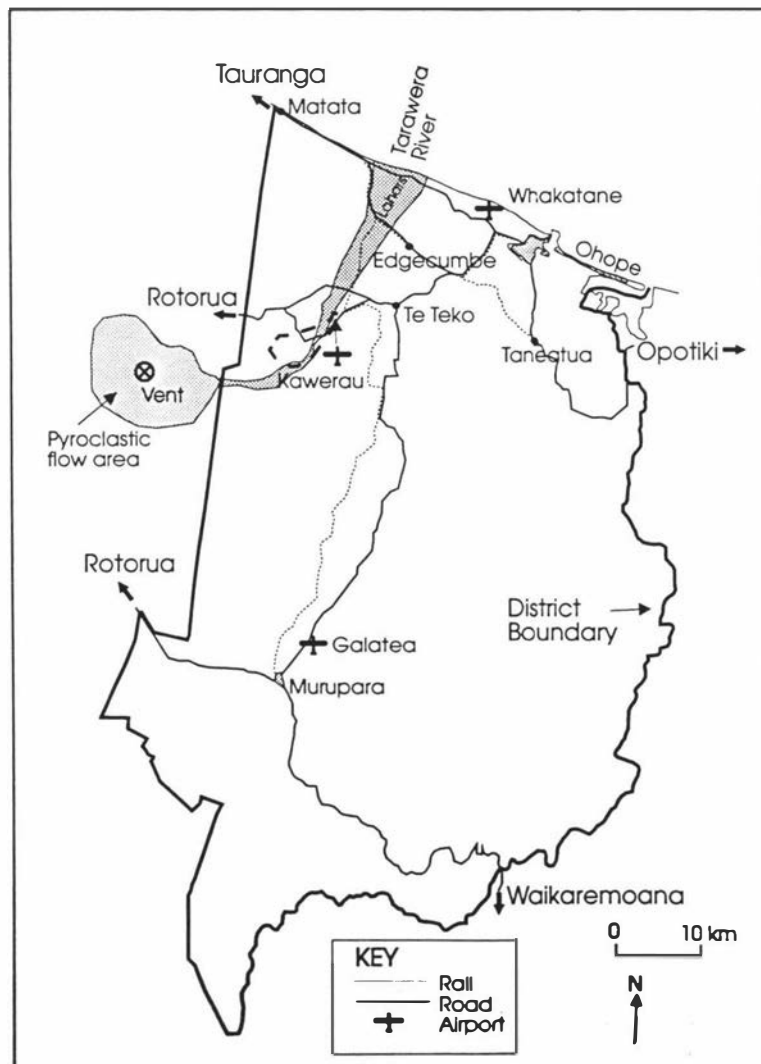


FIGURE 7.5 Main transportation routes and airport locations in the Whakatane District

TABLE 7.4 WHAKATANE TRANSPORTATION VULNERABILITY CHART

* See Chapter 4, Table 4.1 for vulnerability chart key

Component	Importance	Ash condition	Vulnerability to direct ash falls								Interdependence		Backup or redundancy	Impact of being damaged			
			Becoming Inoperative				Damage				Element	Reliance		During ash falls	Immed. after	Period following	Return to normal
			< 5 mm	5-20 mm	20-100 mm	> 100 mm	< 5 mm	5-20 mm	20-100 mm	> 100 mm							
AIR (a)	1	wet dry	3 3	3 3	3 3	3 3	1-2 1-2	2-3 2-3	3 3	3 3	airports require electricity, VIIF radio, radar	{ all 3	Altern. modes of transport	1	2	3	3
Airspace		n/a	3	3	3	3	0	0	0	0							
Airports and aircraft (a,b)		wet dry	3 3	3 3	3 3	3 3	2 1	2 2	3 3	3 3							
ROAD (a)	5	wet dry	1-2 1-2	2-3 2-3	2-3 2-3	3 3	1 1	2 2	3 3	3 3	all aircraft, vehicles and locomotives require fuel	{ 3	3	3	3	3	
Vehicles (b)		wet dry	1 1-2	2-3 2-3	2-3 2-3	3 3	2 1	2 2	2 2	2 2							
Roads (a)		wet dry	1-2 1-2	2-3 2-3	2-3 2-3	3 3	1 1	2 2	3 3	3 3							
RAIL (a)	1	wet dry	1-2 1-2	2-3 2	2-3 2-3	3 3	1 1	2 2	3 3	3 3	needs electricity	3	1	2	3	3	
Tracks and signals (a)		wet dry	1-2 1-2	2-3 2	2-3 2	3 3	2 1	2 2	3 3	3 3							
Locomotives (b)		wet dry	1-2 1-2	2 2	2 2	3 3	2 1	2 2	2 2	2 2							

- a. damage includes cost of clean-up operations.
- b. damage assessment assumes exposure to direct ash fall but the item is not used.

7.5.7 ELECTRICITY SUPPLY AND RETICULATION

There are two hydroelectric power stations on the Rangitaiki River, Matahina dam (72 MW) owned by ECNZ and Aniwhenua (25 MW) owned by Bay of Plenty Electricity (Fig. 7.4). Bay of Plenty Electricity also operates two small geothermal generation plants (9 MW total) in Kawerau and a co-generation plant (10 MW) at the Bay Milk Products facilities in Edgecumbe. Over 60% of electricity used in Whakatane is produced by Bay of Plenty Electricity generating facilities, distributed in part by the national grid operated by TransPower. The grid's high voltage lines (220 kV and 110 kV) feed into Edgecumbe, Kawerau and Matahina substations (Fig. 7.6) operated by TransPower, and then on to Bay of Plenty Electricity's 33 kV substations for distribution to customers, using underground cables and aerial lines. TransPower's Edgecumbe substation is one of the most critical facilities, feeding four local substations (Whakatane, Ohope, Station Road and Edgecumbe) (Fig. 7.7). Kawerau town is fed by a 11 kV line out of the TransPower substation. Anawhina Dam's main feed is to the Matahina substation but it also feeds a substation at Galatea and is linked to Edgecumbe by a 33 kV tie line thus providing a direct feed in the event of disruption to the TransPower supply into the district. An ash fall vulnerability assessment is summarised in the vulnerability chart presented in Table 7.5.

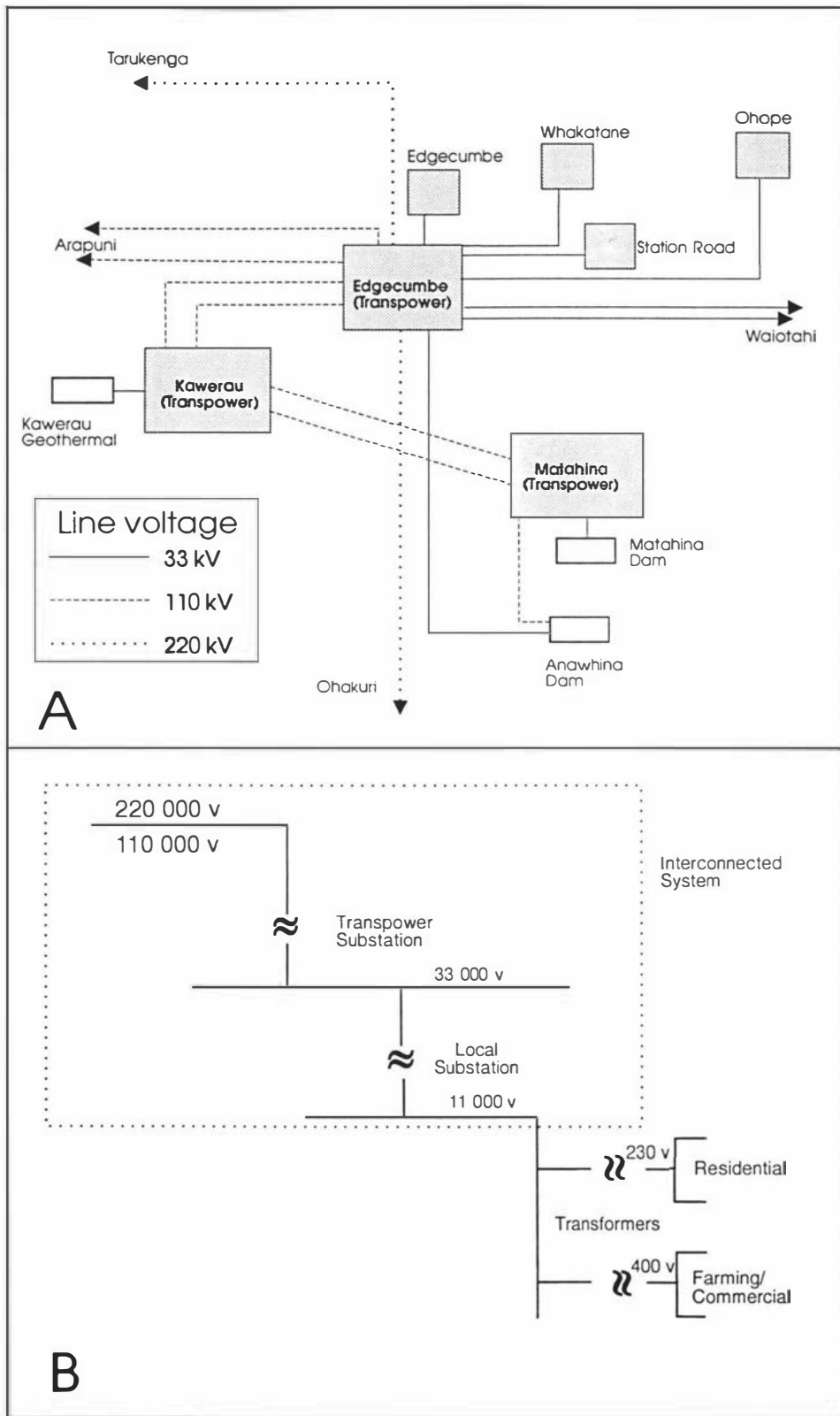
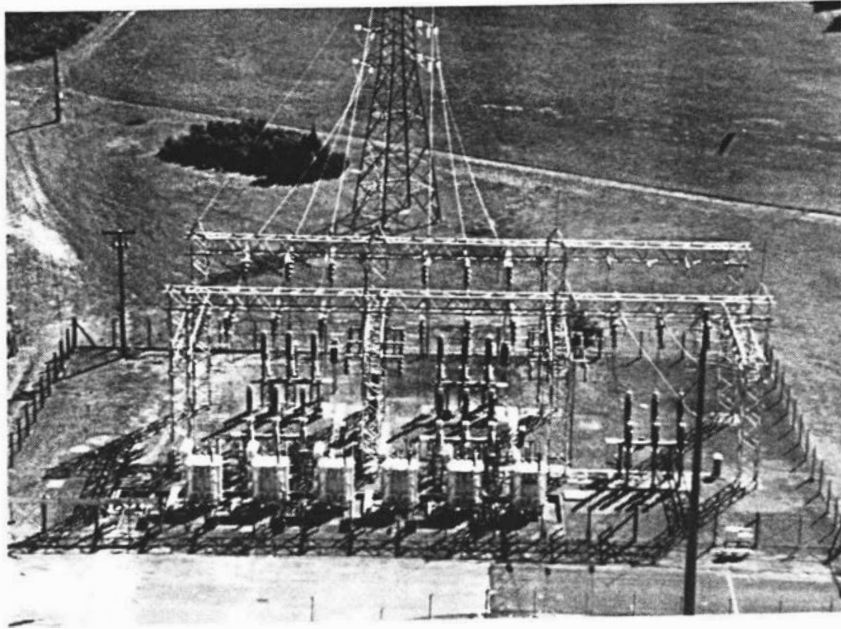


FIGURE 7.6 Electricity distribution substations and high-voltage lines within the Whakatane District.

A. Electricity substations and lines. B. System configuration.

A



B

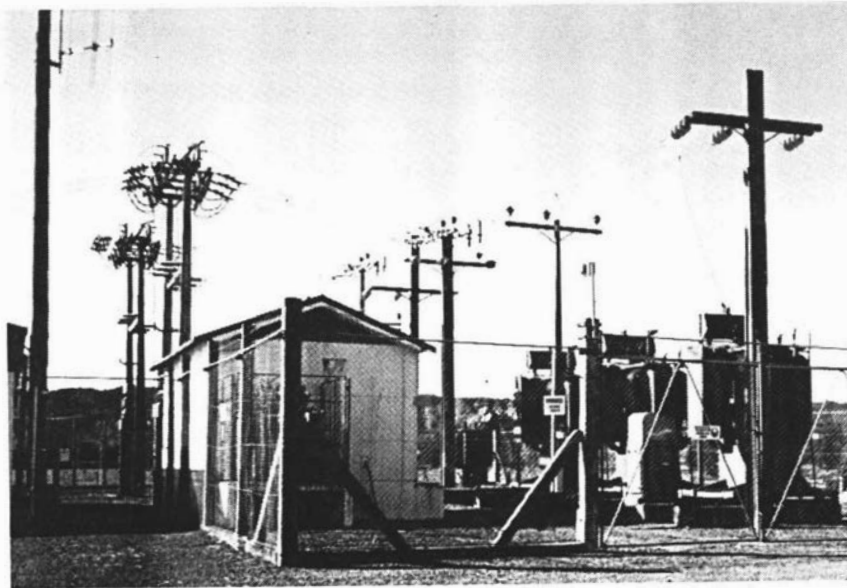


FIGURE 7.7 Examples of two substations: A) Matahina (located below the hydroelectric dam); and B) Station Road (33 kV→11 kV).

TABLE 7.5 WHAKATANE ELECTRICITY VULNERABILITY CHART

* See Chapter 4, Table 4.1 for vulnerability chart key

Component	Importance	Ash condition	Vulnerability to direct ash falls								Interdependence		Backup or redundancy	Impact of being damaged			
			Becoming Inoperative				Damage				Element	Reliance		During ash falls	Immed. after	Period following	Return to normal
			< 5 mm	5-20 mm	20-100 mm	> 100 mm	< 5 mm	5-20 mm	20-100 mm	> 100 mm							
TransPower Substations	4																
Edgecumbe	3	{wet {dry	2 1	3 2	3 3	3 3	2 1	3 2	3 3	3 3	outside supply	2-3	altern. supply routes	3	3	3	3
Kawerau	2																
Matahina	1																
BoP Electricity	5																
Ohope	2	{wet {dry	2 1	3 2	3 3	3 3	2 1	3 2	3 3	3 3	Transpower supply	2-3	none	3	3	3	3
Whakatane	3																
Edgecumbe	2																
Matahina Dam	1		1	2	2	3	1	2	3	3	water quality of the Rangitaiki River	3	none	1	1	2	2

Impacts of the scenario eruption

The heavy falls of volcanic ash will disrupt electricity supply over a wide area in several ways. Heavy accumulations of ash on tree limbs will break them, and where they fall onto local distribution lines, will short or break the lines. Damp or wet ash-coatings on substation and line insulators would induce flashovers causing widespread outages. The high-voltage substations at Edgecumbe and Kawerau are closer to the volcano and would receive greater ash thickness. Failures at either substation will result in loss of supply to Whakatane. High-voltage lines to Edgecumbe pass through areas of >500 mm of ash fall, to the north and south of the volcano. Light post-eruption rainfalls are more likely to induce flashovers than are heavy rainfalls, which will tend to remove ash coatings from insulators. The abrasive nature of ash causes some damage to mechanically moving parts, such as substation switches and cooling fans. Corrosion damage will also be a major problem to all equipment. Both Matahina and Aniwhenua hydroelectric power stations will be affected by high river turbidity, causing abrasion to turbines if generation is continued post-eruption.

The consequences of loss of electricity supply are widespread, and many other public utilities will be inoperative for the duration of the power loss. The cleaning and repair of the damaged electricity system will be an expensive and time-consuming process, hindered by lack of personnel and equipment, and on-going hazards (lahars, reworking of ash and minor ash falls). Local power companies may have problems if large sections of powerlines need to be replaced and a shortage of line would hinder recovery of the services. TransPower high-voltage lines may need to be physically cleaned of ash and if a large section of line requires cleaning, the operation would be a costly procedure and require major resources.

7.5.8 WATER SUPPLY

The water supply for Whakatane town is derived from the Whakatane River. Water is pumped from the river to the treatment plant (Figs. 7.8-7.10) located on the south bank of the river. On entering the plant, water passes through a silt trap before moving through a clarifier and sand filter system and then into holding tanks, where chlorine and fluoride are added. Water is then pumped to a series of reservoirs as outlined in Figure 7.8. The water stored in reservoirs offers a 12 to 24 hour buffer to the supply. An ash fall vulnerability assessment is summarised in the vulnerability chart presented in Table 7.6.

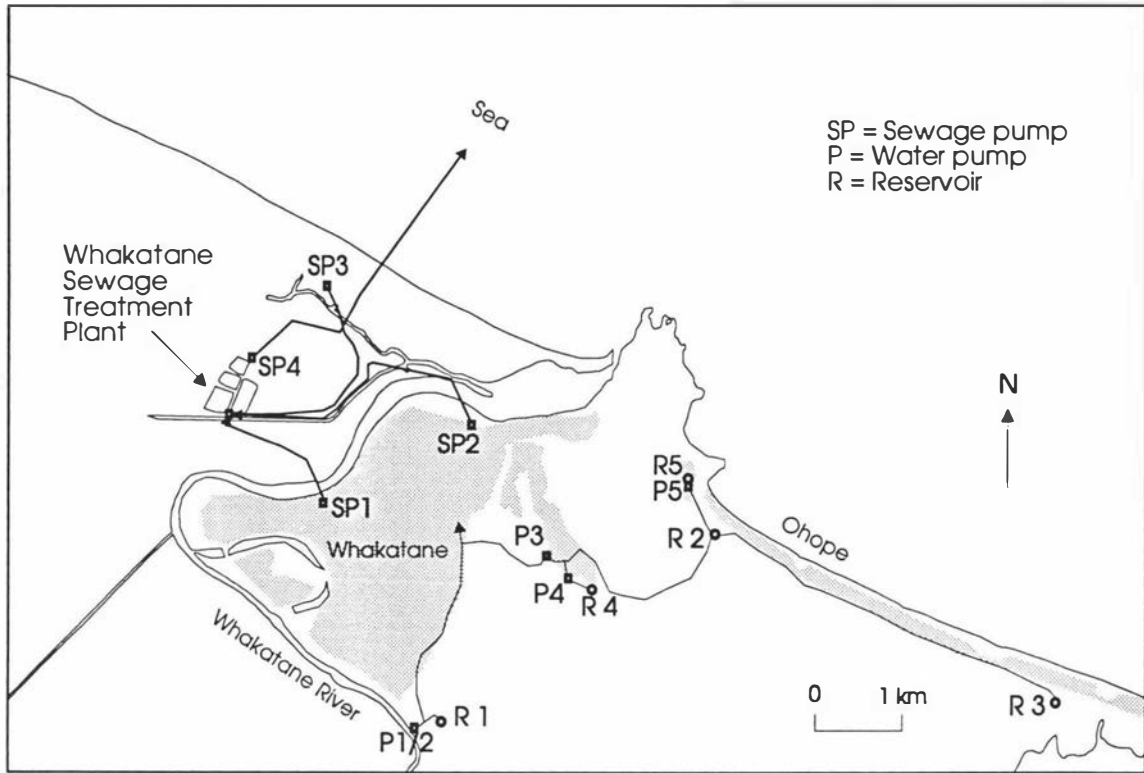


FIGURE 7.8 Location map of water and wastewater reticulation system in Whakatane.

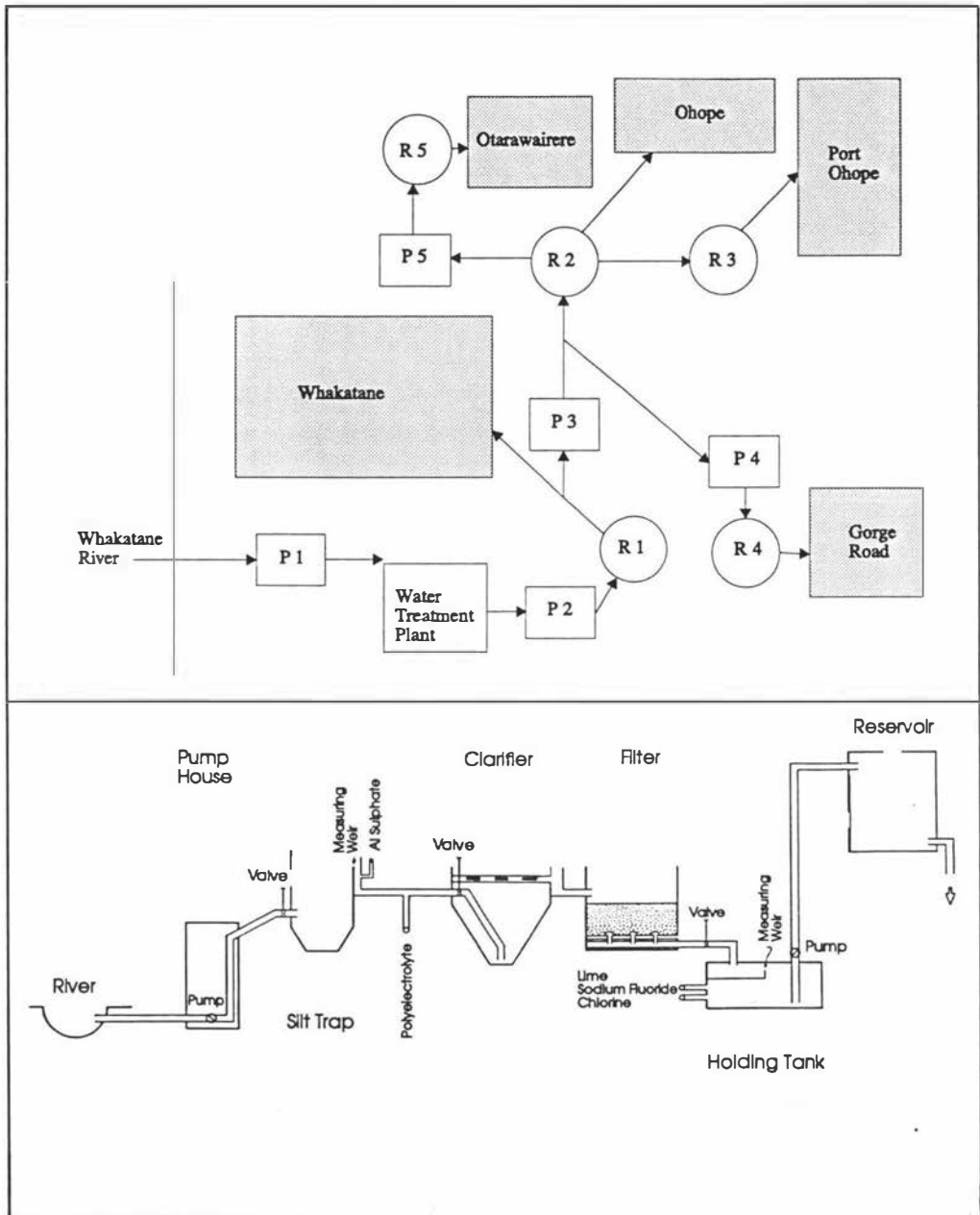


FIGURE 7.9 A. Systems map of the Whakatane water supply; B. Diagram of the water treatment plant.

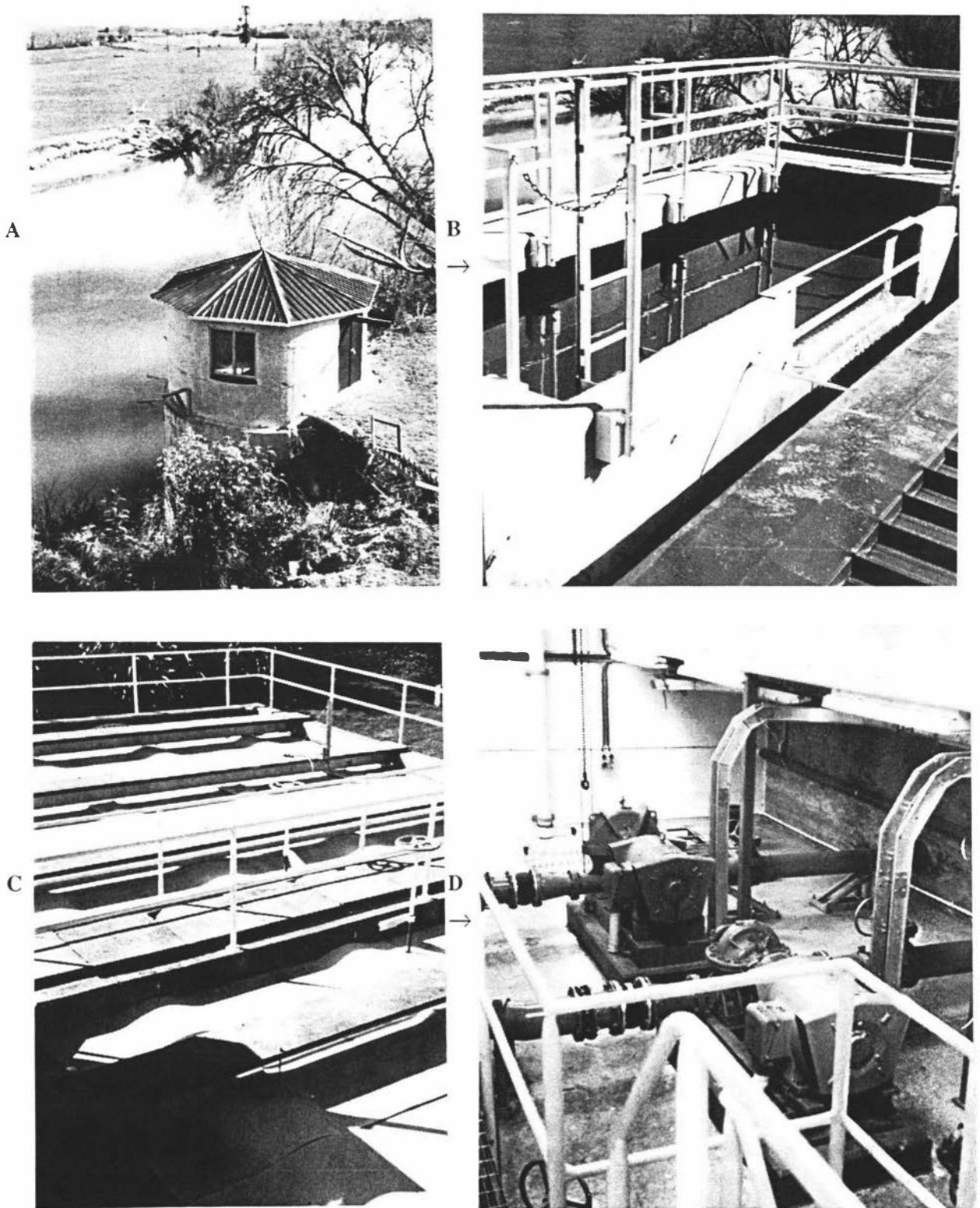


FIGURE 7.10 Whakatane Water Treatment Plant

A. The Whakatane River and pump house. B. Silt trap. C. Clarifier. D. Electric water pumps that feed the town's reservoirs.

TABLE 7.6a WHAKATANE WATER SUPPLY VULNERABILITY CHART

* See Chapter 4, Table 4.1 for vulnerability chart key

Component	Importance	Vulnerability to direct ash falls								Interdependence		Backup or redundancy	Impact of being damaged			
		Becoming Inoperative				Damage				Element	Reliance		During ash falls	Immed. after	Period following	Return to normal
		< 5 mm	5-20 mm	20-100 mm	> 100 mm	< 5 mm	5-20 mm	20-100 mm	> 100 mm							
Whakatane River	5	2	3	3	3	0	1	2	2	river catchment area	3	none	1	2	3	3
Water Treatment Plant	5	1	2	3	3	1	2	3	2	needs electricity water- quality	3 3	none	2	2	3	3
Pumps																
P 1	5	1	1	1	2	1	1	2	2	needs electricity	3	none	1	2	3	3
P 2	2	0	1	1	2	1	1	2	2	needs electricity VIII: telemetry	3 2	none none	1	2	3	3
P 3	1	0	1	1	2	1	1	2	2	needs electricity VIII: telemetry	3 2	none none	1	2	3	3
P 4	1	0	1	1	2	1	1	2	2	needs electricity VIII: telemetry	3 2	none none	1	2	3	3

TABLE 7.6b WHAKATANE WATER SUPPLY VULNERABILITY CHART

* See Chapter 4, Table 4.1 for vulnerability chart key

Component	Importance	Vulnerability to direct ash falls								Interdependence		Backup or redundancy	Impact of being damaged			
		Becoming inoperative				Damage				Element	Reliance		During ash falls	Immed. after	Period following	Return to normal
		< 5 mm	5-20 mm	20-100 mm	> 100 mm	< 5 mm	5-20 mm	20-100 mm	> 100 mm							
Reservoir																
R 1	5	0	1	1	2	0	0	1	2	needs water VIII ² telemetry	3 2	up to 24 hours supply when full for all	3	3	3	3
R 2	2	0	1	1	2	0	0	1	2	needs water VIII ² telemetry	3 2		3	3	3	3
R 3	1	0	1	1	2	0	0	1	2	needs water VIII ² telemetry	3 2		3	3	3	3
R 4	1	0	1	1	2	0	0	1	2	needs water VIII ² telemetry	3 2		3	3	3	3
R 5	1	0	1	1	2	0	0	1	2	needs water VIII ² telemetry	3 2		3	3	3	3

Impacts of scenario on Whakatane town

Whakatane's water supply system would be severely affected by the eruption through loss of electricity, contamination of the river water and direct damage to the treatment plant.

Both turbidity and acidity of Whakatane River water will increase with direct ash falls in the river's catchment. Intense rainfalls will wash further ash into the river. Water pumps at the riverside water treatment stations will be blocked by suspended ash, and water intake at the treatment stations would be stopped until the river had cleared. Hazardous changes in river water chemistry are possible, induced by toxic trace elements (including selenium, mercury, arsenic, fluorine and boron) contained in condensates on in-falling ash. However, this is considered unlikely due to the dilution and buffering properties of the relatively large volumes of river water. Continuing contamination of the Whakatane River by the movement of sediment from the ash-covered catchment areas will present on-going problems for water supplies at Whakatane for months after the eruption. Conditions will gradually improve but turbidity levels will increase rapidly and repeatedly after periods of heavy rain.

Direct ash falls (200 mm) on the treatment plant will cause damage to facilities, in-filling the contact chambers, silt traps, clarifier and filters (all open to the atmosphere) and may cause contamination of much remaining water. If electricity supplies were available ash-induced pump damage could occur if contaminated water is pumped. Ash falls may cause collapse of reservoir roofs. Corrosion damage of equipment and buildings will result from ash in direct contact with metal surfaces.

7.5.9 WASTEWATER RETICULATION AND TREATMENT

Whakatane uses an oxidation pond sewage treatment system which relies on electric pumping stations (Figs. 7.8 & 7.11). Sewage and stormwater are not combined. Stormwater is pumped from parts of the town into the Whakatane River. Sewage is treated by a three stage process at the treatment plant before being pumped to the ocean (Figs. 7.11 & 7.12). An ash fall vulnerability assessment is summarised in the vulnerability chart presented in Table 7.7.

Impacts of the scenario eruption on Whakatane town

Ash falls of 200 mm will cause serious problems for Whakatane's sewage and stormwater systems. Ash from roads, roofs and other impervious areas will be easily washed into the stormwater system by rain. Where stormwater drains are partially blocked the hydraulic capacity will be reduced, lowering the overload threshold. Local flooding will occur following periods of rain where drains are completely blocked.

Ash will enter the sewage system via illegal connections but most will rapidly settle out. Ash

that does remain in suspension will be transported to the sewage treatment plant if pumps remain operative. This is unlikely due to loss of electricity, and sewage will bank up in urban areas. However, since most people would have left the town this is not of major immediate concern.

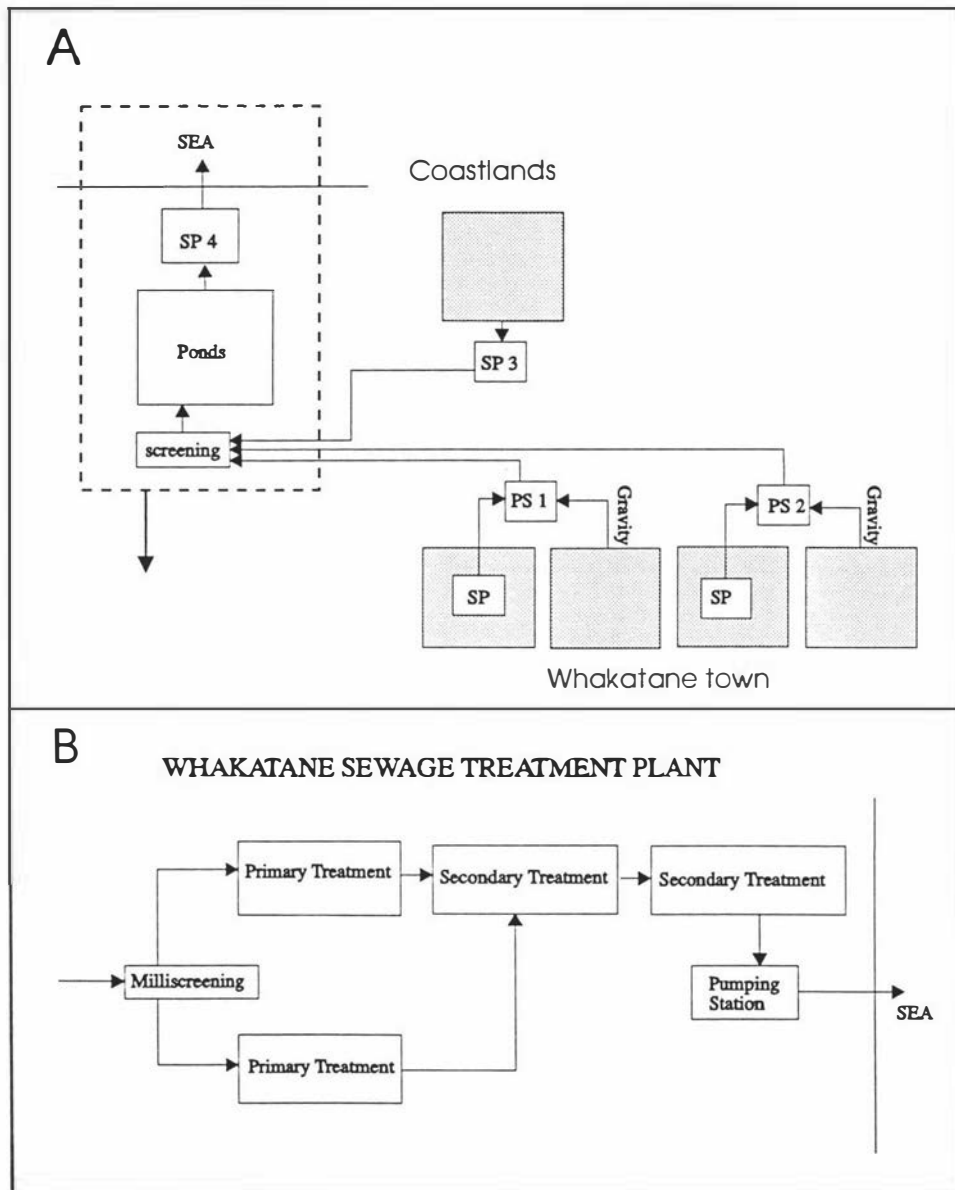
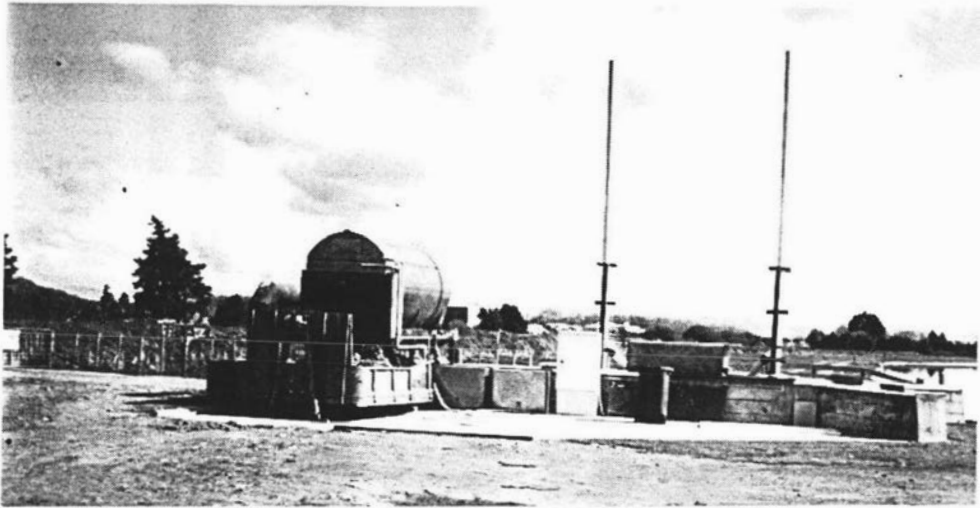


FIGURE 7.11 A. The sewage system in Whakatane; B. Sewage treatment plant. Primary treatment involves passing the sewage through sedimentation ponds and secondary treatment involves biological oxidation.

A



B



C

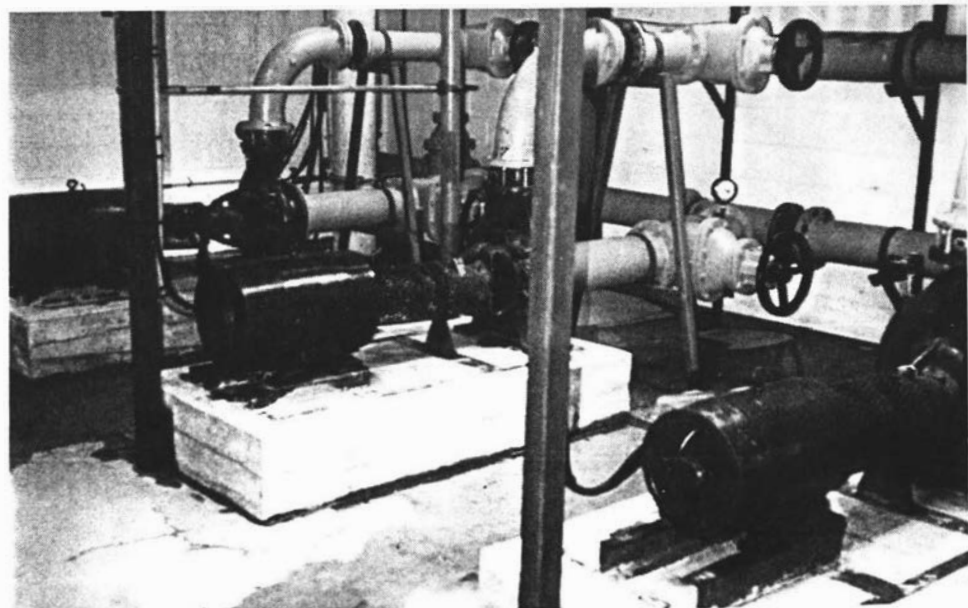


FIGURE 7.12 Whakatane sewage treatment plant

A. The milliscreening plant: B. Sewage ponds: C. Treated sewage outflow pumps.

TABLE 7.7 WHAKATANE SEWAGE SYSTEM VULNERABILITY CHART

* See Chapter 4, Table 4.1 for vulnerability chart key

Component	Importance	Vulnerability to direct ash falls								Interdependence		Backup or redundancy	Impact of being damaged			
		Becoming Inoperative				Damage				Element	Reliance		During ash falls	Immed. after	Period following	Return to normal
		< 5 mm	5-20 mm	20-100 mm	> 100 mm	< 5 mm	5-20 mm	20-100 mm	> 100 mm							
Sewage pumps	5	1	1-2	2	2	1	1	1	2	needs electricity VHF telemetry	3	none	1	3	3	3
Sewage mains	5	1	1-2	2	3	1	1	1	2				1	3	3	3
Sewage plant	5	2	2	3	3	1	1	1	2	needs electricity	3	back-up generator	2-3	3	3	3
Screening plant	5	2	2	3	3	1	1	1	2				2-3	3	3	3
Primary pond	5	1	2	3	3	1	1	1	2				2-3	3	3	3
Tertiary pond	5	1	2	3	3	1	1	1	2				2-3	3	3	3
Outflow pump SP 4	5	1	2	3	3	1	1	1	2	needs electricity supply	3	back-up generator	2-3	3	3	3

Any ash-laden sewage which enters the treatment plant will overload the solid-removal equipment at the pre-treatment and primary treatment stages. Milliscreens and other equipment that comes into contact with ash-laden sewage are likely to be rapidly worn and/or damaged. Ash falling directly into sedimentation tanks will add to the volume of solid material. Ash entering the oxidation ponds will halt the oxidation process, with pumice and pumiceous ash initially floating to form a mat on the surface of the ponds. The ash will affect the acidity or toxicity level of the effluent to an extent that bacterial growth will be lost. Release of untreated sewage will most likely result from failure of the plant.

Restoration of the town's wastewater system will be an expensive process and will be required before the majority of evacuees would be able to return.

7.5.10 COMMUNICATIONS

The Bay of Plenty Telecom network provides local and external telephone links in the district. The telecommunications network in the Bay of Plenty is shown in Figure 7.13. Local lines are connected to local telephone exchanges (Figs. 7.14 & 7.15) which are in turn linked to microwave repeater radio stations (nodal points) by underground copper or fibre cables. The microwave radio stations transmit and receive calls to and from neighbouring stations. A number of microwave stations are also the sites of VHF and cellular telephone stations. A fibre-optic cable now links Whakatane with Tauranga. An ash fall vulnerability assessment is summarised in the vulnerability chart presented in Table 7.8.

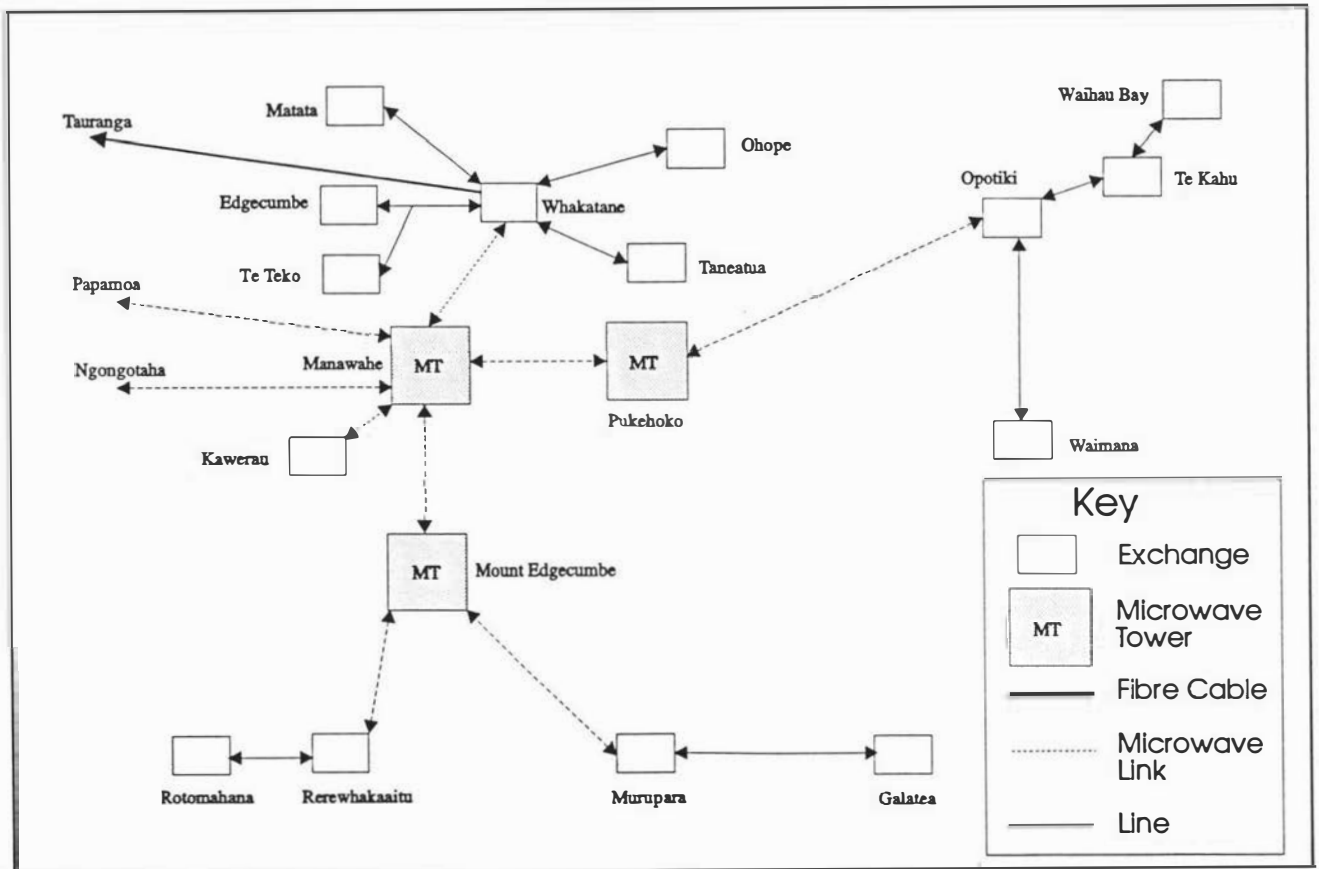
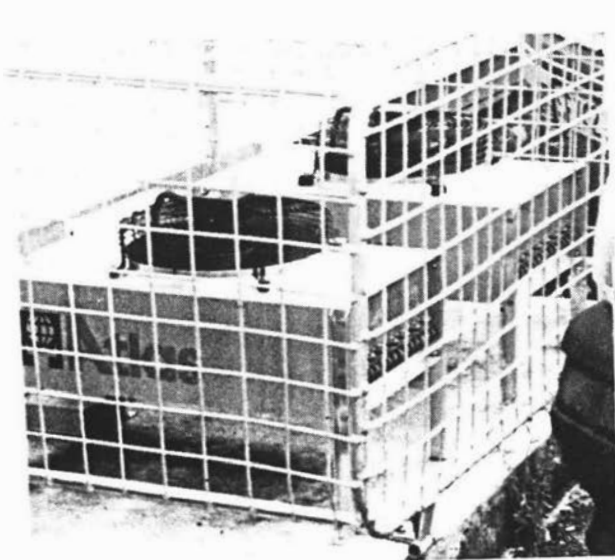
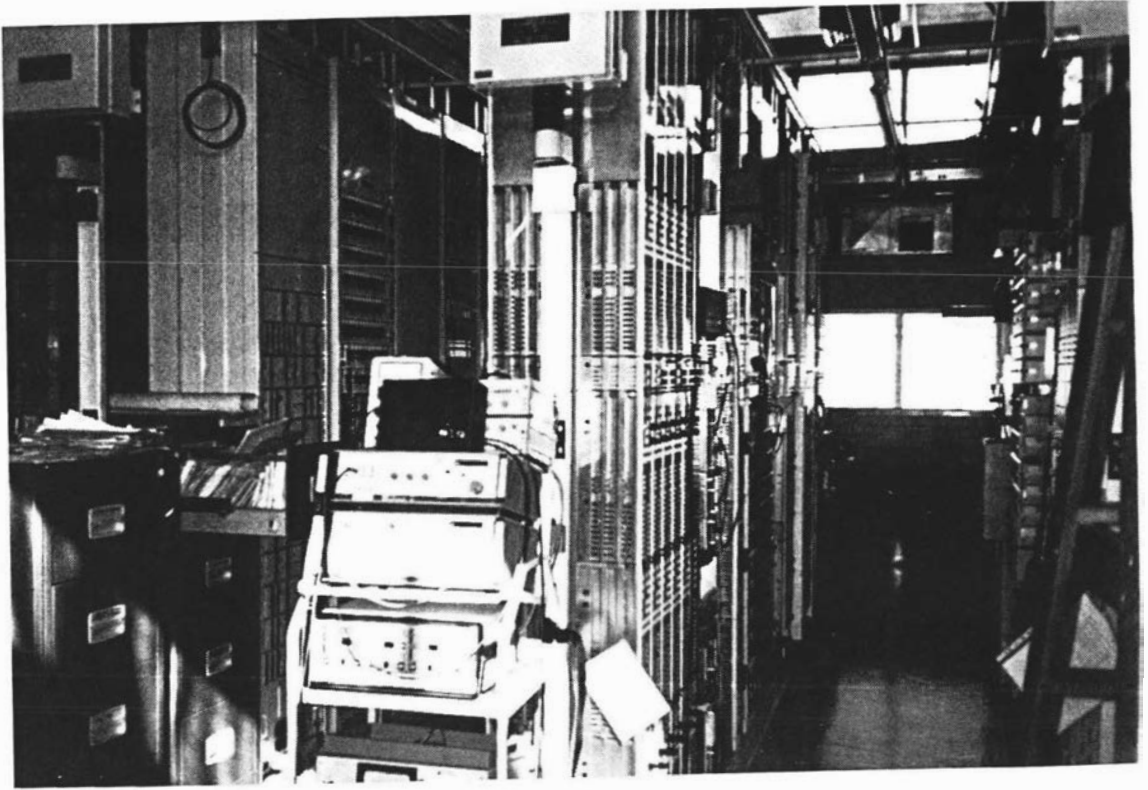
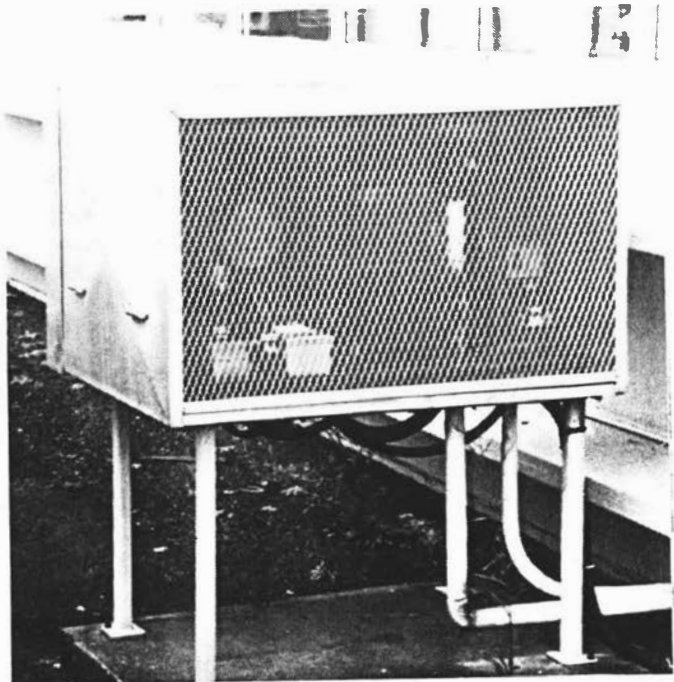


FIGURE 7.13 The Telecom network in the Whakatane District. Many exchanges have multiple interconnections by both fibre-optic cables and microwaves, providing system redundancy and back-up links. See Figure 7.4 for microwave tower locations.

A



B



C

FIGURE 7.14 Whakatane Telephone Exchange

A. Switching gear; B and C. Air-conditioning units.

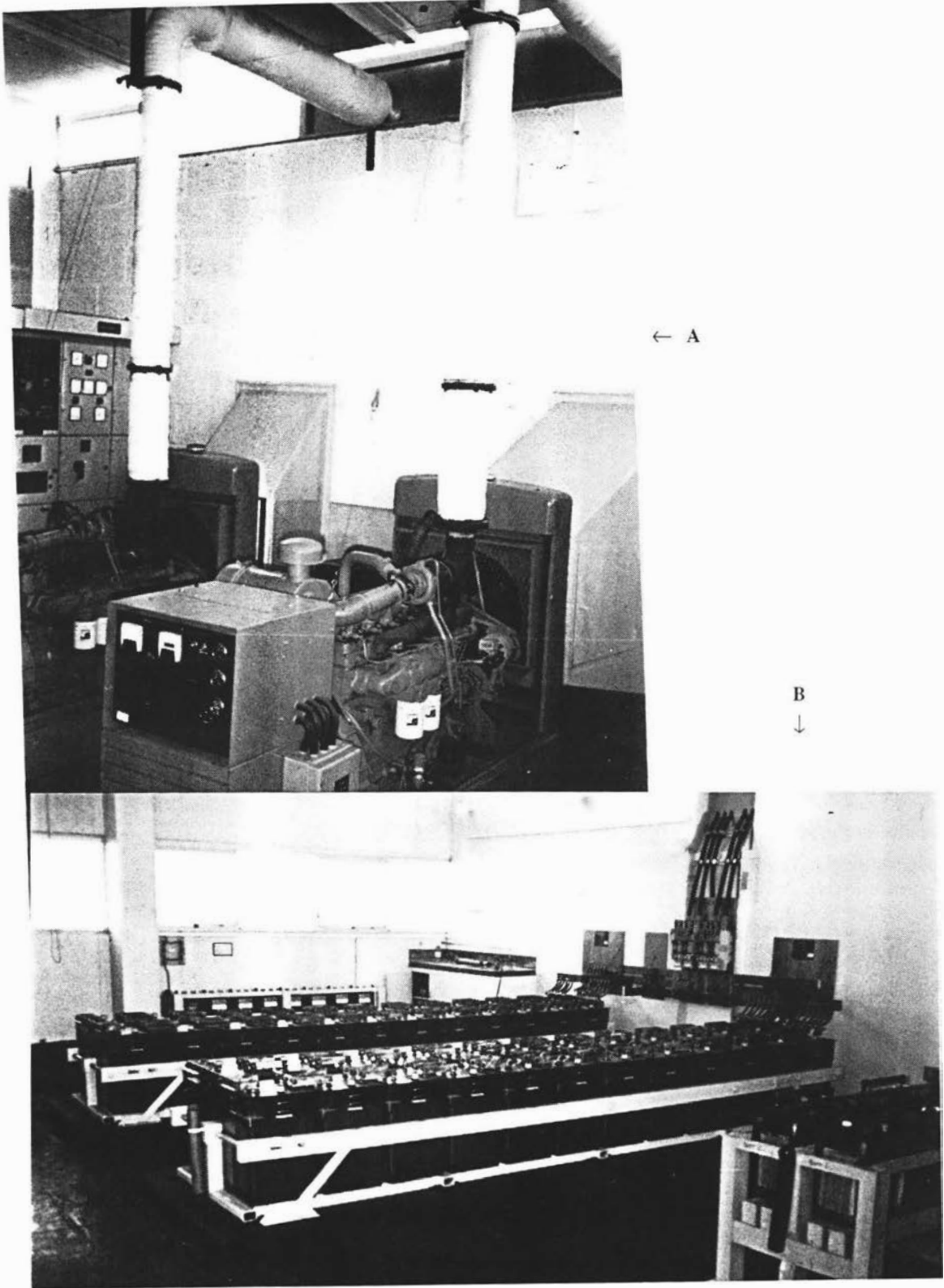


FIGURE 7.15 Whakatane Telephone Exchange

A. Back-up diesel generator: B. Battery room

Exchanges require electricity supplies but all have back-up batteries, and some have back-up generators.

TABLE 7.8 WHAKATANE TELECOM NETWORK VULNERABILITY CHART

* See Chapter 4, Table 4.1 for vulnerability chart key

Component	Importance	Vulnerability to direct ash falls								Interdependence		Backup or redundancy	Impact of being damaged			
		Becoming inoperative				Damage				Element	Reliance		During ash falls	Immed. after	Period following	Return to normal
		< 5 mm	5-20 mm	20-100 mm	> 100 mm	< 5 mm	5-20 mm	20-100 mm	> 100 mm							
Exchanges (a)	5	3	3	3	3	1	2	2	2	needs electricity, cooling	3 3	Back-up generator/batteries	2	3	3	3
Air-con. units (b)	5	3	3	3	3	2	2	3	3	needs electricity	3		3	3	3	3
Microwave towers	3	1	1	2	3	1	1	2	3				2	3	3	3
Lines	4	1	1	2	2-3	1	1	2	3				2	3	3	3
Cables	3	0	0	0	0	0	0	0	0				2	3	3	3

a. assumes external air-conditioning.

b. damage assessment assumes exposure to direct ash fall but the item is not used.

Impacts of the scenario eruption

Communications will be severely disrupted during an eruption in the district, resulting from interference to radio waves due to disturbed atmospheric electrical conditions, overloading of telecommunication systems due to increased demand, direct damage to communications facilities by eruption products or lightning strikes and indirect impacts resulting from disruption to electricity supplies or transportation of communication workers (preventing operations or maintenance). Ash entering telephone exchanges can cause damage to electrical and mechanical systems and general damage to buildings. Failure of air-conditioning units will result in overheating of switching equipment resulting in its shut-down (even if electricity supplies are still available). Exchanges have battery/generator backup power systems to enable continued operation in the event of loss of electricity supply; however, generators rely on external air intakes to air filters. Clogging of these filters by ash would result in failure of the generator, followed by exhaustion of the battery capacity after a few hours' demand.

Any loss of communications will make disaster management extremely difficult before, during and after the eruption. Restoration of the telephone network will be largely driven by the speed and extent of the rehabilitation of the district.

7.5.11 GAS SUPPLY AND RETICULATION

Treated natural gas is piped from the Maui gas field to the Whakatane area by the Natural Gas Corporation and supplied to domestic customers. The pipes are usually buried to more than 0.9 m depth. Automatic shutdown equipment at points along the pipeline is designed to cut off the gas supply if the pipe is ruptured. Gas pressure is reduced at pressure-reducing stations (sales gates) for local supply (Fig 7.16). Metering equipment does require mains electricity but has back-up battery supplies. However, long term loss of supply may cause problems.

Impact of the eruption scenario

Most gas pipes are located below ground and are thus protected from the direct effects of ash falls. Above-ground pumping stations, pressure reduction facilities, pipeline bridge crossings and gas meters at consumers' sites are vulnerable to damage from a range of volcanic hazards. Sales gates will be covered by varying thicknesses of ash which will cause some problems but initially few disruptions to users. However, ground-shaking induced by volcano seismicity may rupture the main feeder pipelines, cutting supplies.

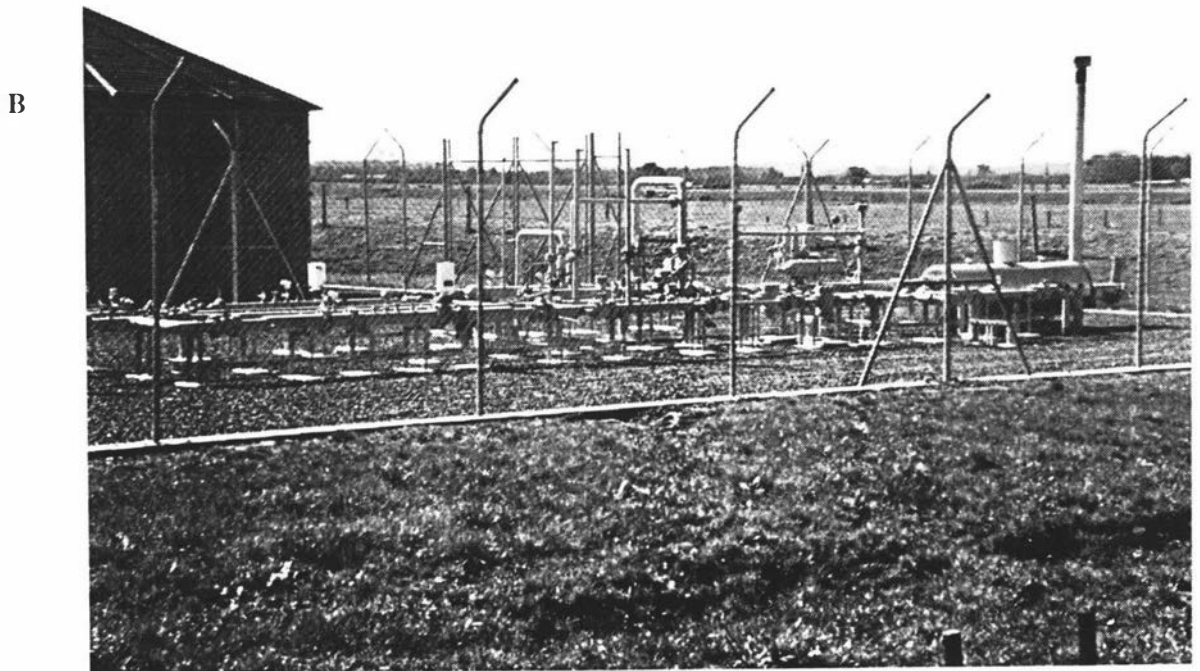
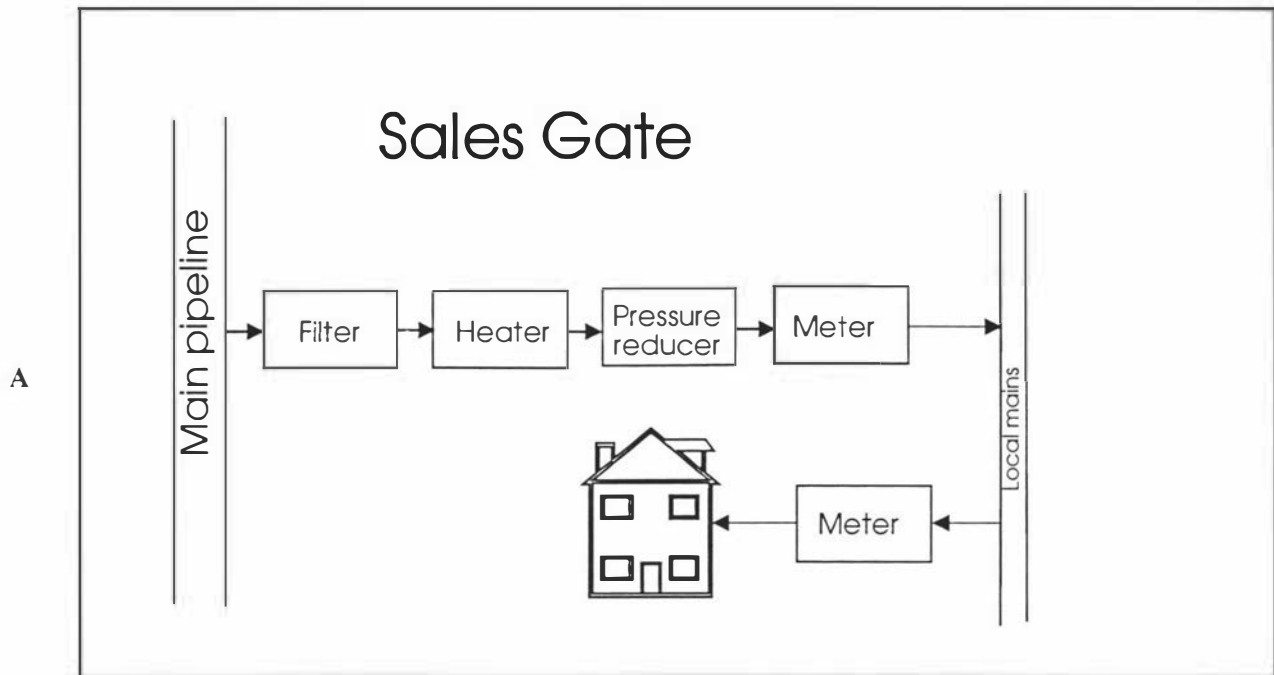


FIGURE 7.16 Gas supply sales gate.

Sales gates are used to reduce the gas pressure between the supply pipeline and the local mains. A. shows a schematic layout of their operation. Gas is filtered and heated before decompression at the next stage. The Edgumbe sales gate is shown in B. and has a low vulnerability to minor ash falls (a few mm) but the heater unit is vulnerable to greater ash thickness.

7.6 INTERDEPENDENCE OF 'LIFELINES'

The interdependence of 'lifelines' has been discussed in detail in the previous chapter and many of the same conclusions hold for Whakatane. However, the greater magnitude of the physical impacts in this scenario to key 'lifelines' will have serious repercussions to most others. Table 7.9 shows the interdependence of the Whakatane 'lifelines'.

TABLE 7.9 The interdependence of Whakatane 'lifelines'.

Depends on													Total Importance		
	Water Supply	Gas Supply	Sewerage	Storm Water	Mains Electricity	Standby Electricity	VHF Radio	Telephones	Roads	Rail	Air transport	Fuel Supply		Fire Fighting	Air-conditioning
Water Supply	*	*	1	*	*	*	*	*	*	*	*	*	3	2	6
Gas Supply	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0
Sewerage	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0
Storm Water	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0
Mains Electricity	2	1	2	2	*	2	3	*	1	3	2	*	3	21	
Standby Electricity	3	1	3	3	*	1	3	*	3	2	*	2	2	21	
VHF Radio	3	3	3	2	3	*	2	2	2	3	*	3	*	26	
Telephones	2	1	1	*	1	1	2	*	1	1	1	2	*	13	
Roads	2	2	2	2	3	2	1	2	2	3	2	3	1	27	
Rail	*	*	*	*	*	*	*	*	*	*	*	*	*	0	
Air Transport	*	*	*	*	*	*	*	*	*	*	*	*	*	0	
Fuel Supply	3	1	1	1	*	3	1	2	3	2	3	3	*	23	
Fire Fighting	*	*	*	*	*	*	*	*	*	2	1	*	*	3	
Air-conditioning	*	*	*	*	2	2	*	3	*	2	*	*	*	9	
Equipment	3	3	3	2	3	3	3	3	3	3	3	2	3	40	
Total Dependence	18	12	16	12	12	11	10	18	8	11	23	10	17	11	
Priority Factor	24	12	16	12	33	32	36	31	35	11	23	33	20	20	

Note: 3 = High Dependence
 2 = Moderate Dependence
 1 = Low Dependence
 * = No Dependence

Priority Factor = Importance + Dependence

7.7 EVACUATION AND PUBLIC HEALTH ISSUES

Evacuation will be deemed necessary by the Regional Civil Defence Controller for most people in the district (as well as several tens of thousands of residents of neighbouring districts). The district civil defence has the responsibility for implementing the evacuation. It is estimated around 60 to 70% of people are able to self-evacuate. Numbers needing help include people without access to private vehicles and those with special needs (eg. those from Whakatane Hospital, rest homes and disabled persons), possibly as many as 5000 people in Whakatane town alone. Any large scale evacuation will require careful coordination. With a police force of just over 300 in the Bay of Plenty Region, additional man-power would be needed from outside. Post-eruption evacuation may also become necessary in areas where people have survived the ash fall without difficulty, but in which the long term disruption to 'lifelines' such as water and food supply, electricity and waste disposal, along with loss of

livelihood make continued habitation untenable. This would also apply to areas subject to continuing inundation by lahars and/or flooding caused by lahar-induced changes to drainage patterns.

Those remaining in areas close to the vent during the climactic eruptive event have a high risk of death from pyroclastic flows. People caught in pyroclastic flows are most unlikely to survive unless protected in some way by substantial buildings or natural features on the periphery of the flow (Baxter 1990). Lahars down the Tarawera River will be fatal to anyone caught in their path. Loss of life would be from severe crush injuries, drowning or asphyxiation. The collapse of long span flat-roofed buildings in Whakatane and other ash-affected communities presents a high risk to anyone sheltering beneath them. Even after the ash falls have stopped, roofs may continue to collapse. Those still in ash fall areas are advised to stay indoors preferably in well pitched roof buildings, but where it is necessary to move outside a protective filter mask should be worn. The presence of thick ash on roads and poor visibility may result in numerous vehicle accidents.

The disruption to daily life and forced evacuation will cause high levels of stress. Stress and/or distress of individuals may last for some time. This does not necessarily lead to mental illness or mental health problems, but rather to temporary problems in everyday living (Taylor 1988). However, rates of mental health problems are likely to increase in the affected populations.

7.8 SOCIOECONOMIC CONSEQUENCES

An accurate estimate of the economic impacts of this scenario eruption is extremely difficult to assess and beyond the scope of this thesis. A volcanic eruption from the Okataina Volcanic Centre would impact on all aspects of urban and rural life in the Whakatane District (as well as neighbouring districts) and would have a major impact on the national economy. In this scenario the recovery process would be driven largely by a range of interrelated social, political and economic decisions and would involve the rehabilitation of the district rather than a simple restoration of damaged 'lifelines', industries and communities.

7.8.1 Forestry - agriculture - horticulture

The effects to forestry, agriculture and horticulture would be severe. Forests within the path of pyroclastic flows will be destroyed and others damaged by thick ash falls. Pine seedlings and small trees will be killed as a result of excessive bending and burial while large mature trees will suffer from branch breakage under the load of ash. Despite the wide-spread ash fall, large volumes of timber would still be available for harvest post-eruption.

The Rangitaiki Plains would be covered by 100- 500 mm of ash, which would be sufficient

to bury grasses and kill small trees. The loss of buried pasture would result in food shortages to stock. Livestock farmers may be faced with a number of hard choices. The removal of stock before an eruption raises a number of problems, not least in requiring confidence that a predicted eruption will actually occur. Since most farms in New Zealand currently run at or near peak carrying capacity, they would find it hard to cope with large numbers of additional animals from this district. Likewise freezing works may not be able to increase their killing capacity to sufficiently cope with any wholesale destocking of farms. The degree to which abattoirs could take increased numbers of stock would obviously be dependent on the time of year. The logistical problems of moving stock out of the district would also need to be considered. Stock stranded in areas without feed would most probably need to be shot as the only practical and humane way of dealing with them.

The recovery of land buried under ash is dependent on the ash thickness and the land slope. Arable land with less than 200 mm of ash could be ploughed, revitalizing the soil by mixing the ash with the buried former soil. Such land could be brought back into production within one year once it is resown. Additional nutrients may need to be added. Where ash is too thick for ploughing to reach the former soil layer two options are possible. Land of high agricultural value could be (a) graded or 'mined' to remove the ash to a thickness to allow ploughing; or (b) the new ash may need to be utilized in situ by planting deep rooting species that can survive in nutrient-depleted and usually droughty soils (possibly pines). Problems associated with lahars down the Tarawera River will affect western parts of the Rangitaiki Plains for many years. Hill country may recover faster where ash is naturally stripped from steep slopes, exposing the former soil layer or previous vegetation. Redeposition of eroded ash will create many problems downslope and downstream.

7.8.2 Business and industry

All businesses and industry in the district would be required to deal with a huge range of issues prior to, during and after the eruption. Prior to any eruptive activity implementation of mitigation measures and decisions about the relocation of transportable assets would need to be considered. The uncertainty of the timing of the eruption or whether there will even be an eruption would impose enormous pressure on those in decision-making positions. Business slow-downs and loss of staff could occur in this pre-eruption period.

The eruption would have devastating impacts on the district's four largest industrial sites. The paper mills at Kawerau would be extensively damaged, with wide-spread roof collapse and inundation by lahars. Combined with the damage to the nearby town and continuing laharc activity for years to come the site would most likely be abandoned. A similar fate could befall the Bay Milk plant at Edgecumbe, with the near total loss of milk production on the Rangitaiki Plains and extensive ash loading damage to the plant. Extensive damage from collapsed roofing would occur at the Whakatane Board Mills but less than at Kawerau.

Depending on the extent of damage, restoration of the plant may be possible but disruption to supporting 'lifelines' would hinder this process.

In general, the ability for businesses to recover and the time required is dependent on: a) the amount of physical damage to plant and equipment; b) loss of or interruption to vital 'lifelines' (electricity, water supplies, waste disposal, transport, communication); c) disruption of raw material supplies; d) loss of workforce; and e) loss or disruption of the market for goods. The decision to reestablish certain industries would have a major impact on the viability of many smaller businesses and may drive their recovery.

7.8.3 Individuals

The eruption would affect individuals in many ways including forced evacuation, damage to property and possessions, loss of personal income, depletion of personal savings and unemployment. Losses will not be evenly distributed across the community, with certain groups more vulnerable than others (Paton 1996). Those with relocatable assets and skills will be far less affected than those without. Damage to properties and contents would be covered by the Earthquake Commission and private insurance companies. However, the issue of whether full insurance cover would be extended to evacuees whose properties receive only minor damage but are uninhabitable due to damaged 'lifelines' (e.g. electricity, water, sewerage) needs to be addressed. Many individuals and families will simply 'cut their losses' and resettle elsewhere in the country, even when a return to the district is possible.

7.8.4 Local government

This scenario will have extreme impacts on both the regional and district councils, in terms of management of the pre-eruption crisis, response to the eruptive events and rehabilitation of the affected areas. Many of the councils' assets will be damaged or destroyed and many of their traditional functions temporarily suspended or reduced. The loss of residents (permanently or temporarily) would have a major effect on the rating base of the district, and the economic impacts suffered by those remaining will be exacerbated by their inability to pay for traditional services. As the recovery process would require resources beyond those available locally, it would be driven by decisions made at both the regional and national level.

7.8.5 Central government

Almost all government departments and organisations will be affected by this scenario. Those listed in the previous chapter will have an even greater range of issues to contend with. The economic effects will be felt nationally due to factors such as: diversion of investment capital into recovery, alteration of land and property values, alteration of population growth and migration and increased tax burdens to finance the response and recovery.

7.9 CONCLUSIONS

The Whakatane District's infrastructure would be severely damaged by this eruption scenario and would suffer socioeconomic effects for many years. Immediately after the eruption all forms of transportation would be halted by the ash falls. Electricity supplies would be cut by shorting at substations, loading damage and/or breakage of power lines. Water supplies in Whakatane town would be cut due to river turbidity, damage to the treatment plant and failure of electricity. High turbidity will continue for many months to years. Sewage and stormwater systems would be blocked. Many flat roofed buildings in Whakatane town would collapse but most pitched roofed residential houses would survive. However, most houses will suffer some loading and corrosion damage. This scenario would impact on all aspects of urban and rural life in the Whakatane District (as well as neighbouring districts) and would have a major impact on the national economy. The recovery process would be driven largely by a range of interrelated social, political and economic decisions and would involve total rehabilitation of the district rather than a simple restoration of damaged 'lifelines', industries and communities. The recovery process would be expensive and time-consuming, and would need to be carefully coordinated in order to maximise the use of limited resources to meet a range of social and economic circumstances.

CHAPTER 8

PERCEPTIONS OF VOLCANIC HAZARDS AND RISK IN WHAKATANE AND HASTINGS

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8.1 INTRODUCTION

An individual's perceptions of a subject are simply intuitive judgements and represent an active process whereby an individual attempts to 'fit' new data into pre-existing psychological schemata (i.e. they impose meaning on information). Researchers have attempted to explain the differences in individual perceptions of hazards and risk over the past three decades, and to develop techniques for assessing the complex opinions that individuals have about risk (Drabek 1986; Lindell 1994). There are often subtle variations in perceptions between individuals and groups in our society. The public's perception of risk is often found to be biased with people often overestimating small probability events and underestimating large ones (Slovic 1987). Typically individuals do not reason about risk by weighing and combining available evidence in a rational and logical way, but employ a number of mental strategies (heuristics) which sometimes yield reasonable judgments and sometimes lead to severe systematic errors (Kahneman & Tversky 1973). People appear not to be motivated solely to be accurate or correct. Accuracy may be sacrificed to some extent in favour of other motivations (e.g. maintenance of self-esteem, interpersonal goals) (Higgins & Bargh 1987). This is against the assumption that inaccurate or biased processing of information must be due to cognitive limitations rather than motivational factors. Perceptual/psychological approaches to hazard/risk involve accessing the conceptual structures that facilitate awareness and understanding.

Numerous studies of risk have attempted to isolate individual risk perception factors. Slovic *et al.* (1981) measured 18 characteristics of risk and found they relate to three factors: 1) dread (controllability, fatal or non-fatal consequences, high or low catastrophic potential); 2) familiarity (known or unknown, rapid or delayed manifestations); and 3) exposure (numbers exposed, personal exposure). Lindell (1994) suggests four categories of perceived risk characteristics should be utilised when investigating environmental hazards. These four categories are: (i) characteristics of the hazard agent; (ii) characteristics of the impact; (iii) perceived personal consequences; and (iv) affective reactions to the hazard. Factors affecting risk perception are usually not independent and vary between different hazard types. Relevant characteristics relating to the hazard agent include the magnitude and frequency of the hazard, ease of reducing the risk and the hazard's preventability. Familiarity and salience of a threat are significant determinants of people's responses to it and are usually correlated with geographic vulnerability to a hazard (Perry 1985). Relevant characteristics relating to the impact include speed of onset, extent of impact, duration of impact and existence of environmental cues.

Although there is an obvious link between hazard knowledge and the perceived degree of risk, there is often a denial or diminished perception of risk even when the hazard is well

understood (Mulilis & Duval 1995). This represents a psychological defence mechanism that individuals use to deal with unpalatable or threatening possibilities. An example is found in residents of Los Angeles surveyed after a 1989 earthquake, who readily acknowledged the threat of earthquakes but had a low perception of personal risk (Burger & Palmer 1992). People also tend to divide hazardous events into controllable and uncontrollable categories and subsequently they may deal with the uncontrollable events by the emotional response of denial. This link can also operate in unexpected ways. For example, knowledge of risk reduction activities can increase risk as individuals assume that the risk has been eliminated. Lehman and Taylor (1987) suggest that individuals at risk from catastrophic events of high probability but whose timing is unknown may cope with the threat by ignoring or denying the seriousness of the situation. This biased perception of risk has been explained by several possible underlying mechanisms including lack of knowledge or understanding (Weinstein 1980) and the need for personal control (Perloff 1983). Cognitive explanations develop the concept of "*illusions of unique invulnerability*" or downward comparisons (Perloff & Fetzner 1986). Individuals create a stereotype of the sort of person who is likely to be victimized by an event. If they believe they do not fit that stereotype they perceive that the risk to them is less than that of the stereotype. A key individual dimension that relates to affective reactions to the hazard is locus of control, i.e. people's belief in the extent to which they can control their environment. People with internal locus of control believe that the situation they find themselves in is largely a consequence of their own actions, whereas those with an external locus of control believe external forces, such as nature, luck or society have the dominant control over their situation. A positive relation between internal locus of control and taking action to reduce risk has been shown in several studies (Sims & Baumann 1972; Baumann & Sims 1978; Simpson-Housley & Bradshaw 1978). The nature of the individual's response is also influenced by the attributes they make regarding previous disaster or threatening experience, e.g., behavioural self-blame can provide better coping, while other-blame may intensify (subsequent) reactions and affect the level of perceived threat in actual or anticipated events. Socioeconomic factors and the availability of resources have a significant influence on an individual's locus of control (Vaughan 1995).

How people respond to natural hazards is determined by their individual and community vulnerability and how they perceive and cope with them (Lazarus, 1966; Lazarus & Folkman, 1984). Lazarus proposes that a person engages in a process of cognitive appraisal when faced with a threatening event. Two concurrent coping efforts then occur: 1) attempts to control the threatening situation (problem-focused coping); and 2) endeavours directed towards regulating emotional reactions to the threatening situation (emotion-focused coping).

The ways in which individuals and communities perceive natural hazards has been shown to affect a variety of hazard-relevant behaviours, for example their response to warning and

hazard preparedness (Mileti & Sorensen 1990; Lindell & Perry 1992; Mileti & O'Brien 1993; Lindell 1994). However, hazard awareness amongst adults alone does little to influence behaviour for the reasons outlined above. Research by Mileti & Fitzpatrick (1992, 1993) and Ward and Mileti (1993) found that multiple messages, delivered by multiple agencies, delivered by multiple channels, but carrying a consistent theme can stimulate an interactive personal search for more information. From this "*personal information searching*" may emerge a personal definition of risk which in turn leads to protective behaviour. However, intervening variables may counter this, including efficacy (belief in the ability to act and influence future outcomes) and influence about the effectiveness of safety devices (e.g. which can increase risk because it is assumed that they may eliminate threat from the hazards).

The importance of the links between (1) a person's perception of the hazard agent, impacts of the hazard and perceived personal consequences and (2) affective reactions and subsequent behaviour vary across different socioeconomic, gender and ethnic groups (e.g. Perry 1987; Farley *et al.* 1993; Vaughan 1995; Fothergill 1996).

8.2 PERCEPTION OF VOLCANIC RISK

A number of studies have measured individual and community perceptions and understanding of volcanic hazards and risk. These studies have been undertaken both in periods of quiescence at a volcano and after a volcanic crisis. A number of these studies are listed in Table 8.1.

The majority of these studies simply present observations and measurements of perceptions and responses to volcanic hazards in the various communities. However, more in-depth analysis has been undertaken by several researchers following major volcanic disasters, notably by Greene *et al.* (1981), Perry & Lindell (1990), Perry & Hirose (1991) and Lindell (1994), who attempted to isolate the links between factors that shape perceptions and adjustment to volcanic threats. The results of my study will be compared with their conclusions.

TABLE 8.1 Examples of studies of volcanic hazard and risk perceptions.

Country/ volcano	Timeframe	Communities	Sample	Reference
<i>Japan</i>				
Mt Usu	Post-eruption	Onsen-cho Hon-cho	600 households 400 households	Perry & Hirose 1991
Mt. Unzen	Post-eruption	Shimabara Fukae	800 households 500 households	Yoshii 1992
<i>Martinique</i>				
Mt. Pelee	Quiescent period	Saint-Pierre Morne Rouge Le Precheur	? adults	D'Ercole <i>et al.</i> 1995
<i>New Zealand</i>				
Egmont	Quiescent period	Taranaki region	900 households	Taranaki Regional Council 1995
Taupo Volcanic Zone	Quiescent period	Whakatane, Rotorua, Taupo, Turangi	407 children	Johnston & Houghton 1995
Taupo Volcanic Zone	Quiescent period	Bay of Plenty region	700 adults	Ponter <i>et al.</i> 1993
<i>Papua New Guinea</i>				
Rabaul	During seismic crisis	Rabaul	273 adults	Kuester & Forsyth 1985
<i>U.S.A.</i>				
Hawaii	Quiescent period	Puna district	101 residents	Murton & Shimabukuro 1974
Mt. St Helens	Post-eruption	Cougar, Toutle/ Silverlake Woodland	120 households	Greene <i>et al.</i> 1981
	Post-eruption	Toutle Lexington	353 households	Perry & Lindell 1990, Perry & Hirose 1991
	Post-eruption	Longview-Kelso Yakima	1494 residents	Langran & Terich 1982
	Post-eruption	Eastern Washington State (multiple communities)	130 individuals from responding agencies	Dillman <i>et al.</i> 1982
	Post-eruption	Washington State	26 local governments	Saarinen & Sell 1985
	Post-eruption	Washington State	211 residents & 92 non- residents	Kartez 1982
	Post-eruption	Longview	102 households	Lindell 1994
Mt Shasta	Quiescent period	Mt. Shasta City	102 residents	Perry 1990
Long Valley	Caldera unrest	Mammoth Lakes	1845 property owners	Bernknopf <i>et al.</i> 1990

8.3 OBJECTIVE

This study looks at changes in perceptions in two communities as a consequence of the 1995 eruption of Ruapehu, the largest volcanic eruption in New Zealand this century. It utilises a unique and unplanned opportunity to test the effect of a large natural event on two populations' perceptions of natural hazards. The original survey was conducted in February 1995 prior to the 1995 eruption in the towns of Hastings and Whakatane, evaluating individuals' hazard knowledge, perceptions of volcanic risk, individuals' sources of volcanic hazard information and the perceived credibility of each information source.

A repeat of the survey was undertaken in November 1995, to establish the immediate impacts of the 1995 Ruapehu eruption on perceptions, awareness and response in these communities. Participants were asked to again complete a similar questionnaire with the addition of questions pertaining to the 1995 Ruapehu eruption. The latter evaluated the source and effectiveness of the information they received during this eruption. Whakatane and Hastings supply interesting contrasts. Both were subjected to intense media coverage during the eruption, but Whakatane has been spared any direct effects, whereas Hastings experienced hazards directly in the form of ash fall in September and October 1995. Despite the effects in Hastings the level of impact was still relatively benign compared to many of the communities assessed post-eruption by other researchers (e.g. Greene *et al.* 1981; Perry & Lindell 1990; Perry & Hirose 1991; Yoshii 1992; Lindell 1994).

8.4 DATA COLLECTION

Research was undertaken in accordance with the ethical guidelines of the Massey University Ethics Committee. Two urban centres, Whakatane and Hastings, were chosen for the February 1995 study. A general survey design was used to obtain the data, with identical research procedures followed in each community. The data gathering was based on a questionnaire given to 450 households from each centre. The questionnaire (see Appendix 4) was constructed to collect quantitative data on elements of individuals' perceptions of natural hazards and risk, with an emphasis on volcanic hazards. Construction of the questionnaire was guided by the method outlined by Dillman (1978), with attention paid to content and design to enhance the return rate. Households were randomly selected from census mesh blocks within the urban boundaries of the chosen locations. These households received a letter inviting the adult member of the household who had the most recent birthday to take part in the study. Participants were asked to complete a questionnaire which had been delivered to them in person or as a letter drop. It asked for general demographic data and included 14 questions on perceptions of the occurrence of and preparedness for natural hazards. Two weeks after the delivery a follow-up letter was posted to those households not returning the

questionnaire, again inviting them to participate. The return rates generated by the procedure were 45% for Whakatane and 48% for Hastings (Table 8.2).

Following the eruptions of Ruapehu in September to November 1995 a second questionnaire was mailed in November 1995 to the households selected in the first survey. The respondents of the first survey were invited to complete the questionnaire. If the first survey respondent was unavailable or did not exist the adult member of the household who had the most recent birthday was invited to take part in the study. Two weeks after the questionnaire was sent out a follow-up letter was posted to those households not replying. The return rates generated by the second survey were 33% for Whakatane and 32% for Hastings. Of those who completed the first survey 50% in Whakatane and 45% in Hastings completed the second survey (Table 8.2).

Data was coded and stored for analysis using the Statistical Package for the Social Sciences (SPSS/PC+) program.

TABLE 8.2 Survey completion rates.

Survey 1	Whakatane	Hastings
Total delivered	450	450
Total returned	202	216
Return rate	44.9%	48.0%
Survey 2		
Total posted	450	450
Not delivered	12	15
Total delivered	438	435
Total returned	145	140
Return rate	33.1%	32.2%
First survey respondents who returned the second survey	101 (50.0%)	98 (45.4%)

8.4.1 Assessment of representativeness

Demographic characteristics from the samples can be compared to that of the 1991 census to measure for sample bias. The sample data is similar to that of the census for most variables in both communities (Table 8.3). The samples do contain some bias since they under-represent both the Maori population and the number of less educated people. Nevertheless, there is sufficient variation in all variables to ensure that sample bias does not negatively affect the general conclusions drawn from this study.

TABLE 8.3 Summary of respondents' socio-demographic information compared to the 1991 census data for each centre.

Whakatane	Survey 1 %	Survey 2 %	1991 Census %
Age			
20 - 29	9.6	7.7	19.4
30 - 39	17.7	15.4	21.3
40 - 49	20.2	18.2	18.5
50 - 59	14.6	16.8	13.8
60 - 69	17.7	23.1	14.3
70 - 79	16.7	14.0	9.5
80 and over	3.5	4.9	3.3
Household composition			
Family	76.5	73.9	75.4
Non-family	3.0	3.5	3.6
Live alone	19.5	21.1	20.0
Other	1.0	1.4	1.1
Ethnicity			
NZ Maori	14.1	12.7	27.6
NZ European	77.8	79.6	70.4
Pacific Island	1.0	0.0	0.7
Other/ non-disclosed	7.1	7.7	1.3
Highest educational qualification			
No school qualification	25.3	30.0	42.2
School certificate passes	22.7	23.6	10.1
School qualifications. UE or above	12.1	10.7	7.0
Trade or professional certificate	26.3	22.9	31.5
University qualification	13.6	12.9	5.2
Income			
below \$15 000	49.2	46.7	55.5
\$15 001 - \$20 000	9.4	8.1	10.5
\$20 001 - \$30 000	16.2	19.3	14.1
\$30 001 - \$40 000	10.5	8.9	7.9
\$40 001 - \$50 000	7.3	9.6	4.4
\$50 001 and over	7.3	6.7	3.9
Primary work role			
Employed (full and part-time)	49.8	48.2	48.6
Not in paid employment	50.3	51.8	51.4

TABLE 8.3 Cont.

Hastings	Survey 1 %	Survey 2 %	1991 Census %
Age			
20 - 29	13.7	8.6	21.7
30 - 39	24.1	18.7	21.6
40 - 49	18.9	24.5	18.5
50 - 59	13.7	13.7	13.5
60 - 69	17.0	17.3	12.5
70 - 79	8.5	10.8	8.5
80 and over	4.2	6.5	4.0
Household composition			
Family	70.8	69.6	74.5
Non-family	8.5	8.1	4.7
Live alone	20.3	21.5	20.3
Other	0.5	0.7	0.6
Ethnicity			
NZ Maori	5.7	4.5	21.9
NZ European	86.7	85.8	74.0
Pacific Island	1.0	0.0	2.4
Other / non-disclosed	6.7	9.7	1.7
Highest educational qualification			
No school qualification	22.0	24.0	47.7
School certificate passes	20.0	24.0	10.8
School qualifications. UE or above	14.6	13.2	8.0
Trade or professional certificate	28.3	27.9	24.7
University qualification	15.1	10.9	5.1
Income			
below \$15 000	40.9	46.5	54.3
\$15 001 - \$20 000	16.7	17.3	11.5
\$20 001 - \$30 000	16.2	13.4	17.0
\$30 001 - \$40 000	16.2	14.2	7.7
\$40 001 - \$50 000	7.1	4.7	2.9
\$50 001 and over	3.0	3.9	2.5
Primary work role			
Employed (full and part-time)	59.4	61.5	52.8
Not in paid employment	40.6	38.5	47.2

8.5 RESULTS

8.5.1 Threat knowledge

Whakatane is situated on the coast of the Bay of Plenty (see Chapter 7 for details). On a clear day White Island volcano is visible 50 km to the north, commonly with a white steam plume rising above it. White Island is one of the most frequently active cone volcanoes in New Zealand (Naim *et al.* 1991; Scott *et al.* 1995b), although eruptions are usually small and rarely do they directly affect Whakatane. White Island may have a significant influence on the salience of volcanoes to Whakatane residents although this was not tested in the study. However, White Island was the most recognised volcano in the region in a study of school children's perceptions, reported by Johnston & Houghton (1995), with over 90% describing it as an active volcano. To the south-east (35-50 km away) lies Mount Edgecumbe and the volcanic domes of Okataina Volcanic Centre (Tarawera and Haroharo), although they are not visible from the town. Just over 100 years ago a basaltic eruption from Tarawera spread ash over a wide part of the Bay of Plenty region and killed over 100 of the sparse population (Keam 1988). Whakatane was covered by about 7-8 cm of ash. When asked the thickness of ash that had fallen on the town from the 1886 Tarawera eruption only 18.5% of respondents prior to the 1995 Ruapehu eruption and 14.6% post-eruption identified the correct range of ash thickness (Table 8.4). The largest group (~40%) in both time periods were those who did not know if ash from Tarawera had fallen on the town.

TABLE 8.4 The thickness of ash falling on Whakatane from the 1886 eruption of Mount Tarawera.

Variable	Pre-eruption n	%	Post-eruption n	%
None	3	1.5	0	0
<1 cm	16	8.0	15	10.4
1-5 cm	29	14.5	24	16.7
5-10 cm	37	18.5	21	14.6
>10 cm	35	17.5	27	18.8
Don't know	80	40.0	57	39.6
Total	200		144	

In contrast to Whakatane, the active volcanoes of the North Island are not visible to Hastings residents from the city but all lie within an arc to the north and west (see Chapter 6 for details). In historic times Hastings has received volcanic ash from Tongariro in 1896 (Hill 1897) and Ruapehu in 1945, 1975, 1995 and 1996 (Chapter 2, Naim *et al.* 1979). All historic ash falls have been minor (less than a few millimetres), but more significant ash falls are

preserved in the pre-historic record as measured from lake sediments in the Hawke's Bay region (Eden *et al.* 1993, Eden & Froggatt 1996).

Prior to the 1995 Ruapehu eruption, half (50.2%) of the respondents in Hastings either did not know or thought that volcanic ash had never fallen on the region (Table 8.5). Only 32.4% knew that there had been ash falls some time in the past 50 years. The ash falls of September and October 1995 resulted in the shift in hazard knowledge with only 7.2% claiming not to know about the recent ash falls.

TABLE 8.5 Timing of the last time ash fell on the Hawke's Bay

Variable	Pre-eruption n	%	Post-eruption n	%
In the past 10 years	7	3.3	102	73.9
In the past 20 years	26	12.2	9	6.5
In the past 50 years	36	16.9	15	10.9
In the past 100 years	21	9.9	1	0.7
In the past 500 years	16	7.5	1	0.7
Never	3	1.4	0	0.0
Don't know	104	48.8	10	7.2
Total	213		138	

Prior to the 1995 Ruapehu eruption specific hazard information was available in a limited number of forms in each community. The 1886 Tarawera eruption has an extensive literature and received much attention during its centenary in 1986. In 1991 the Ministry of Civil Defence issued two "yellow books" entitled "Volcanic Hazards at Okataina Volcanic Centre" (Nairn 1991a) and "Volcanic Hazards at White Island" (Nairn *et al.* 1991). The Ministry of Civil Defence organised a "Volcanic Hazard Awareness Year" named Nga Puia from 1991-1992. Nationally, pamphlets, displays and videos promoting volcanic hazard awareness and preparedness were distributed. During that year a two month exercise was held running an eruption scenario from Okataina. This was followed by a symposium for local government and industry in Rotorua (Ministry of Civil Defence 1992). Since 1993 the Bay of Plenty Regional Council (Environment BoP) has commissioned several studies of the regional volcanic threat and these reports have now been publicly released (i.e. Johnston & Nairn 1993; Nairn 1995).

Despite the six year availability of the Okataina "yellow book" the vast majority of Whakatane respondents (96.5%) did not possess copies (Table 8.6). There was little change after the 1995 Ruapehu eruption. Of those with copies the largest group claimed to have received copies from Civil Defence (71.4% pre-eruption and 55.6% post-eruption). Others

reported receiving the booklet by picking it up from libraries (14.3% pre-eruption and 33.3% post-eruption), given out at school (14.3% pre-eruption only) and others (11.1% post-eruption).

TABLE 8.6 Whakatane residents possessing a copy of Ministry of Civil Defence issued booklet, "Volcanic Hazards at Okataina Volcanic Centre" and the method by which they received copies.

Variable	Pre-eruption n	%	Post-eruption n	%
No	195	96.5	134	93.7
Yes	7	3.5	9	6.3
Total	202		143	
Pick up from the library	1	14.3	3	33.3
Given out by C.D.	5	71.4	5	55.6
Given out at school	1	14.3	0	0
Don't know	0	0	0	0
Other	0	0	1	11.1

Published volcanic hazard information in the Hawke's Bay is even more limited than in the Bay of Plenty. One of the only references to the regional volcanic threat appears in the Hawke's Bay Regional Civil Defence Organisation annual publication the "Civil Defender" in an article by Eden (1994). The publication is not distributed to all residents but is available from a number of sources. However, 92.0% of Hastings respondents did not have a copy and there was no change after the eruption since no new copies were distributed in the period between February and November 1995. The few who did have copies received them from a variety of sources (Table 8.7).

TABLE 8.7 Hastings residents possessing the Hawke's Bay Regional Civil Defence Organisation annual publication "Civil Defender".

Variable	Pre-eruption n	%	Post-eruption n	%
No	195	92.0	124	92.5
Yes	17	8.0	10	7.5
Total	212		134	
Pick up from the library	3	17.6	3	30.0
Given out by C.D.	3	17.6	2	20.0
Given out at school	3	17.6	0	0
Don't know	3	17.6	3	30.0
Other	5	29.4	2	20.0

Information searching has been addressed by a number of researchers in hazard perception studies (e.g. Perry and Lindell 1990). The receipt of information often stimulates the respondent to collect additional information from a range of other sources (Mileti and Fitzpatrick 1993). This information is then used to devise a personal definition of the hazard the respondents are exposed to. Additional information is often incorporated into this pre-existing view (perception) of the hazard and associated risk (Higgins and Bargh 1987).

Prior to the 1995 Ruapehu eruption only a small number of Whakatane respondents (11.9%) reported having asked for information about volcanic hazards in the past year. After the Ruapehu eruption this number had only marginally increased to 18.4%. In Hastings prior to the 1995 eruption an even smaller number than Whakatane (1.4%) had searched for information on volcanic hazards. This increased to 12.7% after the 1995 eruption. Of those that had asked for information on volcanic hazards in Whakatane and Hastings, friends or relatives were the principal source (Whakatane 50.0% pre-eruption and 65.4% post-eruption; Hastings 66.7% pre-eruption and 41.2% post-eruption) from whom this was sought. This is consistent with much of the hazard research from overseas studies which shows citizens rely on social networks rather than official agencies for both hazard information and warnings (Kartez & Lindell 1987, Perry 1990). The media is often only used by the public as a surveillance tool and the public then seek advice and suggestions from friends and relatives before deciding what actions to take (Vogt & Sorensen 1994).

Other groups cited included district councils (the second most common), regional councils, schools, Ministry of Civil Defence and the Institute of Geological and Nuclear Sciences. Only in Whakatane were the Police cited (by 11.5% of respondents after the 1995 Ruapehu eruption).

TABLE 8.8

The number of respondents who in the past year have asked anyone for information about volcanic hazards in their region and the sources reported (some respondents identified more than one).

Variable	Pre-eruption	%	Post-eruption	%
Whakatane				
No	178	88.1	115	81.6
Yes	24	11.9	26	18.4
Total	202		141	
Schools	4	16.7	1	3.8
Friends-relatives	12	50.0	17	65.4
G.N.S.	0	0	2	7.7
D.C.	7	29.2	7	26.9
R.C.	6	25.0	6	23.1
M.C.D.	0	0	2	7.7
Police	0	0	3	11.5
Other	3	12.5	2	7.7
Hastings				
No	208	98.6	117	87.3
Yes	3	1.4	17	12.7
Total	211		134	
Schools	1	33.3	2	11.8
Friends-relatives	2	66.7	7	41.2
G.N.S.	1	33.3	3	17.6
D.C.	2	66.7	5	29.4
R.C.	0	0	5	29.4
M.C.D.	1	33.3	0	0
Police	0	0	0	0
Other	0	0	1	5.9

G.N.S. = Institute of Geological & Nuclear Sciences, D.C. = district council, R.C. = regional council, M.C.D. = Ministry of Civil Defence.

Past research has shown that the perceived credibility of the source of information influences the public's behaviour both during a volcanic crisis when warnings may be issued and during non-crisis times when public information is disseminated to improve hazard knowledge and encourage a range of protective behaviours (Perry & Lindell 1990). Table 8.9 shows the sources considered the most trustworthy and reliable for information on protection against volcanic hazards. The three highest rating agencies in both communities before and after the 1995 Ruapehu eruption were the Institute of Geological & Nuclear Sciences, district councils and the Ministry of Civil Defence. The rank ordering was slightly different in both communities before the 1995 Ruapehu eruption with the district council getting the top rating (24.0%) in Whakatane, followed by Institute of Geological and Nuclear Sciences (22.4%) and

Ministry of Civil Defence (20.4%). The Ministry of Civil Defence got the top rating (32.9%) in Hastings, followed by the Institute of Geological and Nuclear Sciences (24.6%) and district council (23.7%). After the 1995 Ruapehu eruption the Institute of Geological and Nuclear Sciences (G.N.S.) received the top rating in both communities (29.8% in Whakatane and 26.7% in Hastings), although G.N.S. was only marginally ahead of the other two (district councils 27.7% in Whakatane and 25.2% in Hastings; Ministry of Civil Defence 22.0% in Whakatane and 25.2% in Hastings). The regional council was the fourth ranked in both communities, receiving support from 17.9% in Whakatane before the Ruapehu eruption and 12.1% after; and 7.7% in Hastings pre-eruption and 6.7% after. It is interesting to note the higher response to the regional council in Whakatane compared to Hastings.

The data shows that, although some agencies are perceived as more credible than others for volcanic hazard information, no single agency has a monopoly on perceived credibility. In other words different people recognise different agencies as the best source of information on volcanic hazard information and warnings. This has important implications for the issuing of warnings and disseminating public information and supports the idea of using multiple agencies carrying a consistent message to enhance public response. This conclusion also supports the need for integrated planning, coordination of information collection and dissemination, inter-organisation communication and communication with the community. Although not investigated in this study, Perry and Lindell (1990) found that two principal dimensions attributed to credibility are past reliability (trustworthiness) and access to skills and information (expertise).

TABLE 8.9 The single source considered the best (i.e. trustworthy and reliable) for information about protection from volcanic hazards in Whakatane and Hastings.

Variable	Pre-eruption n	%	Post-eruption n	%
Whakatane				
G.N.S.	44	22.4	42	29.8
D.C.	47	24.0	39	27.7
R.C.	35	17.9	17	12.1
M.C.D.	40	20.4	31	22.0
Police	15	7.7	7	5.0
Other	15	7.7	5	3.5
Total	196		141	
Hastings				
G.N.S.	51	24.6	36	26.7
D.C.	49	23.7	34	25.2
R.C.	15	7.2	11	8.1
M.C.D.	68	32.9	34	25.2
Police	16	7.7	9	6.7
Other	8	3.9	11	8.1
Total	207		135	

G.N.S. = Institute of Geological & Nuclear Sciences, D.C. = district council, R.C. = regional council, M.C.D. = Ministry of Civil Defence.

Before the 1995 Ruapehu eruption when asked "what is the most effective way for officials to give out information about volcanic hazards that may occur in the future?", the largest single group in both Whakatane and Hastings suggested mail (33.8% in Whakatane and 34.6% in Hastings) followed closely by TV (25.4% in Whakatane and 26.6% in Hastings) and radio (20.9% in Whakatane and 13.6% in Hastings) (Table 8.10). After the Ruapehu eruption TV (29.9% in Whakatane and 26.5% in Hastings) fractionally overtook mail (29.2% in Whakatane and 25.0% in Hastings) as the most preferred option in both communities. The increase in TV may be linked with results presented in Table 8.11, listing the sources from which respondents received information about the 1995 Ruapehu eruption. Support for newspapers dropped slightly in Whakatane after the 1995 eruption (10.9% pre-eruption and 7.6% post-eruption) but increased in Hastings (12.6% pre-eruption and 19.9% post-eruption). The data clearly shows, as was the case with source of information, that no one channel is the best method to disseminate information. Different people rely on different channels for information and this should be acknowledged when issuing warnings and releasing public information. Similar results were found in the USA, in communities around Mount St. Helens (Perry & Lindell 1990) and Mount Shasta (Perry 1990). The use of mail is one of the most

preferred methods and also one of the most cost effective dissemination strategies. At times of high risk, one option is for councils and other organisations to include flyers with their bills, identifying hazards and instructing the public what to do should a crisis develop. This method was used in Taupo during the 1995 Ruapehu eruption when flyers were sent with the rates demand. Other New Zealand councils used paid advertising in local newspapers in September 1995 to carry information about potential impacts of ash fall (see Chapter 2). It must also be recognised that there is no such thing as the "average person" and material may need to be written to accommodate the needs of various vulnerable groups, particularly with respect to cultural and language differences.

TABLE 8.10 The most effective way for officials to give out information about volcanic hazards that may occur in the future.

Variable	Pre-eruption n	%	Post-eruption n	%
Whakatane				
Public meetings	4	2.0	3	2.1
Telephone	3	1.5	5	3.5
Post	68	33.8	42	29.2
TV	51	25.4	43	29.9
Radio	42	20.9	30	20.8
Newspaper	22	10.9	11	7.6
Other	11	5.5	10	6.9
Total	201		144	
Hastings				
Public meetings	3	2.0	2	1.5
Telephone	1	0.5	0	0
Post	74	34.6	34	25.0
TV	57	26.6	36	26.5
Radio	29	13.6	25	18.4
Newspaper	27	12.6	27	19.9
Other	23	10.7	12	8.8
Total	214		136	

Table 8.11 shows the channels by which respondents reported receiving information about the 1995 Ruapehu eruptions. The data show that the three channels from which the largest proportion of respondents reported receiving information are the same in both communities, namely television, radio and newspapers. Few people reported receiving information directly from organisations which had principal roles in responding to the eruptions. These data highlight the significant role of the media in the hazard information dissemination process. This finding is consistent with observation following the 18 May 1980 Mount St Helens

eruption, where residents of ash-affected areas turned to the media for official information on how to respond (Barnes 1986). Unfortunately, in that case immediate authoritative information was not available to the primary media sources and authoritative guidance was lacking.

TABLE 8.11 The channel by which respondents received information about the 1995 Ruapehu eruption.

Variable	Whakatane n	%	Hastings n	%
TV	132	91.0	109	77.9
Radio	105	72.4	97	69.3
Newspaper	84	57.9	99	70.7
D.C.	5	3.4	5	3.6
R.C.	3	2.1	3	2.1
M.C.D.	4	2.8	0	0
G.N.S.	4	2.8	4	2.9
Other	3	2.1	6	4.3
Total	145		140	

G.N.S. = Institute of Geological & Nuclear Sciences, D.C. = district council,
R.C. = regional council, M.C.D. = Ministry of Civil Defence.

8.5.2 Perceived vulnerability

The concept of perceived vulnerability is important in the understanding of how people think about natural hazards (Lindell 1994). Individual beliefs about vulnerability have been shown to relate to a variety of disaster behaviours. People who perceive they are vulnerable are more likely to respond to warnings (Mileti & Sorensen 1990) and undertake protective behaviours (assuming they have the resources to do so, which is not always the case) (Perry & Lindell 1990; Mileti & Fitzpatrick 1993). In this study two issues are explored: individuals' perceived threat to their personal safety and the perceived threat to daily life (e.g. work, leisure, property). Six major hazards are assessed: earthquakes, volcanic eruptions, floods, high winds, wildfires and landslides.

In the event of each hazard's occurrence, respondents ranked the likelihood of physical risk ("how likely is it that it will seriously threaten your personal safety?") on a 5-point scale (extremely likely = 1, very likely = 2, 50/50 = 3, very unlikely = 4, extremely unlikely = 5) (Table 8.12). In Whakatane prior to the 1995 Ruapehu eruption only earthquakes and volcanic eruptions were ranked as likely to threaten personal safety if they occurred in the future (i.e. means less than 3). The remaining hazards were ranked as unlikely to threaten personal safety (i.e. means greater than 3). Floods and wind storms fell between even odds (50/50) and very unlikely to threaten personal safety whereas landslides and wildfires fell

between very unlikely and extremely unlikely. The 1995 Ruapehu eruption had little effect on the mean scores and the significance of this is tested (Table 8.13) using the sub-population of respondents who answered both questionnaires (i.e. before and after the 1995 Ruapehu eruption). No significant change in perceived personal vulnerability to any of the hazards is seen and no change to the rank ordering of the hazards was observed after the 1995 Ruapehu eruption.

In Hastings prior to the 1995 Ruapehu eruption only earthquakes were ranked as likely to threaten personal safety if they occurred in the future (i.e. means less than 3). The remaining hazards were ranked as unlikely to threaten personal safety (i.e. means greater than 3). Floods, wind storms and volcanic eruptions fell between even odds (50/50) and very unlikely to threaten personal safety whereas landslides and wildfires fell between very unlikely and extremely unlikely. The 1995 Ruapehu eruption had some effect on the mean scores of certain hazards, with volcanic eruptions being ranked as more likely and floods less likely. The significance of this is tested (Table 8.13) using the sub-population of respondents who answered both questionnaires (i.e. before and after the 1995 Ruapehu eruption). The rank ordering of the hazards changed slightly with volcanic eruptions exchanging places with floods to become the third highest ranked hazard in terms of threatening personal safety.

TABLE 8.12 Comparison of respondents' mean scores for the perception that personal safety is threatened by natural hazards for periods pre- and post- the 1995 Ruapehu eruption.

Variable	Pre-eruption mean (rank)	s.d.	n	Post-eruption mean (rank)	s.d.	n
Whakatane						
Volcanic eruption	2.72 (2)	1.15	185	2.70 (2)	1.10	136
Earthquake	2.04 (1)	0.87	194	2.09 (1)	0.88	140
Flood	3.29 (3)	1.11	177	3.25 (3)	1.07	134
Wind storm	3.41 (4)	0.98	181	3.30 (4)	0.98	133
Landslide	4.37 (6)	0.80	174	4.32 (6)	0.92	126
Wildfire	4.06 (5)	1.06	175	4.25 (5)	1.07	130
Hastings						
Volcanic eruption	3.79 (4)	1.11	185	3.28 (3)	1.06	139
Earthquake	1.89 (1)	0.90	204	1.97 (1)	0.98	131
Flood	3.19 (3)	1.07	191	3.43 (4)	1.16	127
Wind storm	3.05 (2)	1.02	190	3.17 (2)	1.02	121
Landslide	4.56 (6)	0.86	187	4.57 (6)	0.75	120
Wildfire	4.27 (5)	0.97	188	4.33 (5)	0.93	139

1 = extremely likely, 2 = very likely, 3 = 50/50, 4 = very unlikely, 5 = extremely unlikely

TABLE 8.13 Comparison of mean scores for respondents who completed both surveys: perception that personal safety is threatened by natural hazards for periods pre- and post- the 1995 Ruapehu eruption.

Variable	Pre-eruption mean (rank)	s.d.	Post-eruption mean (rank)	s.d.	n	t
Whakatane						
Volcanic eruption	2.74 (2)	1.19	2.75 (2)	1.13	92	-0.08
Earthquake	1.96 (1)	0.81	2.09 (1)	0.89	93	-1.22
Flood	3.23 (3)	1.25	3.33 (3)	1.03	87	-0.84
Wind storm	3.41 (4)	1.03	3.43 (4)	0.98	87	-0.10
Landslide	4.47 (6)	0.75	4.40 (6)	0.88	77	0.73
Wildfire	4.15 (5)	1.03	4.37 (5)	1.00	82	-1.72
Hastings						
Volcanic eruption	3.75 (4)	1.17	3.15 (2=)	1.06	84	4.26***
Earthquake	1.76 (1)	0.83	1.92 (1)	0.95	93	-1.86
Flood	3.20 (3)	1.06	3.45 (4)	1.20	84	-2.23*
Wind storm	3.05 (2)	0.94	3.15 (2=)	1.03	82	-0.80
Landslide	4.56 (6)	0.85	4.58 (6)	0.71	78	-0.11
Wildfire	4.26 (5)	1.01	4.28 (5)	0.98	78	-0.21

1 = extremely likely, 2 = very likely, 3 = 50/50, 4 = very unlikely, 5 = extremely unlikely

* $p < .05$ *** $p < .001$.

In the event of each hazard's occurrence, respondents ranked the likelihood of disruption to their daily life such as work, leisure and/or property ("how likely is it that it will seriously disrupt your daily life?") on a 5-point scale (extremely likely = 1, very likely = 2, 50/50 = 3, very unlikely = 4, extremely unlikely = 5).

In Whakatane prior to the 1995 Ruapehu eruption, earthquakes, volcanic eruptions and floods were ranked as likely to disrupt daily life if they occurred in the future (i.e. means less than 3). The remaining hazards were ranked as unlikely to threaten personal safety (i.e. means greater than 3). Wind storms fell between even odds (50/50) and very unlikely to disrupt daily life whereas landslides and wildfires fell between very unlikely and extremely unlikely. The 1995 Ruapehu eruption had little effect on the mean scores. The significance of this is tested using the sub-population of respondents who answered both questionnaires. No significant change in perceived lifestyle vulnerability to any of the hazards is seen and no change to the rank ordering of the hazards was observed after the eruption.

In Hastings prior to the 1995 Ruapehu eruption, earthquakes and floods were ranked as likely to disrupt daily life if they occurred in the future (i.e. means less than 3). Earthquakes fell between extremely likely and very likely and floods close to even odds (50/50). The remaining hazards were ranked as unlikely to disrupt daily life (i.e. means greater than 3).

Wind storms and volcanic eruptions fell between even odds (50/50) and very unlikely to threaten personal safety, whereas landslides and wildfires fell between very unlikely and extremely unlikely. The 1995 Ruapehu eruption had a marked effect on the mean scores of certain hazards. The significance of this is tested (Table 8.15) using the sub-population of respondents who answered both questionnaires. Volcanic eruptions showed a significant change ($p < .001$) being ranked as between very likely and 50/50 to disrupt daily life. The rank ordering of the hazards changed slightly with volcanic eruptions exchanging places with floods to become the third highest ranked hazard in terms of threatening daily life.

The perceived threat from volcanoes to personal safety and disruption to daily life was compared to respondent's characteristics (Table 8.3) in both communities before and after the 1995 Ruapehu eruption; however, analysis revealed no significant associations.

TABLE 8.14 Comparison of respondents' mean scores: perception that lifestyle is threatened by natural hazards for pre- and post- the 1995 Ruapehu eruption.

Variable	Pre-eruption mean (rank)	s.d.	n	Post-eruption mean (rank)	s.d.	n
Whakatane						
Volcanic eruption	2.62 (2)	1.21	185	2.41 (2)	1.13	135
Earthquake	2.00 (1)	0.93	195	1.96 (1)	0.88	139
Flood	2.90 (3)	1.20	182	2.93 (3)	1.15	137
Wind storm	3.37 (4)	1.12	180	3.19 (4)	1.05	136
Landslide	4.17 (6)	0.91	173	4.02 (5)	1.13	131
Wildfire	4.03 (5)	1.05	180	4.08 (6)	1.15	130
Hastings						
Volcanic eruption	3.68 (4)	1.22	179	3.08 (2)	1.11	130
Earthquake	1.95 (1)	0.91	206	2.11 (1)	1.05	139
Flood	2.99 (2)	1.12	189	3.27 (4)	1.19	131
Wind storm	3.02 (3)	1.10	184	3.13 (3)	1.08	127
Landslide	4.39 (6)	0.97	183	4.40 (6)	0.87	121
Wildfire	4.09 (5)	1.11	183	4.23 (5)	0.92	120

1 = extremely likely, 2 = very likely, 3 = 50/50, 4 = very unlikely, 5 = extremely unlikely

TABLE 8.15 Comparison of mean scores for respondents who completed both surveys: perception that lifestyle is threatened by natural hazards for pre- and post- the 1995 Ruapehu eruption.

Variable	Pre-eruption mean (rank)	s.d.	Post-eruption mean (rank)	s.d.	n	t
Whakatane						
Volcanic eruption	2.49 (2)	1.21	2.46 (2)	1.11	89	0.26
Earthquake	1.87 (1)	0.91	1.97 (1)	0.90	94	-0.95
Flood	2.90 (3)	1.26	3.11 (3)	1.10	88	-1.78
Wind storm	3.44 (4)	1.09	3.34 (4)	1.07	86	0.74
Landslide	4.28 (6)	0.85	4.09 (5)	1.16	79	1.30
Wildfire	4.14 (5)	0.98	4.24 (6)	1.20	83	-0.65
Hastings						
Volcanic eruption	3.67 (4)	1.23	2.85 (2)	1.04	82	5.23***
Earthquake	1.87 (1)	0.88	2.03 (1)	1.01	95	-1.66
Flood	3.04 (3)	1.67	3.30 (4)	1.20	84	-1.85
Wind storm	2.98 (2)	1.09	3.07 (3)	1.12	82	-0.70
Landslide	4.39 (6)	0.91	4.42 (6)	0.82	77	-0.40
Wildfire	4.03 (5)	1.18	4.23 (5)	0.96	77	-1.65

1 = extremely likely, 2 = very likely, 3 = 50/50, 4 = very unlikely, 5 = extremely unlikely

*** $p < .001$

Table 8.16 shows the hazards perceived to be the most likely to seriously threaten each of the communities. In Whakatane earthquakes were believed to be the mostly likely hazard to threaten personal safety seriously (79.6% pre-eruption and 76.6% post-eruption). However, a volcanic eruption was the second most commonly cited hazard (13.3% pre-eruption and 13.8% post-eruption). Floods, high winds and scrub or forest fires were mentioned by only a few respondents.

Despite the significant shift in perceived vulnerability from volcanoes, in Hastings earthquakes still remain the hazard perceived to be the most likely to seriously threaten personal safety by the vast majority of respondents (93.1% pre-eruption and 93.5% post-eruption). Other hazard types (volcanic eruptions, floods, high winds and scrub or forest fire) were only believed to be the most likely by a few respondents.

TABLE 8.16 Perceptions of the most likely hazards to affect both communities.

Variable	Pre-eruption		Post-eruption	
	n	%	n	%
Whakatane				
Earthquake	156	79.6	111	76.6
Volcanic eruption	26	13.3	20	13.8
Flood	9	4.6	8	5.5
High winds	5	2.6	5	3.4
Scrub or forest fire	0	0.0	1	0.7
Total	196		145	
Hastings				
Earthquake	189	93.1	130	93.5
Volcanic eruption	4	2.0	4	2.9
Flood	7	3.4	2	1.4
High winds	2	1.0	3	2.2
Scrub or forest fire	1	0.5	0	0.0
Total	203		139	

8.5.3 Perceived preparedness

The level of preparedness of various organisations for future volcanic eruptions was ranked by respondents, along with their perceived personal preparedness, on a 4-point scale (very prepared = 1, somewhat prepared = 2, not very prepared = 3, not prepared at all = 4). A similar result was seen in both Whakatane and Hastings prior to the 1995 Ruapehu eruption, with the level of preparedness for volcanic hazards amongst central government (i.e. Ministry of Civil Defence) and local/regional government (i.e. local and regional civil defence, Police, Fire Service) being rated between somewhat prepared and not very prepared (i.e. mean score less than 3) (Table 8.17). Local and regional government was the highest ranked in both communities. Personal and community preparedness rated between not very prepared and not prepared at all. Personal preparedness ranked higher than that of the community in both samples.

Perceived preparedness levels in Whakatane after the 1995 Ruapehu eruption showed improvements in a number of groups (Table 8.17). The significance of this is tested using the sub-population of respondents who answered both questionnaires with central government ($p < 0.05$) and personal ($p < 0.001$) preparedness showing a significant improvement in perceived preparedness. In Hastings after the 1995 Ruapehu eruption preparedness levels showed improvements in all groups. Again, the significance of this is tested (Table 8.18) using the sub-population of respondents who answered both questionnaires and all groups showed a significant change ($p < 0.001$). The rank ordering was unchanged in both communities. This result can be used indirectly as a measure of the public view of the handling of the response to the Ruapehu eruption. It could be speculated that the improvement in perceived preparedness would not have occurred if the public were dissatisfied with the response to the eruption. The relatively benign impact of the eruption on most residents in Hastings and Whakatane obviously contributed to this, but personal experience (in Hastings) of the eruption and respondents' observations of the response clearly influenced individual's improved perception of organisational and personal preparedness.

Levels of preparedness were compared to respondents' characteristics (Table 8.3). The analysis revealed no significant associations with perceived levels of preparedness in Whakatane before the Ruapehu eruption. However, household type was correlated with preparedness levels of central ($r = -0.24$) and local ($r = -0.22$) government in Whakatane after the eruption. In Hastings prior to the eruption, age was correlated with community ($r = -0.24$) and personal ($r = -0.22$) preparedness. After the 1995 Ruapehu eruption, ethnicity correlated with central government preparedness ($r = 0.22$) and education with both central ($r = 0.24$) and local ($r = 0.27$) government preparedness. However, these associations are all relatively low and suggest that the perceived levels of preparedness were largely unaffected by these

socio-demographic variables.

TABLE 8.17 Comparison of respondents' mean scores of levels of organisational and personal preparedness for volcanic hazards, pre- and post- the 1995 Ruapehu eruption.

Variable	Pre-eruption mean (rank)	s.d.	n	Post-eruption mean (rank)	s.d.	n
Whakatane						
Central govt.	2.49 (2)	0.72	199	2.30 (2)	0.66	142
Local govt.	2.38 (1)	0.68	200	2.14 (1)	0.68	142
Community	3.12 (4)	0.73	200	2.94 (4)	0.61	143
Personal	3.01 (3)	0.77	200	2.76 (3)	0.71	144
Hastings						
Central govt.	2.71 (2)	0.73	210	2.36 (2)	0.71	138
Local govt.	2.64 (1)	0.78	210	2.22 (1)	0.71	138
Community	3.44 (4)	0.62	213	3.11 (4)	0.59	137
Personal	3.35 (3)	0.77	213	2.96 (3)	0.78	138

1 = very prepared, 2 = somewhat prepared, 3 = not very prepared, 4 = not prepared at all

TABLE 8.18 Comparison of respondents' (those who completed both surveys) mean scores of levels of organisational and personal preparedness for volcanic hazards, pre- and post- the 1995 Ruapehu eruption.

Variable	Pre-eruption mean (rank)	s.d.	Post-eruption mean (rank)	s.d.	n	t
Whakatane						
Central govt.	2.50 (2)	0.74	2.36 (2)	0.66	98	2.10*
Local govt.	2.30 (1)	0.68	2.20 (1)	0.65	99	1.48
Community	3.17 (4)	0.69	3.04 (4)	0.55	99	1.88
Personal	3.03 (3)	0.70	2.73 (3)	0.72	100	4.02***
Hastings						
Central govt.	2.69 (2)	0.76	2.38 (2)	0.73	97	3.65***
Local govt.	2.60 (1)	0.81	2.19 (1)	0.73	97	4.99***
Community	3.43 (4)	0.61	3.13 (4)	0.61	97	3.78***
Personal	3.24 (3)	0.83	2.94 (3)	0.77	98	3.83***

1 = very prepared, 2 = somewhat prepared, 3 = not very prepared, 4 = not prepared at all

* $p < .05$ *** $p < .001$

The degree to which respondents thought that the threat was over-rated (i.e. 'the threat to the regional economy or environment from volcanic eruptions affecting your region is over-rated') was assessed (Table 8.19) on a 4-point scale (strongly agree = 1, agree = 2, neutral = 3, disagree = 4, strongly disagree = 5).

Prior to the 1995 Ruapehu eruption Whakatane respondents disagreed (i.e. mean greater than 3) that the threat to the regional economy or environment from volcanic eruptions was over-rated (mean 3.24), whereas Hastings respondents marginally agreed (mean 2.93). After the 1995 eruption there was no significant change in view amongst Whakatane residents (mean 3.21) but a significant change in Hastings residents (mean 3.29) who now disagreed with the statement. The significance was tested using the sub-sample of respondents who completed both questionnaires (Table 8.20). This change was also seen in the response to the question in the second survey that asked directly if the 1995 Ruapehu eruption had changed the view of respondents to potential volcanic hazards in their region (Table 8.21). A small majority of Whakatane respondents (54.5%) claimed that the eruptions had not changed their views whereas a larger majority of Hastings respondents (61.3%) claimed that the eruption had indeed changed their view of the potential volcanic threat. When asked what were the main reasons for changing their views on the potential volcanic threat a variety of reasons were given. In Whakatane 75.4% stated that information provided by the media was one of the factors that caused a change in their view, 63.1% stated the ash falls and their impacts, 26.2% stated information provided by Civil Defence, G.N.S. or other organisations, 23.1% stated acid rain and sulphur dioxide smell and 4.6% listed other factors. In Hastings 86.9% stated that the ash falls and their impacts was one of the factors that caused a change in their view, 59.5% information provided by the media, 50.0% acid rain and sulphur dioxide smell, 10.7% information provided by Civil Defence, G.N.S. or other agencies and 4.8% listed other factors.

The respondents' agreement (or disagreement) that the volcanic risk was overrated was compared to respondents' characteristics (Table 8.3) before and after the 1995 Ruapehu eruption and analysis also revealed no significant associations.

TABLE 8.19 The extent to which respondents agreed or disagreed with the statement: "the threat to the regional economy or environment from volcanic eruptions affecting the region is over-rated".

	Pre-eruption mean	s.d.	n	Post-eruption mean	s.d.	n
Whakatane						
Volcanic threat	3.24	1.10	198	3.21	1.09	145
Hastings						
Volcanic threat	2.93	0.99	206	3.29	1.05	139

1 = strongly agree, 2 = agree, 3 = neutral, 4 = disagree, 5 = strongly disagree

TABLE 8.20 The extent to which respondents (those who completed both surveys) agreed or disagreed with the statement: "the threat to the regional economy or environment from volcanic eruptions affecting the region is over-rated".

	Pre-eruption mean	s.d.	Post-eruption mean	s.d.	n	t
Whakatane						
Volcanic threat	3.29	1.08	3.27	1.16	100	0.87
Hastings						
Volcanic threat	3.00	1.02	3.41	1.02	95	-3.27**

1 = strongly agree, 2 = agree, 3 = neutral, 4 = disagree, 5 = strongly disagree

** $p < .01$

TABLE 8.21 Respondents who reported that the 1995 Ruapehu eruption changed their view of potential volcanic hazards and the reasons for changes.

Variable	Whakatane		Hastings	
	n	%	n	%
Yes	65	45.5	84	61.3
No	78	54.5	53	38.7
Total	143		137	
Media	49	75.4	50	59.5
Organisations	17	26.2	9	10.7
Ash impacts	41	63.1	73	86.9
Acid rain/gas	15	23.1	42	50.0
Other	3	4.6	4	4.8

8.5.4 Adjustment to volcanic hazards

Past research has shown that the adoption of protective measures correlates with risk perception and other disaster behaviours, such as warning compliance (Perry *et al.* 1981; Drabek 1986; Perry & Lindell 1990). This study asked if individuals had undertaken any protective measures in view of possible natural hazards and listed a number of options to choose from: purchased insurance, planned evacuation routes, obtaining battery powered radio and having supplies of food and water.

Prior to the 1995 Ruapehu eruption, two thirds (66.3%) of Whakatane respondents claimed to have undertaken protective measures (Table 8.22). Purchasing insurance was the most popular measure (81.1%) followed by obtaining battery operated radio (62.9%), maintaining emergency supplies of food and water (48.5%) and planning evacuation routes and a place to stay (24.2%). Other options were given by 18.9% of respondents. Following the 1995 eruption there was very little change in both the numbers undertaking protective actions and the percentage undertaking particular options, and no change in the rank ordering. Purchasing insurance remained the most popular measure (81.4%), followed by obtaining a battery operated radio (63.9%), maintaining emergency supplies of food and water (52.6%) and planning evacuation routes and a place to stay (26.8%). Other options were given by 14.4% of respondents.

Like Whakatane, almost two thirds (63.0%) of Hastings respondents before the 1995 eruption claimed to have undertaken protective measures. Purchasing insurance was the most popular measure (88.0%), followed by obtaining a battery operated radio (54.9%), maintaining emergency supplies of food and water (44.4%) and planning evacuation routes and a place

to stay (21.1%). Other options were given by 9.8% of respondents. Following the 1995 eruption there was a drop in the numbers undertaking protective actions (down to 52.9%). Of those undertaking protective actions, purchasing insurance was still the most popular measure (71.2%), followed by obtaining battery operated radio (56.2%), maintaining emergency supplies of food and water (52.6%) and planning evacuation routes and a place to stay (32.9%). Other options were given by 11.0% of respondents.

Taking protective action was compared to respondents' characteristics (Table 8.3); however, analysis revealed no significant associations. The link between taking protective action and perceived risk was also tested but showed only weak links. In Whakatane, after the 1995 Ruapehu eruption, those undertaking protective actions had a lower perceived threat to disruption to lifestyle from volcanic activity ($t(135) = -2.32, p < .001$) than those not undertaking protective actions. In contrast, Hastings respondents showed differences before the 1995 eruption only, with those undertaking protective actions having a higher perceived threat to personal safety from volcanic activity ($t(180) = 2.06, p < .001$) and disruption to lifestyle from earthquakes ($t(201) = 2.47, p < .001$) than those not undertaking protective actions. However, caution should be placed on these findings as the result may reflect question design. Questions of perceived risk related to specific hazards and assessed two dimensions of risk (personal safety and potential disruption to lifestyle), whereas questions relating to protective action related all possible natural hazards. A more rigorous assessment of specific actions related to specific hazards is needed to fully test the link between perceived risk and protective action. Perry and Lindell (1990) did find that the higher the level of perceived risk the greater the hazard adjustment in communities in the aftermath of the 1980 Mount St. Helens eruptions. However, these communities had experienced a greater level of volcanic impact than those in this study.

TABLE 8.22 Protective measures undertaken in view of any possible natural hazards

Variable	Pre-eruption n	%	Post-eruption n	%
Whakatane				
No	67	33.7	46	32.2
Yes	132	66.3	97	67.7
Total	199		143	
Purchased insurance	107	81.1	79	81.4
Planned evac. route	32	24.2	26	26.8
Obtained battery radio	83	62.9	62	63.9
Food and water	64	48.5	51	52.6
Other	25	18.9	14	14.4
Hastings				
No	78	37.0	65	47.1
Yes	133	63.0	73	52.9
Total	211		138	
Purchased insurance	117	88.0	52	71.2
Planned evac. route	28	21.1	24	32.9
Obtained battery radio	73	54.9	41	56.2
Food and water	59	44.4	41	56.2
Other	13	9.8	8	11.0

8.6 DISCUSSION

8.6.1 Comparisons between communities

Comparisons between the two communities should be treated with caution as both sites are subject to different magnitudes and frequency of hazards. However, direct comparisons are useful as a way of exploring factors that may explain the results observed. Both communities have been exposed to a range of past hazardous events which have helped shape each community's perception of the hazard. Earthquakes were perceived as most likely to threaten both communities and both have been exposed to major earthquakes in the past 70 years. Hastings was devastated by a magnitude 7.2 earthquake in 1931 that killed 256 people in the region and Whakatane was impacted by a magnitude 6.2 earthquake in 1987, although causing no loss of life. In the case of volcanic hazards, Whakatane and Hastings supply interesting contrasts. Both were subjected to intense media coverage during the 1995 Ruapehu eruption, but Whakatane was spared any direct effects, whereas Hastings experienced the hazard directly in the form of ash falls in September and October 1995. Only Hastings respondents showed a significant change in the perceived volcanic threat. However, even though there was no significant change in the perception of volcanic threat in Whakatane, residents still continued to perceive the volcanic threat as higher than Hastings residents. Many of the results were the same or very similar in both communities, as well as consistent with overseas findings (e.g. preferred methods of dissemination, credible sources of information, levels of organisational preparedness etc) and this has implications for hazard management in other New Zealand communities.

8.6.2 Correlation between factors shaping perceptions

This study found only weak correlations between a few respondents' characteristics and perceptions. It may be argued that a generally low level of awareness (understanding) of the hazard issues means that most respondents have the same or similar "low awareness values" and therefore it is not statistically possible to assess the co-variations between respondents characteristics and perception levels. Perry and Lindell (1990) suggest that the lack of a variable sample means there are not subjects to examine who represent the full range of awareness levels, therefore by definition they can't be assessed as a way of explaining dependent variables. However, this should not take away from the value of the findings presented in the chapter, because they do represent a measure of the communities' understanding and the perceived threat of various hazard types. But it does place a limit on the extent to which the data can be manipulated to produce meaningful results beyond the observations already presented. Studies by Greene *et al.* (1981); Perry and Lindell (1990); Perry and Hirose (1991); Yoshii (1992); and Lindell (1994) followed major volcanic events,

which resulted in high levels of awareness through personal experience, therefore providing a better opportunity to examine the links between factors that shape perceptions and adjustment to volcanic threats. This study has not attempted to replicate the more detailed analytical approach of Perry and Lindell (1990) and is in many ways limited by a simpler survey design. The initial survey was intended to provide a general overview of community perceptions and the opportunity to test changes in perceptions following a volcanic eruption had not been anticipated.

8.6.3 Implications for hazard management

This study has two classes of conclusions: those specific to each community (Whakatane and Hastings) and those addressing the implications for volcanic hazard management in general in New Zealand. A more general discussion on volcanic hazard management issues is presented in Chapter 9, combining observations from this study with a review of the general literature on hazard management.

At a specific community level there was good support for the issues addressed in the survey, reflected in the high return rate and considerable written feed-back on the completed questionnaires. The belief that volcanic hazards are not over-rated gives a clear signal that the public does see natural hazards as a serious community issue, even if awareness of certain aspects is limited. The lack of specific local material on hazards in each community is one issue that needs to be addressed. The improved levels of perceived preparedness of organisations after the 1995 Ruapehu eruption and the belief that local government is the most prepared should be viewed as encouraging by regional and territorial authorities who have a statutory responsibility for hazard management.

Experiencing the direct and indirect impacts of the 1995 Ruapehu eruption may make subsequent warnings and information releases more salient, thereby enhancing the likelihood of engaging in protective actions or other forms of response. This is likely to be the case for those individuals and organisations that experienced the greatest impacts. However, the relatively benign impacts may make many prone to a "normalisation bias" (cf. Mileti & O'Brien 1993), whereby individuals or organisations believe that the volcanic eruptions did not affect them negatively and therefore any future volcanic events will not have a negative impact on them. This may be prevalent in communities close to Ruapehu which escaped the direct ash falls as a consequence of favourable but chance wind directions. This conclusion suggests that the 1995-1996 Ruapehu eruptions may have both improved and reduced individual, organisational and community preparedness for future volcanic events.

In conclusion: assessing risk by focusing purely on the physical processes that cause it does

not fully accommodate the public's assessment of risk. In the past this has led to problems in communicating hazard information and persuading the public to undertake appropriate mitigation measures. Research has shown that individual and societal perceptions of risk relate to planning behaviour, warning compliance and recovery behaviour. Thus understanding a community's perceptions of risk is an important part of any decision making process and should be considered an essential component in natural hazard management.

8.7 SUMMARY

Both Whakatane and Hastings residents have a limited knowledge of past volcanic events. Few residents have copies of specific volcanic hazard information and few had undertaken any form of information searching prior to the 1995 Ruapehu eruption. The 1995 eruption resulted in a small increase in the numbers searching for information on volcanic hazards in both communities. Friends and relatives were the most frequently asked group, followed by a range of other organisations. Although some agencies are perceived as more credible than others as the source of volcanic hazard information, no one agency has a monopoly on perceived credibility (i.e. different people recognise different agencies as the best source of information on volcanic hazard information and warnings). This has important implications for the issuing of warnings and disseminating public education and supports the idea of using multiple agencies carrying a consistent message to enhance public response. During the 1995 Ruapehu eruption the media (TV, radio and newspapers) were the principal sources of information about what was happening. The data clearly show, as was the case with source of information, that no one channel is the best method to disseminate information. Different people rely on different channels of information and this should also be acknowledged when issuing warnings and releasing public information.

In Whakatane, earthquakes and volcanic eruptions are perceived as likely to threaten personal safety and disrupt life in the future. Floods are perceived as likely to disrupt daily life. The 1995 Ruapehu eruption had no significant impact on residents' perceived vulnerability. In Hastings, only earthquakes were perceived to be likely to threaten personal safety and lifestyle in the future. However, a significant change in the perceived threat from volcanoes was measured after the 1995 Ruapehu eruption.

In Hastings, perceived levels of preparedness to volcanic threat in central and local government, the community and individuals showed significant improvements after the 1995 Ruapehu eruption, whereas perceptions of only personal and central government preparedness improved in Whakatane. However, personal and community preparedness still rated poorly in both communities (between being not very prepared and not prepared at all). The improved perception of central government preparedness suggests that the response to the

Ruapehu eruption was judged to be satisfactory by residents of both communities. This is also suggested for the local government response in Hastings. However, the lack of any significant change in Whakatane relates more to the fact that the town was spared any direct impact of the eruption. Local government is still perceived to be the most prepared of all four groups. Both communities clearly believe that the volcanic threat to their regions is not over-rated.

CHAPTER 9

VOLCANIC HAZARD MANAGEMENT IN NEW ZEALAND: AN OVERVIEW

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9.1 INTRODUCTION

New Zealand contains a number of potentially active volcanoes and volcanic centres (Fig. 1.1). Although the probability of an eruption affecting a significant portion of the country is relatively low in any one year, an eruption will undoubtedly reoccur at some time in the future. During and following an eruption a number of destructive hazards exist, notably pyroclastic falls (ash falls), pyroclastic flows/surges and lahars; evacuation may be required to protect inhabitants from them (see Chapter 3). Ash falls are the most likely hazard to affect communities distal to a volcano and, in most cases, they will be disruptive rather than destructive, impacting on services such as water, sewerage, electricity and transportation, for hours to a few weeks (see Chapters 2, 3, 6, 7).

The risk to New Zealand from a volcanic eruption can be expressed by the relationship:

$$\text{Risk} = \text{Hazard} \times \text{Vulnerability}$$

in which the hazard from a future volcanic eruption is a combination of the probability of an eruption occurring in any given (say 100 year) period, plus the nature and extent of the eruptive products. Vulnerability is an expression of the effects of the eruption on people, buildings, infrastructure and economic activity.

For hazard management strategies to be effective the hazards posed by the various volcanoes of the region must be well understood. Prior analysis of the hazards and their potential impacts will provide the vital information needed for preliminary planning to minimise the unexpected. The management of disasters has traditionally been divided to four tasks: mitigation, preparedness, response and recovery. These terms capture the types of requirements society must face if it is to coexist with a variety of natural and man-made hazards (Perry & Lindell 1990). There are a number of options available to society to address this risk management and these can be placed into three basic groups: education, economic and regulatory (Somers 1995).

Effective response to impending volcanic hazards depends on an effective warning time, thus an acceptable level of long-term surveillance of New Zealand's volcanoes must be maintained. Signs of volcano unrest, once recognised, must be responded to in an orderly fashion, with all responding parties clearly understanding their own roles and responsibilities. The public must also be concisely and rapidly informed. It is contingent upon regional and district councils, emergency services and other relevant organisations to be able to understand the significance of information received and respond appropriately.

9.2 AIM OF THIS CHAPTER

The aim of this chapter is to identify significant issues that need to be considered in developing a response to a volcanic crisis affecting New Zealand. The chapter outlines a number of principles that should be considered in preparing volcanic contingency plans, and in part is based on the information and findings presented in the previous chapters. As contingency planning is a complex and dynamic process, involving a range of social, political and economic functions and various organisations with differing responsibilities, there may well be other issues not identified in this chapter that should also be considered.

9.3 VOLCANIC CONTINGENCY PLANNING

Volcanologists refer to a "volcanic crisis" as the whole realm of events concerned with the awakening of a volcano, the building up to an eruption, the eruption and the aftermath as the affected region recovers. Any plan for dealing with a volcanic crisis requires a comprehensive emergency management approach, part of an "all hazards" strategy, linking mitigation, preparedness, response and recovery (Wenger 1988; Drabek & Hoetmer 1991). However, there needs to be sufficient flexibility to accommodate and target the different hazards and corresponding degrees of risk (May 1997). Emergency management in contingency planning must be linked with broader provisions of land-use management generated by the Resource Management Act (1991) and contained in Regional Policy Statements and District Plans (cf. Britton & Lindsay 1995).

A universal criteria of contingency plans is that they remain simple and flexible, and focus on principles rather than details. Their purpose is to facilitate an effective and appropriate response. The appropriateness of the response is often more important than its speed. The contingency planning process is a continuous and evolutionary one (i.e. the plan is never complete). It seeks to form and maintain a clear and accurate understanding of the roles and responsibilities of all the organisations involved in the management of a crisis (disaster). However, a number of researchers have documented that emergency planning in New Zealand and overseas is often based on false assumptions and inappropriate analogues (e.g. Perry 1985; Britton 1986, 1995; Dynes 1994). These may include perceptions of human reactions and response (e.g. panic vs. effective coping), planning assumptions (e.g. focus on hazards vs. general principles) and effectiveness assumptions (e.g. safety devices, warnings etc). Other obstacles to good planning practices include the lack of experience with past events and the lack of an effective planning process (Kartez & Lindell 1987).

Perry (1985) notes:

Too often emergency plans which are administratively derived turn out to be based on misconceptions of how people react and therefore potentially create more problems than they solve.

9.4 THE NATIONAL CIVIL DEFENCE PLAN

Emergency management in New Zealand operates under the Civil Defence Act (1983), its subsequent amendments and the National Civil Defence Plan. These regulations bind the Crown, local government and state-owned organisations. Regional councils and territorial authorities have responsibilities to perform a number of functions, as outlined in the National Civil Defence Plan, including preparation of civil defence plans. The Ministry of Civil Defence is responsible for preparing the National Civil Defence Plan, overseeing its implementation and coordinating national strategies. Currently, emergency management in New Zealand is under review (Teagle 1995). The eight principles adopted by the New Zealand Cabinet on 2 September 1996, as a basis for an overarching emergency management framework are (from Ministry of Civil Defence "Newline" newsletter, December 1996):

1. Comprehensive and integrated emergency management systems;
2. An all hazards approach;
3. Structures underpinned with appropriate technical information and expertise;
4. Recognition and involvement of volunteer organisations;
5. Declarations made at the most appropriate level of government by elected representatives;
6. Individual and community responsibility and self-reliance;
7. The owner of any property be responsible for its reconstruction;
8. Routine events and emergencies are best handled at the local level wherever possible.

The current National Civil Defence Plan outlines the following responsibilities for regional councils and territorial authorities with respect to volcanic hazards:

Ministry of Civil Defence are to:

1. *Pre-eruption*
 Maintain the National Volcanic Contingency Plan
 Convene the Volcanic Working Group of the Scientific Advisory Committee as necessary.
 Provide assistance and advice to regional councils, territorial authorities and other agencies as applicable.

Maintain the National Civil Defence Warning System.

Promote volcanic research.

Establish such working groups and advisory committees as may be necessary to investigate or coordinate national level mitigation, response and recovery measures.

Advise Government and its agencies on the most appropriate actions to take in response to the likelihood, or event of, a major volcanic eruption.

Distribute GNS Science Alert Bulletins, hazard maps, ash fall predictions and any other applicable information and advice.

Issue Volcanic Information Notices.

2. *Eruption*

Issue Volcanic Information Notices as appropriate.

Activate the National Civil Defence Warning System.

Coordinate any national level response which may be required.

Deploy staff to provide direct liaison with GNS.

Deploy staff to provide Commissioner Support Teams as required to assist and advise regional councils and territorial authorities.

As required, activate an 'information hot-line' to address public concerns.

Issue Situation Reports and, as required, coordinate the distribution of GNS Science Alert Bulletins, hazard maps, ash fall predictions and any other applicable information and advice.

Coordinate with Ministry of Foreign Affairs and Trade (MFAT) and with the Department of the Prime Minister and Cabinet (DPMC) regarding international responses to the event.

3. *Post-eruption*

Distribute GNS Science Alert Bulletins, hazard maps, ash fall predictions and any other applicable information and advice.

Issue Volcanic Information Notices.

Provide advice and assistance to regional councils and territorial authorities during the recovery phase.

Receive and administer claims for emergency expenditure.

Facilitate post-eruption research and study.

Carry out an analysis of the event and responses and review and amend national plans accordingly.

Regional Councils are to:

1. *Pre-eruption*
 - Undertake hazard assessments of volcanoes within the region.
 - Identify the probable effects of volcanic eruption (both near and distant) on the region.
 - Prepare and maintain contingency plans.
 - Participate in tests of the National Civil Defence Warning System.
 - Assist with, and coordinate constituent territorial authority response planning and evacuation and/or reception plans.
 - Identify additional resources likely to be required in the eruption phase.
 - Coordinate the planning necessary to absorb displaced people from outside the region.
 - Formulate and issue Volcanic Information Notices as applicable.
 - Coordinate information and advice to the public at a regional level.
 - Consider a 'precautionary' declaration of regional civil defence emergency over all or part of the region.

2. *Eruption*
 - Respond to information passed through the National Civil Defence Warning System or direct from GNS.
 - Activate and coordinate regional contingency/response plans.
 - Assist constituent territorial authorities with the implementation of their respective contingency/response plans.
 - Identify additional resources required and arrange the acquisition of same.
 - Coordinate the provision of information and advice at the regional level.
 - Implement a recovery plan when appropriate and feasible.

3. *Post-eruption*
 - Continue implementation of the recovery plan.
 - Coordinate the provision of information and advice at the regional level.
 - Identify requirements for additional support and resources.
 - Assist constituent territorial authorities with recovery measures.
 - Carry out post-eruption analyses and incorporate results in contingency, response and recovery plans.

Territorial authorities are to:

1. *Pre-eruption*
 - Identify geographical areas likely to be impacted by volcanic effects.
 - Identify probable effects on the constituent population.

Prepare and maintain response plans, including appropriate contingency plans for the evacuation of high-risk areas.

Prepare plans for countering the effects of ash fall.

Identify additional support and resource requirements and make arrangements for the acquisition of same.

Prepare and maintain effective warning systems.

Carry out public education activities.

2. *Eruption*

Implement local contingency/response plans.

Arrange the acquisition of such additional support and resources as may be required.

Provide information and advice to the public at local level.

Initiate a recovery plan when feasible/applicable.

3. *Post-eruption*

Continue implementation of the recovery plan.

Identify the need for additional support or resources.

Coordinate the provision of information and advice to the public.

Carry out an analysis of the event and responses, and amend local plans accordingly.

9.5 HAZARD AND RISK ANALYSIS

Considerable progress has been made over the past three decades in the understanding of the volcanoes of New Zealand, principally by detailed geological mapping, volcano surveillance and eruption observations undertaken by the NZ Geological Survey (now the Institute of Geological and Nuclear Sciences (GNS)) and New Zealand universities (e.g. Neall 1972; Wilson 1985; Houghton *et al.* 1987; Houghton & Nairn 1989; Nairn 1989; Houghton *et al.* 1992; Allen & Smith 1994). The Ministry of Civil Defence has produced the *Volcanic Hazard Information Series*, translating this detailed scientific knowledge into publicly accessible form. Booklets now cover Egmont Volcano (Neall & Alloway 1991), Okataina Volcanic Centre (Nairn 1991a), White Island (Nairn *et al.* 1991), the Kermadec Islands (Latter *et al.* 1992), Auckland Volcanic Field (Smith & Allen 1993) and Mayor Island (Houghton *et al.* 1994).

Volcanic hazard maps have been prepared for two volcanic centres: Egmont Volcano (Neall 1982, [updated in] Neall & Alloway 1996) and Tongariro Volcanic Centre (Latter 1987). Preparation of a third map has begun, covering the Okataina Volcanic Centre. Eruption scenarios also provide one way of illustrating the types of impacts that might realistically be expected from a volcanic eruption (see Chapters 4, 6 and 7). Scenarios have been developed

for the Auckland Volcanic Field (Allen 1992; Johnston *et al.* 1997), Okataina Volcanic Centre (Johnston & Nairn 1993) and Edgecumbe volcano (Nairn 1995).

Hazard maps can be used to produce risk maps by combining them with social data such as population densities, locations of critical facilities such as schools and hospitals and the location of infrastructural 'lifelines' of water, sewerage, transportation routes and electricity systems. Risk analysis involves assessing the risks to the population and infrastructure from specific hazards and can be undertaken at various levels. The Australia/New Zealand Risk Management Standard (1995) provides a framework for risk management which has been adopted by many stakeholders in both countries (Helm 1996a, Salter 1996). The move towards a greater focus on community vulnerability in risk management provides a more holistic and flexible framework (Anderson 1995), along with increasing recognition that vulnerability of populations to natural hazards is created by certain social and economic processes and frequently increases with time. This concept of increasing vulnerability within our society is illustrated by the comparison of the consequences of the similar-sized 1945 and 1995-1996 Ruapehu eruptions (see Chapter 2). Any assessment of social impacts must consider the complex factors that create social vulnerability (Anderson 1995; Salter 1995). Salter (1995) proposed a range of information sets that can be used as vulnerability indicators, listed in Table 9.1.

TABLE 9.1 Information sets that can be used as vulnerability indicators (from Salter 1995)

Information sets	Examples
1. Physical	infrastructure, built environment, natural environment, services, utilities, industry, communications, isolation, transportation, equipment, shelter, hazard substances and processes.
2. Emergency management	management strategies, plans, evacuation strategies, trained people, public safety ethos, appropriate resources.
3. Demographic	numbers, density, distribution, structure, tourists, migrants, occupation, temporal distribution.
4. Health	disabilities, mental health, patients, age, public health, sanitation, disease, service dependence.
5. Economic	income, production, productivity, wealth levels, welfare recipients, government grants, level of insurance, land valuations, business register, occupations (in region).
6. Communication	public education, warnings, warning systems, awareness, media, inter/intra-agency, public information, access to information, availability of information, ability to monitor, decision-making power.
7. Psychological	coping strategies, experience, knowledge, stress, acceptance, bravado, isolation, realisation.

8. Societal/cultural	cohesion, ethnicity, language, age, gender, family, education, functional literacy, friends, community leaders, parochial organisations, religion, rituals, beliefs, history.
9. Organisation	networks, communication(s), resources, logistics, government, services, non-government services, legal, political.

The recent development of 'lifelines' engineering risk assessment methodologies, as outlined in Chapter 4, provides a valuable tool for communities to examine the risk to their utilities and services from all hazards. 'Lifelines' studies must, however, move beyond a simple assessment of physical vulnerability, to consider the social implications of hazards and any identified mitigation options. Failure to consider all aspects of vulnerability is illustrated by the example from Anchorage, Alaska, following the 1992 Mount Spurr eruption, when a light ash fall caused major water shortages to the city (see Appendix 3 for details).

Individuals and society are frequently required to make decisions about risk. Determining an acceptable level of risk requires making decisions based on individual and community perceptions of the risk (Gough 1990). The level of acceptable risk is commonly set by society on behalf of individuals in the form of legislation (i.e. laws, building codes, resource consents etc). Decisions about risk are almost always politically influenced, therefore an understanding of community perceptions of risk is a necessary input in the decision making process (Slovic 1993). The public frequently have a low personal interest in risk but a high expectation of government responsibility. This is shown in the previous chapter (8) in which local and central government are rated ahead of individuals and the community in perceived levels of preparedness by Whakatane and Hastings respondents. However, lack of knowledge and uncertainties are common in decision-making about natural hazards. For analytical approaches to be useful for decision making they must take into account the differences in perception and conflicts between the many 'players' and plausibility of alternative actions, and they must encourage creativity and generate decisions with flexible capacities (Horlick-Jones & Rosenhead 1996).

9.6 MITIGATION

The requirement to mitigate natural hazards in New Zealand is covered by the Resource Management Act (1991) which seeks to provide a structure for natural hazard management that focuses responsibilities and requires effective means of control to be adopted. Implementation of this new regime is carried out by regional and territorial authorities through regional policy statements, regional plans, district plans and resource consents. Economic options can consist of both positive and negative incentives to control hazards. However, funds spent on engineering solutions to control hazards may draw resources away from equally effective less costly social solutions (Bates *et al.* 1990). The Regional Policy Statements and

regional/district plans of volcanic areas should recognize explicitly that parts of these regions are susceptible to hazards associated with future volcanic eruptions. Such zones, like those close to potential vents and/or on vulnerable flood plains, need to be identified.

Lava flows, ballistic block impacts, pyroclastic flows and surges, lahars and lightning strikes from ash clouds present a high risk to life and damage to facilities in near-vent areas, but the extent of these hazards is mostly limited to within a few kilometres of the vent except for lahars which present a more extensive hazard (see Chapter 3). Apart from the evacuation of people and removal of transportable assets (if possible), there are few or no mitigation options available to pre-existing facilities to counteract many of these hazards.

Past eruptions illustrate the vulnerability of urban areas receiving only a few mm or cm of ash but sufficient to cause disruption of transportation, electricity, water, sewage and stormwater systems (see Chapter 2, 3 and Appendix 1, 3). However, most systems, if affected only by thin ash fall (<50 mm), can be restored within a few days to weeks after an eruption has ended.

Once the vulnerability has been assessed mitigation strategies can be developed. Three types of approaches can be used:

- * Policy and management measures that reduce the likelihood of damage and/or failure.
- * Engineering design measures that reduce vulnerability.
- * Preparedness and response planning to deal with consequences of the event.

Mitigation options should be evaluated in terms of risk reduction and the benefits or opportunities created (AS/NZS 1995). In selecting any appropriate option or options the cost of implementation must be balanced against the benefits derived from it (Fig 4.3). Limitation on the building of permanent structures in risk areas is a low cost mitigation measure, as would be recommending building codes that require steeper roof pitches, particularly for important public buildings such as schools, hospitals, police and fire stations, in areas where thick ash falls could be expected.

9.6.1 Mitigation measures for volcanic ash falls

Volcanic ash is highly abrasive, mildly corrosive and potentially conductive (especially when wet). Mitigation actions have two basic purposes: 1) preventing or limiting ash entering systems or enclosures; and 2) effective and efficient removal of ash to prevent or reduce damage.

The most effective method to prevent ash-induced damage is to shut down, close off and/or seal off equipment until the ash is removed from the immediate environment. In many cases this is not practical or acceptable. Some mitigation procedures can cause additional problems or may be counter-productive. No one technique is the solution to all situations and a range of measures will often provide the best results. Constant monitoring of ash effects and mitigation procedures is required to achieve the most effective balance between operational requirements and damage limitation.

Pre-planning can reduce the severity of ash impacts. Mitigation, planning and preparation measures should include the following activities:

- * Conduct a vulnerability analysis of equipment and facilities to determine which would be the most affected and which are adequately protected.
- * Identify appropriate methods of protecting vulnerable equipment and facilities.
- * Develop a priority list of facilities that must be kept operative versus those that can be shut-down during and after ash falls.
- * Identify effective and efficient ash-removal methods for equipment and facilities.
- * Establish plans to implement ash mitigation measures containing procedures for: warning and notifying of potential ash falls, reducing or shutting down operations, accelerated maintenance and ash-clean-up operations.
- * Stockpile spare parts for critical equipment, filters and cleaning/disposal equipment.

9.7 PREPAREDNESS AND RESPONSE

A volcanic contingency plan should contain the following elements:

- * Presentation of hazard analysis results and mapping of volcanic hazard zones;
- * Definition of the roles and responsibilities that all responding agencies will have, from pre-planning to recovery, within the region;
- * Clarification of response procedures and responsibilities to scientific alert level changes during a volcanic crisis;
- * Definition of procedures for communication of public warnings;
- * Clarification of response procedures and responsibilities for evacuations within and outside the region;
- * Consideration of appropriate public education activities during both non-crisis (quiescent) and crisis periods;
- * Provisions for revising and updating the plan at regular intervals.

9.7.1 Definition of roles and responsibilities for all responding agencies

A key element of a volcanic contingency plan is the definition of the roles and responsibilities of all responding agencies and critical industries involved in the management of volcanic hazards in the region. Conflict and misunderstanding between organisations appears to be common and often stems from differing perceptions of respective roles and responsibility. In the first instance it will be necessary to identify these agencies and industries, then define their roles and responsibilities.

Listed below are some of the major issues that need to be addressed:

- * Who are the agencies with roles and responsibilities for the management of volcanic hazards in the region and when should they become involved ?
- * What are the statutory responsibilities of these agencies (e.g. Civil Defence Act (1983); National Civil Defence Plan; Resource Management Act (1991) etc) ?
- * Who are the critical industries, why are they and what roles should/could they play ?
- * Who decides on the level of acceptable risk, how is risk defined ?
- * Who talks to the media ?
- * Who distributes educational material and who compiles it ?
- * Who interfaces with the science community ?
- * Who interfaces with the Ministry of Civil Defence ?
- * What are the roles of the regional and district councils' civil defence committees ?
- * How do agencies respond without a declaration of civil defence emergency ?
- * Is there a need for a regional (or local) emergency management group ?
- * Where should the emergency control centre be located ?

The establishment of inter-organisational groups has proved successful in the management of volcanic hazards in New Zealand and overseas. During the 1995-1996 Ruapehu eruption a management group comprising representatives from key organisations (see Chapter 2) met regularly to examine the hazard to the public and to consider appropriate responses (Keys & Williams 1996). Another example is the Egmont Volcano Scientific Advisory Group consisting of representatives from the Institute of Geological and Nuclear Sciences, universities and the Ministry of Civil Defence. They provide advice on volcanic management of Egmont volcano to the Taranaki Regional Council (Taranaki Regional Council 1996). Setting up such groups during quiescent periods will enhance their effectiveness during a volcanic crisis. Such groups should be a part of, or at least associated with the Emergency Management Groups (EMG) proposed by the Emergency Services Review (Teagle 1995).

9.7.2 Response to scientific alert level changes

Volcano surveillance in the New Zealand region is carried out by the Institute of Geological and Nuclear Sciences (GNS). Scott *et al.* (1995a) provides a review of surveillance of New Zealand's volcanoes and Figure 9.1 shows the locations of seismometers within the five volcano-seismic networks in New Zealand. Monitoring enables the background state of the volcano to be determined. Departures from this state may indicate the onset of an eruptive episode.

As detailed in the National Civil Defence Plan each volcano is assigned a Scientific Alert Level by GNS denoting the **current status** of the volcano. The scientific alert system is based on a 6-stage classification (Table 9.2) where the lowest level is 0 (dormancy) and the highest level is 5 (large scale hazardous eruption in progress). The New Zealand system has two parallel tables, one for **frequently active cone volcanoes** and the other for **reawakening volcanoes**. GNS will adjust the alert level based on observations from the surveillance programmes at each volcano and notify Ministry of Civil Defence, regional councils and the media (as per the National Civil Defence Plan).

At any volcano a move from Alert Level 0 to Alert Level 1 does not necessarily signal imminent volcanic activity. However, responding organisations/agencies/industries need to know and plan for their respective responses and understand their responsibilities. There is a danger of an over-reactive and inappropriate response to a change in the alert level, especially at volcanoes showing signs of unrest after prolonged inactivity. This response may be in the release of inappropriate advice, unwarranted declarations of civil defence emergency and enforced evacuation, or premature cessation of economic activity and community services. Volcanoes can experience unrest events/episodes that do not lead to eruptions and this can cause severe political and economic problems [as seen at Long Valley caldera (Mader & Blair 1987; Bemknopf *et al.* 1990; Hill 1997)] if mishandled by authorities.

Alert Level 1, especially for reawakening volcanoes, simply means that indications of unrest have been detected by the scientific community and are being evaluated. Level 2 is confirmation that the apparent unrest is volcanic in origin and indicates that an eruption may occur in the future. Volcanoes can undergo long periods of unrest without eruptions. Summarised in Table 9.3 are some recent examples of volcanic crises in New Zealand and overseas. The pre-eruption crises have ranged from two months to over twenty years. In some cases no eruptive activity has occurred despite long periods of recognisable unrest. A

disturbing aspect is the rapid transition in volcano state from minor (usually phreatic) or no visible activity to major eruption (e.g., Rabaul, 27 hours after 22 years of unrest; Mount St. Helens, only seconds after 3 months of pronounced seismicity and ground deformation, accompanied by intermittent weak phreatic activity).

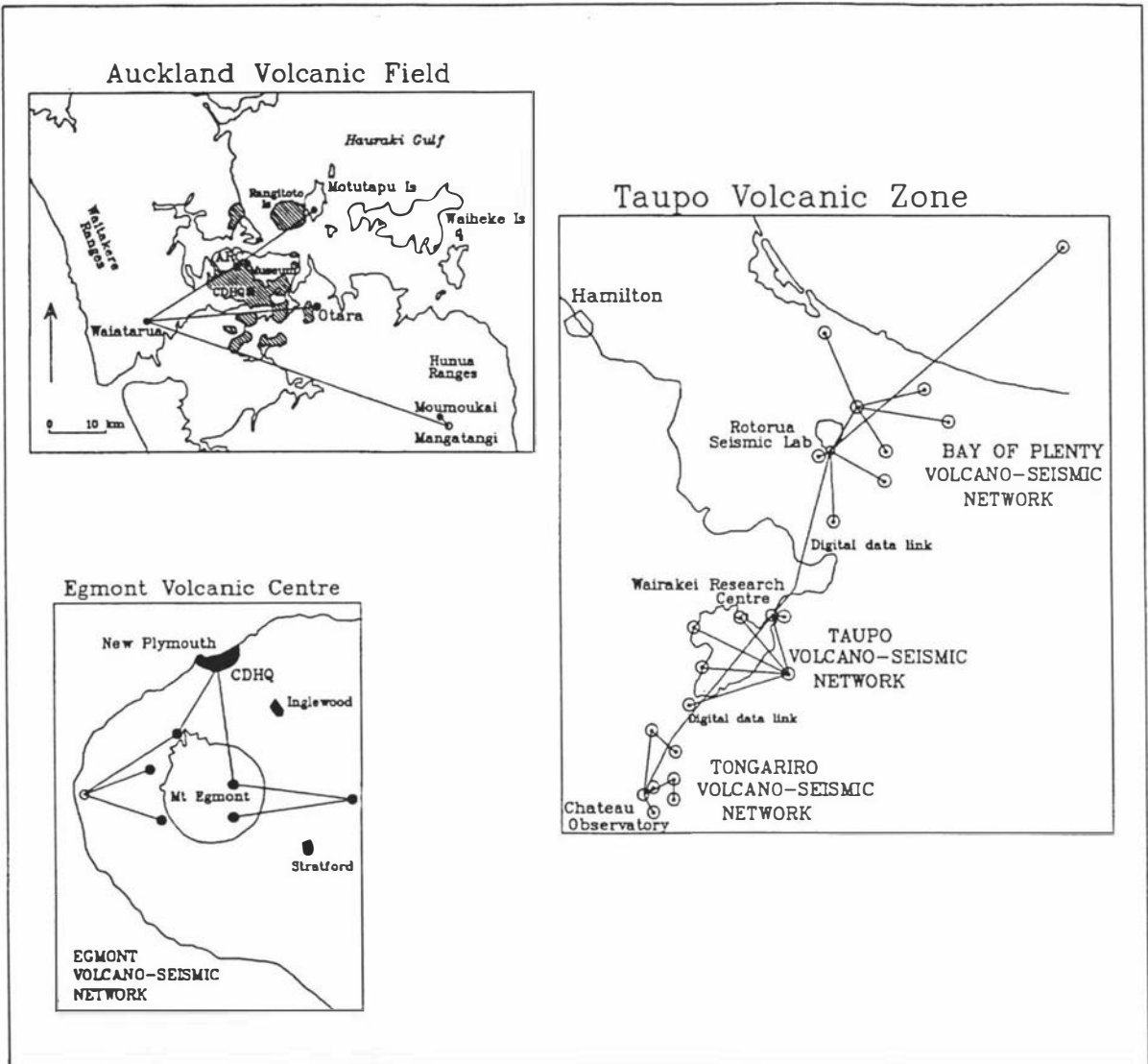


FIGURE 9.1 Composite sketch maps showing volcano-seismic networks presently installed in New Zealand.

Table 9.2

SCIENTIFIC ALERT LEVELS

Frequently Active Cone Volcanoes

Reawakening Volcanoes

White Island, Tongariro-Ngauruhoe, Ruapehu		SCIENTIFIC ALERT LEVEL	Kermadecs, Northland, Auckland, Mayor Island, Rotorua, Okataina, Taupo, Taranaki	
Volcano Status	Indicative Phenomena		Indicative Phenomena	Volcano Status
Usual dormant, or quiescent state	Typical background surface activity; seismicity, deformation and heat flow at low levels.	0	Typical background surface activity; deformation, seismicity, and heat flow at low levels.	Usual dormant, or quiescent state.
Signs of volcano unrest	Departure from typical background surface activity.	1	Apparent seismic, geodetic, thermal or other unrest indicators.	Initial signs of possible volcano unrest. No eruption threat.
Minor eruptive activity	Onset of eruptive activity, accompanied by changes to monitored indicators.	2	Increase in number or intensity of unrest indicators (seismicity, deformation, heat flow etc).	Confirmation of volcano unrest. Eruption threat.
Significant local eruption in progress	Increased vigour of ongoing activity and monitored indicators. Significant effects on volcano, possible effects beyond.	3	Minor steam eruptions. High increasing trends of unrest indicators, significant effects on volcano, possible beyond.	Minor eruptions commenced. Real possibility of hazardous eruptions.
Hazardous local eruption in progress	Significant change to ongoing activity and monitoring indicators. Effects beyond volcano.	4	Eruption of new magma. Sustained high levels of unrest indicators, significant effects beyond volcano.	Hazardous local eruption in progress. Large scale eruption now possible.
Large hazardous eruption in progress	Destruction with major damage beyond volcano. Significant risk over wider areas.	5	Destruction with major damage beyond active volcano. Significant risk over wider areas.	Large hazardous volcanic eruption in progress.

TABLE 9.3 Aspects of volcanic crisis at seven volcanoes

Unrest period	Caldera Volcano	Remarks	Reference
1980-continuing	Long Valley (USA)	Major unrest continuing, without culminating in volcanism.	Mader & Blair (1987) Farrar <i>et al.</i> (1995)
1982-continuing	Campi Flegrei (Italy)	Located in heavily populated region near Naples; during height of 1982-1984 crisis, volcanic seismicity resulted in collapse of older structures, prompting temporary evacuation of 40 000 people	Barberi <i>et al.</i> (1984) Barberi & Carapezza (1996)
1972-1995	Rabaul (Papua New Guinea)	During height of 1983-84 crisis, officials issued a Stage 2 Alert and were prepared to order evacuations of populace. Crisis abated quickly after issuance of alert. Eruptions finally occurred 10 years later, with little immediate warning.	McKee <i>et al.</i> (1985) Naim & Scott (1995)
Cone Volcanoes			
1980-1986	Mount St Helens (USA)	Three months of precursory activity after 123 years quiescence prior to the main eruption on 18 May 1980. Activity continued for six years	Lipman & Mullineaux (1981) Wright & Pierson (1992)
1989-1990	Redoubt (USA)	Long-frequency earthquakes recorded two months prior to the start of the eruptive episode. 20 explosive eruptions in a four month period.	Miller & Chouet (1994)
1995-continuing	Ruapehu	Ten months of unrest prior to the first significant eruption on 18 September 1995. Activity continued for three months.	Bryan <i>et al.</i> (1996)
1991-continuing	White Island	Unrest since 1991 with increases in measured parameters (temperature, deformation, magnetics). No eruptions to date.	Scott <i>et al.</i> (1995b)

9.7.3 Revision and updating of the plan

The contingency planning process is a continuous one (i.e. the plan is never complete). It seeks to form and maintain a clear and accurate understanding of the roles and responsibilities of all the organisations involved in the management of a volcanic crisis. Provision must be made for regular updating of the plan as new research is completed, changes in social/economic factors and land-use occur and key personnel within organisations are

replaced. This could conveniently be done at the same time as civil defence plans, which are required to be renewed every three years. Feedback at review time is necessary to ensure that all agencies and organisations maintain accurate perceptions. Complacency could arise if response to small events is taken as indication of an effective plan.

9.8 PUBLIC EDUCATION

Non-eruptive times provide the best opportunity to develop public education programmes. Dissemination of information about potential volcanic hazards is important in encouraging an appropriate public response and in reducing social impacts. Research over the past two decades has shown that the majority of the public do not carry out the self-protective measures recommended by civil defence authorities during non-crisis times (Gregory 1995). This finding may question the value of public education activities but there is good evidence that hazard knowledge and understanding leads to appropriate responses during a crisis (evacuation, warning compliance etc) (Drabek 1986; Perry & Lindell 1990). However, research by Mileti and Fitzpatrick (1992, 1993), and Ward and Mileti (1993) found that multiple messages, delivered by multiple agencies, through multiple channels, but carrying a consistent theme can lead to an interactive personal search for more information. From this '*personal information searching*' emerges a personal definition of risk which in turn leads to protective behaviour. The survey of Whakatane and Hastings residents (Chapter 8) found that although some agencies are perceived as more credible than others as the source of volcanic hazard information, no one agency has a monopoly on perceived credibility (i.e. different people recognise different agencies as the best source of information on volcanic hazard information and warnings) and this finding supports the need for inter-organisational cooperation in hazard education. Risk communication is a social process, not an act, and should seek to start a conversion within the community. Mileti (1996) summarises the findings of two decades of research and concludes:

"To be effective hazard education programmes require an ongoing multimedia campaign involving television, radio, schools and it has to exist for several years before it makes the issue salient for the population in question. A campaign needs to be punctuated after several years by a direct mailed brochure or newspaper insert, something the public can hold and keep, a written document that explains what they should do if they have some free time available. The people will keep it after two years of hype that precedes it, as opposed to ignoring it and/or throwing it out. It needs to be preceded by another several years' worth of additional multimedia campaigns and then after people start searching for additional information and talking about it with one another, what happens: protective behaviour just drops out and people think it was their own idea".

Schools play a vital role in natural hazard education, with volcanic hazards included in the science and geography curricula. Research into the content of educational material suggests that the following ingredients are important: personalised information, facts about the likelihood and severity of the hazard and practical precautionary measures (Weinstein 1989).

Slovic *et al.* (1981) review psychological factors and social implications of perceived risk and conclude:

"that much of the responsibility lies with the school, whose curricula should include material designed to teach people that the world in which they live is probabilistic, not deterministic, and to help them learn judgement and decision strategies for dealing with that world."

Alexander (1992) reviews natural hazard teaching and concludes:

"Natural hazards should be considered in an integrated way in terms of their geophysical impacts, their human repercussions and the opportunity for monitoring and mitigating them."

The current school curriculum in New Zealand affords the perfect opportunity to teach children about hazards. The primary school science curriculum's (Ministry of Education 1993) strand of "Making sense of the planet earth and beyond" allows for teaching about the processes that cause hazardous events (i.e. weather, volcanoes, floods, earthquakes). The draft primary school social studies curriculum (Ministry of Education 1994) can be used to focus on social vulnerability, impacts and consequences of events and options for mitigation both in the local environment and beyond. The social studies curriculum encourages an integrated approach, linking with other subject areas and this should be used in dealing with hazards. At secondary school, science, social studies (years 8 and 9) and geography (years 10 - 12) provide a range of opportunities for hazards education (Macauley 1993). The current knowledge of each region's volcanic hazards should be fully integrated into the local school curriculum.

Volcanic eruptions by their nature are rare; therefore, in most cases children (and adults) seldom gain personal experience of such events. The mass media provides a large amount of natural disaster news annually. Disasters that do occur within New Zealand and overseas provide an ideal opportunity for children (and adults) to get an understanding of the event. When disasters occur locally, schools play a vital role in both educating children about what has happened and helping with the coping process. Research in schools adjacent to Ruapehu volcano showed that hazard-relevant education programmes in the aftermath of the 1995

eruption helped children reduce fears and increased their ability to cope with stimuli related to the hazard (Ronan & Johnston 1996; Ronan & Johnston *in prep*).

At a local level Anderson (1987) suggests that :

"most catastrophic events that strike communities should be given temporary precedence over the normal curriculum in order to help students understand the causes, consequences and recovery alternatives, as well as to allay whatever trauma, fear of recurrence, and general fear of isolation and helplessness that might accompany such an event."

But a note of caution: media reporting often contributes to biased perceptions that exist. The media frequently give an uneven coverage focusing on high impact low frequency events. There is commonly a bias towards reporting on the victims and not those who survived or who were only lightly impacted within the disaster area. Wrathall (1992) also comments on the lack of valuable follow-up reporting when disaster-impacted communities successfully cope with their predicament.

During a volcanic crisis demand for information is intense and this demand will place a strain on all responding agencies. Experience during the 1995 Ruapehu eruption has shown that a crisis period is not the best time to prepare the content of public information material. However, public information prepared in advance can be printed during the crisis (if required) and disseminated rapidly. As communications can be severely disrupted during and after an eruption, information about what to expect and what to do during an eruption must be distributed early. When an emergency is in progress civil defence officials have to distinguish the function of sending messages which direct an emergency response from providing public information about the emergency. It is important that responding agencies put information into the news instead of waiting for the media to discover their own "news" (i.e. the need for a media response plan or plan component) (Vogt & Sorensen 1994). Results from the survey in Whakatane and Hastings after the 1995 Ruapehu eruption (Chapter 8) show that the majority of people received information through the media not directly from the response agencies which issued it. Since news media are not a passive channel to the public, attempts should be made to meet the needs of the media. This can often be helped by establishing long-standing links during non-crisis times.

During a crisis systems often break down, data is misinterpreted and conditions rapidly change rendering previously released information 'out-of-date'. Incorrect or misleading information should be corrected by follow-up information, accompanied by explanations as to the origins of apparently 'unreliable' information (Perry & Lindell 1990). When the current information

is full of uncertainty (a common situation prior to an eruption and during an eruption) it is important to avoid making or disseminating unrealistic forecasts. This will lessen concerns about the "cry wolf syndrome" which is common among many public officials (Green *et al.* 1992). Rumour control is a critical function for agencies responsible for giving out public information and these agencies should be proactive in identifying and correcting incorrect or misleading information. However, some caution is needed because immediate and harsh official denouncement of popular views may be counterproductive and treated with suspicion as the public often prefer to hear a range of opinions before drawing their own conclusions on a subject (Showalter 1993). This was illustrated by the public response to the Browning earthquake 'prediction' in the United States in 1989-1990 (Farley *et al.* 1993; Showalter 1993) where authorities had only limited success in countering the unsubstantiated public statements of an amateur scientist who forecast an imminent earthquake (that did not occur).

The planning process should address the following:

- * Identification of existing education resources related to volcanic hazards and all current methods of disseminating public information of volcanic hazards;
- * Consideration of the appropriateness of current resources and method of dissemination;
- * Development of new resources and methods of dissemination where required.
- * Identification of resources to staff and operation of media/public information functions.

9.9 WARNINGS

The procedures for issuing of warnings are covered by Part 3 of the National Civil Defence Plan and all responding agencies must understand their responsibilities as per that plan. It is important that responding agencies also separate "information notices" from warnings.

Warning messages are usually given to a specific community or communities when a direct response to a threat is required. The response to warnings by individuals has been found to relate to i) individual risk perception (understanding, belief and personalisation); ii) the nature of the warning information (specificity, consistency, certainty, accuracy, clarity, media, frequency etc); and iii) the personal characteristics of the recipient (demographics, knowledge, experience of the hazard, social network and so on) (Mileti & O'Brien 1993). Summarised in Figure 9.2 is a flow model of the decision making process for individuals when a warning message is received (from Perry 1985).

A consistent and clear conclusion of social science research is that the warning message itself is one of the most important factors that influences the effectiveness of the warning system (Mileti & Sorensen 1990). Unfortunately one or more of the important attributes required of

warning messages (specificity, consistency, certainty, accuracy, clarity) is usually deficient or missing during a volcanic crisis. Commonly specificity and certainty about the time and nature of the eruption are missing. Responding authorities must recognise this.

Five topics are important when constructing a warning message: the hazard or risk, guidance, location, time and source. The warning message must contain information about the impending hazard with sufficient simple detail that the public can understand the characteristics of the hazard that they need to protect themselves from. The message should include guidance about what they should do to maximize their safety. The warning message must describe the exact location that is at risk and address the "when" aspect of the required response.

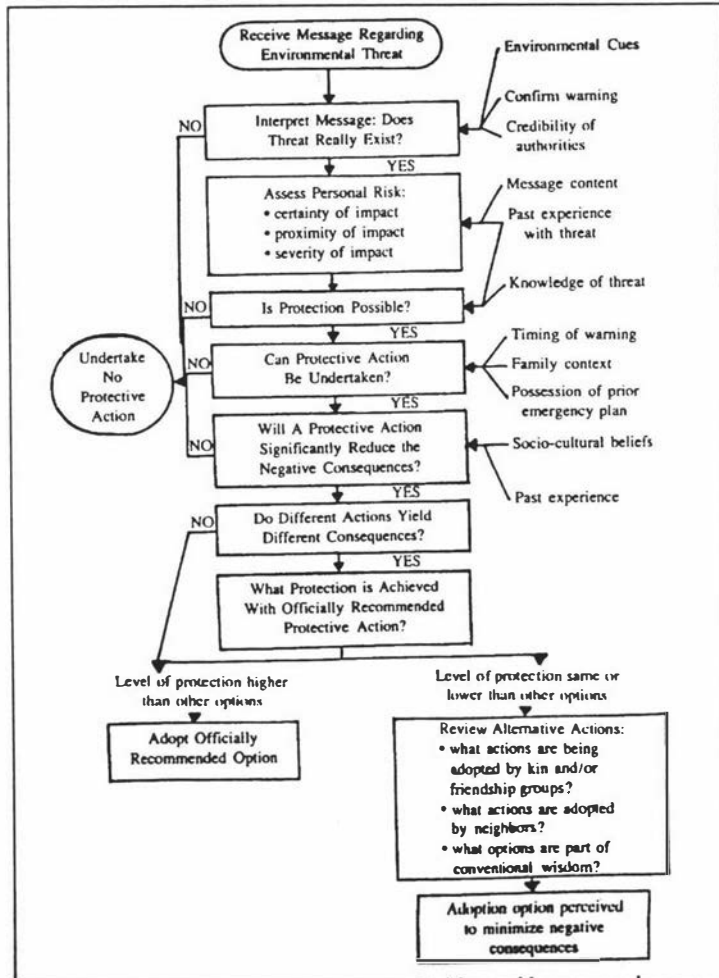


FIGURE 9.2 Flow model of emergency decision-making process in natural disasters (from Perry 1985).

The final important dimension is the source of the information. Warnings are more likely to be believed if they come from 'credible' sources. As briefly discussed in Chapter 8 the public's perception of credibility of information sources is a subjective judgement and has been shown to be related to notions of expertise and trustworthiness. Perry and Lindell (1990) noted three general bases on which credibility can be judged: 1) the "credentials" of the person or agency issuing the warning; 2) the relationship of the organisations to other "credible" organisations; and 3) the past history of job performance. Trust and credibility are valuable assets - difficult to obtain and once lost, almost impossible to regain (Slovic 1993; Vogt & Sorenson 1994). In the survey of Whakatane and Hastings residents (previous chapter) no one agency was regarded by a majority of respondents as being the most credible, but the Institute of Geological and Nuclear Sciences (GNS), the Ministry of Civil Defence and District Councils were the three groups ranked highest. Prior to a volcanic crisis, agencies which may have to issue warnings or at least have a role in their dissemination can take a pro-active step towards enhancing their credibility. Agencies working in a coordinated and collaborative way with other agencies can improve their own credibility. Having a senior or publicly recognised person issuing or associated with the issuing of a warning notice and issuing warnings in association with other 'lead' agencies will enhance credibility.

A number of issues need to be addressed when designing an effective system of warnings for vulnerable New Zealand communities (modified from Mileti & Sorenson 1990) and these include:

Organisation effectiveness

- * Specify clearly who (identified by role/position rather than by name) has authority and responsibility for volcanic crisis warnings;
- * Identify all the warning tasks for which each organisation is responsible;
- * If multiple tasks and authorities exist within or across an organisation it is helpful to identify the relationships between them;
- * When time and resources are constraints, designate emergency priorities in the warning plan;
- * Ensure roles and tasks are well known and understood (i.e. exercise and simulations);
- * Document what decisions will be made by the organisation, who will make them and how and when they will be made. Present as a flow chart in the final plan;
- * Provide organisations with adequate resources (people and hardware) to do the job, including resources for development and review.

Dealing with other organisations

- * Understand the roles and responsibilities of all organisations involved in warnings;
- * Establish agreements regarding priorities;
- * Identify where compatibility and cooperation with other organisations exists and where it is a problem;
- * Establish efficient communication between organisations in the warning system;
- * Be aware that organisations can resist giving up autonomy to participate in an emergency warning system because some command and control comes from outside the organisation;
- * Establish relationships (collaborative) with the community.

9.9.1 Failures of warning systems

The failure of warning systems to deliver timely or accurate warnings, or delivering ones that are responded to inappropriately, can have tragic consequences. The 1985 Nevado del Ruiz volcanic tragedy in which 21 000 people were killed in the Columbian town of Armero illustrates a worst case scenario. Human error was the cause of the tragedy, in the form of misjudgement, indecision and bureaucratic short-sightedness - not the magnitude of the eruption, lack of scientific warning or technological ineffectiveness or defectiveness (Voight 1990, 1996). Less tragic examples of the failure to effectively transmit warnings include the lack of warning given to residents of eastern Washington (U.S.A.) after the May 1980 eruption of Mount St. Helens of the impending ash falls (Saarinen & Sell 1985) and the failure to warn residents and business people of the rising water levels during the Kaikoura floods of 1993 (Gerrard 1994). In all three cases recipients of warning messages failed to perceive the significance of the information and respond in an appropriate way. It is more often a human element that fails than the hardware of the warning system.

A recently published book on the politics associated with lahars produced by the 1991 eruption of Pinatubo in the Philippines (Rodolfo 1995) provides an interesting insight into the management of post-eruption problems. The eruption not only highlighted the strength and resiliency of people affected by the disaster and the generosity of individuals and organisations, but also exposed weaknesses in the system of information, planning and coordination, divisions among political groups and major interests, and the indifference of many of those in positions that could have helped alleviate suffering and mitigate the social disaster.

9.10 HAZARD ZONES AND EVACUATION

Areas around a volcano are subject to a range of volcanic hazards (see earlier chapters). Such zones can be mapped and shown on hazard maps as described above. During non-eruptive times people are rarely excluded from these zones (from a volcanic hazard perspective) although a range of planning restrictions may be imposed. However, during a volcanic crisis it may be necessary to exclude people from areas of high risk. During the 1995-1996 Ruapehu eruption a series of coloured zones was used to describe varying levels of risk. As the eruption proceeded the extent of zones varied to match changes in the hazard. As volcanic eruption sequences may extend for long periods (months to years) restricted access may be in place for a long time.

During a volcanic crisis restricted access into hazard zones can provide controlling authorities with a number of problems. During the 1995-1996 Ruapehu eruptions hazard zone decision-making was relatively simple because zones occurred largely within national park land. Where hazard zones involve multiple landowners and include areas in which people live or work a range of economic, political and public pressures will be placed on those responsible for establishing and maintaining such zones. This is well illustrated by the events leading up to the 1980 eruption of Mount St Helens (Saarinen & Sell 1985). The phreatic eruptions and deformation of the volcano between March and May 1980 attracted large numbers of sightseers. This has been termed the "convergence phenomenon" and is prevalent in other natural and technical hazard events (Perry 1985; Kartez & Lindell 1987). Dealing with the visitors required signs, barricades and personnel to enforce the restricted zone around the volcano. To satisfy the curiosity of sightseers and to divert people away from the danger zones viewing areas were set up along with information centres. In addition, people who lived and worked in restricted areas were subjected to both economic and psychological stress. Access to restricted zones also caused problems with a number of groups requesting entry, including scientists, residents and journalists. Perry and Hirose (1991) in their review of volcanic hazard management in Japan and the United States, found that conflict between two forces in local communities was common when access restrictions were imposed.

"Local business leaders organised themselves and forcefully fought the controls, whereas emergency managers and public safety personnel vehemently opposed lifting or even seriously modifying access restrictions."

Evacuation may be deemed necessary by the controlling authorities if a perceived risk to human life reaches unacceptable levels. People living within high-risk areas who may need to evacuate should be aware of this fact and be willing to move away if advised to. Conducting practical response exercises has proven invaluable in ensuring correct public

actions when a crisis does occur (e.g. in Rabaul 1994).

The principal function of evacuation is to ensure that people move from a place of relative danger to a place of relative safety via a route that is itself free from significant danger. The destination as well as the route must be considered in the plan, as well as other options such as shelter in the place at risk. There needs to be careful coordination of the timing and conduct of an evacuation and this must be done in association with agencies who are assessing risk and ordering the evacuation, as well as those responsible for receiving evacuees.

Evacuation can be either pre-emptive or responsive. Thick ash falls or lahars may effectively prevent movement by cutting transport routes in affected areas during and after an eruption (for example see Scenario 2, Chapter 7) If evacuation of near-vent areas is deemed necessary to save lives it must be done prior to the peak of the eruption. The higher the population density the earlier an evacuation must begin, to cope with the logistics of a large number of people evacuating in a short period of time. Some recent eruptions (Rabaul, Pinatubo) have forced large scale evacuations with short notice as the climactic phase of the unrest has begun very rapidly. Post-eruption evacuation may also become necessary in areas where people have survived ash fall without difficulty, but in which the long term loss of water and food supply, electricity, waste disposal, and livelihood have made continued habitation untenable. This would also apply to areas subject to continuing inundation by lahars, and/or flooding caused by lahar-induced changes to drainage patterns (Newhall & Punongbayan 1996).

If the evacuation of a hazardous zone is to proceed in an orderly manner it is essential that people know where to go, and what route to take. Unless the risk to life is immediate and obvious people will be reluctant to leave their homes. Assurance must be given that the evacuated area will remain off limits to unauthorised people.

Emergency management research (summarised by Perry 1985) has identified three general variables which are crucial in citizens' evacuation decision-making processes:

1. the definition of the threat as real (that is, the development of a belief in the warning);
2. the level of perceived personal risk (belief about the personal consequences of the disaster impact); and
3. the presence of an adaptive plan (being acquainted with a means of evacuation).

These points reinforce the need for community participation and the provision of mutual information. In addition, research (Drabek 1986) shows three social variables are important with respect to evacuation performance and need to be addressed in evacuation planning; these include family context, level of community involvement and cultural factors.

New Zealanders' experience of large scale evacuations is minimal, and the logistical and social problems associated with such an action would probably be very substantial. People forced to move are likely to feel demoralized and dysfunctional. Both physical and mental health problems may occur at a higher rate than normal as a later consequence. This will depend on the severity of the disaster and the situation of the evacuees.

Evacuations usually involve four types of movement; 1) self-evacuation where people move out in their own vehicles or with friends/relatives; 2) movement of people who do not own or have access to private vehicles; 3) movement of people from institutions (e.g. jails, hospitals); 4) movement of people with handicaps who require specialized vehicles. Emergency planning must make provisions for the latter three types.

Evacuation planning must:

- * Designate the lead agency who will issue the evacuation order;
- * Designate the agencies who will play supporting and receiving roles;
- * Outline the roles and responsibilities of all the agencies involved;
- * Identify the potentially dangerous zones to which or through which the population should not be evacuated;
- * Identify the preferred evacuation routes and ways to keep them open under eruption conditions;
- * Identify assembly points for persons who require transport for evacuation and public information pertaining to these;
- * Consider the means of transport, traffic control, assistance and direction;
- * Identify potential shelters and accommodation in refuge zones.

9.11 RECOVERY

The social and economic impacts of adverse events are determined not only by direct physical consequences but also by the interaction of psychological, social, culture and institutional processes that can amplify and attenuate the public response (Burns *et al.* 1993). Kaspersen *et al.* (1988) refers to this as "social amplification of risk" and it was clearly evident during the 1995-1996 Ruapehu eruption (see chapter 2). Community recovery therefore should be viewed as a social process (Nigg 1995b). The cost of recovery goes beyond the cost of physical repairs and includes the cost of the provision of long-term community support services (Scott 1995). The time required for a community to recover from a volcanic eruption depends on the extent of the impacts and the amount of assistance available. Pre-impact recovery planning can reduce this period and minimize ongoing social and economic effects and must include provision for physical, economic and social recovery. To date no detailed

assessment of recovery requirements has been undertaken in New Zealand for a large scale volcanic eruption. A similar methodology to that used in the study of recovery following an earthquake in Wellington could be considered (Earthquake Commission and Centre for Advanced Engineering 1995).

The effects of eruptions can continue for long periods of time. Lahars may continue to affect areas for years following an eruption as material is washed off the volcano. Rodolfo (1995) and de Jesus (1995) both describe the ongoing lahar problems following the 1991 Pinatubo eruption in the Philippines and note that in the recovery process, solutions that were scientifically and technically sound were not necessarily politically and socially acceptable.

Individuals in New Zealand are covered by the Earthquake Commission (EQC) and are insured against loss or damage to their homes, up to a set limit (currently \$112 500 for dwellings and \$ 22 500 for contents), if ordinary fire insurance is held. Regional councils and territorial authorities are responsible for dealing with the impacts to their own facilities. Where the magnitude of the impact is such that recovery requires central government help. The Civil Defence Act (1983) allows for the appointment of a central government Disaster Recovery Coordinator to coordinate assistance and provide a means of communicating the needs of the community to government.

Recovery planning must consider the following:

- * Who is responsible for planning and implementation of the recovery?
- * The importance of inter-organisational cooperation at all stages of a recovery.
- * A broad approach to recovery so that opportunities for land-use change or rebuilding of safer structures are considered.
- * The need for community involvement.
- * The availability of internal and external resources and the ability to gain access to them.

9.12 CONCLUSIONS

The process of developing a response plan for a volcanic crisis is a complex one. There are many organisations involved and an extensive range of social, political and financial issues need to be considered. Listed below are some of the key points required in preparing a contingency plan.

- * The planning process needs to involve consultation with all organisations involved in the management of volcanic hazards at a particular volcano and the community.
- * A volcanic contingency plan must remain simple and flexible.
- * Emergency management aspects of volcanic contingency planning must be linked with broader provisions of land-use management contained in regional policy statements and regional/district plans.
- * The Resource Management Act (1991), Civil Defence Act (1983), and the National Civil Defence Plan require regional councils to take the lead role in regional volcanic contingency planning. The widespread extent of volcanic impacts reinforces this requirement.
- * An effective programme of hazard definition is required to interpret the known volcanic history of the region.
- * Effective response to impending volcanic eruption depends on warning time. Thus it is important that an acceptable level of long-term surveillance of the region's volcanoes is maintained.
- * Roles and responsibilities need to be defined for all responding agencies involved in the management of a regional volcanic crisis.
- * Procedures for responding to changes in scientific alert levels need to be developed.
- * Procedures need to be developed for presenting public warnings.
- * Evacuation may be required if a perceived volcanic risk reaches an unacceptable level; therefore methods to warn threatened populations need to be maintained and tested under various conditions.
- * Evacuation planning must be kept up-to-date and reflect current hazard information, population and land-use patterns.
- * Appropriate public education systems need to be developed for both pre-crisis and crisis periods.
- * Recovery planning must be considered within the contingency plan.
- * Individual and societal perceptions of risk relate to planning behaviour, warning compliance and recovery behaviour; therefore, understanding a community's perceptions of risk is an important part of the decision making process and should be used as an input into natural hazard management.

REFERENCES

- A.I.D.A.B. 1994. *Final Report: Rabaul volcanic disaster needs assessment mission*. Australian International Development Assistance Bureau, 63 p.
- Alexander, D. 1992. Natural disasters: a framework for research and teaching. *Disasters* 15: 209-224.
- Allen, S.R. 1992. *Volcanic hazards in the Auckland Volcanic Field*. Unpublished M.Sc. thesis, University of Auckland, 153 p.
- Allen, S.R., Smith, I.E.M. 1994. Eruption styles and volcanic hazard in Auckland Volcanic Field, New Zealand. *Geoscience Reports of Shizuoka University* 20: 5-14.
- Anderson, J. 1987. Learning from Mount St Helens: catastrophic events as education opportunities. *Journal of Geography* (September-October): 229-233.
- Anderson, M.B. 1995. Vulnerability to disaster and sustainable development: a general framework for assessing vulnerability. In: Munasinghe, M., Clarke, C. (eds.), *Disaster Prevention for Sustainable Development: Economic and Policy Issues*. The International Decade for Natural Disaster Reduction (IDNDR) and The World Bank, p. 41-59.
- Anderson, R., Bjornsson, S., Blanchard, D.C., Gathman, S., Hughes, J., Jonasson, S., Moore, C.B., Survilas, H.J., Vonnegut, B. 1965. Electricity in volcanic clouds. *Science* 148: 1179-1189.
- Armienti, P., Macedonio, G., Pareschi, M.T. 1988. A numerical model for the distribution of tephra transport and deposition: applications to May 18, 1980 Mt. St. Helens eruption. *Journal of Geophysical Research* 93(B6): 6463-6476.
- Australian/New Zealand Standard 1995. *Risk Management*. AS/NZS 4360, 32 p.
- Barberi, F., Carapezza, M.L. 1996. The problem of volcanic unrest: the Campi Flegrei case history. In: Scarpa, R., Tilling, R.I. (eds.), *Monitoring and Mitigation of Volcanic Hazards*. Springer-Verlag, p. 771-786.
- Barberi, F., Carapezza, M.L., Valenza, M., Villari, L. 1993. Control of lava flow during the 1991-1992 eruption at Mount Etna. *Journal of Volcanology and Geothermal Research* 56: 1-34.
- Barberi, F., Corrado, G., Innocenti, F., Luongo, G. 1984. Phlegraean Fields 1982-1984: brief chronicle of a volcano emergency in a densely populated area. *Bulletin Volcanologique* 47: 176-185.
- Barnes, R. 1986. Broadcasting in the public necessity, Mount St. Helens. In: Keller S.A.C. (ed.), *Mount St. Helens: Five Years Later*. Eastern Washington University Press, p. 399-400.
- Bates, F.L., Dynes R., Quarantelli, E.L. 1990. The importance of the social sciences to the International Decade for Natural Disaster Reduction. *Disasters* 15: 288-289.
- Baumann, D.D., Sims, J.H. 1978. Flood insurance: some determinants of adoption. *Economic Geography* 54: 189-196.
- Bautista, M.C.R.B., Tadem, E.C. 1993. Brimstone and ash: the 1991 Mt. Pinatubo eruption. In: Bautista, M.C.R.B. (ed.), *In the Shadow of the Lingering Mt Pinatubo Disaster*. University of Philippines, p. 3-15.
- Baxter, P.J. 1990. Medical effects of volcanic eruptions: I. Main causes of death and injury. *Bulletin of Volcanology* 52: 532-544.
- Beanland, S., Houghton, B.F. 1991. Rotokawau Tephra: basaltic maars in Okataina Volcanic Centre, Taupo Volcanic Zone. In: Research Notes 1990. *New Zealand Geological Survey Record* 43: 37-43.
- Beck, A.C. 1950. Volcanic activity at Mount Ruapehu from August to December 1945. *Journal of Science and Technology* Vol. B31: 1-13.

- Bernard, A., Rose, W.I. 1990. The injection of sulfuric acid aerosols in the stratosphere by the El Chichon Volcano and its related hazards to international air traffic. *Natural Hazards* 3: 59-67.
- Bernknopf, R.L., Brookshire, D.S., Thayer, M.A. 1990. Earthquake and volcano hazard notices: an economic evaluation of changes in risk perception. *Journal of Environmental Economics and Management* 18: 35-49.
- Bitschene, P.R. 1995. Environmental impacts and hazard assessment of the August 1991 eruption of Mt. Hudson (Patagonian Andes). In: Bitschene P.R., Mendiola J. (eds.), *The August 1991 Eruption of Hudson Volcano (Patagonian Andes): A thousand days after*. Universidad Nacional de la Patagonia San Juan Bosco Servicio Nacional De Geologia, Comodoro Rivadavia, Argentina, p. 2-15.
- Blong, R.J. 1981. Some effects of tephra falls on buildings. In: S. Self and R.S.J. Sparks (eds), *Tephra Studies, Proceedings NATO Advanced Studies Institute, Laugarvata and Reykjavik, June 18-19, 1980*, Reidel, Dordrecht, Series C, 75, p. 405-420.
- Blong, R.J. 1982. *The Time of Darkness, Local Legends and Volcanic Reality in Papua New Guinea*. Washington University Press, Seattle/Australia National University Press, Canberra, 257 p.
- Blong, R.J. 1984. *Volcanic Hazards: A sourcebook on the effects of eruptions*. Academic Press, Australia, 424 p.
- Blong, R. 1996. Rabaul update...volcano building codes. *Natural Hazards Quarterly* 2 (Issue 1): 4.
- Blong, R.J., Aislabie, C. 1988. The impact of volcanic hazards at Rabaul, Papua New Guinea. *Institute of National Affairs Discussion Paper No 33*, Port Moresby, Papua New Guinea, 201p.
- Blong, R., McKee, C. 1995. *The Rabaul eruption 1994: destruction of a town*. Natural Hazards Research Centre, Macquarie University, Australia, 52 p.
- Bradford, S.A. 1992. *Corrosion Control*. Van Nostrand Reinhold, New York.
- Brantley, S.R. (ed.) 1990. The eruption of Redoubt volcano, Alaska, December 14, 1989 - August 31, 1990. *U.S. Geological Survey Circular* 1061, 33 p.
- Britton, N.R. 1986. Developing an understanding of disasters. *Australian and New Zealand Journal of Sociology* 22: 254-271.
- Britton, N.R. 1995. Local government's role in disaster management: what to do for the future? *Local Government News* 95/6 (appendix 6): 1-8.
- Britton, N.R., Lindsay, J. 1995. Integrating city planning and emergency preparedness: some of the reasons why. *International Journal of Mass Emergencies and Disasters* 13(1): 93-106.
- Bryan, C., Christenson, B.W., Hodgson, K.A., Houghton, B.F., Johnston, D.M., Jurado-Chichay, Z., Lindsay, J., Manville, V., Nakagawa, M., Nairn, I.A., Otway, P., Sherburn, S., Scott, B.J., Thordarson, T., Wood, C.P., Wilson, C.J.N. 1996. Volcanic eruption at a New Zealand ski resort prompts reevaluation of hazards. *Eos, Transactions, American Geophysical Union* 77: 189-191.
- Buck, M.D. 1985. An assessment of volcanic risk on and from Mayor Island. *New Zealand Journal of Geology and Geophysics* 28: 283-298.
- Burger, J.M., Palmer, M.I. 1992. Changes in and generalization of unrealistic optimism following experiences with stressful events: reactions to the 1989 California earthquake. *Journal of Personality and Social Psychology* 18(1): 39-43.

- Burns, W.J., Slovic, P., Kasperson, R.E., Kasperson, J.X., Renn, O., Emani, S. 1993. Incorporating structural models into research on social amplification of risk: implications for theory construction and decision making. *Risk Analysis* 13: 611-623.
- Bursik, M.I., Sparks, R.S.J., Gilbert, J.S., Carey, S.N. 1992. Sedimentation of tephra by volcanic plumes: I. Theory and its comparison with a study of the Fogo A plinian deposits, Sao Miguel (Azores). *Bulletin of Volcanology* 54: 329-344.
- Carey, S.N., Sparks, R.S.J. 1986. Quantitative models of the fall out and dispersal of tephra from volcanic eruption columns. *Bulletin of Volcanology* 48: 109-125.
- Cas, R.A.F., Wright, J.V. 1987. *Volcanic Successions: modern and ancient*. Chapman and Hall, London, 528 p.
- Casadevall, T.J. 1993. Volcanic ash and airports: Discussions and recommendations from the workshop on impacts of volcanic ash on airports facilities, Seattle, Washington, April 26-28, 1993. U.S. Geological Survey Open-File Report 93-518, 58 p.
- Casadevall, T.J. 1997. Volcanic ash and aircraft. Paper presented at the IAVCEI General Assembly, Puerto Vallarta, Mexico, January 1997.
- Centre for Advanced Engineering 1991. *Lifelines in Earthquakes: Wellington case study, project report*. Centre for Advanced Engineering, University of Canterbury, 210 p.
- Christchurch Engineering Lifelines Project 1994. *Christchurch Engineering Lifelines Project 1994 Workshop 10-12 October 1994* (notes), 514 p.
- Collins, C.M. 1978. Contamination of water supplies and water courses. Appendix 2, In: Healy, J., Lloyd, E.F., Rishworth, D.E., Wood, C.P., Glover, R.B., Dibble, R.R., The eruption of Ruapehu, New Zealand, on 22 June 1969. *DSIR Bulletin* 224: 72-75.
- Cordoba, G.A. 1997. Shock-wave hazard map for Galeras volcano, Colombia. Abstracts IAVCEI General Assembly, Puerto Vallarta, Mexico, January 19-24 1997, p. 54.
- Cotton, C.A. 1945. Ruapehu in 1945. *New Zealand Science Review* 3: 3-4.
- Cotton, C.A. 1946. The 1945 eruption of Ruapehu. *Geographical Journal* 107: 140-143.
- Cronin, S.J. 1997. *Late Quaternary volcanic stratigraphy within a portion of the northeastern Tongariro Volcanic Centre*. Unpublished Ph.D. Thesis. Massey University, New Zealand.
- Cronin, S., Hedley, M., Smith, G., Turner, M. 1996. Impacts on soil and pasture chemical composition. In: Impacts of October 1995 Ruapehu ash fall on soil fertility. *Department of Soil Science and Fertilizer and Lime Research Centre, Massey University*, 33 p.
- Cronin, S.J., Neall, V.E., Lecointre, J.A., Palmer, A.S. 1997. Changes in Whangaehu river lahar characteristics during the 1995 eruption sequence, Ruapehu volcano, New Zealand. *Journal of Volcanology and Geothermal Research* 76: 47-61.
- Cunningham, I.J. 1946. Ruapehu ash not toxic to stock. *New Zealand Journal of Agriculture* 72: 275.
- D'Ercole, R., Rancon, J-P., Lesales, T. 1995. Living close to an active volcano: popular hazard perception in three communities of North Martinique (F.W.I.). In: *IUGG XXI General Assembly Abstracts*, Boulder Colorado, July 2-4th 1995, p. B20.
- Day, T.G., Fisher, J.E. 1980. Mt. St Helens: How a wasteland coped with its aftermath. *Water Pollution Control Federal Journal* 52(8): 2082 - 2089.

- de Jesus, J.P. 1995. The Philippines after the 1990 quake and the Pinatubo eruptions. In: *Wellington After the Quake: the challenge of rebuilding cities*, proceedings of a conference held in Wellington, New Zealand, 27-29 March 1995, p. 209-216.
- De Lisle, J.F. 1969. Upper wind statistics for New Zealand stations. *New Zealand Meteorological Service Miscellaneous Publication* 129.
- Deer, W.A., Howie, R.A., Zussman, J. 1980. *An Introduction to Rock-forming Minerals*. Longman, 528 p.
- Deguchi, K. 1988. Effects of volcanic ash from Sakurajima on living environment and anti-ash device for housing. *Proceedings Kagoshima International Conference on Volcanoes*, p. 724-727.
- Dillman, D. 1978. *Mail and Telephone Surveys: The Total Design Method*. Somerset, NJ: Wiley, 325 p.
- Dillman, J.J., Roberts M.L. 1982. The impacts of the May 18 Mount St. Helens ashfalls: Eastern Washington residents report - related damage and clean up. In: Keller, S.A.C. (ed.), *Mount St Helens: one year later*. Eastern Washington University Press, p. 191-198.
- Dillman, D.A., Schwalbe, M.L., Short, J.F. 1982. Communication behavior and social impacts following the May 18, 1980, eruption of Mount St. Helens. In: Keller, S.A.C. (ed.), *Mount St Helens: one year later*. Eastern Washington University Press, p. 173-179.
- Donoghue, S.L. 1991. *Late Quaternary volcanic stratigraphy of the southeastern sector of the Mount Ruapehu ring plain*. Unpublished Ph.D. Thesis, Massey University, New Zealand.
- Donoghue, S.L., Neall, V.E., Palmer, A.S. 1995. Stratigraphy and chronology of late Quaternary andesitic tephra deposits, Tongariro Volcanic Centre, New Zealand. *Journal of the Royal Society of New Zealand* 25: 115-206.
- Drabek, T. 1986. *Human System Responses to Disasters: An Inventory of Sociological Findings*. Springer-Verlag, New York, 479 p.
- Drabek, T.E., Hoetmer, G.J. (eds.) 1991. *Emergency Management: principles and practice for local government*. Municipal management series, International City Management Association, 368 p.
- Dueker, K.J., Pendleton, P., Robinson, L., Gihring, T., Rabiega, B. 1980. *Impacts of Volcanic Ashfall on Travel Behavior*. Final Report, October 1980. The Center for Urban Studies, School of Urban Affairs, Portland State University, Portland, Oregon. 78 p.
- Dynes, R.R. 1994. Community emergency planning: false assumptions and inappropriate analogies. *International Journal of Mass Emergencies and Disasters* 12: 141-158.
- Earthquake Commission and Centre for Advanced Engineering 1995. *Wellington After the 'Quake: the challenge of rebuilding cities*. Proceedings of a conference held in Wellington, New Zealand, 27-29 March 1995. Earthquake Commission and Centre for Advanced Engineering, 284 p.
- Eden, D.N. 1994. Volcanoes deadly ash legacy. *The Hawke's Bay Region Civil Defender*. The Official Publication of the Hawke's Bay Civil Defence Organisations, p. 15-19.
- Eden, D.N., Froggatt, P.C. 1996. A 6500-year-old history of tephra deposition recorded in sediments of Lake Tutira, eastern North Island, New Zealand. *Quaternary International* 34-36: 55-64.
- Eden, D.N., Froggatt, P.C., Trustrum, N.A., Page, M.J. 1993. A multiple-source Holocene tephra sequence from Lake Tutira, Hawke's Bay, New Zealand. *New Zealand Journal of Geology and Geophysics* 36: 233-242.
- Erickson, N.J. 1975. Scenario methodology in natural hazards research. *Program on Technology, Environment and Man Monograph* 34. Institute of Behavioral Science, University of Colorado, 169 p.

- Erskine, W.F. 1962. *Katmai: a true narrative*. Abelard-Schuman, London, 223 p.
- F.E.M.A. 1980. Ash particles and home clean-up problems. *Mount St. Helens Technical Information Network Bulletin 7*. Federal Emergency Management Agency, USA.
- F.E.M.A. 1984. *The mitigation of ashfall damage to public facilities. Lessons learned from the 1980 eruption of Mount St. Helens, Washington*. Federal Emergency Management Agency, Regional X, 70 p.
- Farley, J.E., Barlow, H.D., Finkelstein, M.S., Riley, L. 1993. Earthquake hysteria, before and after: a survey and follow-up on public response to the Browning Forecast. *International Journal of Mass Emergencies and Disasters* 11: 305-321.
- Farrar, C.D., Sorey M.L., Evans, W.C., Howie, J.F., Kerr, B.D., Kennedy, B.M., King, C.-Y., Southon, J.R. 1995. Forest-killing diffuse CO₂ emission at Mammoth Mountain as a sign of magmatic unrest. *Nature* 376: 675-678.
- Fierstein, J., Nathenson, M. 1992. Another look at the calculation of fallout tephra volumes. *Bulletin of Volcanology* 54: 156-167.
- Fink, J.H. 1993. The emplacement of silicic lava flows and associated hazards. In: Kilburn, C.R.J., Luongo, G. (eds.), *Active lavas: monitoring and modelling*. UCL Press, p. 5-24.
- Finnimore, E.T., Low, B.S., Martin, R.J., Karam, P., Nairn, I.A., Scott, B.J. 1995. *Contingency planning for and emergency management of the 1994 Rabaul volcanic eruption, Papua New Guinea: results of a fact-finding visit*. Ministry of Civil Defence, Wellington, 39 p.
- Fisher, R.V., Schmincke, H.V. 1984. *Pyroclastic Rocks*. Springer-Verlag, Heidelberg, 472 p.
- Fitzharris, B., Owens, I., Chinn, T. 1992. Snow and glacier hydrology. In: Mosley, M.P. (ed.), *Waters of New Zealand*. New Zealand Hydrology Society, p. 75-94.
- Folsom, M.M. 1986. Tephra on range and forest lands of eastern Washington: local erosion and redeposition. In: Keller, S.A.C. (ed.), *Mount St. Helens: five years later*. Eastern Washington University Press, p. 116-119.
- Fothergill, A. 1996. Gender, risk and disasters. *International Journal of Mass Emergencies and Disasters* 14(1): 33-56.
- Foxworthy, B.L., Hill, M. 1982. Volcanic eruptions of 1980 at Mount St Helens: the first 100 days. *United States Geological Survey Professional Paper* 1249, 124 p.
- Gerlach, T.M., Krumhansl, J.L., Fournier, R.O., Kjargaard, J. 1989. Acid rain from the heating of seawater by molten lava: a new volcanic hazard. *EOS, Transaction of the American Geophysical Union* 70 (43): 1421-1422
- Gerrard, J. 1994. *Report on the 23 December Kaikoura flood, Jim Gerard, MP Rangiora*. Parliament House, Wellington.
- Gibbon, H. 1992. Land transport and the volcano connection. *Tephra* 11(2): 20-21.
- Giggenbach, W.F. 1996. Chemical composition of volcanic gases. In: Scarpa, R., Tilling R.I. (eds.), *Monitoring and mitigation of volcanic hazards*, Springer, p. 221-256.
- Gilbert, J.S., Lane, S.J. 1994. Electricity phenomena in volcanic plumes. In: Casadevall, T.J. ed. *Volcanic ash and aviation safety: proceedings of the first international symposium on volcanic ash and aviation safety*. U.S. Geological Survey Bulletin 2047: 31-38.

- Gilbert, J.S., Lane, S.J., Sparks, R.S.J., Koyaguchi, T. 1991. Charge measurements of particles fallout from a volcanic plume. *Nature* 349: 598-600.
- Gough, J.D. 1990. A review of the literature pertaining to 'perceived' risk and 'acceptable risk' and methods used to estimate them. *Information Paper* No 14. Centre for Resource Management, University of Canterbury and Lincoln University.
- Green, C.H., Tunstall, S.M., Fordham, M.H. 1992. The risk from flooding: which risks and whose perception? *Disasters* 15: 227-236.
- Greene, M., Perry, R. W., Lindell, M. 1981. The March, 1980 eruptions of Mt. St. Helens: Citizen perceptions of volcano hazard. *Disasters* 5(1): 49-66.
- Gregg, D.R. 1960. The geology of Tongariro Subdivision. *New Zealand Geological Survey Bulletin* No. 40.
- Gregory, G. 1995. Persuading the public to make better use of natural hazard information. *Prometheus* 13(1): 61-71.
- Gregory, N.G., Neall, V.E. 1996. Volcanic hazards for livestock. *Outlook on Agriculture*, 25(2): 123-129.
- Hackett, W.R. 1985. *Geology and petrology of Ruapehu volcano and related vents*. Unpublished Ph.D. Thesis, Victoria University, New Zealand.
- Hackett, W.R., Houghton, B.F. 1989. A facies model for a Quaternary andesitic composite volcano: Ruapehu New Zealand. *Bulletin of Volcanology* 51: 51-68.
- Hastings District Council 1995. *Hastings District Council Volcanic Contingency Plan*. Hastings District Council Emergency Management Office.
- Hausenbuiller, R.L. 1978. *Soil Science: Principles and Practices*. (2nd Ed.). Brown Company Publishing, USA. 611 p.
- Heiken, G. 1994. Volcanic ash: what is it and how it forms. In: Casadevall, T.J. (ed.), *Volcanic ash and aviation safety: proceedings of the first international symposium on volcanic ash and aviation safety*. U.S. Geological Survey Bulletin 2047: 39-45.
- Heiken, G., Wohletz, K. 1985. *Volcanic ash*. University of California Press, 246 p.
- Heiken, G., Murphy, M., Hackett, W., Scott, W. 1995. *Volcanic hazards on energy infrastructure of the United States*. United States Department of Energy, LA-UR 95-1087.
- Helm, P. 1996a. Integrated risk management for natural and technological disasters. *Tephra* 15(1): 5-13.
- Helm, P. 1996b. Case study: Mt Ruapehu 1995. *Tephra* 15(1): 14 - 17.
- Higgins, E.T., Bargh, J.A. 1987. Social cognition and social perception. *Annual Review of Psychology* 38: 369-425.
- Hill, D.P. 1997. Unrest, response levels, and public perceptions in Long Valley caldera, California. Abstracts IAVCEI General Assembly, Puerto Vallarta, Mexico, January 19-24, 1997, p 117.
- Hill, H. 1897. On a volcanic-dust shower in Napier. *Transactions of the New Zealand Institute* 29: 571-572.
- Hill, R. 1984. Establishing validity in the social sciences: an empirical illustration. *New Zealand Science Review* 41: 59-62.
- Hindin, E. 1982. Rendering ash contaminated water potable. In: Keller, S.A.C. (eds.), *Mount St. Helens: One Year Later*. Eastern Washington University Press, p 237.

- Hoblitt, R.P., Miller, C.D., Vallance, J.W. 1981. Origin and stratigraphy of the deposit produced by the May 18 directed blast. In: Lipman, P.W. and Mullineaux, D.R. (eds.), The 1980 eruptions of Mount St Helens, Washington. *U.S. Geological Survey Professional Paper* 1250: 401-419.
- Hodgson, K.A. 1993. *Late Quaternary lahars from Mount Ruapehu in the Whangaehu River Valley, North Island, New Zealand*. Unpublished Ph.D. Thesis, Massey University.
- Hodgson, K.A., Manville, V.R. 1996. Rain-triggered lahars at a temperate volcano: Ruapehu 1995/1996. *Geological Society of New Zealand Miscellaneous Publication* 91A, p. 88.
- Hoff, L. 1980. Ash - a new clean-up problem. *Ways & Means*, July/August: 14-16.
- Hon, K., Kauahikaua, J., Denlinger, R., Mackay K. 1994. Emplacement and inflation of pahoehoe sheet flows: Observations and measurements of active lava flows on Kilauea Volcano, Hawaii. *Geological Society of America Bulletin* 106: 351-370.
- Hopkins, D.C., Lumsden, J.L., Norton J.A. 1993: Lifelines in earthquakes: a case study based on Wellington. *Bulletin of the New Zealand National Society for Earthquake Engineering* 26(2): 208-221.
- Horlick-Jones, T., Rosenhead, J. 1996. Developing methods to enhance the organisational management of ambiguous risks. Abstracts from 1996 SRA-Europe Annual Meeting, Website: <http://www.riskworld.com>.
- Houghton, B.F., Nairn, I.A. (eds.) 1989. The 1976-1982 eruption sequence at White Island volcano, Bay of Plenty, New Zealand. *NZ Geological Survey Bulletin* 103, 136 p.
- Houghton, B.F., Latter, J.H., Hackett, W.R. 1987. Volcanic hazard assessment for Ruapehu composite volcano, Taupo Volcanic Zone, New Zealand. *Bulletin of Volcanology* 49: 737-751.
- Houghton, B.F., Neall, V.E., Johnston, D.M. 1996. *Eruption: Mount Ruapehu Awakes*. Penguin Books (NZ) Ltd, Auckland, 48 p.
- Houghton, B.F., Weaver, S.D., Wilson, C.J.N., Lanphere, M.A. 1992. Evaluation of Quaternary peralkaline volcano: Mayor Island, New Zealand. *Journal of Volcanology and Geothermal Research* 51: 217-236.
- Houghton, B.F., Wilson, C.J.N., Weaver, S.D., Lanphere, M.A., Barclay, J. 1994. Volcanic hazards at Mayor Island. *Ministry of Civil Defence Volcanic Hazards Information Series* No. 6, 23 p.
- Hurst, A.W. 1994. ASHFALL - A computer program for estimating volcanic ash fallout: report and users guide. *Institute of Geological & Nuclear Sciences Science Report* 94/23, 22 p.
- Johnson, R.W., Threlfall, N.A. 1985. *Volcano town: the 1937-43 Rabaul eruptions*. Robert Brown and Associates, Bathurst, Australia, 151 p.
- Johnston, D.M., Houghton, B.F. 1995. Secondary school children's perceptions of natural hazards in the central North Island, New Zealand. *New Zealand Journal of Geography* 99: 18-26.
- Johnston, D.M., Nairn, I.A. 1993. Volcanic Impacts Report. The impact of two eruption scenarios from the Okataina Volcanic Centre, New Zealand, on the population and infrastructure of the Bay of Plenty Region. *Bay of Plenty Regional Council Resource Planning Publication* 93/6, 153 p.
- Johnston, D.M., Neall, V.E. 1995. Ruapehu Awakens: the 1945 eruption of Ruapehu. *The Science Centre and Manawatu Museum Scientific Monograph* No. 1, 28 p.
- Johnston, D.M., Riley, D.E. (comps.) 1996. Ruapehu '95 Volcanic Hazard Awareness Week, 16-23 October 1995. *Institute of Geological & Nuclear Sciences Information Series* 41, 82 p.
- Johnston, D.M., Nairn, I.A., Thordarson, T., Daly, M. 1997. Volcanic Impacts Assessment for the Auckland Volcanic Field. *ARC Environment Division, Technical Publication* 79, 208 p.

- Kahneman, D., Tversky, A. 1973. On the psychology of prediction. *Psychological Review* 80(4): 237-251.
- Kartez, J.D. 1982. Emergency planning implications of local governments' responses to Mount St Helens. *Natural Hazard Research Working Paper* 46. Natural hazards Research and Application Information Center, Institute of Behavioral Sciences, University of Colorado, 26 p.
- Kartez, J.D., Lindell, M.K. 1987. Planning for uncertainty: the case of local disaster planning. *American Planning Association Journal* (Autumn): 487-498.
- Kasperson, R.E., Renn, O., Slovic, P., Brown, H.S., Emel, J., Goble, R., Kasperson, J.X., Ratick, S. 1988. The social amplification of risk: a conceptual framework. *Risk Analysis* 8: 177-187.
- Keam, R.F. 1988. *Tarawera: the eruption of 10 June 1886*. R.F. Keam, Auckland, New Zealand, 472 p.
- Keys, H. 1996. The effects of Ruapehu eruption. *Tongariro - The Annual Journal of the Tongariro Taupo Conservancy* 5: 38-40.
- Keys, H., Williams, K. (ed.) 1996. *Eruption Debriefing: a workshop to discuss the management of the 1995 eruptions of Mt. Ruapehu in Tongariro National Park*. Department of Conservation, Tongariro/Taupo Conservancy. 68p.
- Kienle, C.F. 1980. *Evaluation of eruptive activity at Mt. St. Helens, Washington - March through June, 1980*. Report prepared for Portland Oregon by Foundation Sciences Inc.
- Koyaguchi, T. 1994. Grain-size variation of tephra derived from volcanic umbrella clouds. *Bulletin of Volcanology* 56: 1-9.
- Kusakabe, M., Ohsumi, T., Aramaki, S. 1989. The Lake Nyos gas disaster: chemical and isotopic evidence in water and dissolved gases from three Cameroonian crater lakes, Nyos, Monoun and Wum. *Journal of Volcanology and Geothermal Research* 39: 167-185.
- Kuester, I., Forsyth, S. 1985. Rabaul eruption risk: Population awareness and preparedness survey. *Disaster* 9(3): 179-182.
- Labadie, J.R. 1983. *Teal Granite: Mitigation of volcanic dust effects*. IRT Corporation. (final report prepared for U.S. Air Force Office of Scientific Research and the Defence Advanced Research Projects Agency). 29 p.
- Labadie, J.R. 1994. Mitigation of volcanic ash effects on aircraft operating and support systems. In: Casadevall, T.J. ed. *Volcanic ash and aviation safety: proceedings of the first international symposium on volcanic ash and aviation safety*. U.S. Geological Survey Bulletin 2047: 125-128.
- Langran, K., Terich, T. 1982. Government response to the Mount St. Helens disaster: a survey of perceptions and attitudes in the Longview-Kelso and Yakima areas. In: Keller, S.A.C. (ed.), *Mount St. Helens: one year later*. Eastern University Press, p. 167-170.
- Latter, J.H. 1981. Volcanic earthquakes and their relationship to eruptions of Ruapehu and Ngauruhoe volcanoes. *Journal of Volcanology and Geothermal Research* 9: 293-309.
- Latter, J.H. 1987. *Volcanic Hazard Map of Tongariro National Park Region*. DSIR, Wellington.
- Latter, J.H., Lloyd, E.F., Smith, I.E.M., Nathan, S. 1992. Volcanic hazards in the Kermadec Islands and at submarine volcanoes between southern Tonga and New Zealand. *Ministry of Civil Defence Volcanic Hazards Information Series* No. 4, 43 p.
- Lazarus, R.S., Folkman, S. 1984. *Stress, Appraisal and Coping*. New York, Springer-Verlag, 445 p.
- Lazarus, R.S. 1966. *Psychological Stress and the Coping Process*. New York, McGraw-Hill, 466 p.

- Le Guern, F., Bernard, A., Chevrier, R.M. 1980: Soufriere of Guadeloupe 1976-1977 eruption - mass energy transfers and volcanic health hazards. *Bulletin Volcanologique* 43: 577-593.
- Le Guern, F., Tazieff, H., Faivre-Pierret, R. 1982. An example of health hazard: people killed by gas during a phreatic eruption: Dieng Plateau (Java, Indonesia), February 20th, 1979. *Bulletin Volcanologique* 45: 153-156.
- Lehman, D.R., Taylor, S.E. 1987. Date with an earthquake: coping with a probable, unpredictable disaster. *Personality and Social Psychology Bulletin* 13: 546-555.
- Lindell, M.K. 1994. Perceived characteristics of environmental hazards. *International Journal of Mass Emergencies and Disasters* 12(3): 303-326.
- Lindell, M.K., Perry, R.W. 1992. *Behavioral Foundations of Community Emergency Planning*. New York, Hemisphere Publishing Company, 309 p.
- Lipman, P.W., Mullineaux, D.R. 1981. The 1980 eruptions of Mount St. Helens, Washington. *US Geological Survey Professional Paper* 1250, 844 p.
- Luhr, J.F., Simkin, T. (eds.) 1993. *Paricutin - The Volcano Born in a Mexican Cornfield*. Smithsonian Institution, Geoscience Press, 427 p.
- Lunn, J. 1996. Tasmanian Engineering Lifelines Project. *Proceedings of NDR96 Conference on Natural Disaster Reduction*, 29 September-2 October 1996, Gold Coast, Australia, p. 171-197.
- Macauley, J. 1993. Teaching about hazards and disasters in the New Zealand geography and social science curriculum. In: Lidstone, J., Wilson, P. (eds.), *Learning to live safely in the Australian Environment*. The Centre for Applied Environment and Education Research, p. 95-117.
- Macedonio, G., Pareschi, M.T., Santacroce, R. 1988. A numerical simulation of the plinian fall phase of 79 A.D. eruption of Vesuvius. *Journal of Geophysical Research* 93(B12): 14817-14827.
- Macedonio, G., Pareschi, M.T., Santacroce, R. 1990. Renewal of explosive activity at Vesuvius: models for the expected tephra fallout. *Journal of Volcanology and Geothermal Research* 40: 327-342.
- Machado, F., Parsons, W.H., Richards, A.F., Mulford, J.W. 1962. Capelinhos eruption of Fayal volcano, Azores, 1957-1958. *Journal of Geophysical Research* 67: 3519-3529.
- Mader, G.G., Blair, M.L. 1987. *Living With a Volcanic Threat: response to volcanic hazards, Long Valley, California*. Portola Valley, California: William Sprangle, 105 p.
- Malcolm, L., van Rossen, A. 1997. Ashes to ashes ? Rangipo rebuild. *International Water Power & Dam Construction*. (February), p. 22-24.
- Manville, V., Hodgson, K.A. 1996. Origins, behaviour and sedimentology of a rain-triggered lahar at Ruapehu volcano, New Zealand. *Geological Society of New Zealand Miscellaneous Publication* 91A, p. 121.
- Markesino, J. 1981. Mount St. Helens ash clean-up. *Public Works*, January, p. 52-55.
- Matsumoto, H., Okabayashi, T., Mochihara, M. 1988. Influence of eruptions from Mt. Sakurajima volcano of the deterioration of materials. *Proceedings Kagoshima International Conference on Volcanoes*, p. 732-735.
- Maxwell, I. 1996. Mount Ruapehu eruption 1995 - effects on the Taupo fishery. *Tongariro -The Annual Journal of the Tongariro Taupo Conservancy* 5: 46-48.
- May, P. J. 1997. Addressing natural hazards: challenges and lessons for public policy. *The Australian Journal of Emergency Management* 11(4): 30-37.

- McKee, C. O., Johnson, R.W., Lowenstein, P.L., Riley, S.J., Blong, R.J., de St. Ours, P., Talai, B. 1985. Rabaul caldera, Papua New Guinea: volcanic hazards, surveillance, and eruption contingency planning. *Journal of Volcanology and Geothermal Research* 23: 195-237.
- Metservice 1997. *VAAC Wellington*. Proceedings of the International Seminar on Volcanic Information Network for Aviation Safety, 11-15 March 1997, Tokyo & Kagoshima, Japan.
- Mileti, D.S. 1996. The character and form of effective natural hazard public information. Paper presented at the Pan Pacific Hazards '96 Conference, Vancouver, Canada.
- Mileti, D.S., Fitzpatrick, C. 1992. The causal sequence of risk communication in Parkfield earthquake prediction experiment. *Risk Analysis* 12: 393-400.
- Mileti, D.S., Fitzpatrick, C. 1993. *The Great Earthquake Experiment: Risk communication and public action*. Westview Press, Boulder, Colorado, 140 p.
- Mileti, D.S., O'Brien, P.W. 1993. Public response to aftershock warnings. *U.S. Geological Survey Professional Paper* 1553-B: B31-B42.
- Mileti, D. S., Sorensen, J. H. 1990. *Communication of Emergency Public Warnings: a social science perspective and state-of-the-art assessment*. Oak Ridge Laboratory ORNL-6609.
- Miller, E. 1994. Volcanic ash and aircraft operations. In: Casadevall, T.J. (ed.), *Volcanic ash and aviation safety: proceedings of the first international symposium on volcanic ash and aviation safety*. *U.S. Geological Survey Bulletin* 2047: 203-206.
- Miller, T.P., Chouet, B.A. (eds.) 1994. The 1989-1990 eruptions of Redoubt Volcano, Alaska. *Journal of Volcanology and Geothermal Research* 62. 530 p.
- Ministry of Civil Defence 1992. *National Volcanic Hazards Seminar*. Quality Inn, Rotorua, 19 February 1992. Ministry of Civil Defence, 65 p.
- Ministry of Education 1993. *Science in the New Zealand Curriculum*. Ministry of Education, Wellington. 136 p.
- Ministry of Education 1994. *Social Studies in the New Zealand Curriculum (Draft)*. Ministry of Education, Wellington, 134 p.
- Moen, W.S., McLucas, G.B. 1980. *Mount St. Helens ash: properties and possible uses*. Washington Department of Natural Resources, Division of Geology and Earth Resources, Report of Investigations 24, 60 p.
- Moore, J.G. 1967. Base surges in recent volcanic eruptions. *Bulletin of Volcanology* 30: 337-363.
- Moore, J.G., Nakamura, K., Alcaraz, A. 1966. The 1965 eruption of Taal volcano. *Science* 151: 955-960.
- Mulilis, J-P., Duval, T.S. 1995. Negative threat appeals and earthquake preparedness: a person-relative-to-event (PrE) model of coping with threat. *Journal of Applied Social Psychology* 25: 1319-1339.
- Murton, B.J., Shimabukuro, S. 1974. Human adjustment to volcanic hazard in Puna District, Hawaii. In: White, G.F. (ed.), *Natural Hazards - Local, National, Global*. Oxford University Press, New York, p. 151-159.
- Nairn, I.A. 1979. Rotomahana - Waimangu eruption 1886: base surge and basalt magma. *New Zealand Journal of Geology and Geophysics* 22: 363-378.
- Nairn, I.A. 1981. *Some studies of the geology, volcanic history, and geothermal resources of the Okataina Volcanic Centre, Taupo Volcanic Zone, New Zealand*. Unpublished Ph.D. thesis, Victoria University of Wellington.

- Nairn, I.A. 1989. Sheet V16AC - Mount Tarawera. Geological Map of New Zealand 1:50 000 Map (1 sheet) and notes. DSIR, Wellington.
- Nairn, I.A. 1991a. Volcanic Hazards of Okataina Volcanic Centre. *Volcanic Hazards Information Series* No. 2, 29 p.
- Nairn, I.A. 1991b. Report on a visit to Mt. Pinatubo: 11-12 August 1991. *DSIR Geology & Geophysics Internal Report*, 13 p.
- Nairn, I.A. 1992a. The Te Rere and Okareka eruptive episodes - Okataina Volcanic Centre, Taupo Volcanic Zone, New Zealand. *New Zealand Journal of Geology and Geophysics* 35: 93-108.
- Nairn, I.A. 1992b. Pinatubo and Okataina eruptions: similarities and contrasts. *Tephra* 11(2): 14-15.
- Nairn, I.A. 1995. *The Probability and Likely Effects of a Future Eruption at Mount Edgecumbe (Putauaki)*. Environment B.O.P., 24 p.
- Nairn, I.A., Houghton, B.F., Cole, J.W. 1991. Volcanic Hazards at White Island. *Volcanic Hazards Information Series* No. 5, 26 p.
- Nairn, I.A., Scott, B.J. 1995. Scientific management of the 1994 Rabaul eruption: lessons for New Zealand. *Institute of Geological & Nuclear Sciences science report 95/26*, 46 p.
- Nairn, I.A., Self, S. 1978. Explosive eruptions and pyroclastic avalanches from Ngauruhoe in February, 1975. *Journal of Volcanology and Geothermal Research* 3: 39-60.
- Nairn, I.A., Wood, C.P., Hewson, C.A.Y. 1979. Phreatic eruptions of Ruapehu: April 1975. *New Zealand Journal of Geology and Geophysics* 22: 155-173.
- Neall, V.E. 1972. Tephrochronology and tephrostratigraphy of western Taranaki (N108-109), New Zealand. *New Zealand Journal of Geology and Geophysics* 15: 507-557.
- Neall, V.E. 1982. Volcanic hazard map of Mount Egmont 1: 100 000. DSIR, Wellington.
- Neall, V.E. 1996. Hydrological disasters associated with volcanoes. In: Singh, V.P. (ed.), *Hydrology of disasters*. Kluwer Academic Publishers, London, p. 395-425.
- Neall, V.E., Alloway, B.V. 1991. Volcanic hazards at Egmont volcano. Ministry of Civil Defence Volcanic Hazards Information Series No. 1, 39 p.
- Neall, V.E., Alloway, B.V. 1996. *Volcanic Hazard Map of Western Taranaki*. Massey University, Department of Soil Science Occasional Report 12.
- Nellis, C.A., Hendrix, K.W. 1980. *Progress report on the investigation of volcanic ash fallout from Mount St Helens*. Laboratory Report ERJ-80-47. Bonneville Power Administration, U.S. Dept. of Energy.
- Newhall, C.G., Punongbayan, R. S. The narrow margin of successful volcanic risk mitigation. In: R. Scarpa, Tilling R.I. (eds.), *Monitoring and Mitigation of Volcanic Hazards*. Springer-Verlag, p. 807-838.
- Nigg, J.M. 1990: *A comparison of Two Communities: lifeline disruption due to Hurricane Hugo*. Newark, Disaster Research Center, University of Delaware, 14 p.
- Nigg, J.M. 1995a. *Business disruption due to earthquake-induced lifelines interruption*. Paper presented at the Sino - U.S. symposium/workshop on post-earthquake rehabilitation and reconstruction, Kunming, Yunnan, People's Republic of China, May 24-26 1995.

- Nigg, J.M. 1995b. Disaster recovery as a social process. In: *Wellington After the Quake: the challenge of rebuilding cities*, proceedings of a conference held in Wellington, New Zealand, 27-29 March 1995, p. 81-90.
- Nigg, J.M., Tierney, K.J. 1995. *Business vulnerability to disasters-related lifelines disruption*. Paper presented at the 4th U.S. conference on lifeline earthquake engineering, San Francisco, CA, August 10-12, 1995.
- Nordmeyer, A.H. 1946. Report on mental hospitals in the Dominion. *Appendix to the Journal of the House of Representatives of New Zealand*. H-7: 1-26.
- Novak, T., Zais, R. 1981. How to manage ash. *Public Management*, January-February, p. 12-15.
- O'Shea, B.E. 1954. Ruapehu and the Tangiwai Disaster. *Journal of Science and Technology* B36: 174-189.
- Oliver, R.L. 1945. Further activity of Mount Ruapehu, New Zealand, May-July 1945. *Journal of Science and Technology* B27: 24-32.
- Oskarsson, N. 1980. The interaction between volcanic gases and tephra: Fluorine adhering to tephra of the 1970 Hekla eruption. *Journal of Volcanology and Geothermal Research* 8: 251-266.
- Palmer, B.A. 1991. Holocene lahar deposits in the Whakapapa catchment, northwestern ring plain, Ruapehu volcano (North Island, New Zealand). *New Zealand Journal of Geology and Geophysics* 34: 177-190.
- Parry, W.E. 1946. Annual report of the Department of Internal Affairs. *Appendix to the Journal of the House of Representatives of New Zealand* H-22: 1-24.
- Paton, D. 1996. Ruapehu and beyond: issues in the management of community impact and recovery. In: Ruapehu '95 Volcanic Hazard Awareness Week, 16-23 October 1995. *Institute of Geological & Nuclear Sciences Information Series* 41, p. 49-53.
- Patterson, D. 1987. *Future Volcanic Activity in Taranaki: likely impacts and effects on Taranaki infrastructure and the implications for civil defence and emergency response contingency plans*. A report to the Taranaki United Council and Taranaki Civil Defence Committee.
- Perloff, L.S. 1983. Perceptions of vulnerability to victimization. *Journal of Social Issues* 39: 41-61.
- Perloff, L.S., Fetzer, B.K. 1986. Self - other judgements and perceived vulnerability to victimization. *Journal of Personality and Social Psychology* 50: 502-510.
- Perry, R.W. 1985. *Comprehensive Emergency Management: Evacuating Threatened Populations*. Greenwich, Conn.: JAI Press, 203 p.
- Perry, R.W. 1987. Disaster preparedness and response among minority citizens. In: Dynes, R.R., DeMarchi, B., and Pelantla, C. (eds.), *Sociology of Disaster*. Milan: Franco Angeli, p. 135-151.
- Perry, R.W. 1990. Volcanic hazard perceptions at Mt. Shasta. *The Environment Professional* 12: 312-318.
- Perry, R.W., Hirose, H. 1991. *Volcano Management in the United States and Japan*. Greenwich CT: JAI Press Inc, 218 p.
- Perry, R.W., Lindell, M.K. 1990. *Living with Mount St. Helens: human adjustment to volcano hazards*. Washington University Press, Pullman, Washington, 205 p.
- Perry, R.W., Lindell, M.K., Greene, M.R. 1981. *Evacuation Planning in Emergency Management*. Lexington Books, Toronto, 196 p.
- Petak, W.J., Atkisson, A.A. 1982. *Natural Hazard Risk Assessment and Public Policy: anticipating the unexpected*. Springer-Verlag, New York, 489 p.

- Peterson, D.W., Tilling, R.I. 1993. Interactions between scientists, civil authorities and the public at hazardous volcanoes. In: Kilburn, C.R.J., Luonga, G. (eds.), *Active lavas*: UCL Press, London, p 339-365.
- Platt, R.H. 1991. Lifelines: An emergency management priority for the United States in the 1990's. *Disasters* 15(2): 172-176.
- Ponter, D., Doorman, P., Feist, R. 1993. Survey of attitudes and perceptions towards the environment in the Bay of Plenty. *Bay of Plenty Regional Council Resource Planning Publication* 21, 103 p.
- Public Works 1980. Oregon overcomes volcanic ash nuisance. *Public Works* (December), p. 37.
- Pyle, D.M. 1989. The thickness, volume and grain size of tephra fall deposits. *Bulletin of Volcanology* 51: 1-15.
- Quayle, A.M. 1984. The climate and weather of the Bay of Plenty region. *New Zealand Meteorological Service Miscellaneous Publication* 115(1), 2nd edition, 56 p.
- Reed, J.J. 1945. Activity at Ruapehu - March to April 1945. *Journal of Science and Technology* B27: 17-23.
- Rodolfo, K.S. 1995. *Pinatubo and the Politics of Lahars*. University of Philippines Press, 341 p.
- Ronan, K.R. 1997. The effects of a "benign" disaster: symptoms of post-traumatic stress in children following a series of volcanic eruptions. *Australasian Journal of Disaster and Trauma Studies*. (<http://www.massey.ac.nz/~trauma/>).
- Ronan, K.R., Johnston, D.M. 1996. The impacts of volcanic eruptions on childhood psychological functioning. *Proceedings of the Pan Pacific Hazards '96 conference, Vancouver, Canada*.
- Ronan, K.R., Johnston, D.M. (in prep). Collaboration between physical and social scientists following a series of volcanic eruptions: helping children cope.
- Rose, W.I. 1977. Scavenging of volcanic aerosol by ash: atmospheric and volcanologic implications. *Geology* 5: 621-624.
- Rose, W.I., Pearson, T., Bonis, S. 1977. Nuee ardente eruption from the foot of a dacite lava flow, Santiaguito volcano, Guatemala. *Bulletin Volcanologique* 40: 23-38.
- Saarinen, T.F., Sell, J.L. 1985. *Warnings and Response to the Mount St Helens Eruption*. State University of New York Press, Albany, 240p.
- Salter, J. 1995. Towards a better disaster management methodology. *The Australian Journal of Emergency Management* 10(4): 8-16.
- Salter, J. 1996. Risk management in disaster management context. *Proceedings of NDR96 Conference on Natural Disaster Reduction*, 29 September-2 October 1996, Gold Coast, Australia, p. 365-396.
- Sarkinen, C.F., Wiitala, J.T. 1981. Investigation of volcanic ash in transmission facilities in the Pacific Northwest. *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-100, p 2278-2286.
- Scasso, R.A., Corbella, H., Tiberi, P. 1994. Sedimentological analysis of the tephra from 12-15 August 1991 eruption of Hudson volcano. *Bulletin of Volcanology* 56: 121-132.
- Schuster, R.L. 1981. Effects of the eruption on civil works and operations in the Pacific Northwest. In: Lipman, P.W. and Mullineaux, D.R. (eds), *The 1980 eruptions of Mount St Helens*, Washington. *U.S. Geological Survey Professional Paper* 1250: 701-718.
- Scott, B.J., Houghton, B.F., Wilson, C.J.N. 1995a. Surveillance of New Zealand's volcanoes. *Tephra* 14(2): 12-17.

- Scott, B.J., Nairn, I.A., Wood, C.P. 1995b. Volcanic hazards, White Island. *Institute of Geological & Nuclear Sciences science report 95/36*, 25 p.
- Scott, R. 1995. Coordination and accessibility of post-disaster counselling and community support services. In: *Wellington After the Quake: the challenge of rebuilding cities*, proceedings of a conference held in Wellington, New Zealand, 27-29 March 1995, p. 183-190.
- Scott, W.E., McGimsey, R.G. 1994. Character, mass, distribution, and origin of tephra-fall deposits of the 1989-1990 eruption of Redoubt volcano, south-central Alaska. *Journal of Volcanology and Geothermal Research* 62: 251-272.
- Self, S., Walker, G.P.L. 1994. Ash clouds: characteristics of eruption columns. In: Casadevall, T.J. (ed.), *Volcanic ash and aviation safety: proceedings of the first international symposium on volcanic ash and aviation safety*. *U.S. Geological Survey Bulletin* 2047: 65-74.
- Self, S., Sparks, R.S.J., Booth, B., Walker, G.P.L. 1974. The 1973 Heimaey Strombolian scoria deposits, Iceland. *Geological Magazine* 111: 534-548.
- Shepherd, J.B., Aspinall, W.P., Rowley, K.C., Pereira, J., Sigurdsson, H., Fiske, R.S., Tomblin, J.F. 1979. The eruption of Soufriere volcano, St Vincent, April - June 1979. *Nature* 282: 24-28.
- Shibley, S., Sarna-Wojcicki, A.M. 1982. Distribution, thickness, and mass of Late Peistocene and Holocene tephra from major volcanoes in the northwestern United States: a preliminary assessment of hazards from volcanic ejecta to Nuclear reactors in the Pacific Northwest. *United States Geological Survey Note to accompany Map MF-1435*.
- Showalter, P.S. 1993. Prognostication of doom: an earthquake prediction's effect on four small communities. *International Journal of Mass Emergencies and Disasters* 11(3): 279-292.
- Siebert, L. 1984. Large volcanic debris avalanches: characteristics of source areas, deposits, and associated eruptions. *Journal of Volcanology and Geothermal Research* 22: 163-197.
- Simpson-Housley, P., Bradshaw, P. 1978. Personality and the perception of earthquake hazard. *Australian Geographical Studies* 16: 65-77.
- Sims, J.H., Baumann, D.D. 1972. The tornado threat: coping styles of the north and south. *Science* 176: 1386-1392.
- Slovic, P. 1987. Perception of risk. *Science* 236: 280-285.
- Slovic, P. 1993. Perceived risk, trust and democract. *Risk Analysis* 13: 675-682.
- Slovic, P., Fischhoff, B., Lichtenstein, S. 1981. Perceived risk: psychological factors and social implications. *Proceedings of the Royal Society of London A376*: 17-34.
- Smith, D.B., Zielinski, R.A., Rose, W.I. 1982. Leachability of uranium and other elements from freshly erupted volcanic ash. *Journal of Volcanology and Geothermal Research* 13: 1-30.
- Smith, G.A., Fritz, W.J. 1989. Volcanic influences on terrestrial sedimentation. *Geology* 17: 375-376.
- Smith, I.E.M., Allen, S.R. 1993. Volcanic hazards at the Auckland Volcanic Field. *Ministry of Civil Defence Volcanic Hazards Information Series No. 5*, 34 p.
- Somers, E. 1995. Perspectives on risk management. *Risk Analysis* 15: 677-684.
- Sparks, R.S.J. 1976. Grain size variations in ignimbrites and implications for the transport of pyroclastic flows. *Sedimentology* 23: 147-188.

- Sparks, R.S.J., Bursik, M.I., Ablay, G.J., Thomas, R.M.E., Carey, S.N. 1992. Sedimentation of tephra by volcanic plumes. Part 2: controls on thickness and grain-size variations of tephra fall deposits. *Bulletin of Volcanology* 54: 685-695.
- Spence, J.S., Pomonis, A., Baxter, P.J., Coburn, A.W., White, M., Dayrit, M., Field Epidemiology Training Program Team 1996. Building damage caused by Mount Pinatubo eruption of June 15, 1991. In: Newhall, C.G., Punongbayan, R.S. (eds.) 1996. *Fire and Mud: eruptions and lahars of Mount Pinatubo, Philippines*. Philippine Institute of Volcanology and Seismology and University of Washington Press, p. 1055-1061.
- Stember G.E., Batiste, A.R. 1981. Impacts of Mt St Helens volcanic ash fallouts on the BPA System. Vol. 43, *Proceedings of the American Power Conference 1981*, p. 495-498.
- Sutton, J., Elias, T. 1993. Volcanic gases create air pollution on the Island of Hawai'i. *Earthquakes and Volcanoes* 24(4): 178-196.
- Swanson, D.A., Wright, T.H., Helz, R.T. 1975. Linear vent systems and estimated rates of magma production and eruption for the Yakima basalt on the Columbia Plateau. *American Journal of Science* 275: 877-905.
- Taranaki Regional Council 1995. *Civil Defence Survey: public awareness and preparedness report*. Taranaki Regional Council.
- Taranaki Regional Council 1996. *Egmont Volcano: regional volcanic contingency plan*. Taranaki Regional Council, 18 p.
- Taylor, T. 1988. Coping with the earthquake. In: Ruscoe, Q. (ed), *Walking on Jelly: the Bay of Plenty earthquake 1987*, DSIR Publishing, p. 64-74.
- Teagle, S. 1995. *Report of the Emergency Services Task Group, November 1995*. Department of Internal Affairs, Wellington.
- Thompson, C.S. 1987. The climate and weather of Hawke's Bay. *New Zealand Meteorological Service Miscellaneous Publication* 115(5) (2nd ed.), 46 p.
- Thorarinsson, S. 1965. Surtsey: island born of fire. *National Geographic Magazine* 127: 713-726.
- Thorarinsson, S. 1969. The Lakagigar eruption of 1783. *Bulletin Volcanologique* 33: 910-927.
- Thorarinsson, S. 1979. On the damage caused by volcanic eruptions with special reference to tephra and gases. In: Sheets, P.D., Grayson, D.K. (eds.), *Volcanic Activity and Human Ecology*. Academic Press, New York, p. 125-156.
- Thorpe, R., Brown, G. 1985. *The Field Description of igneous rocks*. Open University Press, 154 p.
- Tierney, K.J. 1994. *Business vulnerability and disruption: data from the 1993 Midwest floods*. Paper presented at the 41 st North American meetings of the Regional Science Association International, Niagara Falls, Ontario, November 16-20, 1994.
- Tierney, K.J. 1995. *Impacts of recent U.S. disasters on Business: the 1993 midwest flood and the 1994 Northridge earthquake*. Paper presented at the National Center for earthquake engineering research conference on economic consequences of earthquakes: preparing for the unexpected. New York, NY, Sept 12-13, 1995.
- Topping, W.W. 1973. Tephrostratigraphy and chronology of late Quaternary eruptives from the Tongariro Volcanic Centre. *New Zealand Journal of Geology and Geophysics* 16: 375-395.

- Truill, W.E. 1978. Appendix 1: Damage to buildings and equipment; Part 1 - Damage to Tourist Hotel Corporation buildings. In: Healy, J., Lloyd, E.F., Rishworth, D.E., Wood, C.P., Glover, R.B., Dibble, R.R., The eruption of Ruapehu, New Zealand, on 22 June 1969. *DSIR Bulletin* 224, p. 74.
- Trusdell, F.A. 1995. Lava flow hazards and risk assessment on Mauna Loa Volcano, Hawaii. In: Rhodes, J. M., Lockwood, J. P. (eds.) *Mauna Loa Revealed: structure, composition, history and hazards*. Geophysical Monograph 92: 327-336. American Geophysical Union.
- Tuck, B.H., Huskey L., Talbot L. 1992. *The Economic Consequences of the 1989-90 Mt. Redoubt Eruptions*. Institute of Social and Economic Research, University of Alaska Anchorage. 42 p.
- Tyley, J.L., Reynertson, K.D. 1981. A pain in the ash: the effort of the men and women of Fairchild AFB overcame the neighborhood nuisance. Mt. St. Helens. *Engineering and Services Quarterly*: 16-19.
- Vaughan, E. 1995. The significance of socioeconomic and ethnic diversity for risk communication process. *Risk Analysis* 15: 169-180.
- Vogt, B.M., Sorensen, J.H. 1994. *Risk communications and the chemical stockpile emergency-planning program*. Oak Ridge National Laboratory ORNL-6824, 174 p.
- Voight, B. 1990. The 1985 Nevado del Ruiz volcano catastrophe: anatomy and retrospection. *Journal of Volcanology and Geothermal Research* 42: 151-188.
- Voight, B. 1996. The management of volcano emergencies: Nevado del Ruiz. In: R. Scarpa, Tilling R.I. (eds.), *Monitoring and Mitigation of Volcanic Hazards*. Springer-Verlag, p. 719-769.
- Voight, B., Glicken H., Janda, R.J., Douglass, P.M. 1981. Catastrophic rockslide avalanche of May 18. In: Lipman, P.W., Mullineaux, D.R. (ed.). The 1980 eruptions of Mount St. Helens, Washington. *United States Geological Survey Professional Paper* 1250: 347-378.
- Waldron, H.W. 1967. Debris flow and erosion control problems caused by the ash eruptions of Irazu volcano, Costa Rica. *United States Geological Survey Bulletin* 1241-I: 1-37.
- Walker, G.P.L. 1971. Grain size characteristics of pyroclastic deposits. *Journal of Geology* 79: 696-714.
- Walker, G.P.L. 1973. Lengths of lava flows. *Philosophical Transactions of the Royal Society of London* A274: 107-118.
- Walker, G.P.L. 1981. Plinian eruptions and their products. *Bulletin of Volcanology* 44: 223-240.
- Walker, G.P.L., Wilson, L., Bowell, E.L.G. 1971. Explosive volcanic eruptions - I. The rate of fall of pyroclasts. *Geophysical Journal of the Royal Astronomical Society* 22: 377-383.
- Ward, P.L., Mileti, D.S. 1993. Public education and communication for disaster mitigation. *Proceedings of the Workshop on Volcanic Disaster Prevention: the first meeting of the Panel on Volcanic Disaster Prevention under Japan-US Science and Technology Agreement*, p. 226-227.
- Warrick, R.A., Anderson, J., Downing, T., Lyons, J., Ressler, J., Warrick, M., Warrick, T. 1981. *Four communities under ash - after Mt St Helens*. Program on Technology, Environment and Man, Monograph 34, Institute of Behavioral Science, University of Colorado, 143 p.
- Weinstein, N.D. 1980. Unrealistic optimism about future life events. *Journal of Personality and Social Psychology* 39: 806-820.
- Weinstein, N.D. 1989. Effects of personal experience on self-protective behaviour. *Psychology Bulletin* 105: 31-50.

- Wenger, D. 1988. Volcanic disaster prevention, warning, evacuation, and rescue. *Hazard Reduction and Recovery Center*.
- White, J.D.L. 1996. Impure coolants and interaction dynamics of phreatomagmatic eruptions. *Journal of Volcanology and Geothermal Research* 74: 155-170.
- White, J.D.L., Houghton, B.F., Hodgson, K.A., Wilson, C.J.N. 1997. Delayed sedimentary response to the 1886 A.D. eruption of Tarawera, New Zealand. *Geology* 25: 459-462.
- White, W.T., Day, T.G., Berteck, D.; Fisher, J. 1980. Mt. St. Helens volcanic ash vs. Yakima wastewater treatment facility. *Institute for Water Resources Newsletter* 6(2): 4-8.
- Wilcox, R.E. 1959. Some effects of recent volcanic ash with special reference to Alaska. *United States Geological Survey Bulletin* 1028-N: 409-476.
- Williams, R.S., Moore, J.G. 1973. Iceland chills a lava flow. *Geotimes* (August): 14-17.
- Wilson, C.J.N. 1985. The Taupo eruption, New Zealand, II: the Taupo Ignimbrite. *Philosophical Transactions of the Royal Society of London*. A314: 229-310.
- Wilson, C.J.N., Walker, G.P.L. 1985. The Taupo eruption, New Zealand. I. General aspects. *Philosophical Transactions of the Royal Society, London* A.314: 199-228.
- Wrathall, J.E. 1992. Natural hazard reporting in the UK press. *Disaster* 12: 177-182.
- Wright, T.L., Pierson, T.C. 1992. Living with volcanoes. *U.S. Geological Survey Circular* 1073, 57 p.
- Yanagi, T., Okada, H., Ohta, K. (eds.) 1992. *Unzen Volcano the 1990-1992 Eruption*. The Nishinippon & Kyushu University Press, 137p.
- Yoshii, H. 1992. Disaster warnings and social response - the eruption of Mt. Unzen in Japan. *Disaster Management* 4(4): 207-214.
- Zhao, J., Turco, R.P., Toon, O.B. 1995. A model simulation of Pinatubo volcanic aerosols in the stratosphere. *Journal of Geophysical Research* 100 (D4): 7315-7328.
- Zinser, L.M. 1994. Effects of volcanic ash on aircraft powerplants and airframes. In: Casadevall, T.J. (ed.), Volcanic ash and aviation safety: proceedings of the first international symposium on volcanic ash and aviation safety. *U.S. Geological Survey Bulletin* 2047: 141-146.

APPENDIX 1

A CHRONOLOGY OF THE 1945 ERUPTION OF RUAPEHU VOLCANO

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INTRODUCTION

The 1945 eruption of Mount Ruapehu was the second largest eruption sequence this century in the central North Island (see Chapter 2). This appendix presents a daily summary of observations of the 1945 eruption. It attempts to bring together a dispersed record of the eruption, compiled from a number of sources including newspapers, letters and telegrams, together with previously published information.

Newspaper articles provided a wealth of information, but doubts exist about the accuracy and validity of some of the reports. There are many examples where different dates are assigned to the same 'apparent' event. This appears to be due to the larger newspapers (i.e. New Zealand Herald, The Dominion) frequently reprinting (at a later date) stories first printed in local papers, without altering the text. Where articles contain terms such as "yesterday", the date of an event is often inferred to have occurred later than it actually did.

There remains a rich record in the oral history of local residents who witnessed the eruption. Unfortunately, since details of the dates of events are rarely remembered, little of this information can be presented in this report. The booklet "Ruapehu Awakens" (Appendix 2) provides a visual record to accompany this detailed account.

MARCH 1945**8 March**

Long plume of steam noted blowing to the east and the eastern slopes covered by mud and ash, reported by Commander F. Allen of United Airways, on a flight from Auckland to Wellington (*Evening Post* 12/3/45). Staff at Waiouru Military camp notice considerable volumes of steam and "smoke" steaming away from the summit (*Taihape Times* 12/3/45).

9 March

In the afternoon a RNZAF plane from Ohakea flies over the mountain observing minor disturbances (*Evening Post* 12/3/45). Staff at Waiouru Military camp notice considerable volumes of steam and "smoke" steaming away from the summit, more than yesterday (*Taihape Times* 12/3/45).

10 March

Mr A. Pritchard and Prof. C. Cotton fly over the mountain but are unable to see the crater due to cloud. They report the smell of sulphur (*Evening Post* 12/3/45). Staff at Waiouru Military camp notice considerable volumes of steam and "smoke" steaming away from the summit with evidence more marked than on previous days (*Taihape Times* 12/3/45).

12 March

Several residents of Palmerston North report having felt earth rumbles with the occasional dull thuds in forenoon and a perceptible tremor shortly before 10 am. None were recorded on the seismograph at Bunnythorpe (*Manawatu Evening Standard* 12/3/45). Activity less than Thursday - Saturday (*Taihape Times* 12/3/45).

16 March

Tremor felt in Ohakune at 8.30 am (many felt in recent weeks) (*Taumarunui Press* 22/3/45).

18 March

"Immense volumes of steam with dark coloured blotches, evidently debris, were being erupted up to about 2000 ft on a very wide base." reported by Mr E. Lightband of Ohakune (*Taumarunui Press* 22/3/45). "Ruapehu very active and can hear the rumblings of the mountain like heavy thunder at frequent intervals. As Ruapehu clouded over all the time unable to see the discharge of steam from the crater today." (*Mangatepopo Hut Book* 18/3/45).

19 March

A lava dome observed emerging from the lake. Eruption of steam accompanied by loud rumblings or cracking noises. Explosion of mud, ash and occasional larger fragments alternated by quiet periods of steam. Steam escaping under great pressure (Reed 1945). Steam rising from the mountain is seen in Palmerston North. At 8 am the activity appeared to be at its greatest. By 10 am haze obscured the mountain (*Manawatu Evening Standard* 19/3/45). Steam visible from Wanganui. Eye witnesses reported "when a light wind blew the steam

clear of the cone there could be seen a dull red as of hidden fire beneath it. Although steam and smaller quantities of black smoke were rising steadily from the cone, there were frequent intensive vibrations indicating tremendous pressure somewhere beneath the lake, accompanied by echoing booming sounds. There is no sign of rocks or mud erupting." (*Evening Post* 20/3/45). "Activity increased and continuous." reported Mr E. Lightband of Ohakune (*Taumarunui Press* 22/3/45). King Country residents had a spectacular display from 4 pm yesterday until noon today. Steam visible from Wanganui (*Wanganui Chronicle* 20/3/45).

20 March

Island in the crater, 50 ft across, observed by Mr Manson (*NZ Herald* 26/3/45). Prof. Cotton observed "*had the appearance of being a lava mound, the emergent part of a small tholoid... steam was escaping under great pressure through chinks between blocks which were apparently for the most part, displaced portions of a carapace of chilled lava, though it is possible that at that time some blocks on the surface of the island may have been lifted by it from the old lake floor. No ebullition of the lake water was seen. Solid fragments from the island were occasionally lifted and scattered by steam blast. Showers of these fragments were falling in the lake and occasionally quite large blocks fell on the ice-covered rim of the crater.*" (Cotton 1946).

21 March

Manson observed "*The vent in the islet in the crater lake has grown bigger large rocks were being thrown out ... deposits on the crater edge. The southern slopes of the crater had been covered by so much debris that what had been a permanent ice field till recently, now looked like the surroundings of a thermal mud pool. Fine grey ash fell in a continual shower and had discoloured the snow right to the foot of the mountain. Small red hot rocks were being thrown well out of the lake ... Ejected rocks which did not reach the edge of the crater fell into the lake in a sizzling shower with loud explosions.*" One explosion to 1000 ft with debris falling back into the lake ... Dome 50 ft high was reported by A. Manson (*NZ Herald* 22/3/45). Cone 300 yards across (*Auckland Star* 23/3/45).

22 March

Cone diameter 50 feet and 10 feet high walls. Vent at the top of the cone 10 feet across emitting dense steam (*Wanganui Chronicle* 7/4/45).

23 March

For much of the day the mountain was not visible but rumblings continued. Late at night conditions cleared and steam cloud was lit red and could be seen from the Chateau. Airmen at Waiouru could also see a glow (*Evening Post* 24/3/45).

25 March

Two spectacular displays, one in the morning and the other in the early afternoon, were the only signs of activity on Ruapehu that could be seen from the Chateau. The mountain was clear all day and apart from the two outbursts, there was no sign of any steam rising from the crater (*Dominion* 26/3/45). Activity at a much smaller level than previous days. Island had doubled in size since 20 March being 50 yards across and 12 ft above the lake (*NZ Herald* 26/3/45).

26 March

Most spectacular display to date with steam clouds. First outburst after 10 am with steam shot high into the air (*NZ Herald* 27/3/45). At 1.15 pm large explosive event was seen from Taupo with column to 6-8000 ft (Reed 1945). No noise heard at the Chateau (*NZ Herald* 27/3/45). Party sees lake without cone (*Wanganui Chronicle* 7/4/45).

27 March

Dome disappeared. Concentration of steam rising from vent area of lake. It is suggested that the explosion of yesterday destroyed the dome (Reed 1945). Little sign of activity seen from the Chateau. Steam clouds seen from Taupo with one small outburst at 10.30 am (*NZ Herald* 28/3/45).

29 March

Eruption seen from Taupo 10 am. Greater steam than 26 March, up to over 8000 ft above the mountain. Some residents report explosion around 6 am (*NZ Herald* 30/3/45).

31 March

Lake steaming quietly. Report by party visiting the crater area. They moved down inside the rim to get a better view but beat a hasty retreat when without warning activity began with a tremendous roar. Rocks and mud were hurled high into the air and a huge steam column belched upwards from the centre of the lake for several thousand feet. The eruption was short lived and the water was soon steaming placidly again. Several other small disturbances were seen over the weekend (*Taihape Times* 4/4/45).

APRIL 1945**1 April**

Two displays when white clouds of steam rose high into the air from Crater Lake. The last display was seen at 11 pm (*Taihape Times* 4/4/45).

2 April

"A layer of about two inches of mud and fine rock extends right across the upper portion of the Whangaehu glacier and this should cause the Whangaehu stream to be badly discoloured immediately the weather breaks. A large portion of the ice wall on the north side of the lake has collapsed or subsided to a considerable degree and this has caused a widening of a big crevasse a short distance above..... The entrance to the lake on the southeast corner has been blown away and a completely new development is an ice cave of perhaps seven or eight feet high in the ice wall directly below Tahurangi peak. The lake level had decreased somewhat but there was no increase whatever in the area of the lake nor was there any evidence of the reported island or cone..." reports Mr T Shout (*Waimarino Call* 6/4/45).

15 April

"Plenty of activity in the crater lake and endeavoured to get right down but only got as far as the ice cliffs (too much steam). Big deposits of sulphur covering the ice and much volcanic ash and mud everywhere." (Mangatepopo Hut Book 16/4/45).

16 April

Outburst of steam, mud and ash rising thousands of feet above the crater. No major outburst since 2 April (Reed 1945). No sign of steam from the Chateau in the morning (*Auckland Star* 16/4/45).

MAY 1945**5 May**

Layer of fine, sandy ash discoloured the snow on the north side down to 4000 ft (*Dominion* 10/5/45)

7 May

Three skiers report a rock-covered island has reappeared above the steaming lake in the same position as last time. "It was larger than the one that disappeared in March..... Large numbers of rocks were being hurled out of the orifice, but all fell back into the lake. The water was a grey-green colour and though apparently close to boiling point was not bubbling. Continual rumbling accompanied the activity and there was a strong smell of sulphur round the crater. No glow was visible from the vent but as with the earlier activity, so much steam was rising that it was difficult to see beyond the crater's edge..." (*Dominion* 10/5/45). Loud rumblings reported from the Chateau (*NZ Herald* 11/5/45).

8 May

Loud rumblings reported from the Chateau (*NZ Herald* 11/5/45).

9 May

Renewed activity has reached an intensity equal to the most violent outburst of March. Steam and fine ash are pouring out in a continuous column and loud rumblings can be heard at the Chateau (*Dominion* 10/5/45).

12 May

Huge column visible from the Hawke's Bay (*Dominion* 14/5/45).

13 May

Enormous volume of steam reported pouring from the crater. Neither the lake nor the island were visible. A heavy ash was falling and large rocks were being thrown up but none beyond the crater's edge (*Dominion* 14/5/45). Steam pillar visible from Napier and Hastings (*Evening Post* 14/5/45).

14 May

At approximately 8 pm a "huge flamewas seen to shoot over 300 ft skyward. followed a few minutes later by a second flame reaching not quite so high but which developed into a tall dark cloud. After obscuring the mountain for 15 min the cloud drifted northwards". No further reported eruptions. A dull rumbling was heard immediately before the display and steam clouds had been issuing from the crater all day (*Dominion* 15/5/45).

JUNE 1945**2 June**

When the crater was visited on King's Birthday weekend (2-4 June) the only sign of the present island was a circular reef in the same position as the island's outer edge (*Dominion* 26/6/45).

17 June

Activity first noticed in the evening by residents of Ohakune who remarked that it looked like a picture of the Vesuvius eruption (*Ohakune Times* 22/6/45).

19 June

Although no particular high shots were observed a steady volume of what appeared to be a mix of dust and steam coming from the crater. Reports of a light dusting of ash in Taupo (*NZ Herald* 20/6/45). Dense clouds of dirty "smoke" belching out furiously were reported by Ohakune residents (*Ohakune Times* 22/6/45). "More activity than for some time... steady volume of steam and dust rising... northern slopes covered by dust" (Ruapehu Ski Club (R.S.C.) Bulletin, September 1945).

20 June

Large rocks observed being thrown out of the crater with slopes of the mountain blackened by volcanic ash (*Wanganui Herald* 21/6/45). A tremendous pall of smoke over the summit and stretching away to the horizon on the Ohakune side (*Ohakune Times* 22/6/45). "T.H Bierre (member) while on the Dome saw boulders "the size of the Hut" thrown up to fall back into the vent. Stones 3 feet across were seen on the upper part of the Glacier. A coating of ash made skiing impossible on the Chateau side of the mountain." (R.S.C. Bulletin, September 1945).

21 June

Thick misty cloud which had hung around mountain for some days was still evident (*Wanganui Herald* 21/6/45).

23 June

Raining, "Ruapehu boomed all night" (Mangatepopo Hut Book 24/6/45).

24 June

Mr A. Manson reports that *"only a quarter of the former lake remained and there was a huge island of volcanic rock about five feet high. The outside of the island appeared to be solid, but the centre was shaking like a jelly and periodically steam pressure beneath would lift a great lid of viscid lava aside and dense black smoke and steam would issue with a roar. When this occurred every few minutes flames leaped 30 ft out of the vent. The vent remained in no fixed position and steam was discharged wherever the covering lava was weakest at the time. At each burst a mass of molten, light-red rock rolled away from the orifice and spread over the island. A continuous shower of rocks ejected by the steam column hurtled over 500 ft into the air and fell back on the island. In this way the island was slowly growing. What water remained in the lake was discoloured black and steaming violently. A huge cloud rose from the crater for over 5000 feet and streamed away southward. The level of the lake had been lowered several feet exposing a narrow rock shelf round the edge. When the crater was visited on King's Birthday weekend the only sign of the present island was a circular reef in the same position as the island's outer edge. Since then the whole area enclosed by the reef had been built up. The island was on the southern side of the lake."* A good deal of rumbling audible at the Chateau (*Dominion* 26/6/45). A continuous plume of dirty brown "smoke" and steam billowed from the crater for the first time since activity began. In the past, a light cloud of steam has hung from the summit all the time but only occasional bursts of ash and "smoke" poured forth. No rumblings heard at the Chateau. Dust fell on Ohakune. Two detonations with shocks were heard in Ohakune at about 11 am. Excellent views were gained from Durie Hill and Marybank from where the smoke appeared in the form of a giant umbrella (*Wanganui Herald* 25/6/45). Rumbling sounds reported by residents of Rangataua (*Ohakune Times* 26/6/45). *"After being hidden by cloud for some days, Ruapehu again visible to Taupo residents who observed steam and ash rising to 5 000 ft above the summit."* (R.S.C. Bulletin, September 1945).

25 June

Bad weather obscured mountain but no rumbles heard (*Dominion* 26/6/45).

27 June

"Dust particles large enough to irritate the eyes fell continuously throughout day. Over three pounds of dust swept up from concrete in front of the Chateau". Account from Godfrey De Lautour (R.S.C. Bulletin, September 1945).

29 June

"Liberal coatings" of ash covering Ohakune and Waiouru (*Wanganui Herald* 29/6/45). Account from Godfrey De Lautour: *"S.G. Eade.... and I ascended to the Dome. Most of the ejecta has so far gone in the direction of Pyramid Peak, Ruapehu Peak and Pare-te-tai-tonga A splendid view was obtained from the low ridge between Pyramid Peak and the Dome. From there it was possible to see the narrow strip of water at the foot of the ice cliffs on the northern side of the crater. This strip may have been up to 50 yards in width. The remainder of the former lake appeared to have been supplanted by the "island". The "island" was composed of a scoria-like mass, reddish-brown to black in colour. The main vent was situated towards the S.E. side of the crater. Intermittently from this throat rose, with considerable velocity, great columns of brown vapour mingled with rock fragments. Loud hissing and rumbling sounds were heard and occasional reports caused, possibly, by those hot fragments which fell into what remains of the Lake waters. Most of the rocks, after rising several hundred feet,*

fell back into the crater, but some hurtled over to fall in the snow at the base of Pare-te-tai-tonga where they sent up clouds of steam from the holes they left. One boulder which fell back into the Crater was estimated to be at least 8 feet across. The average was probably 2-3 feet in diameter " (R.S.C. Bulletin, September 1945).

30 June

A coating of fine dust was noticeable on plants, lawns and buildings in Wanganui, appearing from Mount Ruapehu. (??? date for Wanganui ash, possibly later). Residents of Ohakune had to close their windows because of the dust (*Taranaki Herald* 3/7/45).

JULY 1945

1 July

"The tholoid .. was noticeably flat on top..... The margin was a steep face about 15 ft in height above the lake; the centre of the tholoid was not much more, except for a small protuberance immediately surrounding the vent..... Excluding the central vent, the margins of the tholoid appeared to be most active..... The surface of the tholoid consisted of loose angular scoriaceous boulders Over most of the surface these appeared cold and dead, but the margins of the tholoid was definitely "alive". The loose scoriaceous boulders, averaging 2 ft in diameter were warm; on the steep face....the boulders were moving and heaving as though due to pressure behind..... a red glow between some of the loose boulders on the surface at the margins of the tholoid also testified to its "live condition". A similar glow was visible at night over the whole surface of the tholoid but it was not clear whether this was emitted from between the boulders on the surface or from boulders themselves that had been ejected from the central vent. There were violent explosions from the central vent in the afternoon and rocks and steam were ejected at great force, and at the same time the surface of the tholoid surrounding the vent glowed like an immense brazier." (Gregg 1960). "A party from the ski club went up to observe activity. Very little of the crater was visible owing to large amount of steam present. A strong smell of sulphuretted hydrogen was only too evident." (R.S.C. Bulletin, September 1945).

2 July

Explosion between 8.30 and 9 am showered two trampers with red hot volcanic rocks and ash. The two had been camping in the crater 500 m from the vent and received minor burns and suffered shock. One was knocked unconscious when hit by a flying rock. (*Evening Post* 3/7/45). Apart from a small pool of water on the north side, the whole area formerly occupied by the lake was now piled high with shingle, huge rocks and mud. Nearly 25 distinct vents were visible in the unstable rock mass and each was discharging a great volume of steam and rocks. A coarse volcanic gravel had been showered over the Ohakune slopes and the snow as far down as the bushline was concealed under several inches of this grey coloured material (*Wanganui Herald* 5/7/45). Mr Manson reports *"the explosions ... had completely emptied the lake out of the crater. It was now filled with steaming lava. The whole southern slopes of the mountain were covered with a heavy layer of black ash. The explosion which injured the trampers had hurled rocks estimated to weigh seven and eight tons half a mile down the Whakapapa Glacier. Even a mile down the glacier there were half ton rocks"* (*Dominion* 3/7/45). Godfrey De Lautour reported *"..... Joe Niderost and I left the Chateau at 6 am..... Between the Dome and Pare-te-tai-tonga the snow was studded with holes, each containing a fragment of rock. Some were little wider than the rock and were up to 5 ft deep, and were probably caused by comparatively cool rocks falling from a great height. Others were as much as 15 ft across 2 or 3 feet deep with the boulder lying in a smaller*

cavity inside this pan. Possibly these large pans were formed by the explosive force of steam generated by very hot fragments falling into the snow. The sides of the pans were loose like a bomb crater. Rock fragments ranged in size from a few inches to 5 or 6 feet across and were still hot. A sample from one consisted of andesite, rendered thoroughly glassy by chilling and so fresh in appearance that it seems almost certain that it represents liquid lava forced into the vent and ejected. No dark deposit was on the snow in this area but between the Crater and Ruapehu Peak the whole surface was black with debris. It was in this area that the two unfortunate Wellington men were encamped. At about 10 pm a red glow over the mountain was observed from the Chateau." (R.S.C. Bulletin, September 1945).

3 July

Good views of "smoking" Ruapehu visible from Napier and Hastings (*Daily Telegraph* 5/7/45).

4 July

Good views of "smoking" Ruapehu visible from Napier and Hastings (*Daily Telegraph* 5/7/45). Great volumes of steam and smoke erupted from Ruapehu reported from the Chateau. The eruption was continuous and at times the steam and smoke reached a height of 4000 ft, which formed a low cloud that drifted west. There was no lessening of the eruption when viewed at sunset (*Evening Post* 6/7/45).

11 July

"Wind carrying ash in a heavy drift to the north." (R.S.C. Bulletin, September 1945).

19 July

Activity observed from Taupo with a large volume of steam and smoke pouring out at times reaching 3500 ft and strong winds carrying the smoke in a long low cloud towards the west. Also active over the past few days (*NZ Herald* 20/7/45).

20 July

Big "puff" sketched at 6.45 am by Mrs W.E. Hall from Durie Hill, Wanganui. "The dense black smoke rose from the centre of the mountain and spread out fanwise in inverted cone-shape with edges clearly defined. The smoke was densest upward from the centre and to the south. The sky was absolutely cloudless at the time and of a pale, misty, greeny-blue colour (sunrise about one hour later). The dense smoke was easily 20 000 ft thick and with the dissipated smoke the total was about 35 000 ft. The mountain has shown only normal smoking since." (Letter from Mrs W.E.Hall, dated 25/7/45. GNS Collection).

22 July

"Mr. J.A. Blyth spent the week-end on the mountain and reported that the Crater Lake no longer exists. A small shallow pool about ten square yards is all that remains of the lake's 17 acres. Its place is taken by lava 40 ft high. If it rose another 40 ft it would break out over lower lip of the crater at SE side." (R.S.C. Bulletin, September 1945).

23 July

On and off all day rumblings could be heard from the mountain. At between 9.30 and 10 am it could be distinctly heard on the higher parts of Raetihi and again between 9 and 10 pm (*Waimarino Call* 24/7/45).

24 July

A strong smell of sulphur was noticed at 3 am and was still present at 7 am. Ash falls on Ohakune overnight and in the morning, and a column observed to 12 000 ft and very black. (*Waimarino Call* 24/7/45). "*Mr Joe Niderost made a trip to Salt Hut leaving the Chateau at 9 pm. Heavy dust-laden smoke made the journey very trying and slow. His eyes were affected by the gritty smoke and he was almost forced to turn back due to the suffocating fumes. He left the Salt Hut on the return journey at 2 am but did not reach the Chateau until 4 am.*" (R.S.C. Bulletin, September 1945).

26 July

Reports of suffocating black cloud by guide at Salt Hut on evening of 26 July (*Manawatu Daily Times* 31/7/45). Ash noted in Hawkes Bay in the afternoon (*Auckland Star* 28/7/45).

27 July

Huge pall of black ash and steam spread from the mountain in a northeasterly direction. It was the thickest yet seen from the Chateau. At 5 pm smoke gushed forth in even larger volumes and rose about 5000 ft. Mt Ngauruhoe was obscured at times. Ash noted in Hawkes Bay. (*Auckland Star* 28/7/45). Ash falls on the Chateau (*Manawatu Daily Times* 31/7/45).

31 July

Ash falls in Ohakune and around the Chateau (*Wanganui Chronicle* 31/7/45). "*A "Herald" reporter and a photographer report seeing two additional major vents close to the main vent in the crater. One vent was emitting heavy black smoke under great pressure while the other was pouring out a cloud of fumes ranging in colour from a light coppery coloured hue to a deep purplish red. Three additional smaller vents were sending up powerful jets of yellow sulphur fumes while clouds of steam hissed from a multitude of cracks and blowholes, all over the central mound. The air in the crater vibrated with a thunderous roar likened to an express train approaching through a tunnel. From time to time rocks and pebbles were hurled from the main vent to fall back on the surrounding ejecta.*" (R.S.C. Bulletin, September 1945). "*The main vent in the crater is between 50 and 100 yards wide. It is a black void with precipitous sides and is continuously sending forth shots of black and white smoke, at times under tremendous pressure. A smaller vent closer to the Chateau side of the crater is sending out a more even discharge of red or pinky-shaded smoke, while the third gives off a steady stream of sooty black smoke. Activity in the two smaller and newer vents is steady but it is apparent that explosions which have been heard over a wide area have occurred in the large vent. At about 11 am there was an exceptionally heavy explosion but only a small quantity of rock was thrown out.*" (*Wanganui Herald* 1/8/45).

AUGUST 1945**2 August**

Heavy ash falls on Taihape (*Dominion* 8/8/45). "Mr Angus Manson reports main vent in the crater now 50 to 100 yards wide; a black void with precipitous walls. Shots of black and white smoke were being ejected continuously under tremendous pressure. The new vents seen on July 31 were observed to be just as active as when first noticed. Climbing was difficult as the wet ash on the snow clung to the boots like concrete. Ohakune residents witnessed eruptions today with black smoke rising 10 000 feet accompanied by very heavy rumblings. This eruption was also witnessed from Karioi, Marton and Wanganui." (R.S.C. Bulletin, September 1945). "Mingled with natural fog and misty rain, a cloud of sooty smoke hung over the Chateau but observers in the south including Wanganui had a good view at times. An explosion in the crater about 5 pm was witnessed at first hand by Ohakune residents. "It appeared as if the top of the mountain was coming off" one Ohakune businessman said. "I heard a sudden rumbling and then looked up and saw a column of black smoke climbing to about 10 000 feet directly over the crater." (unknown newspaper article, 3/8/45).

3 August

"At approx 9.50 pm there was a shake about 8 seconds and preceded by distinct rumblings" reported by Mr G. Sainsbury of Wairoa. (Letter from G. Sainsbury to Government Seismologist 6/8/45). "Steady discharge from the crater. Jet black clouds were tumbling from the crater and then being whipped away to the north by a moderately high wind." (unknown newspaper article, 3/8/45).

4 August

Ash falls on Taihape. Ash falls described "as if it was raining.....". Several cases of mild eye irritation were reported. (*Dominion* 8/8/45). Ash starts falling on Waiouru (*Taranaki Herald* 7/8/45).

5 August

"Increasing activity... has caused the authorities at Ohakune and Waiouru to make arrangements for the evacuation of the areas if necessary. The steps taken are precautionary and officials emphasised last night there was no cause for alarm. At Waiouru about 40 lorries are standing ready for instant use should the situation become serious. Culminating in a shattering explosion soon after 7 (am) the mountain made its most spectacular display yet. Ash has been falling heavily on Waiouru and Taihape and has also fallen on Ohakune... All through the night Ruapehu was seen to spout long tongues of flame and to throw white hot boulders high into the air. After the explosion, which was heard and felt as far away as Mangaweka, a column of dense black smoke went up to 10 000 or 12 000 feet. The air round the mountain was thick with sulphur fumes. Smoke continued to pour from the crater throughout the day. One report states that the smoke is coming from the crater in a series of mushroom-shaped balls as though a series of sudden, sharp and distinct explosions was occurring." (*Dominion* 6/8/45). Ohakune suffers ashfall with reports of ash soiling clothes on washing lines (*Dominion* 8/8/45). Layer of ash on buildings, roofs, window sills and in places up to 3 inches thick. (unknown newspaper article).

6 August

A resident of Hihitahi reports that *"We are having a terrible time with the old mountain. We are just about smothered in sulphur dust. The sun-porch is inches deep every morning and the paddocks are grey."* (NZ Herald, 8/8/45). Two rumblings reported from Wairoa at 6.26 and 7.28 am (Letter from G.Sainsbury to Government Seismologist 6/8/45). In Taihape the streets were covered in ash and people have been wearing overcoats to prevent their clothes from becoming discoloured. (Taranaki Herald 7/8/45)

7 August

Waiouru received several heavy falls of ash in the past few days. Ash affects market gardens in the district (Dominion 8/8/45). The ash falls are described as "nuisance value" category. Concern about the effect on vehicles at Waiouru is expressed (NZ Herald 8/8/45). *"Ruapehu was visible from 5.30 pm until dark from Taupo. During this period the largest volume of heavy black smoke yet seen was being emitted from the mountain, reaching to a great height but because of the long, low black cloud formed by the smoke and stretching for miles away to the east, it was not possible to estimate the height of the eruption. So far no rumblings have been heard in Taupo and with the wind most of the time coming from the north there has been no sign of falling ash as reported elsewhere. The weather in the National Park area cleared sufficiently yesterday for Mount Ruapehu to be visible from the Chateau for the first time for about a week. An observer reported that a stream of dark grey smoke was rising from the crater to a height of about 3000 to 4000 ft before being carried off by a north-westerly wind. According to reports from Ohakune the volume of smoke although considerable was not as great as it had been a few days earlier."* (NZ Herald 8/8/45).

8 August

Waipukurau district residents report a light dust-like coating (Daily Telegraph 8/8/45). *"Members of A.T.C. and Messers H.F. Fyfe and A. Beck reach the top of the mountain by 9.30 am when there was an exceptionally heavy explosion and a shower of rocks and boulders were ejected in the midst of a heavy cloud of dust and smoke. Rocks thrown onto the Whakapapa glacier melted their way down out of sight. One hole measured 6 ft diameter."* (R.S.C. Bulletin, September 1945). *"... arrived at a point roughly 1/2 a mile from the crater at 9.20 am when Ruapehu treated us to a display. The volcano has been sending up considerable clouds of ash-laden steam since our arrival here but when we were within a stone's throw + 100 yards there was a violent outburst of ash and steam then detonation like the report of a fair sized blast and stones were shot about 200 yards above the crater lip. One of these that embedded itself so deep in the ice we couldn't see it, made a crater 7 ft diameter and landed about 100 yards away. So I know the distance was "a stone's throw" + 100 yards. It was quite a minor affair really and after we composed ourselves we proceeded to take photos but we didn't further investigate the crater. Fog rather spoilt our view shortly after. Any journalese that may be written about this as a major outburst can be discredited. Later when we know the habits of the beast we may have more courage to make a closer inspection but we're taking no risks."* (Letter from Beck and Fyfe to the Director, NZ Geol. Surv. 8/8/45). From Taupo the mountain was covered in cloud (NZ Herald 9/8/45).

9 August

Ash deposited over Hawkes Bay. Reports from back country that ash made eyes sore (Daily Telegraph 9/8/45). *"Dr. C.O. Hutton and Mr A. Pritchard flew over the mountain today, but conditions were cloudy and unfavourable for observations."* (R.S.C. Bulletin, 30 September 1945).

10 August

"Occasional minor jolts are felt at the Chateau, one at 8.35 rattled Chateau windows" (Letter from Fyfe and Beck to the Director, NZ Geol. Surv. 13/8/45).

11 August

"Ash laden steam constantly emitted interspersed with minor explosive episodes ... Normal eruptions + Fyfe + " (Telegram to NZ Geol. Surv. 11/8/45). *"I watched Ruapehu... from Waihohonu Track junction with Waiouru-Taupo Road, between 12.30 pm and 2.30 pm. "Shots" succeeded each other at frequent intervals, rising from two to three thousand feet initially and the volume of "smoke" was very considerable. A picturesque touch was a column of orange coloured "smoke" that rose just above the summit and blew downward in front of the background of dark grey "smoke" for several minutes. Ash was falling all of the time on the upper slopes. There were two good "shots" from Ruapehu at 10.30 am and 11.40 these were visible from the Chateau and were followed by one at 12.45 pm which we did not see. The first "shot" sent up a vertical column of steam and ash with cauliflower convolutions that rose to an \angle of elevation of 18° as observed from the Chateau after it had drifted about a mile to the N.E. from the crater by the gentle S.W. breeze. The second "shot" sent up 2 similar columns the angle of elevation from the Chateau of the first after 1 mile to N.E. being 30° from the Chateau and the top of the 2nd shot vertically above crater ($19.5^\circ \pm 1$). I did not hear any detonations with these shots. In the afternoon ... the top of the mountain was not visible but 2 members of a skiing party ... ascended the mountain and had a good view of the crater. Five vents were active, some emitting steam, others "glowing gas" and showing the red hot rock close to the vents."* (Letter from Fyfe and Beck to the Director NZ Geol. Surv. 13/8/45).

12 August

Volcanic ash makes street lights hazy and whitens roads in Napier and Hastings. Strong smell of sulphur reported (Dominion 13/8/45). *"Taupo residents awakened at 3 am by heavy rumbling noise following by an earthquake shock. Described as a vertical jolt, it lasted 7 seconds. At the time no undue activity was reported at Ruapehu."* (R.S.C. Bulletin, 30 September 1945). *"Saturday's minor outburst followed by quiet emission of steam and ash to date."* (Telegram to NZ Geol. Survey. 15/8/45). Weather bad. (Letter from Fyfe and Beck to the Director NZ Geol. Surv. 13/8/45).

13 August

"Mr H. Fyfe reports minor explosions and ash-laden steam issuing, but nothing above the now considered normal eruption strength." (R.S.C. Bulletin, 30 September 1945). *"Ruapehu was obscured by cloud from the Chateau the whole day. No detonations were heard or reported."* (Letter from Fyfe and Beck to Director Geol. Surv. 17/8/45).

14 August

"Mountain obscured by cloud The snow on south-east slopes was covered by grey ash which the wind was lifting in "willy-willies" giving the impression of miniature steam vents high up the Wangaehu, but the headwaters of the stream and the mountain top were also obscured on this side by cloud ... The mountain top was visible from Waiouru to Erua and was erupting normally." (Letter from Fyfe and Beck to Director, NZ

Geol. Surv. 17/8/45).

15 August

Ash falls on Hawkes Bay (*Dominion* 22/8/45). "Low cloud, rain, sleet and snow." (Letter from Fyfe and Beck to Director, N.Z. Geol. Surv. 17/8/45).

16 August

"After a period of minor activity from 13th to 15th, Ruapehu became more active at approximately 7 am on Thursday morning in a detonation at 11.15 am that lasted about 4 seconds and caused the windows of the Chateau to rattle with the blast. No quake was noticeable accompanying this detonation. Steam-ash clouds rose from Ruapehu to heights given in my last. After the outburst, activity gradually decreased till 17th." (Letter from Fyfe and Beck to Director, NZ Geol. Surv. 17/8/45). "Considerable increase in ash steam clouds from Ruapehu following explosive outburst at eleven fifteen am Thursday 16th some previous of present cycle has emitted as dense clouds + Fyfe +" (Telegram to NZ Geol. Surv. 17/8/45).

17 August

Ash falls at Chateau overnight (*NZ Herald* 18/8/45). Light coating of ash in Taupo due to southerly wind (Letter from R. Ward Taupo to NZ Geol. Surv. 20/8/45). "We ascended Ruapehu this morning ... with Mr Manson ... After a minor outburst at approximately 10 am which sent a cloud of steam and ash to an angle of elevation of 30° as observed from Salt Hut, the activity tailed off to the emission of steam only at 12.44 pm. We were within 100 yards again of gaining a good view of the crater when at 12.45 pm there was a good shot that sent up a steam-ash cloud and rocks to a considerable height. (Detonation heard at Salt Hut from 12.45 outburst and windows rattled at the Chateau. A second report heard at Salt Hut at 1.20 pm but not noticed by us close to Ruapehu crater). Lightning discharges crackled continuously through this cloud ... Took some photos. Then decided to view the crater from Paretaitonga. A party of ski-club trampers joined us (about a dozen in all), all viewed the crater from the summit of Pare. Two vents, one about the centre of the tholoid the other at the southern side were clearly visible, both discharging considerable volumes of ash + steam but the main vent towards the eastern rim of the crater was emitting so much steam and ash with intermittent minor explosive outbursts shooting stones to about 800 to 1000 ft above the crater, that we couldn't see the vent. Lightning discharges cracked in the steam and ash cloud. One vent emitted a sulphury-yellow cloud "smoke" along with ash-laden steam and another a pink coloured "sublimate" and steam and ash. Whatever these sublimates are, the pink one is not oxidised rock particles and it gives the pink tinge (to the ash clouds) visible at considerable distance i.e. 5 miles or more. The outer wall of the tholoid is still intact along the southern and western rim and at the south side encloses between it and the old crater wall a small remnant of the crater lake. Towards the edge of the tholoid small wisps of steam arise from miniature vents. The surface of the tholoid is now shot to pieces and consists entirely of rock fragments. No glow of lava or any indication of its presence was noted ... Ash fell around the Chateau during Friday 17th but the wind is back to the S.W. and the ash is going over to the eastern side of the mountains. The amount of ash along the Desert Road, Waiouru, Ohakune is insignificant. It certainly is a nuisance to the housewife and others, but apart from that it doesn't amount to much. A smell of sulphuretted hydrogen accompanies the falling ash. Down pipes from spouting at the Chateau are blocked by ash. It is possible of course that this ash may do damage to internal combustion engines not fitted with efficient airfilters; it makes a bit of a mess of tank water. But, as the prevailing winds around this area are from a westerly direction the major part of the ash probably falls over the eastern side of the mountains."

(Letter from Fyfe and Beck to Director, NZ Geol. Surv. 17/8/45).

19 August

Light coating of ash in Taupo, less than on the 17/8/45 (Letter from R. Ward, Taupo to NZ Geol. Surv. 20/8/45).

20 August

Very heavy explosion and concussion felt at the Chateau at 5 pm and 7 pm (*Rotorua Morning Post* 22/8/45). Loud rumbles heard from 5 pm and throughout the night in Hawkes Bay. Brilliant display observed from Taupo but only one or two explosions heard through the night (*Manawatu Daily Times* 23/8/45). An unusual noise was heard in Dannevirke shortly after 5 pm, like a violent explosion. It was heard over a wide area including Mangahei (*Dannevirke Evening News* 21/8/45). "Throughout today Ruapehu was emitting ash-laden "smoke" continuously. This morning the cloud, owing to a southerly wind, appeared from here as a fan shaped mass with the wide end upwards, which obscured the mountain. Later the cloud was carried across the southwest sky and the summit became visible. During the afternoon the emission was considerable and continuous, though no explosive "shots" were seen while the mountain was under observation, and the cloud moved away to the west at a low angle. About 5.10 pm without any prior lessening or alteration in this continuous "smoking" a massive "shot" went up and rapidly reached a height of ten thousand feet at which height an intervening cloud prevented estimation of the total height reached from the initial force of the explosion. The "shot" went up vertically in little more than a minute. This column was greater than any I have noted before, being as wide as the whole top half of the mountain. From this time I watched the mountain until dark. The 5.10 pm explosion was followed by a succession of smaller "shots" reaching initial heights of from 3-5000 ft. At 6.25 pm another outstanding explosion occurred. Its initial outburst took this column, vertically, to 12 000 feet, when it mushroomed out. This column was only a third the width of the 5.10 pm column, though it rose obviously with great force." (Letter from R. Ward, Taupo to NZ Geol. Surv. 20/8/45).

21 August

Ash in Ohakune in evening up to 1/8 inch (*Dominion* 23/8/45, *Wanganui Herald* 23/8/45). Trace of ash reported in Rotorua (*Rotorua Morning Post* 22/8/45). "From 10.30 pm to 11 pm ... Ohakune residents witnessed vivid flashes or sheets of flame every few seconds - believed to be static electricity." (R.S.C. Bulletin, September 1945). "Every four minutes for half an hour before 11 pm last night Ohakune residents were treated to an awe-inspiring sight with vivid flashes of blazing light round the summit, sometimes low over the mountain and other times higher up. These flashes illuminated a 10 000 ft column of black smoke over the crater. One particularly vivid flash on the southern or Ohakune side of the smoke pall appeared to be fully 1000 yards long." (*Wanganui Herald* 22/8/45). "Subterranean rumblings and explosions caused alarm in Hawke's Bay early this morning and led to the belief that considerable volcanic activity is going on in the centre of the North Island. There was no perceptible movement of the ground, but windows and doors rattled periodically and there was a booming sound similar to that preceding earthquakes. In some districts the disturbance was more pronounced and people could not sleep for the constant noise from deep in the earth. Near the ranges farmers' families looked with apprehension at Ruapehu's distant flashes, and made ready to move if necessary. Volcanic ash fell in some districts early this morning." Loud rumble woke people at 3 am. Noises were heard as wide apart as Waipukurau, Hastings, Napier and Haumoana (*Manawatu Daily Times* 23/8/45). Residents of Mangahei report from 1.30 to 4.30 am. "... a roaring like thunder which came in spasms like an electrical disturbance. It seemed as if houses would shake to pieces - windows and doors rattled, electric light fittings swung and the earth

vibrated .. ". About 4.30 am a very severe clap hit one house (*Dannevirke Evening News* 21/8/45). "Between 2 am and 4 am a fierce red glow was detected varying in intensity till actual flames were seen to be rising to a height of approximately 1000 feet every few minutes. Several times a column of what appeared to be red hot sparks rose in the centre of the flames. From the distance there can be no doubt that these could only have been fairly substantial rocks. So bright was this glow that it could be seen from the interior of a brightly-lit room. The fact that the wind was driving the smoke over in the direction of Ohakune may account for the inaccuracy of the earlier statements." (*Dominion* 29/8/45).

22 August

Fall of grey dust observed in Wanganui. Cars travelling in town causing a rush of dust. (Beck 1951, *Dominion* 23/8/45). People wearing spectacles outdoors found that in time lenses were obscured (*Wanganui Herald* 23/8/45). Light falls of ash over much of the Hawke's Bay but less than a week ago (*Dominion* 22/8/45). Ohakune covered by 1/8 inch of ash (*Manawatu Daily Times* 23/8/45). Eruptions at 3 pm and 4.10 pm (R.S.C. Bulletin, September 1945). Reports of vegetable crops suffering in the Ohakune and Raetihi districts and concern over the effects of grit on wool quality after shearing starts (*NZ Herald* 22/8/45). "(Before dawn): A dense cloud of smoke on top with vivid lightning displays and the ejection of red rocks were observed above Salt Hut." (R.S.C. Bulletin, September 1945). "Ruapehu emitting copious steam ash clouds no cause for alarm discount any fantastic storys trace of steam from Ngauruhoe + Fyfe + Beck +" (Telegram to NZ Geol. Surv. 22/8/45). "A tremendous pall of smoke hung over the northern and western skies this morning, giving Wanganui residents the best indication so far of the dimensions of Ruapehu's activity. The city has frequently been coated with a light-coloured volcanic dust, which has loaded the smoky discharge from the mountain crater for many weeks, but today was the first occasion on which there had been such a complete dim-out of the sky-line and all hill features to the north." (*Wanganui Herald* 22/8/45). "At 2.30 pm today an explosion in the crater of Mt Ruapehu shook buildings at Ohakune and Raetihi, and huge plumes of smoke rose to such a height in the air that estimates of their altitude were baffled. Evidently there were other explosions during the night for this morning there was a deposit of ash in Ohakune of a depth of about 2 inches. The ash, borne on a south-easterly wind reached the outskirts of Ohakune. In Ohakune this morning visibility was so bad one driver reported that he was unable to see another car which was only 30 yards ahead of him. The sulphur fumes accompanying the ash were very irritating in Ohakune this morning, and were very noticeable in Raetihi also. The smoke and ash is being blown towards Wanganui and the upper King Country. At Raetihi this afternoon it was impossible to see the hills towards the mountain about five or ten miles away." (*Taihape Times* 22/8/45).

23 August

Ash deposits ("of a heavy black nature") between 2.5 and 5 cm reported on the Desert Road (Letter to the Under-Secretary, Dept. Internal Affairs from Sgd. A. Kean, Conservator of Fish and Game, 29/8/45). Fine grey ash falls on upper part of the Hutt Valley (*Dominion* 24/8/45). Light ash cover in Lower Hutt. There was a pronounced haze over the city. At Paraparaumu the haze almost obscured Kapiti Island (*NZ Herald* 27/8/45). "Our party crossed the central snowfield, now a sandy desert with an average depth of 6 ft of dry sand. With a northerly breeze we approached the crater round the eastern side of the Dome and then after careful observation, went in two instalments to the crater-lip. Its structure appeared as follows: From under the main peak of Pare, a series of ridges and furrows mark where the ash has piled up against the retreating ice wall. Underneath the Whakapapa is a sausage-shaped bog area with a low core wall. Steam jets, fumaroles etc stud these outer areas. A vast pit with distinct vents fills the centre of the crater. From one vent columns of pinkish-white smoke welled up steadily and quietly, thousands of feet. Near it, yellowish sulphur-laden fumes were

rising. Slightly nearer Pyramid Peak, a powerful vent spasmodically gave the huge shots that have been recorded up to 20 000 ft. This was black, almost solid as it shot up with high velocity like a gigantic Norfolk pine. In a matter of seconds, rocks were hurled high above the main peak, probably over 1000 feet up. One such big shot sending rocks towering overhead upset all calculations about relatively safe areas, causing the second group to flee for their lives. Actually we kept out of the range of falling rock, but the margin was too narrow." (R.S.C. Bulletin, September 1945). "No evidence of impending activity at Ngauruhoe stop steam there and at Red Crater coming from old vents always more or less active stop Ruapehu less active than yesterday + Fyfe +" (Telegram to NZ Geol. Surv. 23/8/45).

24 August

"No change to report in Ruapehu stop still freely emitting considerable steam and ash clouds unaccompanied by detonations + Fyfe + " 9.15 am ; "Ngauruhoe commenced steaming 11 this morning Ruapehu maintaining yesterdays increased activities + Fyfe +" 2.30 pm (Telegrams to NZ Geol. Surv. 24/8/45).

25 August

Ash falling at intervals since 22 August creating a number of problems for residents of Ohakune, the majority of whom depend largely on tank water. Fire brigade busy filling tanks with river water (*Auckland Star* 25/8/45). Condition of stock around Ohakune reported as falling off due to ash on pastures; animals "*found the gritty grass unpalatable...*" (*Wanganui Herald* 25/8/45). Reports of ash in Rotorua over the past few days covering paths and verandahs. The grey ash penetrated closed doors and windows and when tested in solution had a weak acidic reaction (*NZ Herald* 25/8/45). "*Borne on the northeast wind from the mountain, ash fell in Palmerston North at the weekend (25-26 Aug). One verandah in the city received a liberal covering.*" (*Manawatu Evening Standard* 27/8/45). "*In the afternoon a clear line demarcation could be seen from Masterton enveloping the mountains in what appeared to be a haze of ash "* (*Wairarapa Times-Age* 27/8/45).

26 August

"Ash from Ruapehu could be seen coating the snow of the Tararuas yesterday. No change in activity over the weekend with ash still falling in Ohakune" (*Wairarapa Times-Age* 27/8/45).

27 August

Ash falls on Ohakune. The ski season at Whakapapa described as "*ruined*" (*Dominion* 27/8/45). Automobile Association urges motorists not to use dry rags to remove ash as it can damage paintwork (*Evening Post* 27/8/45). "*Ruapehu obscured by cloud since Sunday stop no increase in activity stop low rumbling with minor detonations heard at Ohakune and more distant localities are normal and usually heard to leeward of mountain ... + Fyfe +"* (Telegram to NZ Geol. Surv. 27/8/45)

28 August

Wet all day. (Letter from Beck to Director, NZ Geol. Surv. 2/9/45). Rain falling at Ohakune. No sign of activity (*Wanganui Herald* 28/8/45).

29 August

Report on Ohakune: *"The streets, the roofs of the houses, the gardens, the very people themselves are grey with the fine ash that lies over the place and falls continually....."* (NZ Truth 29/8/45). Reports of sulphur particles dropping in Porirua area (*Dominion* 29/8/45). Snowing all day (Letter from Fyfe and Beck to Director, NZ Geol. Surv. 2/9/45). *"Mountain obscured by cloud slight decrease in activity + Beck +"* (Telegram to NZ Geol Surv. 29/8/45).

30 August

"The mountain was clear and the activity was moderate although it was difficult to make a comparative estimate as the gases were blowing towards us down the mountain. A fair sprinkling of ash was deposited on the snow during the day." (Letter from Fyfe and Beck to Director, NZ Geol. Surv. 2/9/45). *"Very cold wind. Obtained good view of large eruption from Ruapehu..."* (Mangatepopo Hut Book 30/8/45).

31 August

"The party including Win and Margaret Wimssett went from Te Heu Heu to the Dome. The crater was and had been much quieter. Without warning, the ground beneath us shook, a sound of rending rock was followed by a series of detonations and everything from the bowels of the earth seemed to be coming up. Flying rock filled the crater area. We could gaze with equanimity at the 12 000 ft smoke shots, but this seemed as if the lid had come off at last. No high column of ash was sent up, but the rocks were flung everywhere, including the Dome. We departed (Party: Dudley Adams, Cliff Leys, Barry Winter, Murray Laird, Noel Jarman and later Win and Margaret Wimssett)." (R.S.C. Bulletin, September 1945). "The steam and ash were very thick on the glacier and affected my eyes so much I was forced to retire. I was going up with a tramping club party. The smell of H₂S and a faint suspicion of SO₂ was very strong." (Letter from Beck to Director Geol. Surv. 2/9/45). *"Activity moderate within frequent explosive episodes namely steam escaping, little ash + Beck+ "* (Telegram to NZ Geol. Surv. 31/8/45).

SEPTEMBER 1945**1 September**

"The wind was still blowing steam and ash down the glacier so I went with the truck to National Park to have the fuel line looked at. Towards midday the activity died away to almost nothing except for occasional bursts and a slight continuous discharge of steam. It was then too late to attempt to climb but some members of the ski club climbed from the Ski Club Hut and reached the top about 3.15. When they reached the top there was a large explosion heard at Salt Hut but not heard at the Chateau. This burst came from a small vent on the north side of the tholoid about which a small cone had been built. There was a small continuous stream of steam from the main east vent. Mr Jenkins left." (Letter from Beck to Director, NZ Geol. Surv. 2/9/45). Sightseers on the dome caught a sudden explosion. They were peppered with stones but no injuries were reported (Letter from Beck to Director, NZ Geol. Surv. 7/9/45) *"Activity greatly decreased intermittent bursts steam with slight continuous steam +Beck+" (Telegram to NZ Geol Surv. 1/9/45).*

2 September

Snowing all day (Letter from Beck to Director, NZ Geol. Surv. 2/9/45).

3 September

"The weather was fine and activity had increased again but the guide said the snow was too soft for climbing and there was no use in trying until it had frozen. The vent must be free as there is very little ash in the steam". (Letter from Beck to Director Geol. Surv. 2/9/45).

4 September

"I have paid a visit to the crater ... and found that there was little change since I last saw it. It was my impression that the dome had risen slightly but this is very hard to judge. The west vent under the saddle between Ruapehu and Paretaitonga is slightly larger and surrounded by a low cone of boulders. The east vent has built a cone and has piled debris up against a pyramidal peak on the large crater edge making it a high steep side of the vent. Small steam vents all over the rest of the dome were emitting small clouds which impaired visibility except for fleeting glimpses. I took only one photograph and could not take advantage of the brief spells of clearness due to a bitterly cold southerly wind which froze my fingers and drove us down. There was a small area on the south wall of the crater where steam is issuing and the walls are free from ice in most places. The activity consisted of a continuous column of steam from both vents with occasional blasts of ash laden gas which lifted boulders about 500 ft above the crater, from the east vent." (Letter from Beck to Director, NZ Geol. Surv. 7/9/45).

5 September

"Little change inside crater activity moderate + Beck +" (Telegram to NZ Geol Surv. 5/9/45). "Shortly after 10 o'clock it was noted that a tremendous cloud of smoke and steam was rising on the western horizon. A magnificent view was obtained of the eruption by a number of people from vantage points on the roofs of two-storeyed buildings. There was a clear blue sky the mushroom-shaped cloud was distinctly outlined, the column being black and the top of the cloud white. There was a southerly wind blowing and the cloud moved slowly northwards. " (Hawke's Bay Herald-Tribune 5/9/45).

6 September

The mountain was clouded (Letter from Beck to Director, NZ Geol. Surv. 7/9/45).

7 September

"At 5.45 am several people here reported a big explosion which was accompanied by a red glow in the cloud which they attributed to flames. No one seems clear as to what they really did see, one saying that the whole cloud was red and another that as it rose it became red and glowing. A possible explanation I think would be the effect of the rising sun on the cloud which the sun at that time would have been high enough to catch the top of the ash column and as I have seen before the reflection would be red." (Letter from Beck to Director, NZ Geol. Surv. 7/9/45). "Slight increase in activity report on crater following + Beck +" (Telegram to NZ Geol. Surv. 7/9/45).

9 September

"I went up the mountain and found a profound change in the shape and position of the vents. There is now only one vent which has moved across from the east side to approximately the centre of the dome. It is about 2/5 diameter of the dome itself and has raised the rim about 10-15 ft high round it. It is very steep walled inside and the Swiss guide here Joe Niderost went down onto the dome and across to the vent early in the morning when activity was slight and was able to see that it was 150-200' deep. He could not see any glow at the bottom as it was veiled with steam. The only other activity is a small issuing of steam from what seem to be concentric fissures some distance from the vent and also a rather more vigorous jet from a radial crack running from the vent wall west to a bastion on the edge of the crater wall. The whole time I was there only variously coloured steam was being blown off and from their direction it seemed as though they were issuing from fissures in the wall of the vent. Consequently I expected a big explosion as steam only had been issuing for about 3 or 4 hours. I could approach the crater quite closely and should have some good photos. However I got going as quickly as possible advising the rest of the party not to linger and my prophecy was justified as at 4.10 about 1/2 an hour after we left there was a heavy explosion heard at Salt Hut 4 1/2 miles away, against the wind and a heavy cloud of gas and ash was shot up 3000 or 4000 ft above the top of the mountain. The cloud retained its form for 15-20 minutes indicating strong electrical forces." (Letter from Beck to Director, NZ Geol Surv. 10/9/45). Aircraft overflying mountain observes eruption and reports noticeable static on the radio "The crater appeared to be quite dead then at about 4 pm there were two tremendous explosions. Jet black geysers that seemed to be composed of solid matter rose to about 1000 ft above the crater and then an awe-inspiring mushroom of smoke rose to a height of about 20 000 ft. The aircraft was flying at 12 000 ft and only the top of the mountain was above the dense blanket of cloud ... Within about three minutes the column of smoke had reached its maximum height and as it began to drift towards the east, light debris fell like rain from the smoke. There were great spurts of white steam from around the lip of the crater after the eruption and then the mountain was quiet again." (NZ Herald 10/9/45).

10 September

"Moderate activity from single large vent two hundred feet deep + Beck +" (Telegram to NZ Geol Surv. 10/9/45)

12 September

"Moderate activity with infrequent heavy explosions + Beck +" (Telegram to NZ Geol Sur. 12/9/45).

13 September

"Large quantities steam emitted occasional ash-laden explosion + Beck +" (Telegram to NZ Geol. Surv. 13/9/45)

16 September

"Raining for the last week but people at the ski club hut report various explosions during the week. I went to the top and found a great increase in activity over the 9 September. The main vent was giving out ash continuously and stones were being thrown up to 100 ft or so in the air. The small steam vents round the margin were all working overtime. The dome seemed to have subsided about 10 ft or so and left a raised rim round the outside." (Letter from Beck to Director, NZ Geol. Surv. 10/9/45)

17 September

"Activity strong to moderate dome slightly collapsed + Beck +" (Telegram to NZ Geol. Surv. 17/9/45). "An explosion which brought more than one household to life in the Ohakune district. At 5.45 am the report was distinctly heard over a wide area and a substantial column of smoke rose high above the crater. It was this morning that many observers had their first glimpse of the mountain in days and they found that the slopes, particularly on the Chateau side, had received a heavy coating of ash. A dust cloud was reported to be blowing in the direction of Rangataua and all morning there was a continuous stream of smoke pouring from the crater." (Wanganui Herald 17/9/45).

20 September

Skiing reported as "out of the question" at Whakapapa (NZ Herald 20/9/45). "I watched the mountain for several hours and noticed a faint glow over the crater which increased and tinged the ash cloud red whenever an extra strong explosion occurred. This was especially noticeable before the moon rose." (Letter from Beck to Director, NZ Geol.Surv. 23/9/45).

21 September

"I went up to the top but found little change in the form of the crater. The only difference was that the slip plane on the north side had widened and a large quantity of steam was issuing from this. The activity was continuous and very strong and at times stones were being shot about 500 ft or more feet into the air. On the underside of each burst as it rose from the vent there was a dark reddish-brown colour which disappeared as the cloud rose above the level of the vent. A possible explanation is that this was the reflection from red-hot material below although it may have been some chemical compound that either became quickly oxidised or readily diffused but the rapidity of its disappearance seemed to rule out this. The cloud did not seem to be heavily charged with ash and there were no electrical effects except during the heaviest bursts. Although the cloud was blown over Ngauruhoe for several hours during the day there seemed very little ash on it." (Letter from Beck to Director, NZ Geol. Surv. 23/9/45). "Strong activity Ruapehu .. slight steam Ngauruhoe" (Telegram to Geol Surv. 21/9/45). "Little change in crater activity increasing in strength + Beck +" (Telegram to Geol Surv. 4 pm. 21/9/45)

22 September

Raining heavily (Letter from Beck to Director, NZ Geol. Surv. 23/9/45).

27 September

"Activity very strong sharp earthquake jolt 7.20 am + Beck +" (Telegram to NZ Geol. Surv. 27/9/45). "Into a clear blue sky, Ruapehu shot almost continuous bursts of jet black smoke this morning, at times as high as 9000 ft. Neither at the Chateau nor at Ohakune have any explosions been heard in the past few days but at 7.20 am today the Chateau reported a slight earth tremor. Heavy banks of cloud have obscured the peak for some days and when conditions cleared today it was seen that the mountain had again changed colour back to the usual white as a result of snowfalls. However, the slopes are not expected to stay white long in view of the present emissions. Ohakune residents this morning were taking precautions against any further ash deposit. The smoke pouring from the crater appeared to be heavily charged with dust and a light northeasterly breeze indicated that

any showers of ash would fall across the Ohakune district." (*Wanganui Herald* 27/9/45). The shock was recorded at the Dominion Observatory at 7.17 am and occurred 20 miles below the mountain (*Dominion* 29/9/45).

28 September

"An explosion shortly after 9 am today in the crater of Ruapehu was felt over miles of surrounding territory and in Ohakune, eight miles away, it made wallboards creak and windows rattle. A heavily charged cloud of smoke curled through the morning air to almost 12 000 ft after the explosion and then descended like an opened umbrella over the mountain cloaking it in a heavy haze. Towards noon a fine dust thought to have been ejected by the explosion began to fall on Ohakune. The Chateau on the other side of the volcano did not get such a hard shaking but about midnight and again about 5.30 am today distinct earth tremors were felt." (*Wanganui Herald* 28/9/45). "Last night about 11 pm a violent blast from the mountain rattled the windows of houses in Ohakune and Raetihi. Again this morning at 9 am two loud blasts like guns firing caused many people to rush to their doors to have a look at the mountain and a great sight was witnessed when a huge volume of smoke shot up into the air for many thousands of feet. Dust and ash has again fallen heavily on the mountain." (*Ohakune Times* 28/9/45). Heavy shower of rain turned it into a deposit resembling thin cement plastered on roofs, windows and exposed surfaces. This was only washed off with difficulty (*Wanganui Herald* 29/9/45, 2/10/45).

29 September

"Activity very strong occasional heavy explosions accompanied by blast effects + Beck +" (Telegram to NZ Geol. Surv. 29/9/45)

30 September

Heavy showers of ash at Chateau (*Wanganui Herald* 2/10/45). "The past week has been cloudy and raining ... I only got a single glimpse of the actual vent due to misty conditions and also the gas blowing over towards the north obscuring the crater. However I did see that the vent was bigger, about 1/2 the diameter of the crater ... There was a great explosion about every 3 hours on the average, that shot up a column to about 20 000' and in one case at 6 pm to about 30 000'. The steam issues with a rushing sound like breaking waves which can be heard as far away as National Park in a southerly wind and no doubt the sound of the explosions can be heard even further afield." (Letter from Beck to Director NZ Geol. Surv. 1/10/45)

OCTOBER 1945

1 October

Taupo receives a heavy dusting of ash. Reports of the gritty grey ash affecting people's throats and eyes (*NZ Herald* 2/10/45). Ash falls at Chateau (unknown newspaper cutting 1/10/45). "Activity is most intense, a great column of ash-laden steam pouring out continuously ... The present phase of activity is the most violent yet." (Letter from Beck to Director, NZ Geol. Surv. 1/10/45). "The smoke which was drifting in a northerly direction was plainly seen from Palmerston North, the atmospheric conditions between the city and the mountain being very clear." (*Manawatu Evening Standard* 1/10/45)

3 October

Beck records that ash-laden steam pluming to 30 000 ft from a vent now half the size of the crater. Particularly heavy explosions occurred periodically every three hours. (R.S.C. Bulletin, March 1946).

5 October

"Mountain obscured since Monday (1st) several explosions heard Thursday (4th). + Beck +" (Telegram to NZ Geol. Surv. 5/10/45)

5-7 October

Ash formed a thin layer over open spaces in Whakatane. Vehicles left outside overnight were *"almost snow-white under a heavy coating of ash"* (Bay of Plenty Beacon 9/10/45).

6 October

Taupo receives heavy fall of ash causing most people to remain indoors. Complaints were generally about the irritating effects on the throat and eyes. Claims that the ash burned like sulphur when lighted. (NZ Herald 8/10/45). *"Very strong activity heavy cloud ash laden steam to NE Heavy explosions at intervals + Beck +"* (Telegram to NZ Geol. Surv. 6/10/45). *"A sharp earthquake shock was felt in the Opotiki District in the early hours of the morning. Explosions from Mount Ruapehu continue to be heard in Opotiki and on early Sunday (7th) morning there was a particularly loud explosion to be followed almost immediately by another one".* (Opotiki News 9/10/45). *"The Chateau Tongariro was shaking and windows were rattling this morning from the force of the most violent explosions which have yet emanated from Ruapehu, according to members of the Chateau staff. The series started at 1 am when there was an explosion of sufficient force to cause a number of people in the Chateau to go outside to see what had happened. There was a tremendous volume of black smoke rising At 7.30 am there was another heavy explosion in the crater and the Chateau quivered under the impact. Smoke, still black, poured from the top of the mountain but did not rise very high because of the high wind which drove it towards the north-east. Heavy explosions followed at short intervals and were described as the most severe which those at the Chateau had so far experienced."* (Wanganui Herald 6/10/45).

7 - 8 October

"The intensified explosions first noticed on Sunday and Monday continued to be heard at the Chateau but apart from the electrical disturbances there have been no new developments." (Wanganui Herald 10/10/45).

9 October

Grey ash deposited as a light dusting on Rotorua during the past 24 hrs (NZ Herald 10/10/45). Ruapehu's most impressive display yet seen in the Hawkes Bay was witnessed today from Napier and Hastings. A tremendous cloud of greyish-white vapour was seen high in the sky. Hazy conditions believed to be due to the large amount of volcanic ash in the atmosphere. Quantities of dry grey ash fall on Taupo (Dominion 9/10/45). *"Strong activity maintained occasional very heavy explosions with strong electrical effects visible at night. + Beck +"* (Telegram to NZ Geol. Surv. 9/10/45). *"When Dr Ongley climbed Ruapehu he found small boulders, one or two feet in diameter, rocketing out of the crater on the Whakapapa Glacier. Stones and pebbles had fallen a mile down*

the side of the mountain and a deposit of dust near the crater rim was up to a foot thick. Heavier explosions had diminished slightly in number but not in intensity." (Auckland Star 10/10/45).

10 October

"Ash reported in Napier causing distress to people allergic to nasal troubles. It has also been noted, as is the case in Wanganui and Rangitikei districts, that following large outbursts of volcanic dust hazy atmospheric conditions result so as to cause a marked reduction in the temperature of the air. Reports from Taupo confirm the increased activity of the mountain in the last few days. Clouds of smoke and dust lay across the town it was stated and quantities of dry grey ash fell." (Daily Telegraph 10/10/45). Reports of ash in Wanganui and Rangitikei districts resulting in hazy atmospheric conditions causing a marked reduction in temperature of the air (Daily Telegraph 10/10/45). *"Very strong activity with frequent very heavy explosions + Beck +"* (Telegram to NZ Geol. Surv. 10/10/45).

11 October

"Activity was still strong and there was little change in the crater except for a small explosion crater having formed near the north wall of the main crater. It contains what remains of the steam fissure there." (Letter from Beck to Director, NZ Geol. Surv. 17/10/45).

12 October

"Activity strong but decreased explosion less frequent little change in crater ... + Beck +" (Telegram to NZ Geol. Surv. 12/10/45).

13 October

"Tokaanu earthquakes no direct connection with Ruapehu. Mountain obscured but no explosions or earthquakes felt here. + Beck +". (Telegram to NZ Geol. Surv. 13/10/45)

14 October

Ash falls on Hawkes Bay overnight, heaviest yet. Residents awake to find streets heavily coated and pastures whitened by the coarse, gritty deposit. Vehicles move on asphalt roads in a flurry of dust and busy streets in a perpetual haze, limiting visibility. Shopkeepers in Napier and Hastings kept busy sweeping the grey dust from footpaths. Ash causing problems in people's homes. Street cleaners remove volcanic ash by the barrow load (Dominion 16/10/45). *"The position at Hastings was almost alarming for the dust came like a storm and was so heavy that cyclists were unable to ride and complaints of grit in the eyes came from all quarters."* (Daily Telegraph 15/10/45). *"The most active part of the vent appeared to have been to the south-east, on the Pyramid side the lowest point of the crater was in that direction and fair quantities of ash and steam were being emitted vertically to a height of probably 3000 ft. How deep that portion of the crater was I couldn't say as vision was obscured by the dense clouds of ash. Rocks were being hurled out all the time for two hundred feet or so but occasionally to a height of about 700 ft. They fell back into the crater. On the north side, under the ice wall between Paretetaitonga and the Dome the original ledge round the margin of the former lake was still in existence, I should imagine. Nobody had seen it because for some time before it had not been regarded as safe to go near the edge or round past the Dome. However that has been such a stable feature since that I*

should think it was there then also, though probably at lower level than at present, because it would have received a fair amount of debris and ash. At present it has a shallow pool on it. Beyond that the slopes fell gradually down towards the active portion of the crater. Halfway down the slopes, that is on the north side of the active part of the vent, and visible from Pare, were a few fissures from which clouds of steam were coming. The fissures were more or less curved and were caused by collapse of the ground there, towards the crater, due to removal of the support of the lava column. The fissures could be compared to the fissures that open up round the back edge of a large landslide during the early stages. More steam clouds were coming from the south-west side of the active part of the vent probably due to a stream from the melting ice". (Report from J. Healy, R.S.C. Bulletin, March 1946). "The activity was still strong and rocks were being thrown up continuously. At one stage they reached a height of 700 - 800 feet above the floor. Most fell back into the vent but a few went out onto the surface of the plug. The wind was from such a direction that another explosion pit was visible. It was almost surely there on Thursday but concealed by gas ... There did not appear to have been any explosion later than the previous weekend (6-7th) strong enough to throw more than a few boulders out on the ice." (Letter from Beck to the Director, NZ Geol. Surv. 17/10/45). "Ruapehu has been intensely active from early Sunday evening and throughout the night. A continuous cloud of dust, much larger than the usual screen of dust, partially obscured the sun. As a result the atmosphere was quite chilled, as when an eclipse of the sun takes place." (Hawke's Bay Herald Tribune 15/10/45).

15 October

Skiing operation reported as being abandoned due to the ash. Ash covers Chateau golf course (GNS file T20/505 vol 1, 15/10/45). "Activity strong over weekend strong emission ash free steam accompanied by long hissing this morning + Beck +" (Telegram to NZ Geol. Surv. 15/10/45). "No ash clouds were visible from the Chateau, just steam alone". (R.S.C. Bulletin, March 1946). Roaring loudly during day and ash erupted during the night. (Letter from Healy to Director, NZ Geol. Surv. 16/10/45). "The activity had changed to a less voluminous steam emission accompanied by a loud hissing sound. The amount of steam was large and continuous." (Letter from Beck to Director, NZ Geol. Surv. 17/10/45).

16 October

"Active vent now occupies about a third the diameter of former crater lake stop steam and ash freely emitted accompanied by subdued roar and detonations stop boulder more widely scattered around crater than formerly within half mile radius stop + Ongley +" (Telegram to NZ Geol. Surv. 16/10/45). "Ash issuing again and had put a grey coat on fresh snow on the Chateau side." (R.S.C. Bulletin, March 1946). "Activity was the same as the 15th, a strong steam emission. In the morning several lateral emissions of steam were noted. The main emission was carried by a steady southerly wind while these were shot at a 45° angle to the west At 6 (pm) there was a clearing explosion which shot out a good mushroom of ashy steam but evidently most fell back into the vent as until 11 pm only steam was emitted. At 11.20 pm there was the heaviest explosion yet felt here and the vent cleared itself temporarily again. About 1/2 minute after the blast itself the gas immediately above the crater showed a red glow. This was not due to lightning as no flashes were seen and there was no static on the radio as there always has been during lightning displays. It must have been reflection from some red hot material in the vent exposed by the explosion. The luminescence was quite distinct even in the moonlight. Half an hour later the outburst dwindled to steam." (Letter from Beck to Geol.Surv. 17/10/45).

17 October

"Moderate emission of steam clearing explosions at intervals + Beck +" (Telegram to NZ Geol. Surv. 17/10/45).
 "Mr. Beck reported a change in the volcanic cycle, decreasing activity accompanied by heavy emissions of ash-full steam." (R.S.C. Bulletin, March 1946).

19 October

Ash reported on road between the Chateau and National Park was falling like silt and blocking wind-screen wipers. 1/8 inch of ash at Chateau by the end of the weekend (21 October) (*Wanganui Herald* 22/10/45).

20 October

"About 6 pm from the summit of Ruapehu we heard a violent explosion and then saw a marvellous display of cauliflower convolutions which rose to over 2500 ft five minutes later there was a shower of fine andesitic chips." (Mangatepopo Hut Book 20/10/45). "A terrific ash laden wind" at the Chateau. "The activity of the mountain has been fairly steady emitting strong ash laden clouds. At irregular intervals there is a heavy explosion some felt as far away as Taumarunui ... One at 4.15 pm being the heaviest." (Letter from Beck to NZ Geol. Surv. 28/10/45). "About 4.15 pm the mountain gave its most spectacular display when the roar of a huge explosion reverberated in the hills and concussion caused loose objects, doors and windows to rattle ... the mountain was partially obscured by cloud." (*Wanganui Herald* 22/20/45).

21 October

A terrific ash laden wind at the Chateau. The activity of the mountain has been fairly steady emitting strong ash laden clouds. At irregular intervals there is a heavy explosion some felt as far away as Taumarunui, one at 11.40 pm. (Letter from Beck to the Director, NZ Geol. Surv. 23/10/45). A loud explosion about 8 pm (*Wanganui Herald* 22/10/45).

23 October

"Strong activity with infrequent very heavy explosions vent on Ohakune side reported from Waiouru unconfirmed + Beck +" (Telegram to NZ Geol. Surv. 23/10/45). "The activity of the mountain has been fairly steady emitting strong ash laden clouds. At irregular intervals there is a heavy explosion some felt as far away as Taumarunui ... I have seen the red glow on the bottom of the cloud after (an explosion) at 1.40 am" (Letter from Beck to the Director, NZ Geol. Surv. 28/10/45). "At about 10.30 pm the ground was rocked by a terrific explosion, was one of the biggest yet.". The glowing display that followed was enhanced by a clear sky and was seen as far away as Taumarunui and Ohura (unknown newspaper articles, 25/10/45).

24 October

Taupo coated in heavy dusting over night. Eruption was heard and explosions caused windows to rattle (*NZ Herald* 25/10/45). "Strong ash cloud to NE heavy explosions at more frequent intervals with electric display + Beck +" (Telegram to NZ Geol. Surv. 24/10/45). "A haze of ash hung over the National Park in the morning and even the early morning sun was obscured" (unknown newspaper articles, 25/10/45).

29-30 October

Rain over the past two days brought to Napier and Hastings a plentiful supply of "*Ruapehu dust*" causing concern to motorists and housewives. Ash resulted in problems with clothes on lines (*Daily Telegraph* 31/10/45). Ash pollutes water supplies at the Chateau (*Wanganui Herald* 29/10/45).

NOVEMBER 1945**2 November**

"The weather was fine for the first time in two weeks so I went up to the top with Mr Fyfe (and others). There was a very noticeable change in the crater which was enlarged southwards under Ruapehu Peak by 5 or 6 chains due to melting of the icewall there. The icecave that had been there had disappeared. The vent itself had increased in size in this direction and now seems to be elliptical in shape and extends to about the position of the former ice wall on the south side. The floor of the crater has been built up about 50 ft to within 50 ft or so of the lowest part of the rim on the northeast. The slip plane of the landslide is now about 20 ft high and there is an abundant emission of steam from it. Several small basin depressions have formed adjacent to the fissures probably due to steam explosions. The activity is very strong, the volume of ash-laden steam being very large possibly greater than ever before but owing to the much increased size of the vent it is not issuing under any great pressure and rocks were not being thrown any more than 300-400 ft up in the air. There seem to be two separate orifices within the vent from which the gas is emitted independently, as when observed for a period, first the gas issues from one spot and then from another. Sometimes they blow off together. These blowholes seem to be located at the two foci of the elliptical vent the one at the northern end being the more violent in eruption. There is possibly a third blowhole on the eastern side but the cloud was too dense to see clearly When the northern vent was quiet and emitting steam only, various coloured gas clouds could be seen rising from the centre. They were pink, reddish brown, pale yellow and a dirty green which I had never seen before." (Letter from Beck to the Director, NZ Geol. Surv. 5/11/45).

2-3 November

Dense cloud of ash descends over Napier-Hastings area, restricting visibility to less than 1 mile and covering countryside with a thin coating (*NZ Herald* 16/11/45). "*An almost choking pall of smoke spread over the district ... Cape Kidnappers could not be seen*" from Napier. People out of doors walked with handkerchiefs to their nostrils to prevent breathing the dust-impregnated air. In Hastings the ash covering was not as bad as previous occasions but ash on cars and in houses caused problems. (*Daily Telegraph* 5/11/45). Ash falls over Lake Taupo making fishing poor. Report from traveller on the Desert Road that "*they had to reduce their speed to below 15 miles per hour because of the poor visibility brought about by what was described as a blanket of Ruapehu dust and smoke*". (*NZ Herald* 5/11/45).

3 November

"Activity strong no explosion since Friday (2nd) reported earthquake 7 am not recorded seismometer due power failure + Beck +" (Telegram to NZ Geol. Surv. 3/11/45). Red glowing balls, obviously rocks, thrown well clear of the crater of Ruapehu during an outburst about 8 pm ... were seen by Ohakune residents. (*Wanganui Herald* 5/11/45). "*A Hastings angler who returned last night from a visit to Taupo stated that conditions in Taupo for fishing were poor last week and on Saturday and yesterday (4th) there was a strong wind blowing directly over*

the lake from Ruapehu. The dust and smoke were unusually thick." (NZ Herald 5/11/45).

4 November

"The crater was largely obscured by cloud and back-eddies of ash in the strong wind. During the night there had been two heavy explosions which had made fresh holes in the glacier up to 6 ft deep. Some of the rocks were still warm 12-16 hrs after the explosions which produced them. The explosions were very rare from Oct 25th to Nov 1st but became more frequent and heavier after this averaging about 2 per day." (Letter from Beck to NZ Geol. Surv. 5/11/45).

5 November

"Activity very strong crater much enlarged and floor risen vent increased in size + Beck +" (Telegram to NZ Geol. Surv. 5/11/45).

6 November

"Mr Fyfe noted that the crater was now enlarged to approximately the area once covered by the lake." (R.S.C. Bulletin, March 46). Beck records ... *"I saw the most spectacular eruption I have yet seen. The vent consisted of one blow hole only which was shooting up rocks over 1000 ft above the floor of the vent. The day was almost calm and we had a very good view of the form of the crater. The inside of the vent seems roughly stratified into bands of large rocks and small rocks and ash. The rocks thrown up from the vent seemed to be very spinous having a jagged appearance as it flew through the air. These rocks when thrown clear of the main ash column trailed a thick gas cloud behind them which was a bluish white (like cigarette smoke). The steam cloud from the north fissure was less and some details of the fissure could be seen. It is about 1 chain across and 5 chains long and the same stratification can be seen in it as in the main vent. From it was issuing from time to time a steam cloud with a pale green tinge At night the volume of steam increased very much and the black spurts that contain the large rocks could be clearly seen from the Chateau. At 9 pm this seemed to die down and at 9.45 pm there was a terrific burst of red hot rocks and ash ... The whole cloud as it rose from the crater was red hot and he could see red hot boulders rising and falling in the centre."* (Letter from Beck to NZ Geol. Surv. 7/11/45).

7 November

"Activity increased heavy eruption red hot rock 9.45 Tuesday night (6th) + Beck +" (Telegram to NZ Geol. Surv. 7/11/45)

10 November

Ash on Hastings and district. No serious adverse effects on gardens have been reported but a certain amount of *"sliming"* in cabbages has been noted (*Daily Telegraph* 10/11/45).

11 November

"The Wangaehu River which rises on the slopes of Mt Ruapehu was discoloured till it resembles slate said a Palmerston North resident who had occasion to pass the river ... In the shade the water seemed almost black

and it appeared that the river must have gathered great quantities of grey ash erupted from the mountain in order to carry so much as far as the Wangaehu village near Wanganui." (*Manawatu Evening Standard* 13/11/45).

12 - 13 November

Ash falls on Napier, visibility on roads restricted with ash, like a thick fog. "*Ruapehu throat*" a common complaint with hundreds of cases reported by doctors and chemists (*Dominion* 14/11/45, *NZ Herald* 16/11/45). Sunglasses were in demand to prevent eye irritation. Watches, clocks and fine machinery were reported as suffering irreparable damage. Army moves 700 vehicles out of Waiouru Military Camp (*Dominion* 14/11/45). The movement of vehicles was due to "*the acid content of the ash ... When exposed to moisture it has a corrosive effect on the canvas tops of vehicles which are stored in the open*" (*Evening Post* 13/11/45). Explosions seen from Taupo and heard from Tokaanu and Taumarunui (*NZ Herald* 15/11/45).

13 November

"At night Ruapehu flared forth in her last major spectacular activity hurling red hot rocks 1000 ft into the clouds. Following this activity inspection of the active area disclosed that the floor had risen over 100 ft in the last month with accompanying enlargements in the south and south-east areas." (R.S.C. Bulletin, March 1946).

15 November

"*Mountain very active loud rumblings frequent occasionally followed by explosions + Beck +*" (Telegram to NZ Geol. Surv. 15/11/45).

16 November

"*Rumours violent activity unfounded activity strong but normal eruption red hot rock (8.39 pm) Thursday (15th) no instrumental disturbances + Beck +*" (Telegram to NZ Geol. Surv. 16/11/45). Ash found to have no toxic effects on rats (*Dominion* 16/11/45).

17 November

Ash falls around Chateau, 1/8 inch in 14 hrs (Beck 1950).

18 November

"*Mt Ruapehu presented an awe-inspiring sight (from Palmerston North) ... as a huge volume of dense smoke surged to great altitude. A Palmerston North resident who was motoring into the city at about 10 pm said that there was a distinct glow at the top of the mountain.*" (*Manawatu Evening Standard* 19/11/45).

20 November

Fine deposit of ash observed by residents of Opotiki District over past week. Cyclists troubled by grit in eyes. Motor-cars covered by blue-grey ash. Several country areas in Gisborne reported a steady fall of ash. Ash penetrates houses, coating interiors (*Opotiki Herald* 20/11/45). Ash again reported falling in Hastings, blocking

any view of the Havelock North hills and coating clothing and footpaths (*Daily Telegraph* 21/11/45).

21 November

Ohakune market gardens report disastrous effects on growing vegetables, causing rotting of cabbage in particular. The rot pierces right to the heart of the cabbage (*Taumarunui Press* 21/11/45).

23 November

Following heavy rain last night the Wanganui River is a mercury grey colour and the condition of the river has brought about a serious problem for the water supply of Taumarunui. The filter plant has stopped pumping. Visitors to Tokaanu over the weekend found the whole countryside between Taumarunui and Lake Taupo covered with a heavy layer of ash. The air was thick with ash and gave the impression of light mist. (*Taumarunui Press* 23/11/45).

24 November

Taumarunui water supply disrupted by ash load in the Wanganui River, filtration becomes impossible with pumping being ceased. The plight was relieved when the hydro-plant on the same site was shut-down and pumping of 7000 gallons/hour (instead of the normal 20 000 gallons) was possible but even then it was impossible to filter efficiently. (*Wanganui Herald* 26/11/45). The river was "*slightly clearer this morning*". (*Taumarunui Press* 24/11/45).

DECEMBER 1945

1 December

Ash falls in Napier (*Daily Telegraph* 1/12/45)

3 December

Ash falls in Hastings (*Daily Telegraph* 3/12/45). Healy reports "*steam only was being emitted. The fissures had spread and the slopes between them and the active part of the crater had slumped quite a bit. Large quantities of steam were coming from these fissures. I had with me Mr Wilson ... and we went round beneath the Dome and looked in from the edge of the ice-wall. The pool on the original ledge, beneath the ice-wall, between Pare and the Dome was now visible from here. Wisps of steam were also escaping from a crack in the ice a chain back from the top of the ice-wall towards Pare.*" (R.S.C. Bulletin, March 1946).

6 December

Napier coated with grey ash overnight, motorists complained that driving was like driving in a fog. Ash entered houses causing soiling of interiors (*Hawke's Bay Herald-Tribune* 6/12/45). Life at Chateau is reported as unpleasant, "*in fine weather it smothers us with dust and in wet weather the rain washes all the dust down and blocks up the intake for the water with the result we are without water of any kind or electricity. no fun here with 180 mental patients and no light or sewerage.....*" (extract from letter from one of the nursing staff, GNS file T20/505 vol 1). "*More steam than ash emitted reduced activity over period of one week no important*

change in crater conditions explosions much less frequent than two weeks ago no seismic or magnetic anomalies cables for mountain microphone laid + Modriniak +" (Telegram to NZ Geol. Surv. 6/12/45).

10 December

"No change over weekend small ash flare stop increased activity intermittent explosive discharge of ash and steam since this morning stop greater area seismically active + Modriniak +" (Telegram to NZ Geol. Surv. 10/12/45).

13 December

"Mountains overcast instrumental observations no change stop activity probably reduced + Modriniak +" (Telegram to NZ Geol. Surv. 13/12/45).

14 December

"Crater observations ceased at 4 pm yesterday simultaneous with decreased activity stop Ngauruhoe quite normal + Modriniak " (Telegram to NZ Geol. Surv. 14/12/45).

18 December

"Slight increase of activity over weekend with one strong explosive ash discharge at 1800 hours on Saturday activity unchanged yesterday crater oscillation quite frequent + Modriniak +" (Telegram to NZ Geol. Surv. 18/12/45). Healy reports *"ash issuing along with the steam. For the first time now it was seen that the area below the fissures on the north side had slumped still farther, forming a depression now filled with water that appeared to be hot. It was steaming round the edges and the water was dark brown in colour. In addition I caught a brief glance of a vigorously boiling spring within the main crater, at the northern edge."* (R.S.C. Bulletin, March 1946).

21-24 December

Water supply of the Chateau fouled resulting in the evacuation of 180 patients of the mental hospital. Ash has also interfered with the Chateau's power house (*Dominion 22/12/45*). *"Mountains obscured morning 21st geophone very active with thumps during the morning every minute quieter towards evening with steam and ash discharged this was repeated on 22nd the crater oscillations were negligible on the 23rd and 24th but ash clouds were continuously evolved there was one large thump on the 23rd at 1857. + Geophysical +*" (Telegram to NZ Geol. Surv. 24/12/45).

29 December

Healy reports *"things much the same (as the 18th) with just a small amount of ash issuing with the steam. The bottom of the inner crater appeared this time to be deeper than formerly"*. (R.S.C. Bulletin, March 1946).

31 December

"From visual observations on Dec. 25 to 27th the mountain was much quieter state has continued to the 30th

Dec and there has been negligible crater seismicity Healy ascended mountain on Saturday and says there is a boiling lake forming this will have to be confirmed + Geophysical + (Telegram to NZ Geol. Surv. 31/12/45).

JANUARY 1946

4 January

"Mountain geophones faulty Monday to Thursday visible observations when mountain cleared for brief intervals indicated slight activity mainly steam today overcast but slight crater oscillations + Geophysical + (Telegram to NZ. Geol. Surv. 4/1/46).

7 January

"Small but frequent crater oscillations since Friday midday increasing today in magnitude confirmed report of lake 150 yards wide forming on the ledge north of main vent photograph taken + Geophysical + (Telegram to NZ Geol. Surv. 7/1/46).

8 January

Speculation about possible losses of stock and reduced butterfat production in the central King Country as a result of the ash falls. Bullock killed near Turangi found to have 10 lb of ash in its stomach. Reports of ash affecting the flavour and quality of cream (*Waikato Times* 8/1/46).

11 January

"Increase in crater oscillation on Jan 7th, 8th large rumbles every two minutes from geophone at highest frequency nothing felt at Chateau activity decreased on 9th but this morning it returns to that of 7th. + Geophysical + (Telegram to NZ Geol. Surv. 11/1/46).

12 January

"I found the crater emitting steam, no ash having been seen by me for some time. The pool previously formed on the shelf between the outer and inner rim on the north side was a bright yellowish-green colour, and I estimated it to be approximately 100 yards by 140 yards, though a small delta was commencing to form at the eastern edge where hot springs from two sulphur-lined fissures were flowing in ... The main central crater appeared to be deep, but there was too much steam present for the walls to be seen to any great depth." (Monthly report to NZ Geol. Surv. from J Healy, January 1946).

16 January

"Power off since Saturday slight crater seismicity Friday visual observations from Saturday to Wednesday indicate sulphurous steam clouds issuing continuously on reduced scale observations at crater on Saturday and Monday by Healy confirmed this + Geophysical + (Telegram to NZ Geol. Surv. 16/1/46).

23 January

"On 17th to 21st only slight crater seismicity with steam cloud issuing continuously but weekly crater observation on 20th confirmed this slight increase noticed on 22nd+Geophysical+" (Telegram to NZ Geol. Surv. 23/1/46).

26 January

"I again climbed Ruapehu, in company with the Director and members of the geophysical party. On this occasion the visibility was very good and humidity apparently low, as the steam coming from the crater was not so thick as usual. We passed round to the east on to the Pyramid, whence the bottom of the crater could occasionally be seen. The inner crater consists of a steep walled vent about 1000 ft deep from the inner rim, and the bottom is occupied by a boiling lake with a diameter of approximately 115 yards. A good view was obtained from the southern rim and photos attached illustrate the appearance of the crater. The pool on the northern shelf has now decreased in size due to the encroachment of the delta from the east end. The water in the boiling lake is muddy in colour, and periodically large quantities of steam issue from the surface, though it is then too thick to enable the activity in the lake to be seen." (Monthly report to NZ Geol. Surv. from J. Healy, January 1946).

? January

"The Glacier presented an evil-smelling, dark grey mass of ash and thawed snow by day; by night a treacherous frozen surface akin to ice-bound scoria. The valleys of the Whakapapa and the Wangaehu filled 10 to 12 feet deep with packed ash, when wet odoriferously glutinous, when dry ubiquitous as the desert sands." (R.S.C. Bulletin. March 1946).

MARCH 1946**17 March**

"Most of this ash had been cleared off the mountain slopes, but lay packed in the valleys, forming an insulating surface for the snow, which lies low on the mountain down to the Hut in Whakapapa Valley and within 300 feet of the waterfall in Te Heu Heu." (R.S.C. Bulletin. March 1946).

REFERENCES

- Beck, A.C. 1950. Volcanic activity at Mount Ruapehu from August to December 1945. *Journal of Science and Technology* Vol. B31, No. 5, 1 - 13.
- Cotton, C.A. 1945. Ruapehu in 1945. *New Zealand Science Review*, Vol. 3, 3 - 4.
- Cotton, C.A. 1946. The 1945 eruption of Ruapehu. *Geographical Journal*, Vol. 107, 140 - 143.

Gregg, D.R. 1960. The geology of Tongariro Subdivision. *New Zealand Geological Survey Bulletin* 40.

Oliver, R.L. 1945. Further activity of Mount Ruapehu, New Zealand, May - July 1945. *Journal of Science and Technology* Vol. B27, 24 - 32.

Reed, J.J. 1945. Activity at Ruapehu - March to April 1945. *Journal of Science and Technology* Vol. B27, 17 - 23.

Newspapers

Auckland Star
 Bay of Plenty Beacon
 Daily Telegraph
 Dannevirke Evening News
 Dominion
 Evening Post
 Hawke's Bay Herald-Tribune
 Manawatu Daily Times
 Manawatu Evening Standard
 New Zealand Herald
 New Zealand Truth
 Ohakune Times
 Opotiki News
 Rotorua Morning Post
 Taihape Times
 Taranaki Herald
 Taumarunui Press
 Wairarapa Times-Age
 Waikato Times
 Waimarino Call
 Wanganui Chronicle
 Wanganui Herald

Other publications

Ruapehu Ski Club Bulletin
 Mangatepopo Hut Book
 Monthly report to the New Zealand Geological Survey by J. Healy, January 1946

Letters

25 July 1945;	Mrs W.E. Hall
6 August 1945;	G. Sansbury to Government Seismologist
8 August 1945;	H. Fyfe and A. Beck to Mr Ongley (The Director, New Zealand Geological Survey)
13 August 1945;	H. Fyfe and A. Beck to Mr Ongley (The Director, New Zealand Geological Survey)

- 17 August 1945; H. Fyfe and A. Beck to Mr Ongley (The Director, New Zealand Geological Survey)
- 20 August 1945; R. Ward to The Director, New Zealand Geological Survey
- 29 August 1945; A. Kean (Conservator of Fish & Game) to The Under-Secretary, Department of Internal Affairs.
- 2 September 1945; A. Beck to Mr Ongley (The Director, New Zealand Geological Survey)
- 7 September 1945; A. Beck to Mr Ongley (The Director, New Zealand Geological Survey)
- 10 September 1945; A. Beck to Mr Ongley (The Director, New Zealand Geological Survey)
- 17 September 1945; A. Beck to Mr Ongley (The Director, New Zealand Geological Survey)
- 23 September 1945; A. Beck to Mr Ongley (The Director, New Zealand Geological Survey)
- 1 October 1945; A. Beck to Mr Ongley (The Director, New Zealand Geological Survey)
- 16 October 1945; J. Healy to Mr Ongley (The Director, New Zealand Geological Survey)
- 17 October 1945; A. Beck to Mr Ongley (The Director, New Zealand Geological Survey)
- 23 October 1945; A. Beck to Mr Ongley (The Director, New Zealand Geological Survey)
- 28 October 1945; A. Beck to Mr Ongley (The Director, New Zealand Geological Survey)
- 5 November 1945; A. Beck to Mr Ongley (The Director, New Zealand Geological Survey)
- 7 November 1945; A. Beck to Mr Ongley (The Director, New Zealand Geological Survey)

Telegrams

- 11 August 1945 - Fyfe
- 15 August 1945 - Fyfe
- 17 August 1945 - Fyfe
- 22 August 1945 - Fyfe + Beck
- 23 August 1945 - Fyfe
- 24 August 1945 - Fyfe
- 27 August 1945 - Fyfe
- 29 August 1945 - Beck
- 1 September 1945 - Beck
- 5 September 1945 - Beck
- 7 September 1945 - Beck
- 10 September 1945 - Beck
- 12 September 1945 - Beck
- 13 September 1945 - Beck
- 17 September 1945 - Beck
- 21 September 1945 - Beck
- 27 September 1945 - Beck
- 29 September 1945 - Beck
- 6 October 1945 - Beck
- 9 October 1945 - Beck
- 10 October 1945 - Beck
- 12 October 1945 - Beck
- 13 October 1945 - Beck
- 15 October 1945 - Beck
- 17 October 1945 - Beck
- 23 October 1945 - Beck
- 24 October 1945 - Beck
- 3 November 1945 - Beck
- 5 November 1945 - Beck
- 7 November 1945 - Beck

15 November 1945 - Beck
16 November 1945 - Beck
6 December 1945 - Modriniak
10 December 1945 - Modriniak
13 December 1945 - Modriniak
14 December 1945 - Modriniak
18 December 1945 - Modriniak
24 December 1945 - Geophysical
31 December 1945 - Geophysical
4 January 1946 - Geophysical
7 January 1946 - Geophysical
11 January 1946 - Geophysical
16 January 1946 - Geophysical

APPENDIX 2

RUAPEHU AWAKENS: THE 1945 ERUPTION OF RUAPEHU

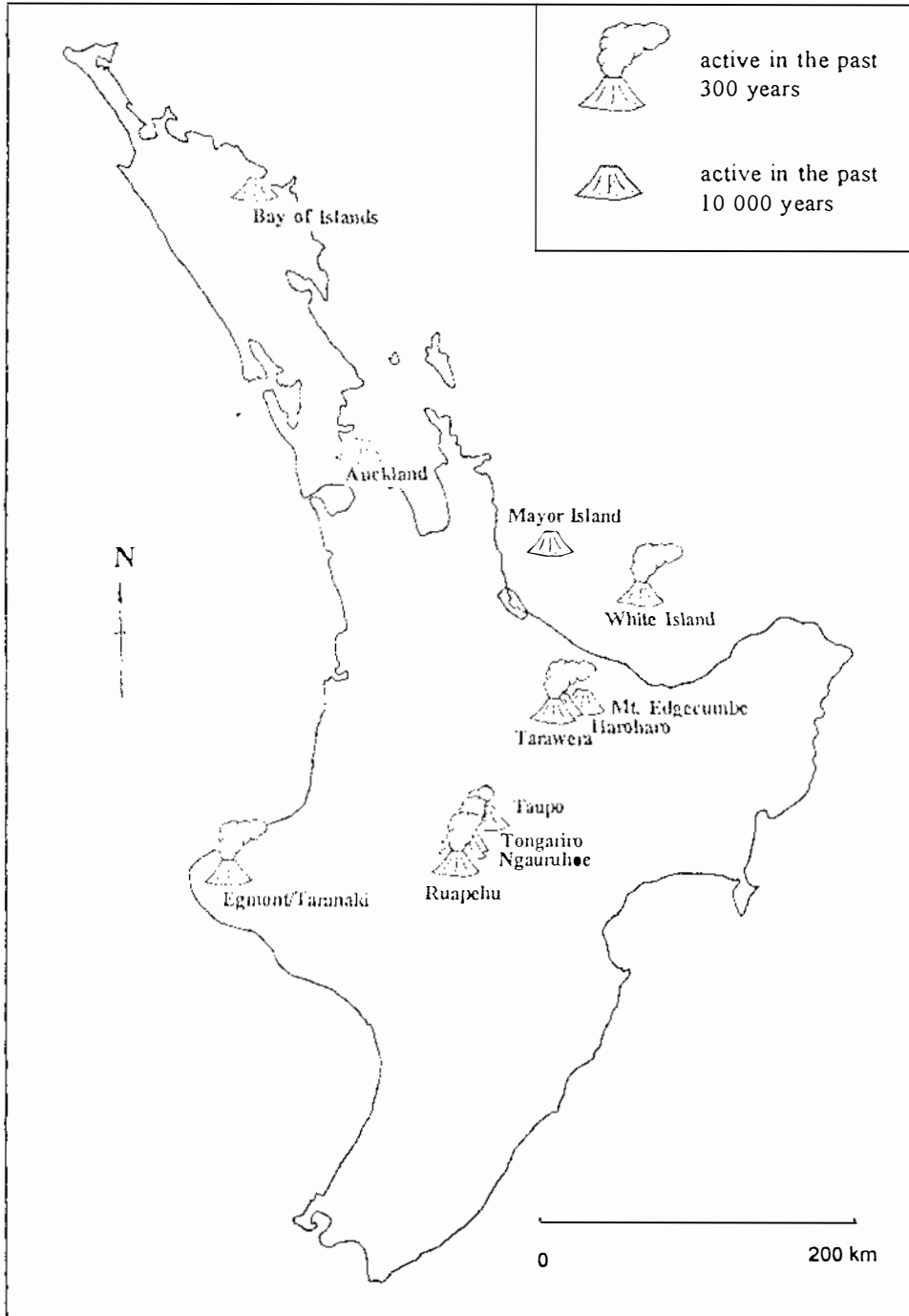
RUAPEHU AWAKENS



The 1945 Eruption of Ruapehu

**David Johnston and Vince Neall
Massey University**

Active Volcanoes of the North Island, New Zealand



RUAPEHU AWAKENS

The 1945 Eruption of Ruapehu

David Johnston and Vince Neall

Department of Soil Science
Massey University
Palmerston North

A collaborative production between

Massey University
Institute of Geological & Nuclear Sciences
The Science Centre Inc.



1995



The Science Centre and Manawatu Museum Scientific Monograph No.1.

Bibliographic Reference

Johnston, D.M. and Neall, V.E. 1995. Ruapehu Awakens : the 1945 eruption of Ruapehu. *The Science Centre and Manawatu Museum Scientific Monograph No. 1.*

CATALOGUING IN PUBLICATION

JOHNSTON, D.M. (David Moore), 1966-

Ruapehu Awakens : the 1945 eruption of Ruapehu / D.M. Johnston, V.E. Neall.
- Palmerston North, N.Z. : The Science Centre and Manawatu Museum, 1995.
(The Science Centre and Manawatu Museum Scientific Monograph, ISSN 1173-5244: no. 1)
ISBN 0-473-03223-6

I. Neall, Vincent Ernest. II. Title III. Series.

Published with the support of Massey University, Institute of Geological & Nuclear Sciences and The Science Centre Inc.

Published by The Science Centre and Manawatu Museum,
Private Bag 11055, Palmerston North,
New Zealand.

Front cover: Eruption of Ruapehu in November 1945, viewed from Ractihi.
(Photo: N. Mosen; Lansdown Collection).
Back cover: Crater Lake of Ruapehu in the 1990's.
(Photo: L. Homer; GNS Collection).

Printed at Massey University, Palmerston North, New Zealand.

RUAPEHU AWAKENS

The 1945 Eruption of Ruapehu.

The 1945 eruption of Mount Ruapehu was the largest eruption in the North Island this century. Activity began in March and culminated in a series of explosive eruptions from late July to December. During this period the crater lake was gradually displaced by a lava dome and disappeared in July. Following the eruptions in December the lake reappeared and subsequently filled the crater to overflowing by 1949.

These stirrings, however, are only the most recent happenings of a volcano that has had a long history of eruption and destruction. Exactly when volcanic activity began at Ruapehu is lost in the mists of geological time, but erosion products of an ancestral volcano probably at the current site are preserved in 250,000-year-old rock strata of the Wanganui district. By 180,000 years ago a volcano of sufficient height had formed to collapse southwards in a major landslide that extended down the Whangaehu and Hautapu Rivers. Following this event, the geological record is substantially better preserved, and indicates frequent flows of volcanic mud and debris, collectively referred to as lahars, which built an apron of broken rock fragments that formed a ring plain surrounding the volcanic cone.

While lava flows oozed from the crater to form the steep volcanic massif, sections collapsed intermittently forming landslides and lahars that spread outwards in all directions. An older eroded segment is represented by Pinnacle Ridge, while younger flows constructed the terrain about Iwikau Village.

Ruapehu was particularly active 80,000 to 10,000 years ago, when numerous eruptions of airfall debris, referred to as tephra, were carried by predominantly westerly winds to the east and into Hawke's Bay. This was during the period colloquially called the Last Glaciation, when the climate was colder than at present. The tephra were mainly pumice and fell on a largely deforested scrubland landscape where they were readily eroded by the wind and the rain. Not until the climate warmed, between 14,000 and 10,000 years ago, did forest expand and stabilise the landscape and soils and prevent further erosion.

Two subsequent large gravity collapses created landslides that formed the line of mounds below the Chateau about 10,000 years ago (mapped as the Murimotu Formation), and crossed the Rangipo Desert about 6,000 years later, destroying the beech forest of the time.

About 2,000 years ago lava flowed down the eastern flank of the cone. This appears to have infilled the former drainage, creating the dam that formed the crater lake. Subsequent smaller eruptions and collapses have discharged large volumes of water from the lake on numerous occasions creating lahars principally in the Whangaehu River, but also in the Mangaturututu and Whakapapa Rivers. Over the last 1,800 years there have been 15 lahars generated in the Whangaehu catchment that left behind sandy or gravelly deposits along the river channel.

Tephra deposits on the ring plain record at least 18 explosive eruptions through the crater lake in the past 1800 years, 11 of which occurred in the past 700 years. All of these tephra deposits precede historical records (before 1860 A.D.).

One of the earliest historical records of volcanic events at Ruapehu is recorded by Henry Serjeant who wrote a letter to the Wanganui Herald in 1895 describing a lahar in the Whangaehu River Valley, thirty-five years previously.

"In the mid-summer of 1860-61 I was one day visiting my brother who lived on the right bank of the Whangaehu. I was standing on the bank and looking up a long reach, the same about 30 chains when I suddenly saw coming around a corner in the distance a huge wave of water and tumbling logs. They filled the whole trough of the stream. I called out to my brother who was close by and together we witnessed the rapid approach. As it passed us it appeared to be covered with what we first thought to be pumice but the intense cold which soon made us shiver and turn blue caused us to discover that what we had first thought was pumice was no less than frozen snow. Mixed with this was a mass of logs and debris. Very soon a bridge passed us stuck in the roots of a giant tree and a few minutes later about a dozen canoes came down".

Before 1945, further significant lahars were produced in 1889, 1895, 1903 and 1925, together with numerous small steam eruptions inbetween.

THE 1945 ERUPTION

Activity was first noticed on 8 March, when the pilot of a Union Airways plane, en route to Wellington, reported a long plume of steam originating from the crater and blowing to the east. On the same day, staff at the Waiouru Military Camp also noticed steam issuing from the crater.



Photo: Aerial view of the crater lake of Ruapehu on 9 March 1945, showing for the first time that year steam issuing from the lake surface. (Photo: RNZAF Collection)

RUAPEHU STEAMS

BOILING CRATER LAKE

AIRCRAFT PAY VISITS

Mount Ruapehu has warmed up again and has been sending up clouds of steam. The disturbance has not ranked as an eruption, but has been one of the well-spaced hottings-up of the deep crater lake. The minor activity disproves again the general belief that Ruapehu is "extinct," dead, quiescent, and for all time harmless, as Egmont is believed to be.

The first report was made by Commander F. Allen, of Union Airways, that when flying from Auckland to Wellington on Thursday he had seen a long plume of smoke or steam blowing east from Ruapehu, and that the eastern slopes of the mountain appeared to be covered with what might be scoria and volcanic ash. Efforts were made by the geological branch of the Department of Scientific and Industrial Research in collaboration with the Public Works Department to ascertain the nature and extent of the disturbance, and on Friday afternoon an R.N.Z.A.F. plane from Ohakea, with a still camera, made a trip to Ruapehu. Only a minor disturbance in the crater was observed.

The Evening Post,
Monday,
12 March 1945

Further steam discharges were observed up until the 19 March when a lava dome was seen emerging from the crater lake. Activity increased with the growth of this dome, accompanied by large steam explosions observed from as far away as Palmerston North and Wanganui.

Spectacular eruptions were seen on the 26 March, with Taupo residents describing a large explosion in the afternoon that sent a column of steam 2500 m above the mountain. The following day the crater lake was reported to be steaming but the lava dome had disappeared. Activity remained relatively quiet throughout April, with sporadic expulsions of water, ash and mud from the lake.

ROCKS AND MUD EJECTED

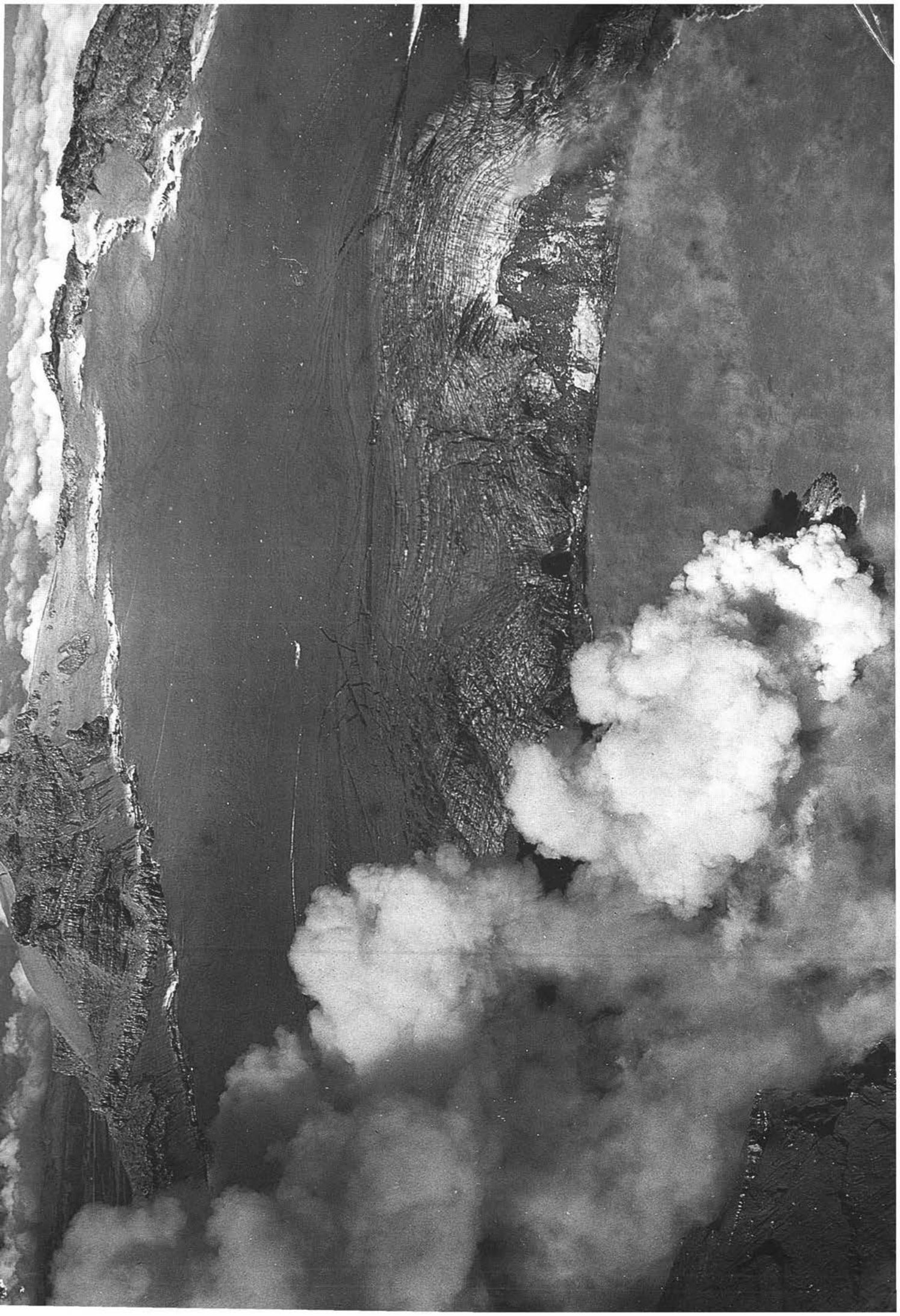
Increased Activity on Ruapehu APPEARANCE OF VENT IN CRATER

Rocks, mud and steam were being ejected from the crater lake of Mount Ruapehu yesterday morning in the greatest display yet of the present period of activity. Since steaming was first reported over 10 days ago crateral activity subsided, but on Sunday there was a fresh outburst and a great column of steam has risen into a cloud estimated at nine miles square, which alters position with the wind.

Rumblings accompanying the activity were heard at the Chateau Tongariro yesterday. Two R.N.Z.A.F. aircraft from Ohakea investigated the disturbance yesterday in the course of a cross-country flight. The crew of one which circled the mountain and flew over the crater observed the display through powerful field-glasses. In the centre of the lake they saw that a small island, about 50 feet across, had emerged several feet out of the water. A vent in the outcrop, estimated at three to four feet in width, was emitting a "gush of steam and sulphurous smoke with a good deal of solid material." The lake was considerably disturbed and water was playing over the island. The rocks ejected were fairly large and were thrown over 40 feet before falling back into the lake.

The Dominion,
Tuesday,
20 March 1945

Right Photo: Aerial view of the crater lake of Ruapehu taken on 20 March 1945, showing for the first time the lava dome growing within the lake. (Photo: RNZAF Collection)



A second larger dome was observed on 7 May, growing at the same location as the first. During the first two weeks of May, steam and ash were emitted in a continuous column, and loud rumblings were heard in communities around the mountain. The growth of the lava dome appeared to stop during the later half of May. Visitors to the crater lake on 2 June, described the once growing lava dome now as a circular reef in the middle of the lake. Activity increased on 17 June, with a large ash and steam cloud observed above the crater from Ohakune in the evening .

Away from the mountain the first ash falls were reported lightly coating Taupo on 19 June. The lava dome grew steadily through the rest of June, entirely displacing the crater lake.

**RUAPEHU ACTIVE
AGAIN
Hugh Lava Island In
Crater Lake
FLAMES 30 FEET HIGH**

With the growth of a small islet to a heaving, molten mass of lava occupying nearly three-quarters of the surface of the crater lake, Ruapehu has broken out into an even more violent eruption than earlier in the year. Since the spectacular outburst on May 14, when flames shot up 300 feet out of the crater, activity had been confined to periodical displays of steaming, but last week renewed rumblings and dense black smoke pouring away from the summit heralded a third period of activity.

Mr. A. Manson, a guide, who climbed to the crater on Sunday found that only a quarter of the former lake remained and that there was an island of volcanic rock about five feet high. The outside of the island appeared to be solid, but the centre was shaking like jelly and periodically steam pressure beneath would lift a great lid of viscid lava aside and dense black smoke and steam would issue with a roar. When this occurred every few minutes flames leaped 30 feet out of the vent.

The vent remained in no fixed position, and steam was discharged wherever the covering lava was weakest at the time. At each burst a mass of molten, light-red rock rolled away from the orifice and spread over the island.

The Dominion,
Tuesday,
26 June 1945

Right Photo: The second lava dome steaming in the crater of Ruapehu on 27 June 1945. Note the remnant of the crater lake to the left of the lava dome. (Photo: RNZAF Collection)

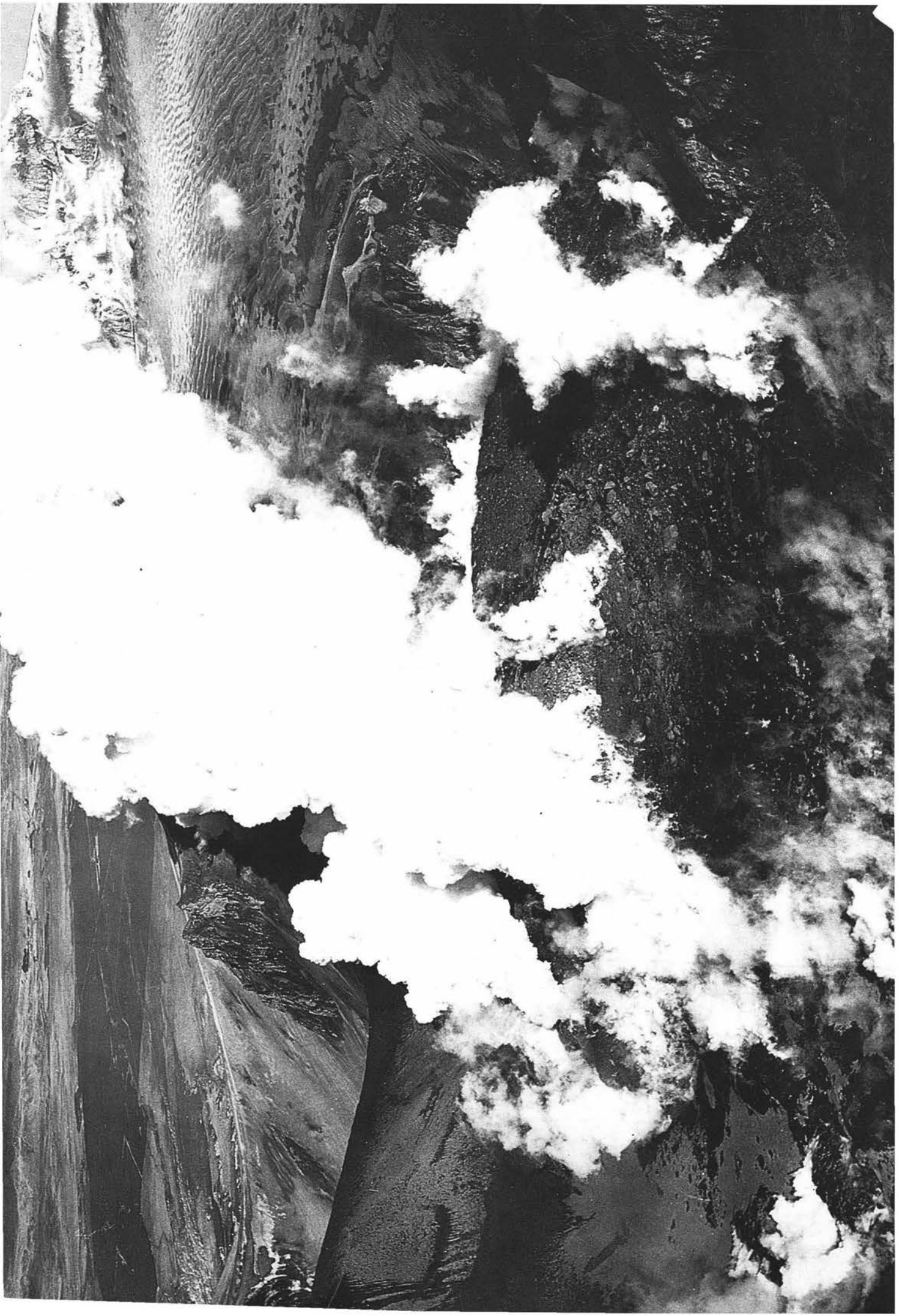


The most serious injuries of the eruption period occurred on 1 July when two trampers, who had camped the night near the crater, witnessed an explosion which showered them with hot rocks. Both received burns and one was knocked unconscious.



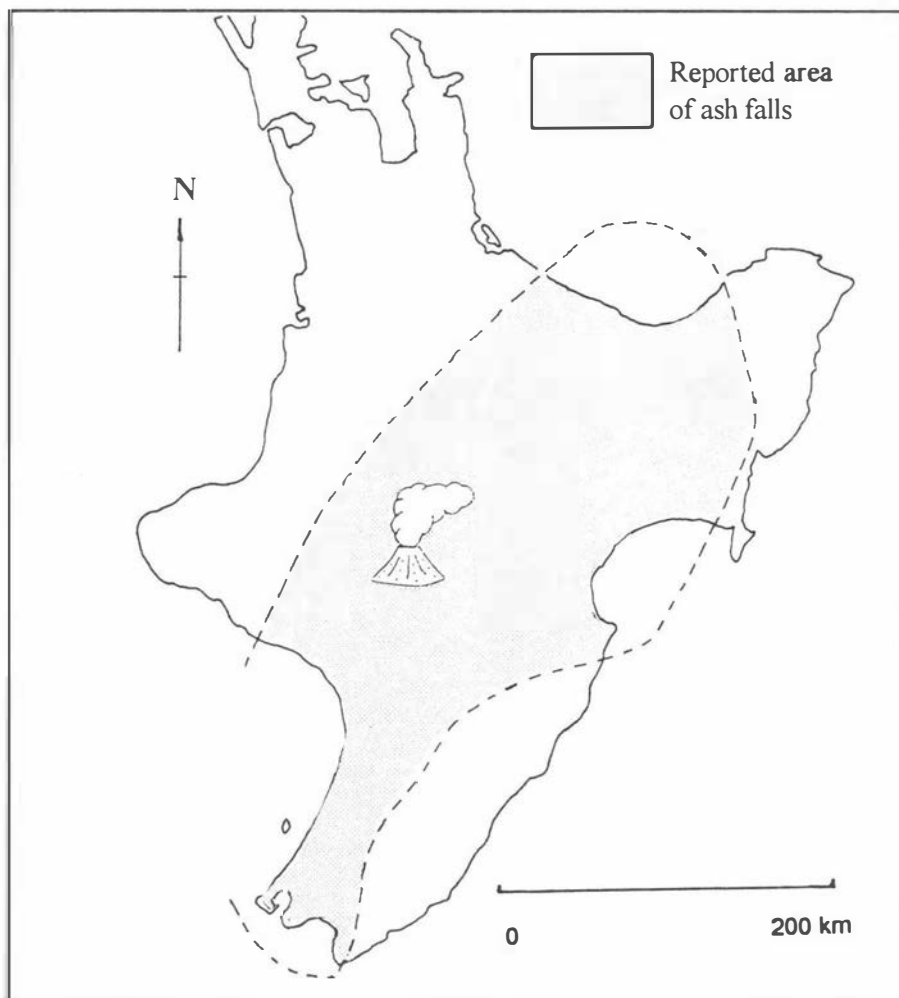
Above Photo: A large hole in the Whakapapa Glacier formed by the impact of an ejected block from the active vent in August 1945. Note the thick ash layer on the surface of the glacier. (Photo: Frame still from the item "Vulcanism...CAMERA ON RUAPEHU" in the National Film Unit film "Weekly Review No.211" (1945). Reproduced with permission of the Director and Chief of National Archives).

Right Photo: An aerial view of crater of Ruapehu on 20 July 1945. The lava dome has entirely displaced the crater lake. (Photo: RNZAF Collection)

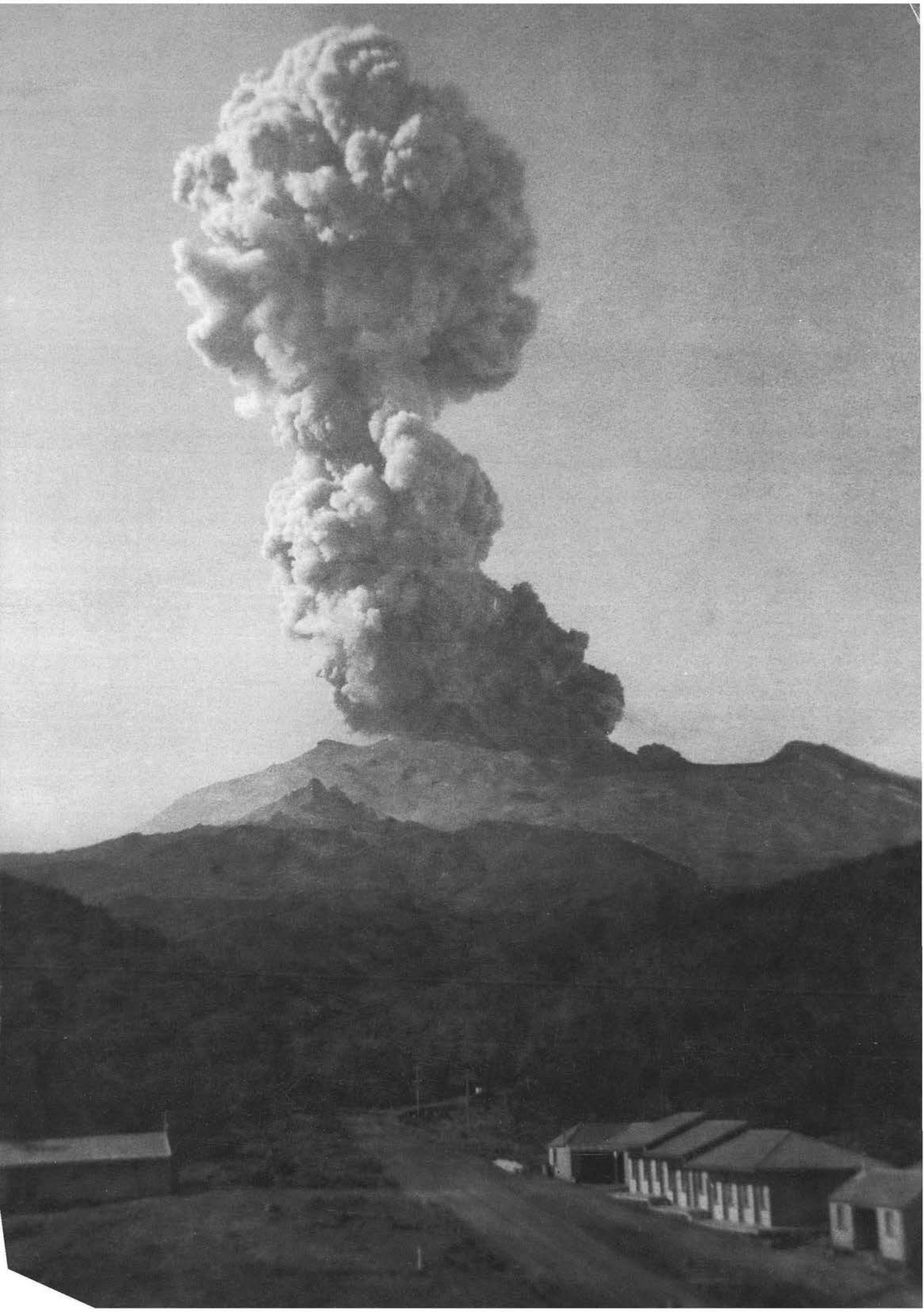


The activity changed its style during July with a series of explosive eruptions producing high columns of steam and ash. The large explosive eruptions in August and early September sent ash and steam columns high above the mountain. The prevailing winds dispersed ash as far afield as Upper Hutt, Wanganui, Whakatane and Opotiki. Numerous ash falls coated Ohakune, Waiouru, Hawkes Bay and the Chateau. Accompanying rumbling noises were heard far from the mountain during a number of explosions. The increased activity in the first week of August caused some concern in communities around the mountain and authorities in Ohakune and Waiouru made arrangements for a possible evacuation, although this was never necessary.

Approximate distribution of reported ash falls from the 1945 eruption of Ruapehu



Right Photo: An eruption column viewed (? August 1945) from the Chateau, Whakapapa Village. (Photo: H. Woods)



Visitors to the crater area on 17 August described three vents: a main vent towards the eastern rim of the crater, emitting ash and steam, and two smaller steam vents to the west (see page 21). Intermittent explosions were observed ejecting ash, rocks and steam in columns that rose several thousand metres above the crater, often with lightning discharges within the rising plume. Activity appeared to reach a climax on 21-22 August.



Above Photo: View of the ash and steam clouds issuing from the crater in August 1945. Photo taken from the col between Dome and Paretetaitonga. (Photo: GNS Collection)

Right Photo: Climbers viewing the active crater of Ruapehu from the summit of Paretetaitonga in August 1945 (? 17 August). Note the large eastern vent (right) from which most of the ash and steam is being erupted. (Photo: GNS Collection)



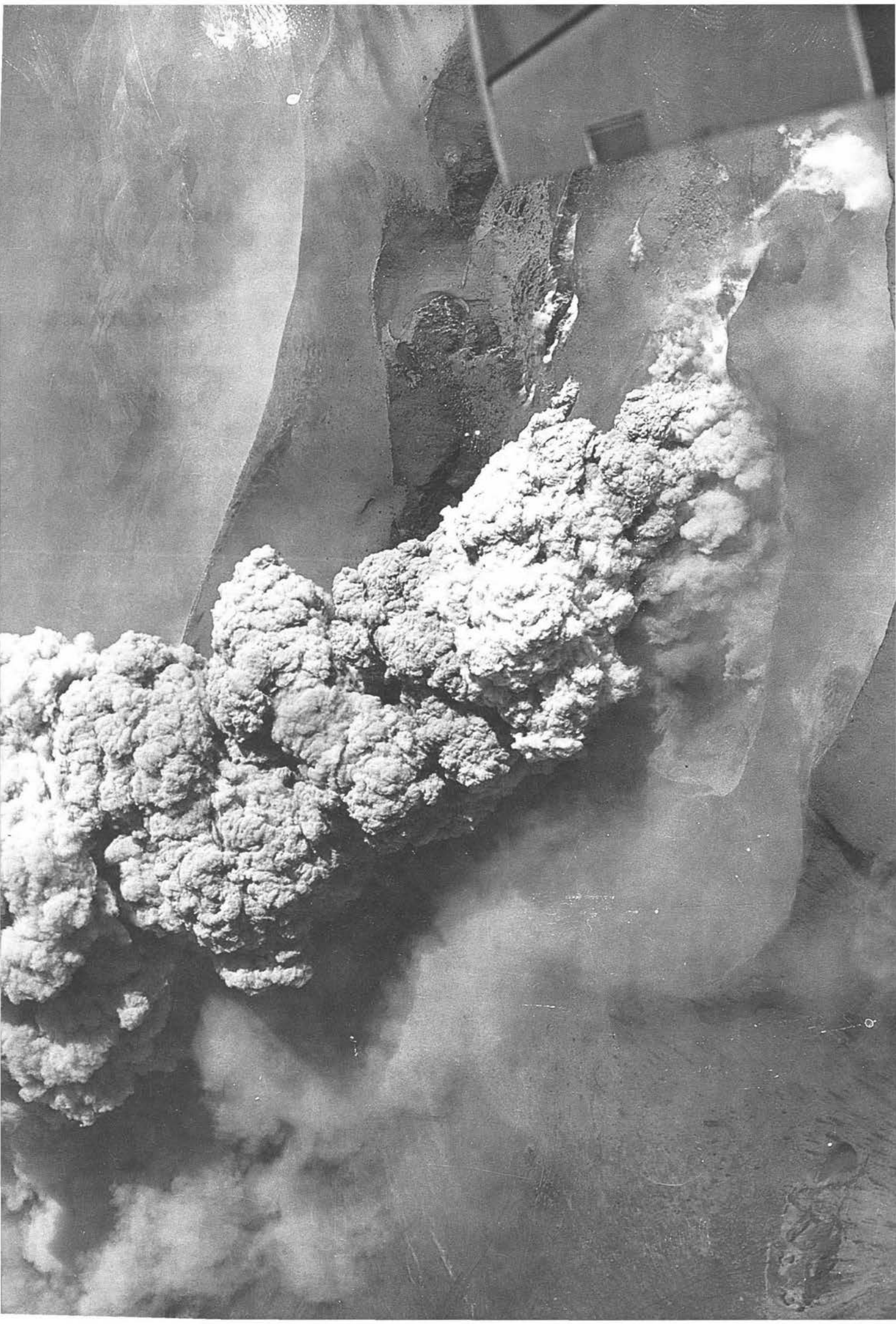
Ash falls proved to be the greatest nuisance with eye and throat irritations reported in most ash-affected communities. During heavy ash falls, descriptions of "*most people remaining indoors*" were recorded. In Napier and Hastings frequent ash falls brought about the term "*Ruapehu throat*" and hundreds of cases were reported to doctors and chemists. One newspaper reported that sunglasses were in demand to prevent eye irritations.

Crop damage was reported around Ohakune, in particular causing rotting among cabbages. Pastures covered by ash were often described as being unpalatable to stock but no significant damage occurred. Farmers in the Taihape area reported that ash found in the wool of sheep during shearing had reduced its quality. Ash frequently entered houses, soiling carpets and curtains, requiring residents to clean their house interiors at frequent intervals. In the Ohakune area wet ash was reported sticking to roofs, windows and flat surfaces like cement, and removing the deposits was described as difficult. The dirtying of washing hung out to dry was a common complaint.

Visibility was reduced on roads. On 12 August falling ash made street lights hazy in Hastings and whitened roads. Deposited ash was easily lifted by passing vehicles. During ash falls in Wanganui on 22 August vehicles using the streets "*raised dust almost to the same extent as though travelling on an unsealed highway*". Reduced speeds were a common consequence of ash on roads and on the Desert Road one driver was forced to reduce his speed to 15 mph. The New Zealand Automobile Association warned motorists to "*treat the ash with the greatest respect as it has a high abrasion value and can destroy paintwork. A dry rag should not be used*". Despite warnings, damage to vehicle paintwork was common. Abrasion also occurred when wipers were used to clear ash-covered windscreens.

Contamination of home water tanks was experienced when households failed to disconnect their downpipes before ash falls. On the 25 August the Ohakune fire brigade was reported to be busy filling home water tanks with river water after ash contamination. Ash falls also severely disrupted skiing at the Whakapapa Ski Field - by the end of August skiing was abandoned.

Right Photo: Aerial view of the ash and steam column erupting from the active vent of Ruapehu on 22 August 1945. Taken from the north-west. (Photo: RNZAF Collection)



Throughout September activity remained at a moderate level with the continuing emission of steam and ash and the enlargement of the main vent. On the 1 September, a group of sightseers on the Dome were peppered by small rocks after an explosion from the crater but no injuries were reported. Activity increased on 27 September with a number of large explosions producing high cauliflower-shaped clouds that spread ash over a wide area.

During October, ash fell in Taupo, Rotorua, Whakatane, Napier and Hastings, as well as on communities around the base of the mountain. On 17 October, ash falling with rain blocked the windscreen wipers of a bus en route to the Chateau. Two days later further problems were reported; " *on the return trip the driver stopped to see whether his lights had failed, but discovered ash was so thick on the headlamps that they were blacked out*".

Ash From Ruapehu

Evidence of the violent volcanic activity taking place within Mt. Ruapehu was plainly visible in Whakatane during the weekend. On Friday, Saturday and Sunday volcanic ash formed a thin layer over all open spaces, whilst cars parked in the Strand on Saturday morning received a thick coating. Motorists who left their cars out during any of the nights, were astonished to find the following morning, that their vehicles were almost snow-white under a heavy coating of ash.

Bay of Plenty Beacon,
Tuesday,
9 October 1945

ASH FROM RUAPEHU

Heavy coating at Taupo

(O.C.) Taupo, Sunday
Taupo on Saturday morning received such a heavy coating of ash from Ruapehu that it caused most people to remain indoors. A heavy, gritty, black ash was carried from the mountain directly towards Taupo by a strong southerly breeze. Complaints were generally about the irritating effects on the eyes and throat. About midday the wind veered more to the west, carrying the ash away from Taupo.

The New Zealand Herald,
Monday,
8 October 1945

Right Photo: Ash and steam plume from Ruapehu on 16 October 1945 drifting to the northeast. Waiouru Military Camp is in the foreground. (Photo: NZ Aerial Mapping)



Explosive eruptions continued into November and early December with Waiouru, Ohakune, the Chateau and Hawkes Bay receiving most of the ash falls. During November the New Zealand Army moved some 700 vehicles from Waiouru to Linton due to the adverse effect of the acidic ash on the canvas tops of vehicles and its reported corrosive effects on metal. On 23 November, Taumarunui's water supply was disrupted by the large quantity of ash being carried in the Wanganui River, the sediment blocking water intake filters. Pumping was reduced from 20 000 gallons/hour to 7000 gallons/hour because of the high sediment content of the river water. Eventually filtration became impossible and pumping ceased. By the following day water quality had improved sufficiently for pumping to resume but the public was advised to boil water for a few days.

**HAWKE'S BAY UNDER
PALL**

**NUISANCE BEING
CREATED**

(O.C.) Hastings, Thursday

With forecasts of "more to come", Hawke's Bay residents, who previously have treated the eruption of Mount Ruapehu only as an interesting phenomenon, are becoming concerned at the continued dust clouds which are swept from the mountain by the prevailing westerly winds over the entire province.

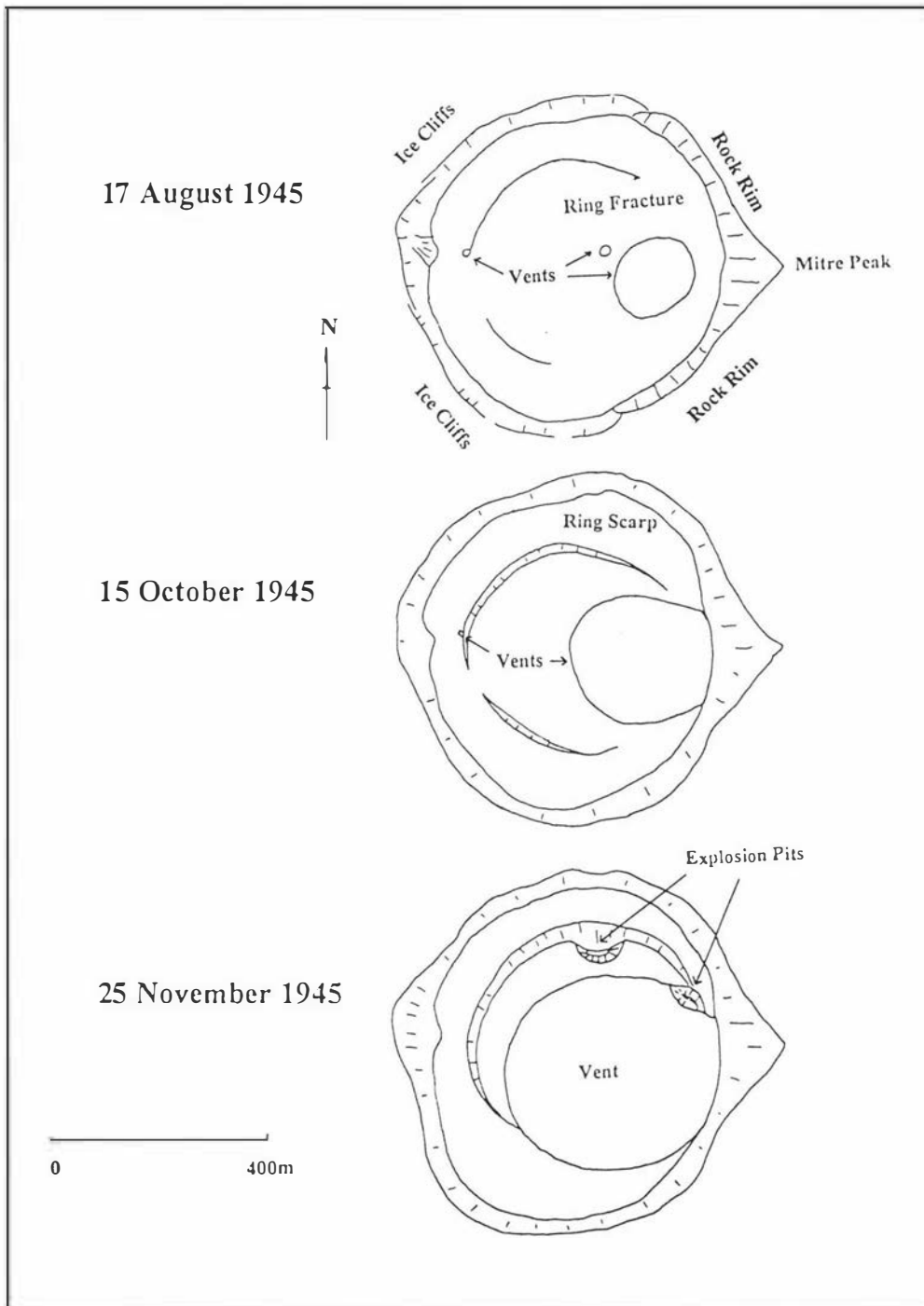
Hastings was anything but attractive, with the green of the foliage and the colour of painted areas neutralised to the drab grey of the volcanic dust. The interiors of buildings were also coated with a thick layer. Efforts to keep dwellings in a state of cleanliness have proved unavailing.

"The dust from Ruapehu is definitely starting to do harm", said a Napier doctor. "Eyes are inflamed, there is a spate of throat trouble, noses are being affected and asthmatics are suffering. I would say also that thousands of pounds of damage is being done to machinery. Even our watches, clocks and other fine machinery are suffering irreparable damage."

The New Zealand Herald,
Friday,
16 November 1945

Changes in the crater of Ruapehu - August to November 1945

(modified from Beck 1951)



At the Chateau (a hospital at the time) numerous disruptions to both water and electricity supply occurred over several months: ash had been falling in the streams that fed the water supply and had penetrated electricity generating plant. Staff members reported that the fine ash in the streams made the filters useless and water could no longer be passed through the settling ponds. The water from the mountain stream to the hospital was described as "*liquid mud*". The hospital was eventually forced to close on 22 December and its 180 patients were relocated to south Auckland.

The last ash falls to affect Napier and Hastings took place on 6 December and after that only infrequent steam and ash explosions occurred. The last strong explosion was on 15 December with small amounts of ash and steam issuing from the crater during the rest of the month.

MENTAL PATIENTS LEAVE CHATEAU

Water Supply Fouled by Volcanic Ash

(By Telegraph - Press Association)

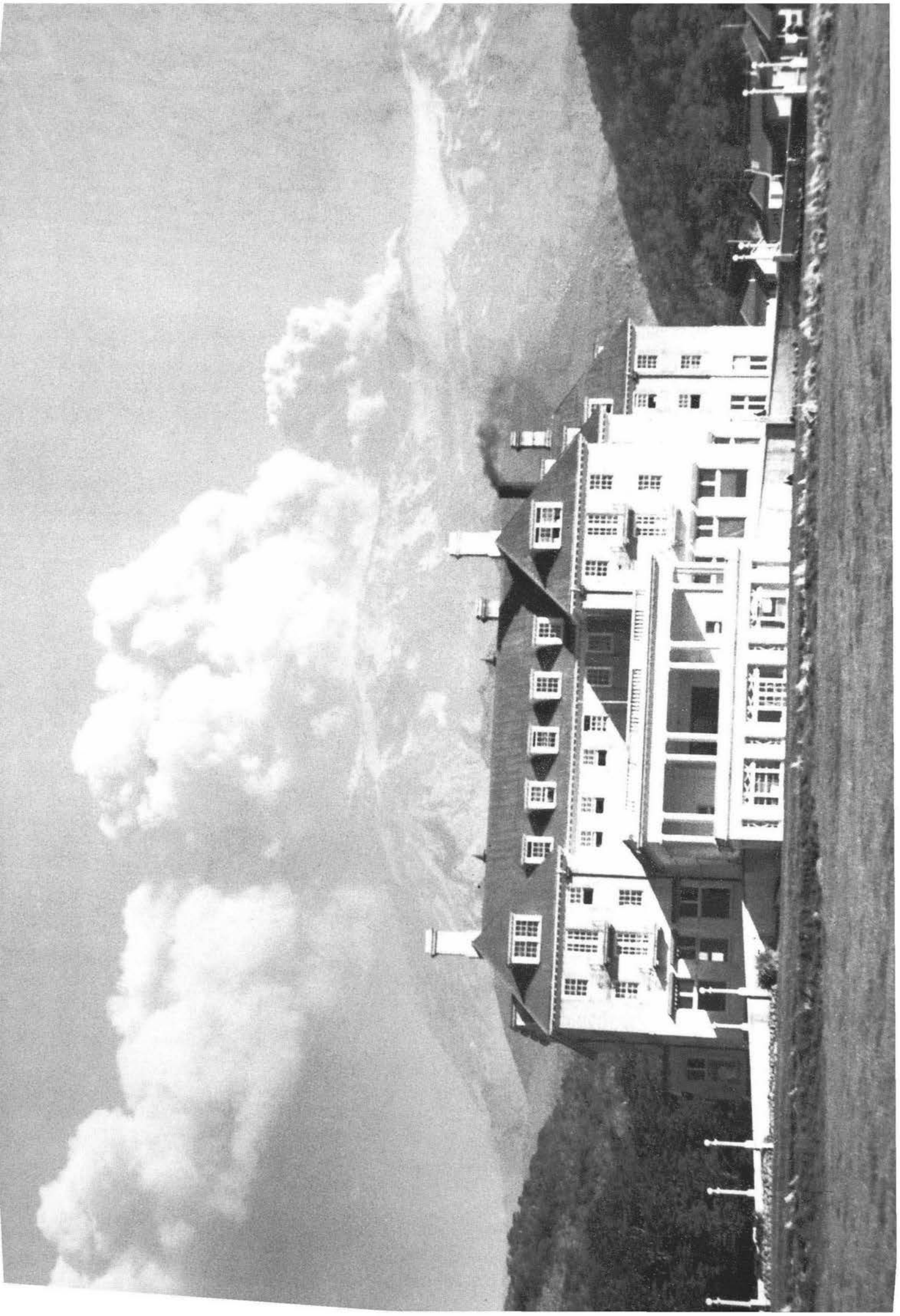
AUCKLAND, December 21

The water supply of the Chateau Tongariro has been so fouled with ash from Mt Ruapehu that all the mental hospital patients at the chateau are being evacuated to Ravensthorpe convalescent depot at Bombay. A special train will leave Waiouru early tomorrow morning with about 180 female patients and 30 members of staff. It is due at Drury shortly before 6 pm and the patients will then be taken to Ravensthorpe by road.

The ash has also interfered seriously with the efficiency of the chateau's power house and has made other conditions increasingly unpleasant and inconvenient.

The Dominion,
Thursday,
22 December 1945

Right Photo: The Chateau Tongariro in November 1945 with ash and steam clouds erupting from Ruapehu in the background. (Photo: Lansdown Collection)



REFILLING OF CRATER LAKE 1946 - 1949

When explosive activity ended the crater consisted of a steep-walled vent about 300 m deep, occupied by a boiling lake. The crater lake gradually refilled, and by 1949 it had returned approximately to its previous level.

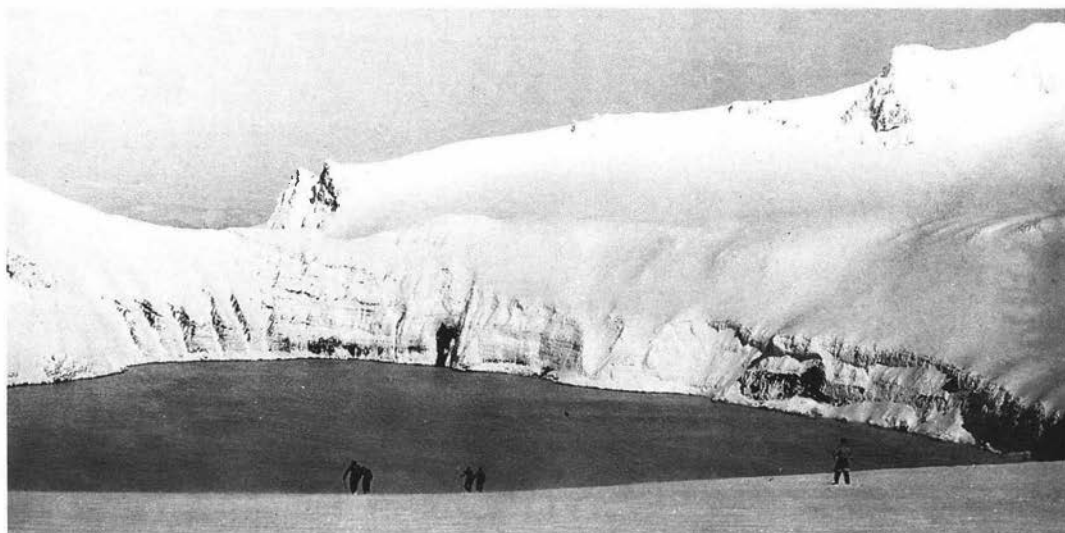


**Above Photo: Climber descending into the crater of Ruapehu on 30 March 1947.
(Photo: J.M.S. Beale Collection).**

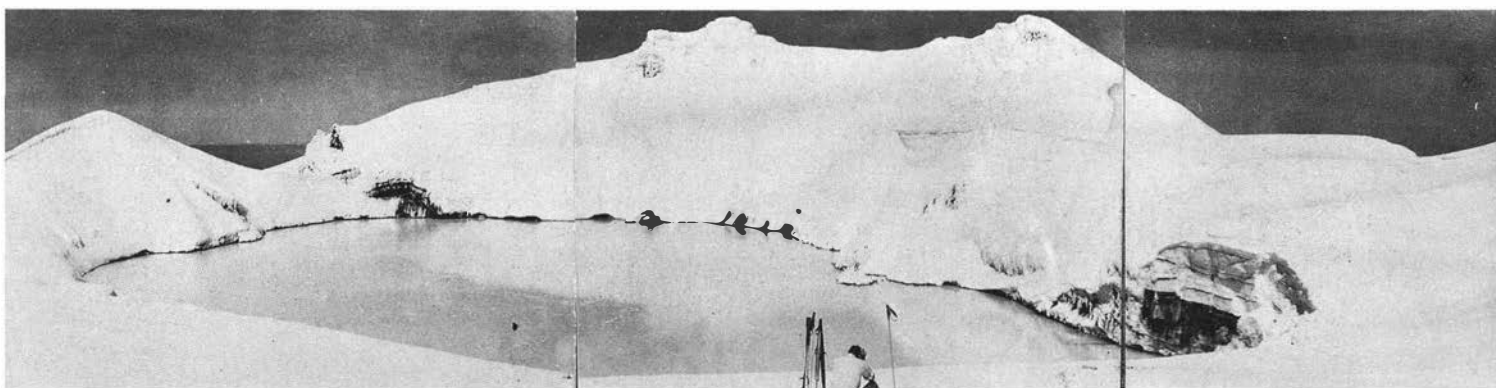
Christmas 1947 (Photo: J.E. Mautner; GNS Collection)



October 1949 (Photo: GNS Collection)



October 1953 (Photo: P. Otway)

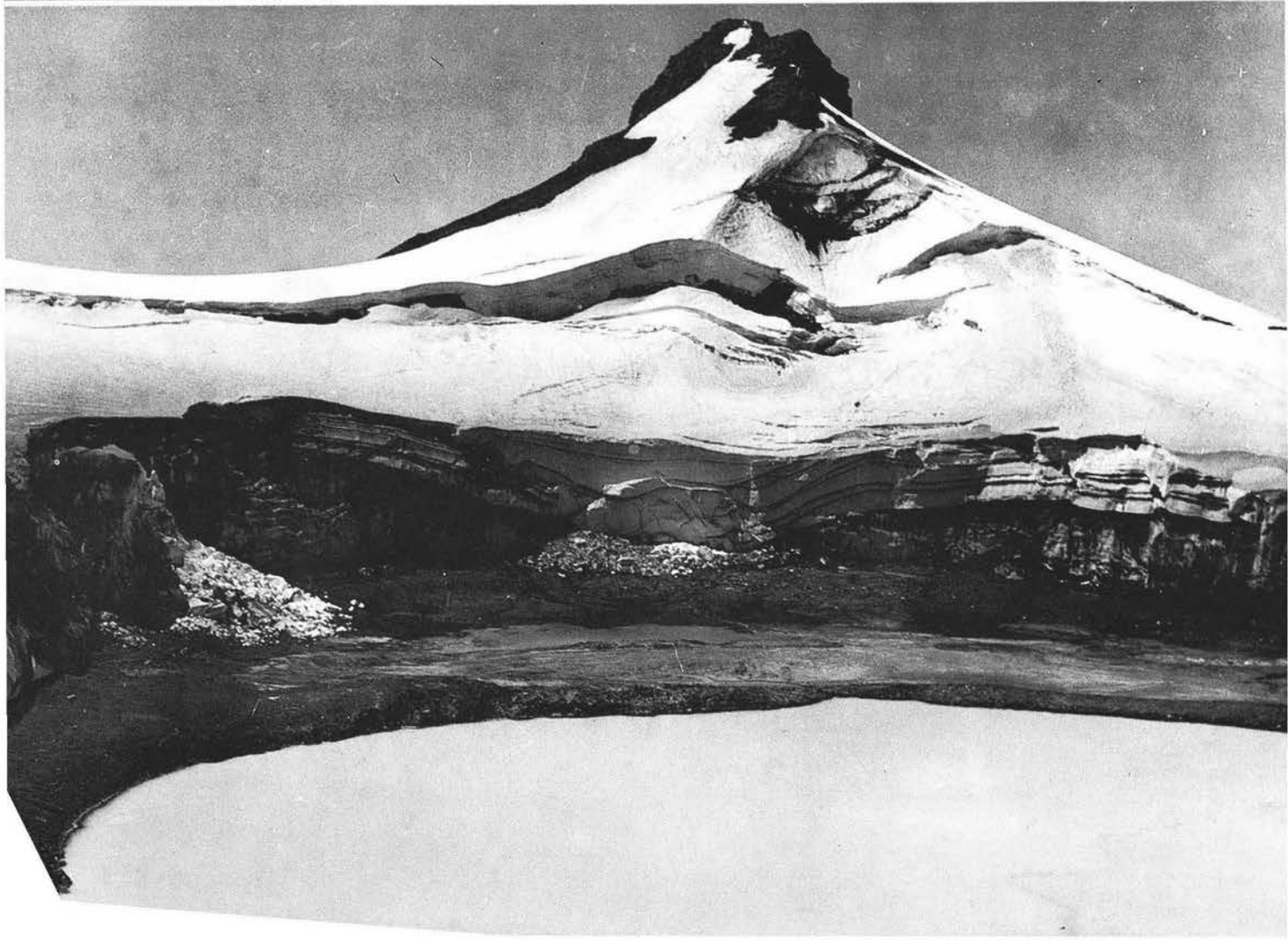


THE TANGIWAI DISASTER - 24 DECEMBER 1953

From 1946 to 1968 Ruapehu entered a new phase with only small steam eruptions and geysering from the crater lake. However, after dusk on 24 December 1953, a portion of the ice, rock and debris barrier confining the crater lake suddenly collapsed. The reasons are unproven but clearly non-volcanic. Maybe it was due to the flow of the glacial ice forming the dam to the lake, possibly it was due to the underground piping of water through the debris rim, or merely to the failure of the rock forming the lip over which the lake outflow descended through an ice-cave. Whatever the reasons, about 340,000 m³ of water were released through the ice-cave and the lake was lowered by about 6 m. Descending the Whangaehu River the waters filled a channel 30 metres wide and 6.7 metres deep before spreading out through a series of channels in the Rangipo Desert to the east. Encountering the Whangaehu escarpment, formed by westward subsidence along the Desert Road fault, the waters reaggregated in the main southward-flowing channel of the river. They then followed its sinuous course to Tangiwai where they arrived about 10.20 pm. The Main Limited Railway Express from Wellington to Auckland was approaching the railway bridge crossing the river and despite the efforts of a motorist who had arrived on the scene of the raging flood minutes before, the train forged ahead. The railway bridge was obviously weakened by the torrent beneath and when the train was halfway across, the bridge collapsed and the engine plunged into the opposite bank. Six carriages fell into the lahar and 151 lives were lost. One of the carriages was carried 2.4 km downstream and a 125 tonne bridge pier was shifted 64 m laterally. It was New Zealand's worst railway disaster. Now a lahar warning gauge upstream alerts New Zealand Rail of any impending lahar above the bridge.

Above Right Photo: Aerial view of the ice cave at Ruapehu's crater lake outlet on 28 December 1953, four days after the catastrophic release of lake water caused the Tangiwai disaster. (Photo: GNS Collection)

Below Right Photo: The crater lake of Ruapehu in January 1954, showing the shoreline platform exposed after the lowering of the lake on 24 December 1953. Paretetaitonga is the peak in the centre background. (Photo: L. Krenek; GNS Collection)



BIBLIOGRAPHY

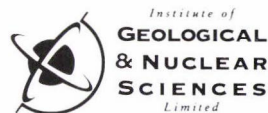
- Beck, A.C. 1951. Volcanic activity at Mount Ruapehu from August to December 1945. *Journal of Science and Technology B31(5)*: 1 - 13.
- Cotton, C.A. 1945. Ruapehu in 1945. *New Zealand Science Review 3*: 3 - 4.
- Cotton, C.A. 1946. The 1945 eruption of Ruapehu. *Geographical Journal, Vol. 107*, 140 -143.
- Cronin, S.J.; Neall, V.E.; Palmer, A.S. (in press). Geological history of the north-eastern ring plain of Ruapehu volcano. *Quaternary International*.
- Donoghue, S.L. 1991. Late Quaternary stratigraphy of the south - eastern sector of the Mount Ruapehu ring plain. *Unpublished Ph.D. dissertation, Department of Soil Science, Massey University*.
- Gregg, D.R. 1960. The geology of Tongariro Subdivision. *New Zealand Geological Survey Bulletin 40*.
- Hackett, W.R.; Houghton, B.F. 1989. A facies model for a Quaternary andesitic composite volcano : Ruapehu, New Zealand. *Bulletin of Volcanology 51*: 51 - 68.
- Hodgson, K.A. 1993. Late Quaternary lahars from Mount Ruapehu in the Whangaehu River valley. *Unpublished PhD dissertation, Department of Soil Science, Massey University*.
- Oliver, R.L. 1945. Further activity of Mount Ruapehu, New Zealand, May - July 1945. *Journal of Science and Technology B27*: 24 - 32.
- O'Shea, B.E. 1954. Ruapehu and the Tangiwai Disaster. *Journal of Science and Technology B36*: 174 - 189.
- Purves, A.M. 1990. Landscape ecology of the Rangipo Desert. *Unpublished M.Sc. thesis, Department of Soil Science, Massey University*.
- Reed, J.J. 1945. Activity at Ruapehu - March to April 1945. *Journal of Science and Technology B27*: 17 - 23.

ACKNOWLEDGEMENTS

The authors would like to thank the following organisations for their support of this project: The Science Centre Inc.; Department of Soil Science, Massey University; Institute of Geological & Nuclear Sciences; Ministry of Civil Defence; Alexander Turnbull Library; National Archives; Royal New Zealand Air Force Museum; Department of Conservation; Taupo Times; Whakatane Beacon; Hawkes Bay Herald Tribune and the New Zealand Herald. In addition, a number of individuals have supplied photographs and information, assisted with the research, and reviewed this publication. We are grateful for the assistance given by: Bruce Houghton; Dinah Riley; Peter Otway; Peter Millward; Karen Williams; Yvonna Chrzanowski; Harry Keys; Clive Sowry; Therese Angelo; Mrs Dorothy Lansdown; Mrs Margaret Welch; Mrs Jeanne Hall; Mrs Alice Monk; Mr K. Hay; Karen Israelson; Mr H. Woods; Alan Graham; Elizabeth Pindar; the Rev. R.G. Neilson; Jack Booth; D. Livingston; Brian Mosen; Helen Tobin; Alan Hull and Tony Hurst. Our sincere thanks to Anne Austin for her valued comments in editing the text and Craig Hockly for layout and printing advice.

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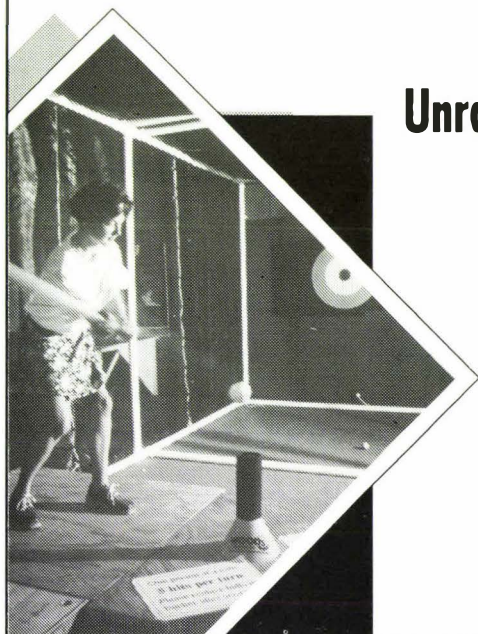
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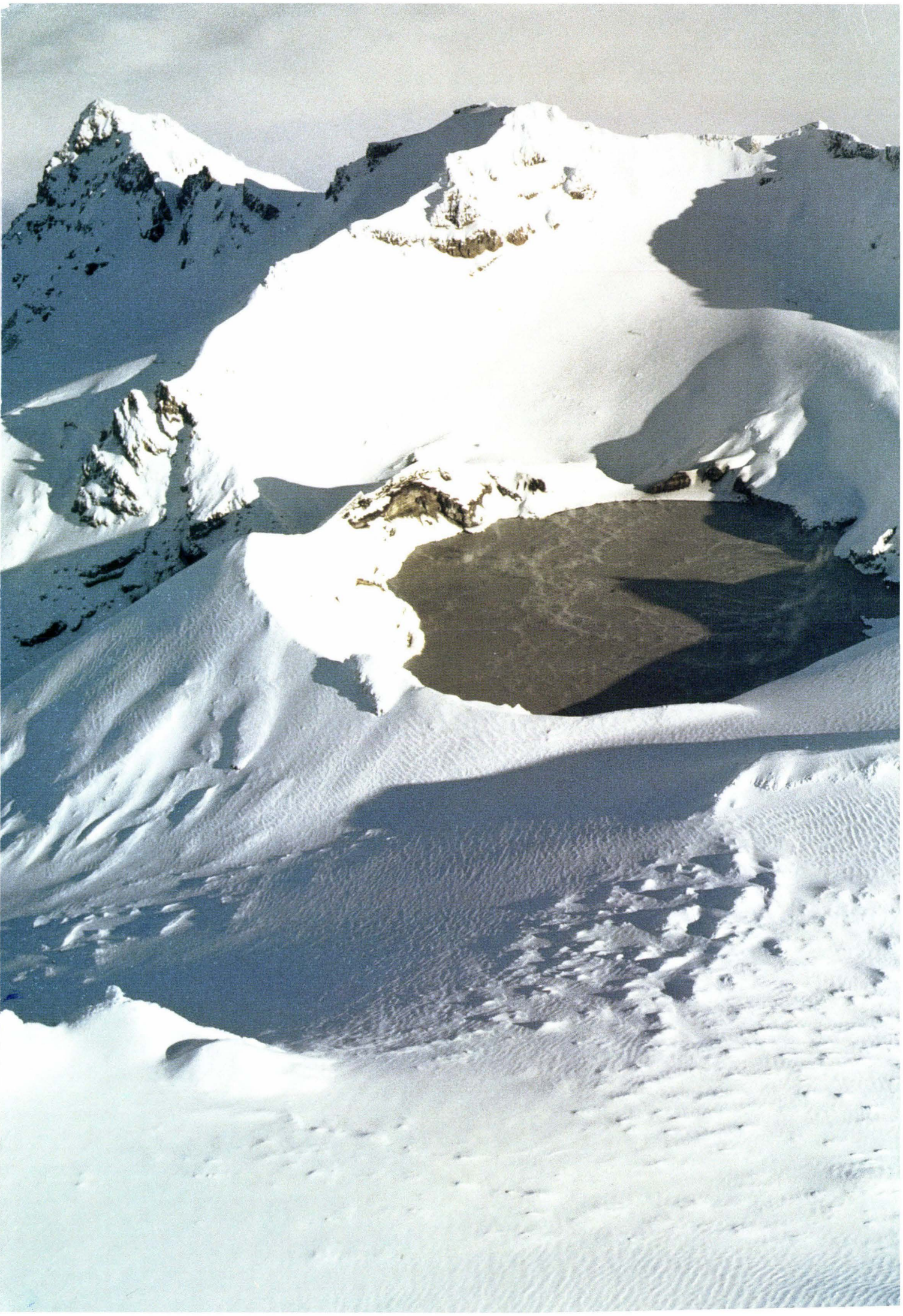
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APPENDIX 3

THE IMPACTS OF RECENT FALLS OF VOLCANIC ASH ON PUBLIC UTILITIES IN TWO COMMUNITIES IN THE UNITED STATES OF AMERICA

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A3.1 INTRODUCTION

The United States of America contains over 65 active and potentially active volcanoes that pose a threat to communities and aircraft routes (Wright & Pierson 1992). The 1980 eruption of Mt St Helens (Washington) was the largest event in the past 50 years, killing 57 people and spreading volcanic ash over a large area of mainland United States. The state of Alaska contains more than 40 active volcanoes with three Cook Inlet volcanoes having deposited volcanic ash on urban communities in the past 50 years: Mt Spurr (1953, 1992), Redoubt (1989/90) and Augustine (1969/69, 1976, 1986). The volcanoes of Hawaii are also frequently active, with a continuing eruption from Kilauea since 1983.

This appendix describes visits to two communities affected by volcanic ash. The city of Anchorage in Alaska was covered by 3 mm of volcanic ash from the 1992 eruption of Mt Spurr. Yakima in Washington received 10 mm from the 1980 Mt St Helens eruption. The purpose of the visits (Yakima in 1995 and Anchorage in 1996) was to gain information on the impacts of both eruptions by meeting with key utility providers and officials of the state governments and the United States Geological Survey's Cascade and Alaskan volcano observatories (CVO and AVO). Both communities distributed printed information on how to deal with ash and copies of these 'flyers' are presented (Fig. A3.11 and A3.12).

A3.2 THE 1992 MT. SPURR ERUPTION

Mt Spurr began a sequence of eruptions on 27 June 1992 (Fig. A3.1), after 39 years of inactivity (Keith 1995). Two further episodes occurred on 18 August and 16-17 September. All three episodes lasted around four hours and sent eruption columns to around 14-15 km in height. Losses from the eruption are estimated at around US\$ 5-8 million (Eichelberger *et al.* 1995).

The city of Anchorage is 120 km from Mount Spurr and is the largest city in Alaska, with a population of over 300 000. The August 1992 eruption deposited about 3 mm of fine sand-sized volcanic ash (Fig. A3.2) on the city and had the greatest social impact.

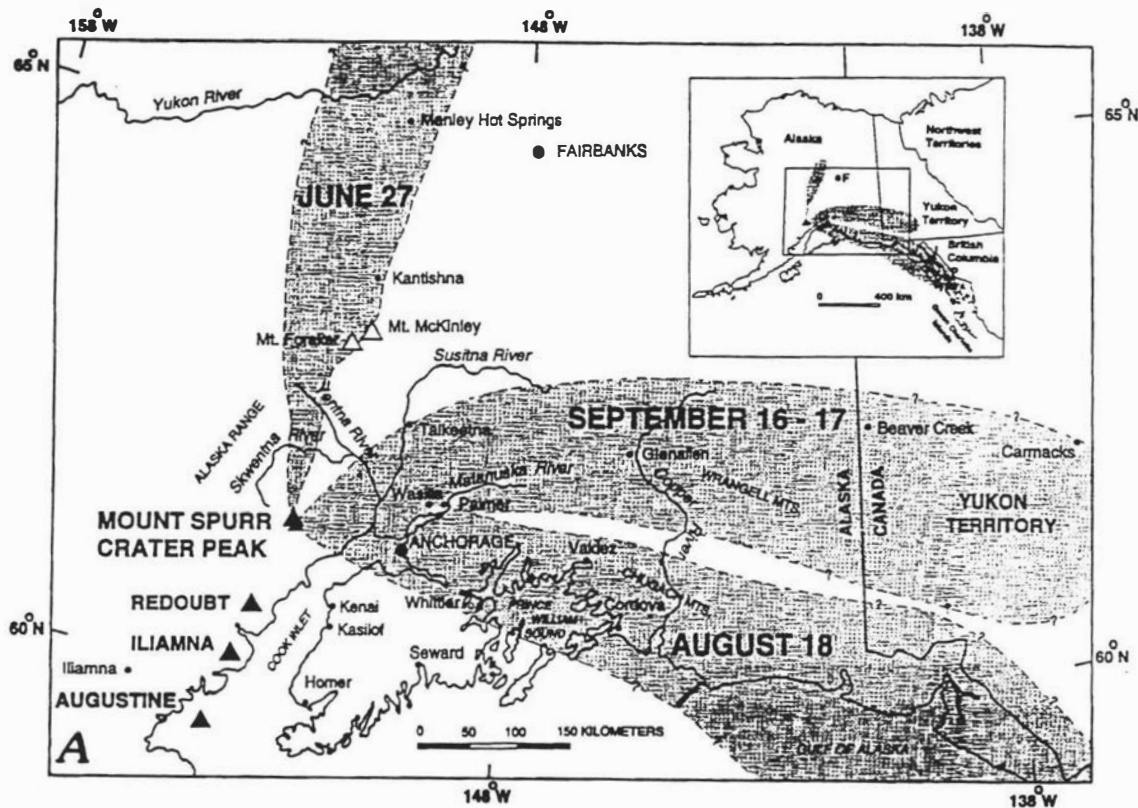


FIGURE A3.1 Generalised map showing the extent of ash falls from the 1992 Mt Spurr eruption (from Neal *et al.* 1995).

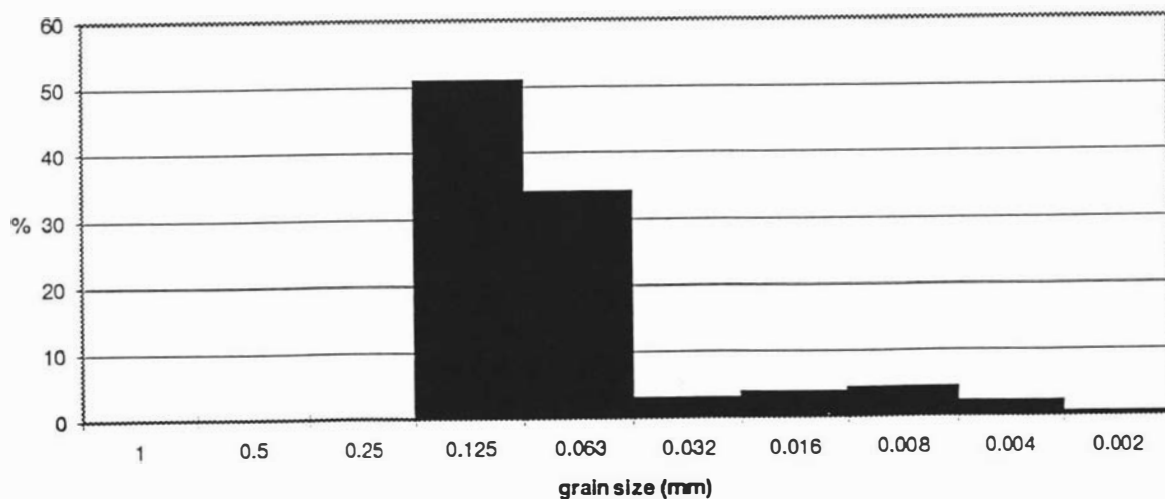


FIGURE A3.2 Grainsize distribution for ash deposited on Anchorage, 18 August 1992 (unpublished data, G. McGimsey, USGS)

A3.3 IMPACTS OF VOLCANIC ASH ON PUBLIC UTILITIES IN ANCHORAGE

A3.3.1 Water supplies

The clean-up of ash resulted in excessive demands for water and caused major problems for the Anchorage Water and Wastewater Utility (AWWU) water production and distribution systems (AWWU *pers comm.*). The AWWU received a warning of the impending ash fall on the afternoon of 18 August. No action was taken that evening. As one staff member described "we did not equate ash fall to high water demand...we were not prepared for what happened...had we known we would have moved to fill reservoirs sooner." By 10 am on 19 August (the day following the ash fall) peak four hour demand of 230 million litres per day was recorded (~ 70% increase) (Fig. A3.3). Despite adequate production capacity, physical restrictions within the distribution system prevented the utility from moving sufficient water volumes to meet demand in parts of Anchorage (Fig. A3.4).

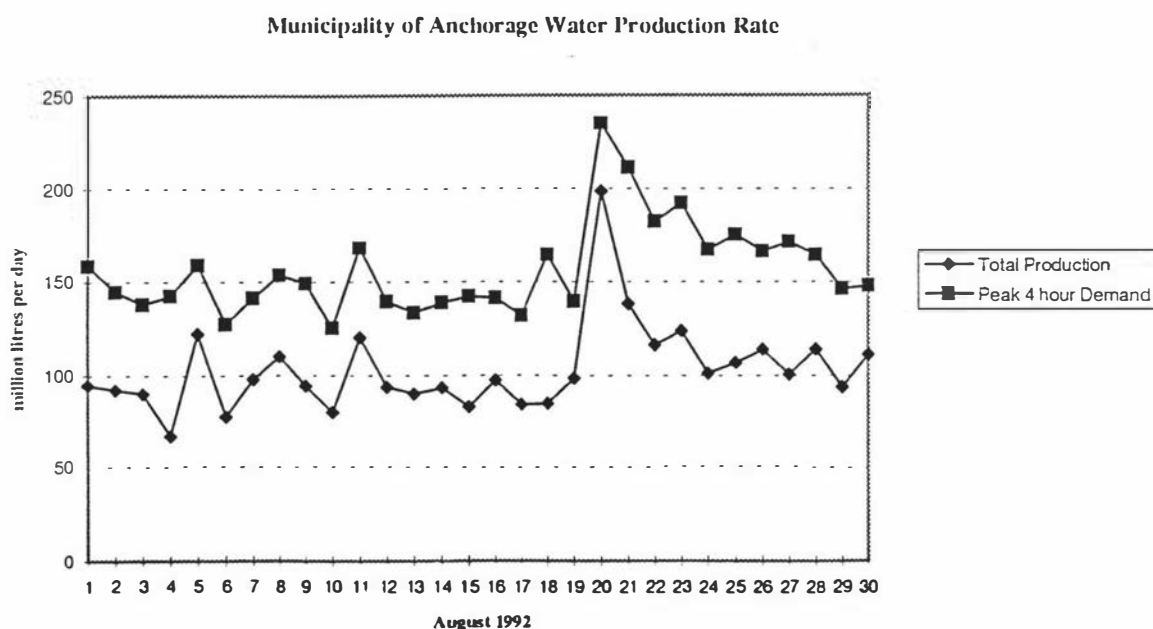


FIGURE A3.3 The August 1992 water production rate for the city of Anchorage. (Source: unpublished Anchorage Water and Wastewater Utility (AWWU) data)

The high water demand caused widespread pressure and supply problems throughout 19 August, with levels in several storage reservoirs dropping to dangerously low levels. Some reservoirs were isolated from the immediate distribution system to ensure adequate volumes for fire suppression if required. At least one reservoir was completely emptied. Had building fires occurred in a number of parts of the city no water would have been available. The opening of the Anchorage International Airport was delayed for several hours due to shortages of water to clean the runways. Stranded passengers were unable to use the toilets due to the lack of water.

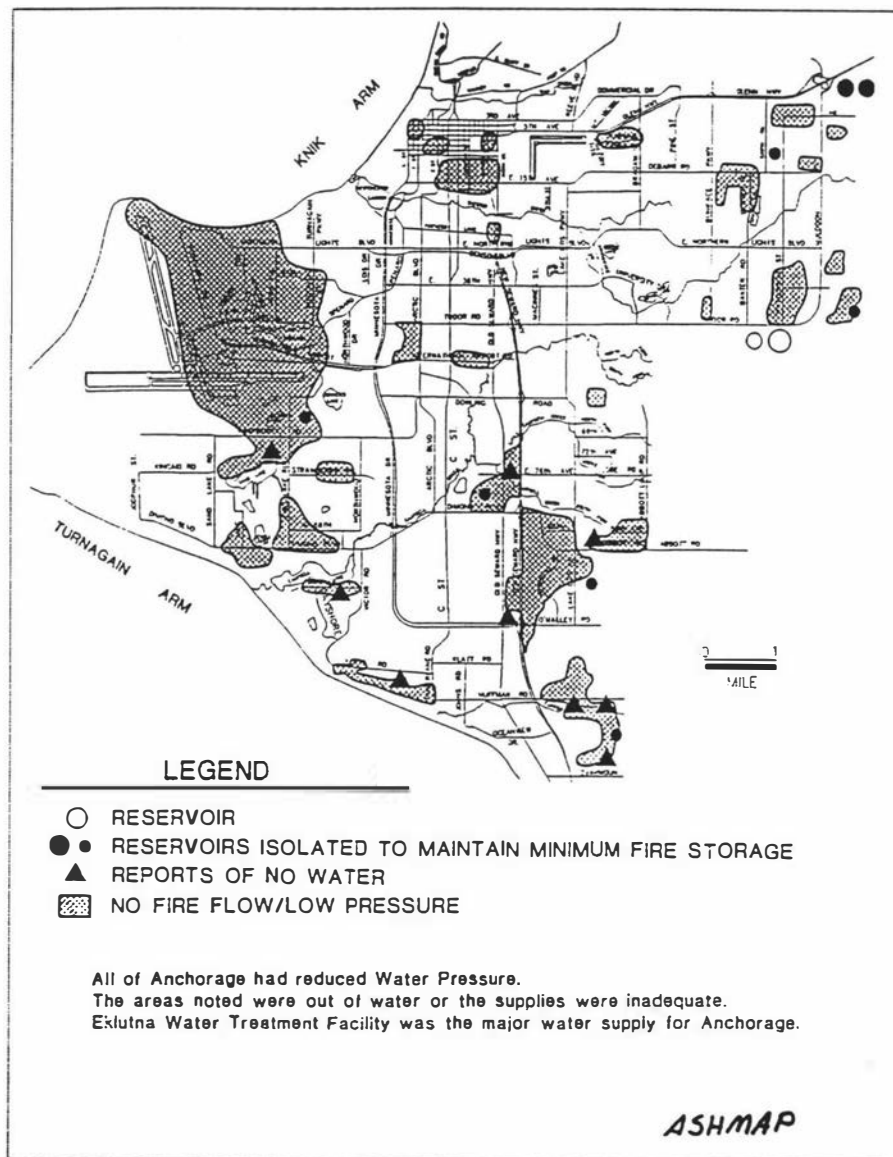


FIGURE A3.4 Water distribution and pressure map for 19 August 1992. (from Municipality of Anchorage, unpublished report, 1993)

A3.3.2 Ash removal from roads and stormwater systems

The Municipality of Anchorage Public Works was responsible for ash removal from streets and the stormwater system (Municipality of Anchorage, unpublished report, 1993). Ash clean-up operations began on the morning of 19 August with the use of water trucks, graders, belt-loaders, dump trucks, sweepers and vacuum trucks. Dry ash was easily raised but caused an air quality problem, whereas wet ash was heavy and hard to move. Ash was first dampened, then sweepers and graders were used to move the ash to the sides of streets. Belt loaders were then used to pick up the ash which was transported to a number of dump sites around the city. Sweepers and water trucks then went over cleaned areas again. Rain on the evening of the 19 August was a significant help in reducing the impact to the community by washing ash from paved surfaces and helping move ash on non-paved surfaces into the soil.

Ash removal from roads was an expensive and slow process. It took 3 to 4 days to clean the Anchorage central business district (CBD) and after 3 weeks only 60-65 % of the city had been cleaned. The complete ash cleanup in Anchorage took over six weeks, using more than 90 staff, at a cost of over US\$ 780 000, or US\$2.6 per capita. Some contractors were used but equipment was scarce immediately after the ash falls, as there was high competition from private organisations involved in their own clean-up operations.

Although care was taken to minimize the amount of ash entering the stormwater system, large amounts of ash had to be removed. This had to wait until the following spring due to the arrival of winter snow. Ash did not move far into the system but settled out rapidly forming a hard deposit. During the spring thaw some local flooding occurred due to pipe blockage. During subsequent clean-up it was found that these deposits could be removed using vacuum trucks.

Major problems and expense resulted from ash being dumped with normal household garbage. Unfortunately there were a number of recommendations in the media that ash be placed in the garbage for kerb-side collection. This was found to be a major problem and expensive for collection contractors because ash from garbage bags soiled and jammed the runners on the inside of garbage trucks. Municipality of Anchorage Solid Waste Services identified the need for alternatives to be developed. A general conclusion is that ash could be disposed of in gardens and lawns or in designated landfills. If ash is collected it should be separated from normal garbage.

A3.3.3 Buildings and building services

The Municipality of Anchorage Property and Facility Management (P&FM) mobilised crews during the ash falls on the evening of 18 August, to shut down air-conditioning units on all

Municipal facilities, to prevent ingestion of ash (Municipality of Anchorage, unpublished report, 1993). Reactivation of these units could only occur after ash had been cleared away from intake structures. The piles of wet ash were too heavy to be removed by hand and heavy equipment had to be used. Air filter supplies ran out and delays in receiving replacements were reported. P&FM officials concluded that more effective methods of ash clean-up need to be found.

A3.3.4 Telecommunications

Telephone services in Anchorage are provided by ATU Telecommunications. Major problems with intakes for air-conditioning at exchange sites were reported. All air-handling units were shut down during the ash falls and conditions were monitored from the ATU Emergency Command Centre. The problem continued for some days after the ash falls due to airborne ash levels. The time of year meant that temperatures within exchanges did not reach critical levels and all systems remained operative. Had the ash falls occurred during hotter weather, temperatures within exchanges may have exceeded operating limits thus requiring the shut down of equipment. ATU staff covered computers, closed doors and restricted access to buildings. Ash infiltration was not a major problem since most key buildings have positive air (internal air pressure exceeding atmospheric pressure) and air-conditioning units were turned off. The majority of staff were sent home for health and safety reasons and to minimise vehicle use. This also allowed staff to clear up their own properties.

Despite having to shut down air-conditioning equipment and operating with reduced staff levels no major system problems occurred. Increased phone demand was recorded and some organisations (Anchorage Police Department and Municipal Light and Power) reported having problems contacting their staff.

After the ash falls buildings and carparks were washed down. An increased maintenance program for fleet vehicles was implemented. Some problems with blocked air-filters on remote equipment were reported.

A3.3.5 Electricity supplies

No electricity outages were recorded in Anchorage as a result of the 18 August ash falls (The Municipal Light and Power Company *pers. comm.*). The Municipal Light and Power Company (ML&P), had learnt from the experience of past ash falls (i.e. Augustine in 1986) and had installed special filters on air intakes of their turbine-generators. These self-cleaning filters can operate in an ash-rich environment and have proved to be an effective mitigation against ash.

The lack of rain during the ash falls and prompt cleaning prevented insulator flashovers at substations. Power outages resulting from insulator flashover had occurred during the 1989 Redoubt eruption and prompt cleaning of substations was recognized as the most effective protective measure. Wind removed most ash from power lines.

A3.3.6 Transportation

Falls of volcanic ash had a major impact on air transportation. Three airports (Anchorage International Airport, Merrill Field and Elmendorf Air Force Base) were closed or had restricted use for several days following ash falls on the 18 August. The cost of removing ash from the airport has been estimated at US\$683 000 and net lost revenue at US\$276 000 (Casadevall & Krohn 1995).

The ash limited visibility on roads. The first falls of rain on the evening of 19 August improved conditions considerably. The city transit bus service was shut down at 9 pm on 18 August and operated only a limited service the following day. No vehicle damage was reported by Municipal departments but most organisations increased vehicle maintenance, changed air filters and engine oil and therefore incurred increased maintenance costs.

The port company reported no major problems but incurred significant costs for the clean-up operation.

A3.3.7 Miscellaneous impacts (Anchorage Daily News 19/8/96, 20/8/92, 21/9/92)

- * 12 major road building projects in the Anchorage area were suspended because of the potential damage to equipment.
- * The city trimmed bus schedules, cancelled meetings and sporting events and sent about 40% of its workforce home.
- * Hospitals reported no serious respiratory problems from the ash. Hundreds showed up at the emergency room asking for masks. One hospital reported four cases of eye problems, such as scratched corneas from sharp ash particles. Two people were reported to have had heart attacks while shovelling ash and one man died. One woman sweeping ash at the International Airport fell through a sky-light and fell 3 metres, breaking a leg.
- * Mail services were disrupted.
- * Customers lined up at stores to buy air filters for their cars and some merchants reported they had sold out. People also bought large numbers of face masks.

A3.4 1980 MOUNT ST. HELENS ERUPTION

The 1980 eruption of Mount St Helens was the most significant eruption in the United States this century, killing 57 people and causing in excess of US\$ 1 billion in damage (Lipman & Mullineaux 1981). On 20 March 1980 a sequence of earthquakes was recorded beneath Mount St Helens, ending 123 years of quiescence. Seven days later steam explosions commenced at the summit and over the next two months earthquakes and minor steam eruptions continued, accompanied by inflation of the volcano's north flank. At 8.32 am (local time) on 18 May 1980 an earthquake-triggered sector collapse removed much of the north flank of the cone to form a massive debris avalanche that travelled 18 km downstream and was followed by an explosive lateral blast, devastating an area of 600 km². Lahars were generated by the rapid melting of snow and ice and flowed down a number of valleys. A Plinian eruption continued for 9 hours, with the column reaching 25 km in height. Heavy ash falls occurred over much of northern USA (Fig. A3.5).

The city of Yakima is 135 km from Mt St Helens, with a population of around 50 000 and received about 10 mm of sand-sized ash on 18 May 1980. This caused the city to undertake a major clean-up operation and resulted in severe problems to its sewage system. During my 1995, visit meetings were held with officials from the City of Yakima and Bonneville Power Administration.

Prior to the eruption the city had made no provision for dealing with the possible impacts of ash fall despite the release of information and a warning from the USGS that Mount St Helens posed a significant threat (Crandell & Mullineaux 1978). Most officials spoken to had not received the published material describing the potential threat, until after the ash falls had occurred.

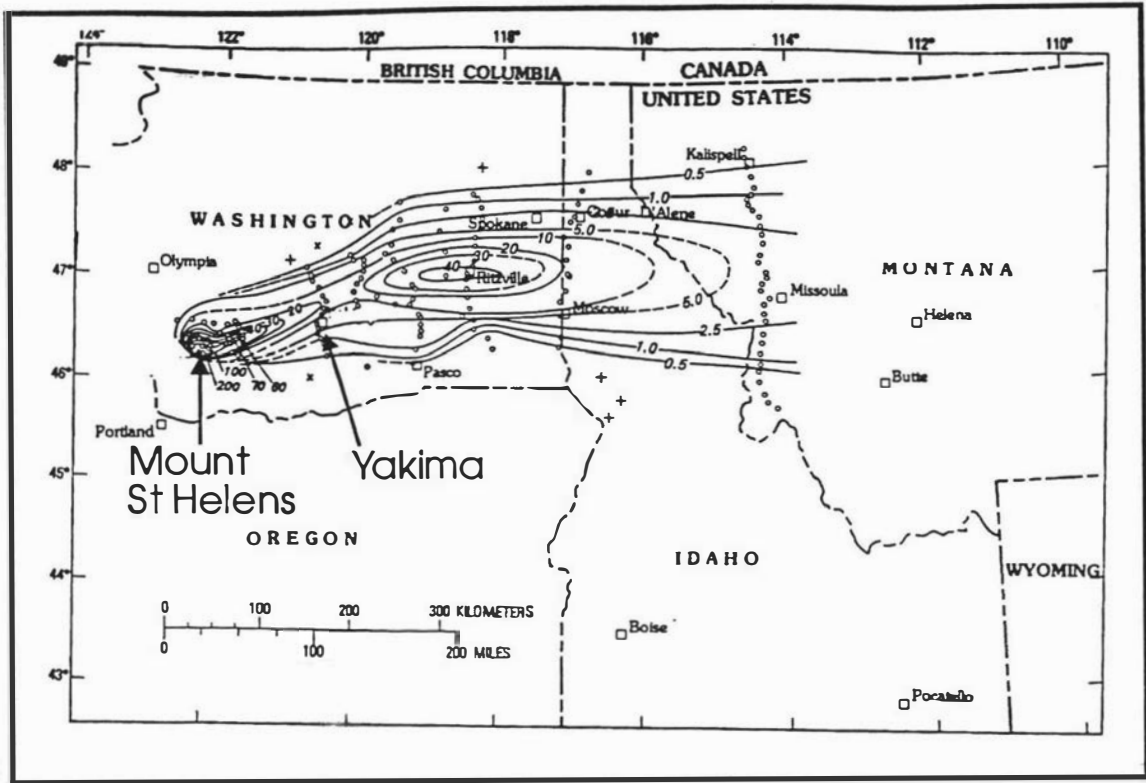


FIGURE A3.5 Isopach map (in centimetres) of ash falls from the 18 May 1980 Mount St Helens eruption (from Sama-Wojcicki *et al.* 1981).

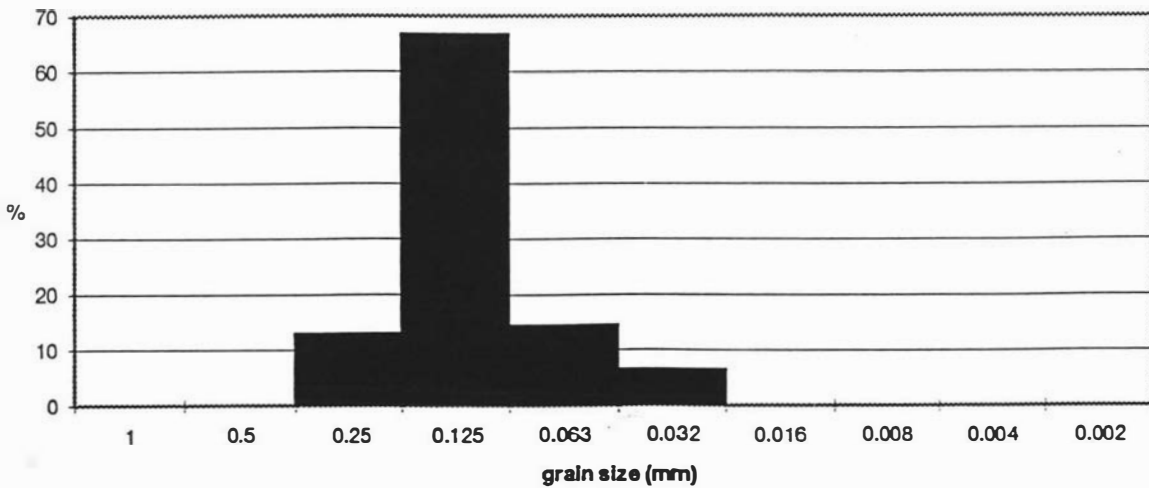


FIGURE A3.6 Grain size distribution for ash deposited on Yakima, 18 May 1980 (from Moen & McLucas 1980).

A3.5 IMPACTS OF VOLCANIC ASH ON PUBLIC UTILITIES IN YAKIMA

A3.5.1 Water supplies

The city of Yakima obtains its water from the Yakima River, along with a number of wells. During the ash falls there was concern that the water supply would fail. The public was advised to store water. Turbidity levels did rise in the Yakima River causing the river water plant to be shut down, and supplies were switched to wells. Wells were able to deliver adequate supplies until turbidity levels returned to acceptable levels. Subsequent clean-up operations drastically increased water demand. Unfortunately no water usage data was obtained during my visit.

A3.5.2 Sewerage

The day following the 18 May 1980 eruption 15 times the usual amount of solid matter was being removed from the pre-treatment process at the sewage plant. Ash was also observed in the sludge beyond this point. By the 20 May it was evident that the plant was suffering as vibrations were occurring in the grit classifier and the gear box of the mechanically cleaned bar screen (Day & Fisher 1980). Raw sludge lines became plugged and pumping difficulties were experienced. On 21 May the comminutor failed completely, the biofilters were virtually stripped of their growth and secondary treatment was curtailed. The sewage was then diverted to a sludge lagoon to bypass the treatment plant. Raw sewage was then pumped straight into the Yakima River. The total damage to the Yakima treatment plant was estimated at US\$4 million (White *et al.* 1980).

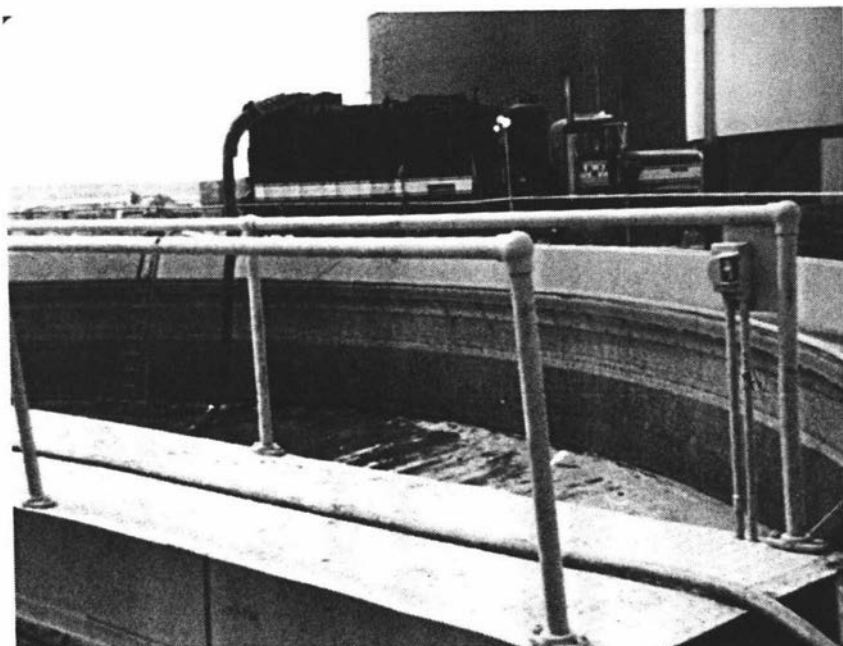


FIGURE A3.7 Ash being removed from the Yakima Sewage Treatment Plant
(*photograph: Public Works, City of Yakimay*)

A3.5.3 Ash removal

After the ash falls the city recruited people with equipment from within the county and beyond. Anyone with graders, loaders, trucks or belt-loaders (Fig. A3.9) was hired. The city was divided into sectors and the clean-up operation went on 24 hours a day, in two shifts and lasted three months. Ash was first dampened then graders were used to move the ash into windrows. Belt loaders were then used to pick up the ash which was then transported to dump sites. Sweepers and water trucks then went over cleaned areas again.

The CBD was closed off for a week while merchants cleaned ash off the buildings and carparks (Fig. A3.8). The area was heavily patrolled by the police department. The public were instructed to clean ash from their roofs and sections, and place it on the roadside (not into the stormwater system). Ash that was left on people's roofs eventually washed into gutters and often blocked down-pipes. Those who did not clean their roofs were sometimes confronted by angry neighbours when the wind blew ash beyond their properties.

Three major sites and several smaller dumps were used for disposal of ash removed from the 400 km of roads and paved areas. The largest dump (Fig. A3.10) contained 70 000 m³ and was covered by 50 mm of top soil, seeded with grass and had underground sprinklers installed to aid compaction. It is now used as a municipal park. The two other sites contained 26 000 m³ and 13 000 m³. The ash clean-up operation cost the city in excess of US\$ 2 million (Blong 1984) or US\$42.3 per capita. The amount of equipment and manpower used during the duration of the clean-up operation was at least ten times that used for normal maintenance (Novak & Zais 1981).



FIGURE A3.8 Ash-covered carpark in Yakima, May 1980. (*photograph: Public Works, City of Yakima*)



FIGURE A3.9 Belt-loader removing ash from a Yakima street, May 1980.
(photograph: Public Works, City of Yakima)

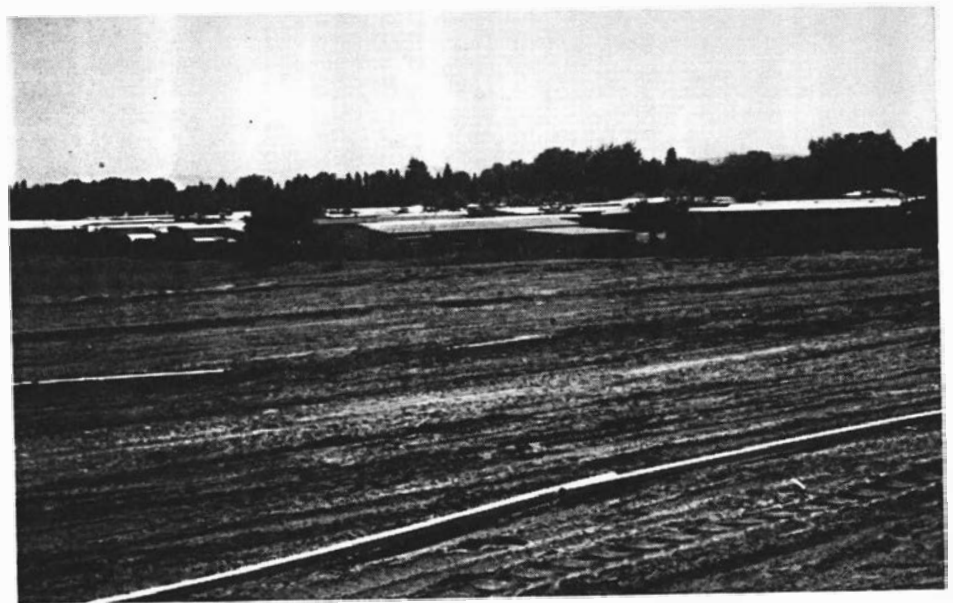


FIGURE A3.10 The largest dump containing 70 000 m³ prior to covering by 50 mm of top soil. Underground sprinklers were installed to aid compaction.
(photograph: Public Works, City of Yakima)

Lessons learnt included: (Joe Jackson, City of Yakima *pers comm.*):

- 1) *Don't panic or rush into the clean-up operation without thinking it through.*
- 2) *Have a good arrangement with contractors prior to a disaster so you know you can count on them when they are needed.*
- 3) *Develop a plan for the systematic clean-up of the city so those involved know what they have to do. Pre-planning can save a community a lot of problems.*
- 4) *The finer the ash the more problems you will have.*
- 5) *Keep good records.*

A3.5.4 Transportation

Volcanic ash falling on 18 May 1980 caused severe visibility problems on roads. The fallen ash continued to be raised by moving vehicles and a speed restriction of 10 mph was introduced in the city area. Residents were advised to drive only if it was really necessary. Up to 35 water tankers were used in the city to keep the ash damp prior to its removal.

There was much concern about the damage the abrasive ash was doing to vehicles and a strict maintenance programme was implemented on all City of Yakima vehicles. Every day during the ash clean-up operations vehicles had their air-filters changed and were greased. Oil and oil-filters were also changed regularly. No major damage was recorded.

A3.5.5 Electricity supplies

The distribution of electricity in the state of Washington is carried out by the Bonneville Power Administration (BPA), equivalent to New Zealand's TransPower. The BPA on-sells to local power companies. During the 1980 eruption of Mount St. Helens volcanic ash disrupted the electricity supplies of several communities in Washington State.

A meeting was held with Chuck Nellis of the Bonneville Power Administration, who in 1980 was a Supervisor in BPA's Division of Laboratories and involved in the testing and analysis of the effects of volcanic ash on their power system. Before and during the eruption there was a complete lack of knowledge on the affects of ash falls and much anxiety about the potential impacts. Investigation of the pattern of outages and follow up laboratory tests provide valuable lessons for assessing future impacts of ash falls on electricity supply and are summarised in Nellis and Hendrix (1980).

The impacts were largely dependent on the weather prevailing at the time. The main 18 May eruption occurred during dry weather and ash did not cause immediate problems except for a few short-duration outages and ash adhesion to horizontal surfaces. No outages were reported in Yakima although outages occurred a few days later in other areas that received rain. Later eruptions affected other parts of Washington. Ash falls from the smaller 25 May eruption occurred to the south-east of the volcano, accompanying rainfall. Low voltage lines and substations experienced numerous outages from insulator flashovers in areas of >5 mm ash thickness when the ash was wet. It was reported that a number of wooden electricity poles caught fire. The ash's conductivity was found to increase with decreasing grain size and the problem of insulator flashovers increased with distance from the volcano. The 12 June ash fell dry but later with rain caused outages.

FIGURE A3.11 How to prepare for and what to do during a volcanic ashfall

This brochure was delivered to every household in Yakima late in 1980. By the time it arrived residents had already learnt how to deal with the ash and there was considerable resentment towards FEMA for wasting tax dollars by providing this material so long after the event (Blong 1984).

FIGURE A3.12 ASH ALERT !!!! How to protect your family, home and business

This brochure was prepared by the Alaska Division of Emergency Services.

HOW TO PREPARE FOR AND WHAT TO DO DURING A

VOLCANIC ASHFALL



- **What Volcanic Ash is**
- **What to do when Ash is Falling**
- **How To Be Prepared for an Ashfall**
 - **Tips for Protection of your Children, your Home, your Pets and Animals, your Automobile.**

Federal Emergency Management Agency
Region X
Federal Regional Center
Bothell, WA 98011

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FEMA—625



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POSTAL PATRON—LOCAL



What is volcanic ash?

Volcanic ash is not "ash" at all. It is pulverized rock. A one-inch layer of dry ash weighs ten pounds per square foot as it lands. It often contains small pieces of light, expanded lava called pumice or cinders.

Fresh volcanic ash may be harsh, acid, gritty, glassy, smelly, and thoroughly unpleasant. Although gases are usually too diluted to constitute danger to a normal person, the combination of acidic gas and ash which may be present within a few miles of the eruption could cause lung damage to small infants, very old and infirm, or those already suffering from severe respiratory illnesses.

- **A heavy ashfall blots out light.** Sudden heavy demand for electric light may cause power supplies to "brown out" or fail.
- **Ash clogs water courses, reservoirs, sewers, sewage plants and machinery of all kinds.**
- **Ash drifts onto roadways, railways, and runways like snow,** but resembles soft wet sand.
- **Fine ash may be slippery.**
- **The weight of ash may cause roofs to collapse.**

What to do if Volcanic Ash is Falling

- Don't panic, stay calm.
- Stay indoors.
- If outside: seek shelter (e.g., car, building); use mask — or a handkerchief/cloth (dampened cloth most effective).
- If at work, go home if possible, before ash begins to fall. If ash is already falling, stay indoors at work if possible, until the heavy ash is settled.
- Go directly home, do not run errands.
- Unless an emergency, do not use the telephone.
- Use your radio for information on the ashfall.

How to be Prepared for an Ashfall

Whether in a car, at home, at work, or play you should always be prepared. Based on past Mount St. Helens volcanic activity, intermittent ashfalls may continue over several years.

Your Home

- Extra face masks. Check your local emergency services office for the nearest source.
- Food stored for two weeks.
- Water (one quart per day per person) in clean plastic containers.
- Medicines.
- First aid kit.
- Battery operated radio with extra batteries.**
- Candles, lanterns, or flashlight with extra batteries.**
- Extra wood, if you have a fireplace or wood stove.
- Extra blankets.
- Extra vacuum cleaner filters and cleaning supplies.

**Ash may interrupt telephone, T.V. and electricity.

Your Auto

Any vehicle can be considered a movable, second home. Always carry a few items in case of delays, emergencies, or mechanical failures.

- Face masks (should be coded "TC-21C").
- Blankets.
- Fire extinguisher.
- Extra clothing.
- Emergency food ration.
- First aid kit.
- Flashlight (extra batteries).
- Basic tool kit.
- Portable radio (extra batteries).
- Water.
- Shovel, axe.
- Road map.
- Matches, candle.
- Emergency flares.
- Waterproof tarp.
- Heavy rope or tow cable.
- Survival manual.
- Extra air filter.
- Extra oil filter.
- Extra oil.
- Extra windshield washer water.
- Window wiper blades in good condition.

Your Children

- Have quiet games and activities available.
- Explain what a volcano is and what they should expect.
- Teach children safety procedures if they are caught in an ashfall.
- Consider organizing a community or neighborhood day-care center to relieve economic and other stresses on working parents during ashfall clean-up, and to keep children in a cleaner environment.

Your Pets or Animals

- Extra dry and clean food.

What to do During an Ashfall

Your Home

- Close doors and windows.
- Close dampers
- Place damp towels at door thresholds and other draft sources.
- Do not run exhaust fans or clothes dryers.
- Remove ash from flat or low pitched roofs and from rain gutters to prevent thick accumulation.
- If you are engaged in ash clean-up, logging or farming activities, have your work clothes laundered at work or outside the home.
- If water source is contaminated, use clean stored water in your hot water heater or toilet tank (turn off main water valve). To purify water, use 10 drops of chlorine bleach per gallon of water. Let sit 30 minutes, or purify by boiling for 5 minutes.
- You may eat vegetables from the garden, but wash them off first. The grit is harmless.
- Dust often—using vacuum attachments rather than dust cloths, which may scratch.
- Vacuum furniture, carpets, etc. and try not to wipe as ash will scratch.
- Clothes—brush, shake, and pre-soak. Use detergent, not soap, as soap will gum up.
- Use extra detergent in washer.
- Use full load of water and two rinse cycles. Front loaders are more effective than top loaders.
- Keep refrigerator closed.
- Bagging lawn clippings and mowing lawns when damp will cut down on dust. Blades will dull faster.
- Use battery operated radio to receive information.

Your Auto

- If possible do not drive.
- If you must drive, drive slowly (15 mph). Remember ashfall will decrease visibility. Do not follow the car ahead too closely.
- Use windshield washer and wipers.
- Change air filter.**
- Change oil and oil filter.
 - Every 50 to 100 miles in heavy dust. (Less than 50 feet visibility.)
 - Every 500 to 1,000 miles in light dust. (Up to 200 feet visibility.)
- Do not drive without air filter.
- If car stalls, push it off the road to avoid collisions, and stay with the auto.

**Do not change air filter until you notice a loss of power in your car's engine. A dirty filter is more effective as long as it allows air to reach engine. If you cannot change air filter, clean by blowing air through from the inside out.

Note: Ash is abrasive rock, therefore it will clog engine, damage motor and scratch finish of auto.

Your Children

- Do not attempt to pick your children up at school. Schools will be notified of emergency procedures to take.
- Keep children indoors.
- Minimize exertion to reduce inhaling ash.
- If possible maintain normal routines for children.
- If prolonged ashfall—take children outside as weather conditions permit. (Use protective masks. Some approved masks which may be adjusted to fit children include: 3-M #8710, #6983 and #8550).

Your Pets or Animals

- Keep pets indoors.
- Get clean water to livestock as soon as possible.
- If pets go out, brush or vacuum them before letting them inside. Don't let them get wet or try to wash them.
- Keep extra dry and clean food available.

This brochure was prepared by the Federal Emergency Management Agency, Region X, Bothell, WA with the assistance of the Washington State Department of Emergency Services, Olympia, WA.

For more information

For details _____
on emergency response planning at the
state or local level, contact:

Alaska Division of Emergency Services
P.O. Box 5750
Fort Richardson, Alaska 99505-5750

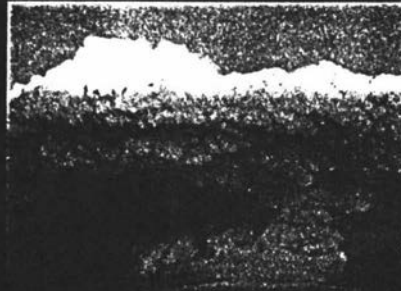
Phone 1-800-478-9525
or your local emergency management office.

Alaska Division of Emergency Services
P.O. Box 5750
Fort Richardson, Alaska 99505-5750



ASH ALERT!

Sharon & Jeff Dallman



Mt. Redoubt

**HOW TO PROTECT
YOUR FAMILY, HOME,
AND BUSINESS**

**More than half of all
Alaskans can be affected
by volcanoes.**

*Since 1700, at least 41 volcanoes
in Alaska have erupted, some of
these as many as 25 times.*

The Alaska Peninsula, Kodiak Island, Kenai Peninsula, and Cook Inlet areas are the most likely to be covered with volcanic ash, which is actually pulverized rock from the volcanic explosion.

Fresh volcanic ash may be harsh, acidic, gritty, and smell like sulphur. Heavy ashfall may reduce sunlight, causing a sudden demand and possibly brownouts of electrical power. Ash can clog watercourses, sewage plants, and all kinds of machinery. A one-inch layer of ash weighs ten pounds per square foot, and fine ash is extremely slippery, hampering both driving and walking.

*Ash can also damage the lungs of
small infants, the very old and infirm,
or those already suffering from
respiratory illnesses.*

Prepare ahead of time.

Checklist

Home

- ___ NIOSH-approved dust/mist respirators (coded TC-21C-XXX). Some will not fit children; check before buying.
- ___ Non-perishable food for two weeks
- ___ Water (1.5 gal/day/person) in clean plastic containers
- ___ Medicines and first aid kit
- ___ Battery operated radio and extra batteries
- ___ Extra pet food if applicable
- ___ Fire extinguisher

Auto

- ___ Dust/mist respirators
- ___ Glasses to replace contact lenses
- ___ Blankets
- ___ Fire extinguisher
- ___ Extra clothing
- ___ Emergency food ration
- ___ First aid kit and critical medication
- ___ Flashlight, extra batteries and bulbs
- ___ Basic tool kit
- ___ Portable radio and extra batteries
- ___ Shovel
- ___ Matches, candles, emergency flares
- ___ Heavy rope or tow cable
- ___ Extra air filter
- ___ Extra windshield washer fluid
- ___ Extra windshield wiper blades

Workplace

- ___ Large plastic bags to protect office equipment
- ___ Critical personal medication

Home Preparation

Store additional water if your water supply is vulnerable to power outages or contamination. Maintain a home emergency kit (see checklist).

During an Ashfall

- Stay indoors if possible.
- Close doors, windows, and dampers.
- Avoid burning woodstoves or fireplaces.
- Eliminate draft sources.
- Do not run exhaust fans or clothes dryers.
- Listen to your radio.
- Vacuum furniture, carpets, etc., and try not to wipe, as ash will scratch.
- Laundry-brush, shake, and presoak clothes. Use plenty of water and detergent; do not use soap as it tends to gum up.
- If you have been working in ashfall, have your work clothes laundered at work or outside the home.
- Cover and don't use personal computers, stereos, and other sensitive equipment.

After an Ashfall

- Wear a respirator during ash cleanup.
- Consider using goggles for eye protection.
- Remove heavy accumulations of ash from flat or low-pitched roofs and from rain gutters.
- When sweeping, dampen or sprinkle ash with "Industrial Sweep" to avoid raising unnecessary dust.
- Mow lawns when damp and bag lawn clippings to reduce dust.
- Replace items used from the emergency kit.

Publication of this brochure supported by funding under a grant from Federal Emergency Management Agency, Washington, D.C. 20472.

Family Preparation

Instruct family on emergency and safety procedures. Have quiet games and activities available. Consider organizing a community day care center to help working parents during ashfall clean-up and to keep children in a cleaner environment. Plan for sheltering pets and livestock.

During an Ashfall

- Stay indoors if possible.
- Keep children indoors.
- Minimize exertion to reduce inhaling ash.
- Do not attempt to pick your children up at school, unless directed to do so. Schools will be notified of emergency procedures to take.
- As much as possible, maintain normal routines for children.
- Use respirators if outdoors.
- If ashfall is prolonged, take children outside as weather conditions permit (use dust/mist respirators).
- If a person with heart or lung disease should experience symptoms, they should consult their physician.
- Use the telephone for emergencies only.
- Keep pets indoors as much as possible.
- Tightly restrict the outdoor movement of pets or livestock to reduce inhaling ash.
- Get clean water to livestock as soon as possible.
- If pets go out, brush or vacuum them before letting them back inside. Do not let them get wet or try to wash them.
- Keep extra dry and clean pet food available.

After an Ashfall

- Limit outdoor activities of children and pets until ash dust is no longer evident.

Auto Preparation

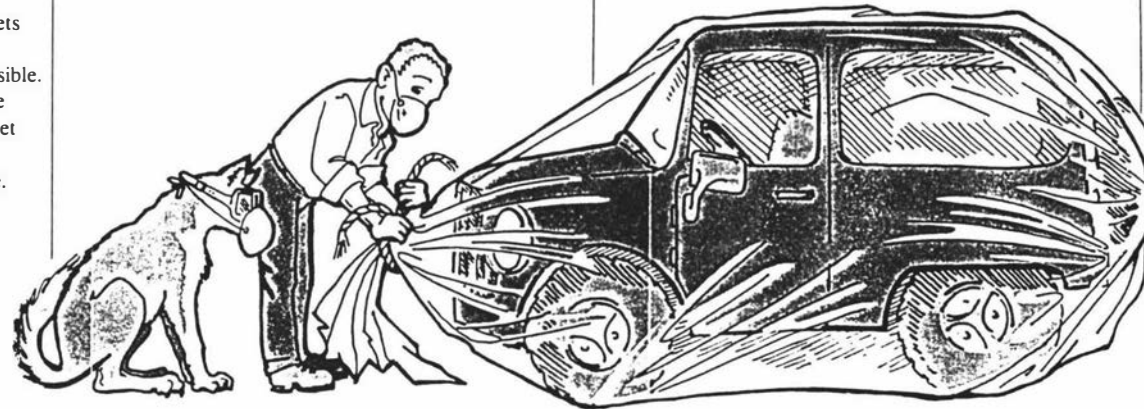
Maintain an auto emergency kit (see Checklist). Insure windshield wiper blades are in good condition.

During an Ashfall

- Do not drive unless absolutely necessary.
- If you must drive, drive slowly. Do not follow the car ahead too closely. Ash is slippery.
- Use your windshield washer system anytime you must use your wipers.
- Do not drive without an air filter.
- Change your air filter if you notice a loss of power in your car's engine.
- If car stalls, push it off the road to avoid collisions, and then stay inside the auto.

After an Ashfall

- Change oil and oil filter.
- Change air filter.
- Wash you car thoroughly with water to remove all ash.
- Replace any item used from the auto emergency kit.



Workplace Preparation

Become familiar with your employer's emergency plans. Encourage employers to have an early release policy to allow employees to get home before an ashfall occurs. Maintain a workplace emergency kit.

During an Ashfall

- Don't operate non-essential equipment.
- Protect office equipment such as copiers, fax machines, and personal computers as recommended by the manufacturer.
- Store computer diskettes inside sealed bags or containers.
- Go home, if possible, before ash begins to fall.
- If ash is already falling heavily, stay, or go indoors until the ash has stopped and settled.
- If it is not possible to go indoors, get into your car and go directly home.

After an Ashfall

- Clean up all ash before removing protective covers from office equipment.
- Replace items used from the emergency kit.

A3.6 REFERENCES

- Blong, R.J. 1984. *Volcanic Hazards: A sourcebook on the effects of eruptions*. Academic Press, Australia, 424 p.
- Casadevall, T.J, Krohn, M.D. 1995. Effects on airports and aviation in United States and Canada. In: Keith, T.C. (ed) 1995, The 1992 eruptions of Crater Peak vent, Mount Spurr volcano, Alaska. *U.S. Geological Survey Bulletin* 2139: 205-220.
- Crandell, D.R., Mullineaux, D.R. 1978. Potential hazards from future eruptions of Mount St. Helens volcano, Washington. *U.S. Geological Survey Bulletin* 1383-C.
- Day, T.G., Fisher, J.E. 1980. Mt. St Helens: How a wasteland coped with its aftermath. *Water Pollution Control Federal Journal*, 52(8): 2082-2089.
- Eichelberger, J.C., Keith, T.E.C., Miller, T.P., Nye, C.J. 1995. The 1992 eruptions of Crater Peak vent, Mount Spurr Volcano, Alaska: chronology and summary. In: Keith, T.C. (ed) 1995, The 1992 eruptions of Crater Peak vent, Mount Spurr volcano, Alaska. *U.S. Geological Survey Bulletin* 2139: 1-18.
- Keith, T.C. (ed) 1995. The 1992 eruptions of Crater Peak vent, Mount Spurr volcano, Alaska. *U.S. Geological Survey Bulletin* 2139.
- Lipman, P.W., Mullineaux, D.R. (eds.) 1981. The 1980 eruptions of Mount St. Helens, Washington. *U.S. Geological Survey Professional Paper* 1250.
- Moen, W.S., McLucas, G.B. 1980. Mount St. Helens ash - properties and possible uses. Washington Department of Natural Resources, Division of Geology and Earth Resources. *Report of Investigations* 24, 60p.
- Neal, C.A, McGimsey, R.G., Gardner, C.A., Harbin, M.L., Nye,C.J. 1995. Tephra-fall deposits from the 1992 eruptions of Crater Peak, Mount Spurr volcano, Alaska: a preliminary report on distribution, stratigraphy, and composition. In: Keith, T.C. (ed) 1995, The 1992 eruptions of Crater Peak vent, Mount Spurr volcano, Alaska. *U.S. Geological Survey Bulletin* 2139: 65-79.
- Nellis, C.A., Hendrix K.W. 1980. *Progress report on the investigation of volcanic ash fallout from Mount St Helens*. Laboratory Report ERJ-80-47. Bonneville Power Administration, U.S. Department of Energy.

- Novak, T., Zais, R. 1981. How to manage ash. *Public Management*, January-February. p. 12-15.
- Sarna-Wojcicki, A.M., Shipley, S., Waitt, R.B., Dzurisin, D., Wood, S.H., 1981. Areal distribution, thickness, mass, volume, and grain size of air-fall ash from the six major eruptions of 1980. In: Lipman, P.W., Mullineaux, D.R. (eds.) 1981. The 1980 eruptions of Mount St. Helens, Washington. *U.S. Geological Survey Professional Paper 1250*, 577-600.
- White, W.T., Day, T.G., Berbeck, D., Fisher, J., 1980. Mt. St. Helens volcanic ash vs. Yakima wastewater treatment facility. *Institute for Water Resources Newsletter*, 6(2), 4-8.
- Wright, T.L., Pierson, T.C. 1992. Living with volcanoes. *U.S. Geological Survey Circular 1073*.

APPENDIX 4

**THE 1995 WHAKATANE AND HASTINGS HAZARD PERCEPTION SURVEY
QUESTIONNAIRE**

CONTENTS

QUESTIONNAIRES

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SURVEY 1 QUESTIONNAIRE

Delivered to 450 households in Whakatane on 6 - 7 February 1995

Please circle the answer that best describes your situation or opinion.

1 How likely is it that the following natural hazards affecting the Bay of Plenty will seriously threaten your personal safety?

(Circle one selection in each row)

	extremely likely	very likely	50/50	very unlikely	extremely unlikely	don't know
Volcanic eruption	1	2	3	4	5	6
Earthquake	1	2	3	4	5	6
Flood	1	2	3	4	5	6
High winds	1	2	3	4	5	6
Landslides	1	2	3	4	5	6
Scrub or forest fire	1	2	3	4	5	6

2 How likely is it that the following natural hazards affecting the Bay of Plenty will seriously disrupt your daily life? (e.g. work, leisure, property)

(Circle one selection in each row)

	extremely likely	very likely	50/50	very unlikely	extremely unlikely	don't know
Volcanic eruption	1	2	3	4	5	6
Earthquake	1	2	3	4	5	6
Flood	1	2	3	4	5	6
High winds	1	2	3	4	5	6
Landslides	1	2	3	4	5	6
Scrub or forest fire	1	2	3	4	5	6

3 In the Bay of Plenty which of the following natural hazards is most likely to seriously threaten your personal safety? (Circle only one)

- 1 . . . Volcanic eruption
- 2 . . . Earthquake
- 3 . . . Flood
- 4 . . . High winds
- 5 . . . Landslides
- 6 . . . Scrub or forest fire

4 Please indicate the extent to which you agree or disagree with the following statement.

"The threat to the regional economy or environment from volcanic eruptions affecting the Bay of Plenty is over-rated".

1 ----- 2 ----- 3 ----- 4 ----- 5
 strongly agree agree neutral disagree strongly disagree

5 How prepared do you think central government and officials (e.g. Ministry of Civil Defence) are for a volcanic eruption affecting the Bay of Plenty ?

1 ----- 2 ----- 3 ----- 4
very somewhat not very not prepared
prepared prepared prepared at all

6 How prepared do you think the local/regional government and public officials (e.g. local/regional Civil Defence, Police, Fire Service) are for a volcanic eruption affecting the Bay of Plenty ?

1 ----- 2 ----- 3 ----- 4
very somewhat not very not prepared
prepared prepared prepared at all

7 How prepared do you think other people in your community are for a volcanic eruption affecting the Bay of Plenty ?

1 ----- 2 ----- 3 ----- 4
very somewhat not very not prepared
prepared prepared prepared at all

8 How prepared do you think you are for a volcanic eruption affecting the Bay of Plenty ?

1 ----- 2 ----- 3 ----- 4
very somewhat not very not prepared
prepared prepared prepared at all

9 Have you undertaken any protective measures in view of any possible natural hazards?

- 1 No (Go to question 10)
- 2 Yes (Circle all that apply)

- 1 . . . Purchased insurance.
- 2 . . . Planned evacuation route and place to stay.
- 3 . . . Obtained-battery operated radio for emergency use.
- 4 . . . Maintained emergency supply of food and water.
- 5 . . . Other, specify _____

10 During the 1886 eruption of Mount Tarawera how much volcanic ash do you think fell on Whakatane? (*Circle only one*)

- 1 . . . None
- 2 . . . Less than 1 centimetre (< 1 cm)
- 3 . . . Between 1 and 5 centimetres (1 - 5 cm)
- 4 . . . Between 5 and 10 centimetres (5 - 10 cm)
- 5 . . . More than 10 centimetres (> 10 cm)
- 6 . . . Don't know

11 In 1991 the Ministry of Civil Defence issued a booklet entitled "Volcanic Hazards at Okataina Volcanic Centre" (Volcanic Hazards Information Series - yellow booklet). Do you have a copy ? (Obtainable from your local Civil Defence organisation).

- 1 No (go to question 13)
- 2 Yes

12 How did you obtain a copy ? (*Circle only one*)

- 1 . . . I picked it up from the library or other public place.
- 2 . . . It was given to me by Civil Defence officials
- 3 . . . It was given out at a school
- 4 . . . Don't know
- 5 . . . Other, specify _____

13 In the past year, have you asked anyone for information about volcanic hazards in the Bay of Plenty ?

- 1 No (go to question 14)
- 2 Yes (Please circle all that apply)

- 1 . . . Schools
- 2 . . . Friends, neighbours, or relatives
- 3 . . . Institute of Geological and Nuclear Sciences (formerly DSIR)
- 4 . . . District Council Officials (includes District Civil Defence)
- 5 . . . Regional Council Officials (includes Regional Civil Defence)
- 6 . . . Ministry of Civil Defence Officials
- 7 . . . Police
- 8 . . . Other, specify _____

14 In general, what **single source** do you consider the best (i.e. trustworthy and reliable) for information about protecting yourself from volcanic hazards in the Bay of Plenty ?

- 1 . . . Institute of Geological and Nuclear Sciences (formerly DSIR)
- 2 . . . District Councils (includes District Civil Defence)
- 3 . . . Regional Councils (includes Regional Civil Defence)
- 4 . . . Ministry of Civil Defence
- 5 . . . Police
- 6 . . . Other, specify _____

15 In your opinion, what is the most effective way for officials to give out information about volcanic hazards that may occur in the future? (*Circle only one*)

- 1 . . . Public meetings
- 2 . . . Telephone
- 3 . . . Send information by post
- 4 . . . Television announcements
- 5 . . . Radio announcements
- 6 . . . Newspaper articles or announcements
- 7 . . . Other, specify _____

Finally, could you please provide us with some background information about yourself.

16 In what year were you born ? 19_____

17 How many years have you lived in the Bay of Plenty Region? _____

18 Into which category does your household belong? (*Circle only one*)

- 1 . . . Family with children
- 2 . . . Family without children
- 3 . . . Non-family
- 4 . . . Live alone
- 5 . . . Other, specify _____

19 What ethnic group do you belong to ? (*Circle only one*)

- 1 . . . New Zealander of Maori descent
- 2 . . . New Zealander of European descent
- 3 . . . New Zealander of Pacific Island descent
- 4 . . . Other, specify _____

20 What is your highest educational qualification ? (*Circle only one*)

- 1 . . . No school qualifications
- 2 . . . School certificate passes
- 3 . . . School qualifications, University Entrance and above
- 4 . . . Trade certificate or professional certificate or diploma
- 5 . . . University degree, diploma or certificate

21 In which range is your present personal gross income (excluding your partner's salary &/or benefits) (*Circle only one*)

- 1 . . . less than \$15,000
- 2 . . . \$15,001 - \$20,000
- 3 . . . \$20,001 - \$30,000
- 4 . . . \$30,001 - \$40,000
- 5 . . . \$40,001 - \$50,000
- 6 . . . \$50,001 - \$60,000
- 7 . . . over \$60,000
- 8 . . . don't know

22 What is your current employment status ? (*Circle only one*)

- 1 . . . Employed full-time
- 2 . . . Employed part time
- 3 . . . Not in paid employment (Unemployed/Retired/On a benefit)

SURVEY 1 QUESTIONNAIRE

Delivered to 450 households in Hastings on 6 - 7 February 1995

Please circle the answer that best describes your situation or opinion.

1 How likely is it that the following natural hazards affecting the Hawkes Bay will seriously threaten your personal safety?

(Circle one selection in each row)

	extremely likely	very likely	50/50	very unlikely	extremely unlikely	don't know
Volcanic eruption	1	2	3	4	5	6
Earthquake	1	2	3	4	5	6
Flood	1	2	3	4	5	6
High winds	1	2	3	4	5	6
Landslides	1	2	3	4	5	6
Scrub or forest fire	1	2	3	4	5	6

2 How likely is it that the following natural hazards affecting the Hawkes Bay will seriously disrupt your daily life in the future? (eg work, leisure, property)

(Circle one selection in each row)

	extremely likely	very likely	50/50	very unlikely	extremely unlikely	don't know
Volcanic eruption	1	2	3	4	5	6
Earthquake	1	2	3	4	5	6
Flood	1	2	3	4	5	6
High winds	1	2	3	4	5	6
Landslides	1	2	3	4	5	6
Scrub or forest fire	1	2	3	4	5	6

3 In the Hawkes Bay which of the following natural hazards has the highest probability of seriously threatening your personal safety? (Circle only one)

- 1 . . . Volcanic eruption
- 2 . . . Earthquake
- 3 . . . Flood
- 4 . . . High winds
- 5 . . . Landslides
- 6 . . . Scrub or forest fire

4 Please indicate the extent to which you agree or disagree with the following statement.

"The threat to the regional economy or environment from volcanic eruptions affecting the Hawkes Bay is over-rated".

1 ----- 2 ----- 3 ----- 4 ----- 5
 strongly agree agree neutral disagree strongly disagree

5 How prepared do you think central government and officials (e.g. Ministry of Civil Defence) are for a volcanic eruption affecting the Hawkes Bay ?

1 ----- 2 ----- 3 ----- 4
very somewhat not very not prepared
prepared prepared prepared at all

6 How prepared do you think the local/regional government and public officials (e.g. local/regional Civil Defence, Police, Fire Service) are for a volcanic eruption affecting the Hawkes Bay?

1 ----- 2 ----- 3 ----- 4
very somewhat not very not prepared
prepared prepared prepared at all

7 How prepared do you think other people in your community are for a volcanic eruption affecting the Hawkes Bay ?

1 ----- 2 ----- 3 ----- 4
very somewhat not very not prepared
prepared prepared prepared at all

8 How prepared do you think you are for a volcanic eruption affecting the Hawkes Bay ?

1 ----- 2 ----- 3 ----- 4
very somewhat not very not prepared
prepared prepared prepared at all

9 Have you undertaken any protective measures in view of any possible natural hazards?

- 1 No (Go to question 10)
- 2 Yes (Circle all that apply)

- 1 . . . Purchased insurance.
- 2 . . . Planned evacuation route and place to stay.
- 3 . . . Obtained-battery operated radio for emergency use.
- 4 . . . Maintained emergency supply of food and water.
- 5 . . . Other, specify _____

10 When was the last time volcanic ash fell on the Hawkes Bay? (*Circle only one*)

- 1 . . . In the past 10 years
- 2 . . . In the past 20 years
- 3 . . . In the past 50 years
- 4 . . . In the past 100 years
- 5 . . . In the past 500 years
- 6 . . . Never
- 7 . . . Don't know

- 11 The Hawkes Bay Regional Civil Defence Organisation publishes the "Civil Defender" (booklet) annually. Do you have a copy ?
- 1 No (go to question 13)
 - 2 Yes
- 12 How did you obtain a copy ? (*Circle only one*)
- 1 ... I picked it up from the library or other public place.
 - 2 ... It was given to me by Civil Defence officials
 - 3 ... It was given out at a school
 - 4 ... Don't know
 - 5 ... Other, specify _____
- 13 In the past year, have you asked anyone for information about volcanic hazards in the Hawkes Bay ?
- 1 No (go to question 14)
 - 2 Yes (Please circle all that apply)
- 1 ... Schools
 - 2 ... Friends, neighbours, or relatives
 - 3 ... Institute of Geological and Nuclear Sciences (formerly DSIR)
 - 4 ... District Council Officials (includes District Civil Defence)
 - 5 ... Regional Council Officials (includes Regional Civil Defence)
 - 6 ... Ministry of Civil Defence Officials
 - 7 ... Police
 - 8 ... Other, specify _____
- 14 In general, what **single source** do you consider the best (i.e. trustworthy and reliable) for information about protecting yourself from volcanic hazards in the Hawkes Bay ?
- 1 ... Institute of Geological and Nuclear Sciences (formerly DSIR)
 - 2 ... District Councils (includes District Civil Defence)
 - 3 ... Regional Councils (includes Regional Civil Defence)
 - 4 ... Ministry of Civil Defence
 - 5 ... Police
 - 6 ... Other, specify _____
- 15 In your opinion, what is the most effective way for officials to give out information about volcanic hazards that may occur in the future? (*Circle only one*)
- 1 ... Public meetings
 - 2 ... Telephone
 - 3 ... Send information by post
 - 4 ... Television announcements
 - 5 ... Radio announcements
 - 6 ... Newspaper articles or announcements
 - 7 ... Other, specify _____

Finally, could you please provide us with some background information about yourself.

16 In what year were you born ? 19_____

17 How many years have you lived in the Hawkes Bay Region? _____

18 Into which category does your household belong? (*Circle only one*)

- 1 ... Family with children
- 2 ... Family without children
- 3 ... Non-family
- 4 ... Live alone
- 5 ... Other, specify _____

19 What ethnic group do you belong to ? (*Circle only one*)

- 1 ... New Zealander of Maori descent
- 2 ... New Zealander of European descent
- 3 ... New Zealander of Pacific Island descent
- 4 ... Other, specify _____

20 What is your highest educational qualification ? (*Circle only one*)

- 1 ... No school qualifications
- 2 ... School certificate passes
- 3 ... School qualifications, University Entrance and above
- 4 ... Trade certificate or professional certificate or diploma
- 5 ... University degree, diploma or certificate

21 In which range is your present personal gross income (excluding your partner's salary &/or benefits) (*Circle only one*)

- 1 ... less than \$15,000
- 2 ... \$15,001 - \$20,000
- 3 ... \$20,001 - \$30,000
- 4 ... \$30,001 - \$40,000
- 5 ... \$40,001 - \$50,000
- 6 ... \$50,001 - \$60,000
- 7 ... over \$60,000
- 8 ... don't know

22 What is current employment status ? (*Circle only one*)

- 1 ... Employed full-time
- 2 ... Employed part time
- 3 ... Not in paid employment (Unemployed/Retired/On a benefit)

SURVEY 2 QUESTIONNAIRE

Posted to 450 households in Whakatane on 13-14 November 1995

Please circle the answer that best describes your situation or opinion.

- 1 How likely is it that the following natural hazards affecting the Bay of Plenty will seriously threaten your personal safety?

(Circle one selection in each row)

	extremely likely	very likely	50/50	very unlikely	extremely unlikely	don't know
Volcanic eruption	1	2	3	4	5	6
Earthquake	1	2	3	4	5	6
Flood	1	2	3	4	5	6
High winds	1	2	3	4	5	6
Landslides	1	2	3	4	5	6
Scrub or forest fire	1	2	3	4	5	6

- 2 How likely is it that the following natural hazards affecting the Bay of Plenty will seriously disrupt your daily life? (e.g. work, leisure, property)

(Circle one selection in each row)

	extremely likely	very likely	50/50	very unlikely	extremely unlikely	don't know
Volcanic eruption	1	2	3	4	5	6
Earthquake	1	2	3	4	5	6
Flood	1	2	3	4	5	6
High winds	1	2	3	4	5	6
Landslides	1	2	3	4	5	6
Scrub or forest fire	1	2	3	4	5	6

- 3 In the Bay of Plenty which of the following natural hazards is most likely to seriously threaten your personal safety? (Circle only one)

- 1 . . . Volcanic eruption
- 2 . . . Earthquake
- 3 . . . Flood
- 4 . . . High winds
- 5 . . . Landslides
- 6 . . . Scrub or forest fire

- 4 Please indicate the extent to which you agree or disagree with the following statement.

"The threat to the regional economy or environment from volcanic eruptions affecting the Bay of Plenty is over-rated".

1 ----- 2 ----- 3 ----- 4 ----- 5
 strongly agree agree neutral disagree strongly disagree

5 How prepared do you think central government and officials (e.g. Ministry of Civil Defence) are for a volcanic eruption affecting the Bay of Plenty ?

1 ----- 2 ----- 3 ----- 4
very somewhat not very not prepared
prepared prepared prepared at all

6 How prepared do you think the local/regional government and public officials (e.g. local/regional Civil Defence, Police, Fire Service) are for a volcanic eruption affecting the Bay of Plenty ?

1 ----- 2 ----- 3 ----- 4
very somewhat not very not prepared
prepared prepared prepared at all

7 How prepared do you think other people in your community are for a volcanic eruption affecting the Bay of Plenty ?

1 ----- 2 ----- 3 ----- 4
very somewhat not very not prepared
prepared prepared prepared at all

8 How prepared do you think you are for a volcanic eruption affecting the Bay of Plenty ?

1 ----- 2 ----- 3 ----- 4
very somewhat not very not prepared
prepared prepared prepared at all

9 Have you undertaken any protective measures in view of any possible natural hazards?

- 1 No (Go to question 10)
- 2 Yes (Circle all that apply)

- 1 ... Purchased insurance.
- 2 ... Planned evacuation route and place to stay.
- 3 ... Obtained-battery operated radio for emergency use.
- 4 ... Maintained emergency supply of food and water.
- 5 ... Other, specify _____

10 During the 1886 eruption of Mount Tarawera how much volcanic ash do you think fell on Whakatane? (*Circle only one*)

- 1 ... None
- 2 ... Less than 1 centimetre (< 1 cm)
- 3 ... Between 1 and 5 centimetres (1 - 5 cm)
- 4 ... Between 5 and 10 centimetres (5 - 10 cm)
- 5 ... More than 10 centimetres (> 10 cm)
- 6 ... Don't know

- 11 In 1991 the Ministry of Civil Defence issued a booklet entitled "Volcanic Hazards at Okataina Volcanic Centre" (Volcanic Hazards Information Series - yellow booklet). Do you have a copy ? (Obtainable from your local Civil Defence organisation).
- 1 No (go to question 13)
 - 2 Yes
- 12 How did you obtain a copy ? (*Circle only one*)
- 1 . . . I picked it up from the library or other public place.
 - 2 . . . It was given to me by Civil Defence officials
 - 3 . . . It was given out at a school
 - 4 . . . Don't know
 - 5 . . . Other, specify _____
- 13 In the past year, have you asked anyone for information about volcanic hazards in the Bay of Plenty ?
- 1 No (go to question 14)
 - 2 Yes (Please circle all that apply)
- 1 . . . Schools
 - 2 . . . Friends, neighbours, or relatives
 - 3 . . . Institute of Geological and Nuclear Sciences (formerly DSIR)
 - 4 . . . District Council Officials (includes District Civil Defence)
 - 5 . . . Regional Council Officials (includes Regional Civil Defence)
 - 6 . . . Ministry of Civil Defence Officials
 - 7 . . . Police
 - 8 . . . Other, specify _____
- 14 In general, what **single source** do you consider the best (i.e. trustworthy and reliable) for information about protecting yourself from volcanic hazards in the Bay of Plenty ?
- 1 . . . Institute of Geological and Nuclear Sciences (formerly DSIR)
 - 2 . . . District Councils (includes District Civil Defence)
 - 3 . . . Regional Councils (includes Regional Civil Defence)
 - 4 . . . Ministry of Civil Defence
 - 5 . . . Police
 - 6 . . . Other, specify _____
- 15 In your opinion, what is the most effective way for officials to give out information about volcanic hazards that may occur in the future? (*Circle only one*)
- 1 . . . Public meetings
 - 2 . . . Telephone
 - 3 . . . Send information by post
 - 4 . . . Television announcements
 - 5 . . . Radio announcements
 - 6 . . . Newspaper articles or announcements
 - 7 . . . Other, specify _____

Part B

16 From what sources did you receive information on the potential impact of the 1995 Ruapehu eruption? (*Circle all that apply*)

- 1 . . . Television
- 2 . . . Radio
- 3 . . . Newspapers
- 4 . . . District Council (Local Civil Defence)
- 5 . . . Regional Council (Regional Civil Defence)
- 6 . . . Ministry of Civil Defence
- 7 . . . Institute of Geological & Nuclear Sciences
- 8 . . . Other, specify _____

17 Has the 1995 volcanic activity at Ruapehu changed your views on the possible volcanic threat to the region ?

- 1 . . . No (go to question 19)
- 2 . . . Yes (go to question 18)

18 What factors have caused this change in your views? (*Circle all that apply*)

- 1 . . . Information provided by the media
- 2 . . . Information provided by Civil Defence, GNS or others agencies
- 3 . . . The ashfalls and their impacts
- 4 . . . Acid rain and sulphur dioxide smell
- 5 . . . Other, specify _____

19 In what year were you born ? 19_____

--	--

20 How many years have you lived in the Bay of Plenty Region? _____

--	--

21 Are you ?

- 1 . . . Male
- 2 . . . Female

22 Did you complete the first questionnaire in March 1995 ?

- 1 . . . Yes
- 2 . . . No

You only need to complete the remaining questions if you did not complete the March 1995 questionnaire.

23 Into which category does your household belong? (*Circle only one*)

- 1 . . . Family with children
- 2 . . . Family without children
- 3 . . . Non-family
- 4 . . . Live alone
- 5 . . . Other, specify _____

24 What ethnic group do you belong to ? (*Circle only one*)

- 1 . . . New Zealander of Maori descent
- 2 . . . New Zealander of European descent
- 3 . . . New Zealander of Pacific Island descent
- 4 . . . Other, specify _____

25 What is your highest educational qualification ? (*Circle only one*)

- 1 . . . No school qualifications
- 2 . . . School certificate passes
- 3 . . . School qualifications, University Entrance and above
- 4 . . . Trade certificate or professional certificate or diploma
- 5 . . . University degree, diploma or certificate

26 In which range is your present personal gross income (excluding your partner's salary &/or benefits) (*Circle only one*)

- 1 . . . less than \$15,000
- 2 . . . \$15,001 - \$20,000
- 3 . . . \$20,001 - \$30,000
- 4 . . . \$30,001 - \$40,000
- 5 . . . \$40,001 - \$50,000
- 6 . . . \$50,001 - \$60,000
- 7 . . . over \$60,000
- 8 . . . don't know

27 What is current employment status ? (*Circle only one*)

- 1 . . . Employed full-time
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SURVEY 2 QUESTIONNAIRE

Posted to 450 households in Hastings on 13-14 November 1995

Please circle the answer that best describes your situation or opinion.

- 1 How likely is it that the following natural hazards affecting the Hawkes Bay will seriously threaten your personal safety?

(Circle one selection in each row)

	extremely likely	very likely	50/50	very unlikely	extremely unlikely	don't know
Volcanic eruption	1	2	3	4	5	6
Earthquake	1	2	3	4	5	6
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High winds	1	2	3	4	5	6
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Scrub or forest fire	1	2	3	4	5	6

- 2 How likely is it that the following natural hazards affecting the Hawkes Bay will seriously disrupt your daily life in the future? (eg work, leisure, property)

(Circle one selection in each row)

	extremely likely	very likely	50/50	very unlikely	extremely unlikely	don't know
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High winds	1	2	3	4	5	6
Landslides	1	2	3	4	5	6
Scrub or forest fire	1	2	3	4	5	6

- 3 In the Hawkes Bay which of the following natural hazards has the highest probability of seriously threatening your personal safety? (Circle only one)

- 1 ... Volcanic eruption
- 2 ... Earthquake
- 3 ... Flood
- 4 ... High winds
- 5 ... Landslides
- 6 ... Scrub or forest fire

- 4 Please indicate the extent to which you agree or disagree with the following statement.

"The threat to the regional economy or environment from volcanic eruptions affecting the Hawkes Bay is over-rated".

1 ----- 2 ----- 3 ----- 4 ----- 5
 strongly agree agree neutral disagree strongly disagree

5 How prepared do you think central government and officials (e.g. Ministry of Civil Defence) are for a volcanic eruption affecting the Hawkes Bay ?

1 ----- 2 ----- 3 ----- 4
very somewhat not very not prepared
prepared prepared prepared at all

6 How prepared do you think the local/regional government and public officials (e.g. local/regional Civil Defence, Police, Fire Service) are for a volcanic eruption affecting the Hawkes Bay?

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very somewhat not very not prepared
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7 How prepared do you think other people in your community are for a volcanic eruption affecting the Hawkes Bay ?

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- 1 No (Go to question 10)
2 Yes (Circle all that apply)

- 1 ... Purchased insurance.
2 ... Planned evacuation route and place to stay.
3 ... Obtained-battery operated radio for emergency use.
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10 When was the last time volcanic ash fell on the Hawkes Bay? (*Circle only one*)

- 1 ... In the past 10 years
2 ... In the past 20 years
3 ... In the past 50 years
4 ... In the past 100 years
5 ... In the past 500 years
6 ... Never
7 ... Don't know

11 The Hawkes Bay Regional Civil Defence Organisation publishes the "Civil Defender" (booklet) annually. Do you have a copy ?

- 1 No (go to question 13)
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12 How did you obtain a copy ? (*Circle only one*)

- 1 ... I picked it up from the library or other public place.
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13 In the past year, have you asked anyone for information about volcanic hazards in the Hawkes Bay ?

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14 In general, what **single source** do you consider the best (i.e. trustworthy and reliable) for information about protecting yourself from volcanic hazards in the Hawkes Bay ?

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- 5 ... Police
- 6 ... Other, specify _____

15 In your opinion, what is the most effective way for officials to give out information about volcanic hazards that may occur in the future? (*Circle only one*)

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- 2 ... Telephone
- 3 ... Send information by post
- 4 ... Television announcements
- 5 ... Radio announcements
- 6 ... Newspaper articles or announcements
- 7 ... Other, specify _____

Part B

16 From what sources did you receive information on the potential impact of the 1995 Ruapehu eruption? (*Circle all that apply*)

- 1 . . . Television
- 2 . . . Radio
- 3 . . . Newspapers
- 4 . . . District Council (Local Civil Defence)
- 5 . . . Regional Council (Regional Civil Defence)
- 6 . . . Ministry of Civil Defence
- 7 . . . Institute of Geological & Nuclear Sciences
- 8 . . . Other, specify _____

17 Has the 1995 volcanic activity at Ruapehu changed your views on the possible volcanic threat to the region ?

- 1 . . . No (go to question 19)
- 2 . . . Yes (go to question 18)

18 What factors have caused this change in your views? (*Circle all that apply*)

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- 2 . . . Information provided by Civil Defence, GNS or others agencies
- 3 . . . The ashfalls and their impacts
- 4 . . . Acid rain and sulphur dioxide smell
- 5 . . . Other, specify _____

19 In what year were you born ? 19 _____

--	--

20 How many years have you lived in the Hawkes Bay Region? _____

--	--

21 Are you ?

- 1 . . . Male
- 2 . . . Female

22 Did you complete the first questionnaire in March 1995 ?

- 1 . . . Yes
- 2 . . . No

You only need to complete the remaining questions if you did not complete the March 1995 questionnaire.

23 Into which category does your household belong? (*Circle only one*)

- 1 . . . Family with children
- 2 . . . Family without children
- 3 . . . Non-family
- 4 . . . Live alone
- 5 . . . Other, specify _____

24 What ethnic group do you belong to ? (*Circle only one*)

- 1 . . . New Zealander of Maori descent
- 2 . . . New Zealander of European descent
- 3 . . . New Zealander of Pacific Island descent
- 4 . . . Other, specify _____

25 What is your highest educational qualification ? (*Circle only one*)

- 1 . . . No school qualifications
- 2 . . . School certificate passes
- 3 . . . School qualifications, University Entrance and above
- 4 . . . Trade certificate or professional certificate or diploma
- 5 . . . University degree, diploma or certificate

26 In which range is your present personal gross income (excluding your partner's salary &/or benefits) (*Circle only one*)

- 1 . . . less than \$15,000
- 2 . . . \$15,001 - \$20,000
- 3 . . . \$20,001 - \$30,000
- 4 . . . \$30,001 - \$40,000
- 5 . . . \$40,001 - \$50,000
- 6 . . . \$50,001 - \$60,000
- 7 . . . over \$60,000
- 8 . . . don't know

27 What is current employment status ? (*Circle only one*)

- 1 . . . Employed full-time
- 2 . . . Employed part time
- 3 . . . Not in paid employment (Unemployed/Retired/On a benefit)

EXAMPLE OF ACCOMPANYING LETTERS

LETTER 1

The letter that accompanied survey 1 in Hastings. The same format was used for Whakatane.

LETTER 2

The letter that accompanied survey 2 in Hastings. The same format was used for Whakatane.

LETTER 3

The letter sent to all non-responding households one week after delivery of the questionnaires.



**MASSEY
UNIVERSITY**

Private Bag 11222
Palmerston North
New Zealand
Telephone 0-6-356 9099
Facsimile 0-6-350 5632

**FACULTY OF
AGRICULTURAL
AND
HORTICULTURAL
SCIENCES**

DEPARTMENT OF
SOIL SCIENCE

INFORMATION TO PARTICIPANTS

Dear Hastings District Resident:

The Department of Soil Science at Massey University, Palmerston North is conducting a study of natural hazards in New Zealand. Findings from the study will help your community better prepare for civil defence emergencies. Your household has been randomly selected from the households in the District to take part in this very important study. We would like to seek your active participation in helping us with the survey.

To learn about the views of Hastings District's residents, we need responses from many different types of people - women and men, young and old. In your household, the person we would like to complete this questionnaire is the adult (age 18 or older) who most recently had a birthday.

Because there have only been 500 households selected in the Hastings District, we hope you will take part in the study and return the questionnaire within the next week. It should only take 10 minutes or so of your time to complete. The overall findings will be made available to your regional council and a summary will be given to your community newspaper. We hope you are able to assist us because your views are very important to the success of the study.

All answers will be confidential. Filling in the questionnaire implies informed consent and participants have the right not to answer all questions. When you have completed the questionnaire, please put it in the enclosed envelope and post in any mail box. No stamp is required to return it to us.

May we thank you in advance for your willingness to take part in this study.

David Johnston
Doctoral Research Student

Vince Neall
Associate Professor

P.S.

Please do not hesitate to contact David Johnston (phone (06) 356 9099 extn 7414) if you have any queries about this questionnaire.



INFORMATION TO PARTICIPANTS

Dear Hastings Resident:

In March this year a member of your household kindly completed a questionnaire as part of your natural hazards study. The response to the survey was very high. The eruption of Ruapehu this year, which followed so closely after the survey, has created a unique opportunity to see how the 1995 eruption has changed people's views. We are hoping to repeat the survey as soon as possible. As far as we can tell this is a unique possibility around the world.

To learn this we would like the person who completed the first questionnaire to complete a second one. If that person is unavailable we would like the adult (over 18 years old) who has most recently had a birthday to complete the questionnaire.

We hope you are able to assist us because your views are important. All answers will be confidential. When you have completed the questionnaire, please put it in the enclosed envelope and post in any mail box. No stamp is required to return to us.

May we thank you in advance for your willingness to take part in this study.

David Johnston

David Johnston
Doctoral Research Student

P.S.

Please do not hesitate to contact me (phone (06) 356 9099 ex 7166) if you have any queries about the questionnaire.

Facsimile



**MASSEY
UNIVERSITY**

Private Bag 11222
Palmerston North
New Zealand
Telephone 0-6-350 9000



Dear Householder:

Recently you received a questionnaire as part of a natural hazards study being undertaken by the Department of Soil Science at Massey University, Palmerston North. Findings from the study will help your community better prepare for civil defence emergencies.

If you have already completed and returned the questionnaire we would like to take this opportunity to thank you. If not, we hope you will be able to assist us by taking part in the survey and returning the questionnaires.

Thank you for your willingness to take part in this study.

David Johnston

David Johnston
Doctoral Research Student