Impact of a Volcanic Eruption on Agriculture and Forestry in New Zealand

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Contents

Page

Disclaimer

Preface

Throughout history, New Zealand has been and remains one of the most active volcanic regions in the world. Much of the North Island has been shaped by eruptions, and the soils resulting from those eruptions greatly influence today's agriculture.

With the intensity of current farming and forestry, even a moderate to minor eruption will have significant impacts. This was well illustrated by the eruptions of Mount Ruapehu during 1995 and 1996 which, although quite minor in nature, did disrupt farming to a degree and could have greater consequences if the eruptions had occurred at different times of the year.

The Ministry of Agriculture and Forestry (MAF), via the Policy Information Group, has a responsibility to report to Government on the impacts of adverse climatic and natural disasters affecting the primary sector, and is likely to be directly involved in any post-event rehabilitation measures. It was clear from the recent Ruapehu eruptions that knowledge of the effect of volcanic eruptions on agriculture and forestry was somewhat scanty; although MAF did publish a brochure Volcanic Alert to assist farmers and growers in their decision making. It was also clear that the institutional arrangements to handle such emergencies, in the absence of a Civil Defence Emergency declaration, were less than satisfactory.

As a result of the Ruapehu experience, MAF commissioned this report; bringing together the expertise of agriculturalists, horticulturalists, volcanologists and foresters to examine the impact a range of eruption scenarios may have on the agriculture and forestry sectors; plus discuss some possible institutional arrangements.

As discussed in the report, most eruption scenarios are likely to have a significant impact on the sectors and consequently on the national as a whole. Organisations likely to be involved need to be cognisant of these implications and plan, as much as is possible, accordingly.

Alan Walker
Director, Policy Information Group

Executive Summary

New Zealand has a number of volcanoes each with its own eruptive characteristics. While the majority are considered dormant rather than extinct, they can be expected to produce eruptions at some indeterminate time in the future.

Volcanic eruptions will produce a number of hazards, some of which will make their effect felt hundreds of kilometres distance from the volcano. Volcanic planning differs from planning for most other hazards such as floods and drought which are generally predictable in their extent, have a short term warning period, and be of short duration. A volcanic event can build up over weeks to years and be unpredictable in its probable course and timing.

The areas at risk from volcanic activity encompass a large agricultural productive area including most of the North Island with significant areas of dairy, meat and fibre, horticulture and production forestry. Intensive farming is young relative to volcanic activity and there is little historic data on the effects of ash showers on land farmed intensively for agricultural production. Where volcanic eruptions have affected agricultural land, the depth of ash have all been at less than 50mm in recent history. Much of the suggested impacts are conjecture and extrapolations of impacts from lesser ash depths such as Mt St Helens, Mt Ruapehu and Hekla. Given New Zealand's exposure to volcanoes, and the importance of agriculture to the economy, it is appropriate to invest in more research on simulating ash showers to determine the actual effects and methods for rehabilitating the land.

The effect on pastures and livestock will vary depending on the:

- ash type
- consistency and depth of ash deposited
- chemical nature of ash and poisonous aerosols attached to the ash
- amount of rainfall immediately following any ashfall
- wind direction
- metabolic and nutritional demands of the livestock at the time
- age of livestock
- pasture length

Generally one could expect rehabilitation of land from ash falls of up to 100mm but it is difficult to foresee a quick recovery from deposits of over 500mm. However even ash falls of less than 5mm can result in significant impacts for livestock enterprises if the ash is high in chemicals such as fluorine.

The impact of ash showers on horticulture can be considerable with both physical and chemical effects. Even light rates of ash at critical times can reduce crop performance significantly. In addition, light ashfalls can affect either predator pests to increase pest management problems or the dust can affect bees reducing crop pollination.

The impact of volcanic activity on plantation forestry can also be significant from burial, breakage and fire. The infrastructure can also be damaged complicating the response to the direct effects on the forest. For example, if waterways and water sources are contaminated by ash, then pumping systems to control forest fires may not be effective.

The major policy issues for responding to volcanic events as identified following the Ruapehu eruptions of 1995 and 1996 were:

- Inadequately defined and co-ordinated roles.

- Poor communication between agencies who normally have little contact with one another. Differences in operating structures, procedures, terminology and technology compounds this difficulty.
- Resource constraints. The decision not to declare a state of civil defence emergency reduced the available financial resources.
- Plans based on untested assumptions - i.e. some organisations expected the Ministry of Civil Defence to co-ordinate the event but the lack of declaration resulted in inconsistency between their planning and the real event.

The issue of communication resulted in 50% of respondents identifying that there was either insufficient information and/or information was difficult to get hold of.

The lack of trained personnel was also cited as an issue by over a third of respondents. Training is seldom a high priority given the low frequency of event.

Management was also an issue, particularly relying on established decision making structures used for routine activities that may not be suitable for crisis management.

Media problems were reported by 43% of organisations. World wide media interest created significant demands.

This highlighted the need for:

- Better networks among the players with more simulations, and exercises to identify and resolve co-ordination problems should be a priority with readiness programmes. There was evidence that the second volcanic eruption was better managed because of the experiences of the first one.
- A nationally co-ordinated effort would certainly place less demands on national resources such as the Crown Research Institute IGNS who provide the technical expertise to local emergency management organisations.
- Funding is a major issue for territorial authorities. The costs associated with low level events that are not declared can be very high relative to annual rateable income.

The institution framework that is necessary to manage a volcanic eruption emergency will need to give priority to:

- Managing networks and resolving co-ordination problems.
- Providing information to rural people to enable them to manage themselves given that most resources will be targeted to higher urban priorities.
- Managing media interest during the event.
- Maintaining institutional memory and taking account of ongoing restructuring in rural communities, and that assets and resources currently available may not be there for the next event.

There would appear to be knowledge gaps on the recovery from volcanic events that should receive funding from the Public Good Science Fund and there is probably information that could be made available to those responsible for emergency management. This updating would need to be ongoing due to staff turnover and change.

1.0 Introduction and Background

This study was commissioned by MAF Policy with the intent of developing some possible scenarios that could face farmers and growers, and the steps that could be taken to bring the land back into production. The study would also outline factors that would need to be considered by Government (and Government agencies) in any post-event rehabilitation programme.

In October 1995 and June 1996, Mount Ruapehu erupted, spreading 40 million m3 of ash on the first occasion and 10 million m3 on the second occasion. These minor eruptions resulted in ash deposits of up to 10 mm closer to the mountain and 1-3 mm in further reaches. The effects from this "small hiccup" of Mt Ruapehu, raised the awareness of the potential impact of volcanic eruptions on New Zealand Agriculture, and the consequential effects on the New Zealand economy.

New Zealand was shaped by the collision of two parts of the earth's crust which creates friction and heat sometimes vented through volcanoes.

About ten volcanic centres in New Zealand have potential for activity with widespread damage to life and property.

A major event would have significant impacts upon agriculture and forestry. There is currently little readily available information as to the situation that could be faced by producers and the processes and programmes they may need to manage in order to rehabilitate their land, or over what time period. Given that Government, via MAF, could be involved in either responding to an event (given that it is beyond the resources of the local community to cope or at a minimum in advising/assisting in post-event rehabilitation of the on-farm sector), this project has been developed:

1. To develop possible scenarios that could face farmers and growers following a volcanic eruption, and the steps that could be taken to bring land back into production.
2. To discuss a possible institutional framework for handling such a post event recovery.

2.0 Objectives and Terms of Reference

2.1 Aim of Research

1. To develop possible scenarios that could face farmers and growers following a volcanic eruption, and the steps that could be taken to bring land back into production.
2. To discuss a possible institutional framework for handling such a post-event recovery.

2.2 Tasks

2.2.1 Discuss **briefly** the volcanic hazard in New Zealand, and the most likely scenarios with respect to possible future eruptions.

2.2.2 Discuss **briefly** potential volcanic impact other than ash fall, e.g. lava flows, pyroclastic flows, on agriculture in New Zealand.

2.2.3 Discuss the degree of damage/destruction likely to be caused by increasing layers of ash - up to 25 mm, 50mm, 100mm, 500mm, and 2 metres on different production systems:

- Pasture
- Arable Crops
- Permanent trees/vine crops
- Production forestry

2.2.4 Discuss the likely physical and chemical nature of the ash.

2.2.5 Discuss possible management strategies to rehabilitate the land with respect to the above ash layers and production systems.

2.3.6 Discuss possible time horizons with respect to 2.2.3 above.

2.2.7 Discuss priorities for action with respect to:

(i) Farmers and Growers

(ii) Government and Government agencies

Discuss possible "institutional" framework (i.e. process/structure) whereby all interested parties (e.g. Central/Regional/Local Government, CRI's, land owners, agri-business) can co-ordinate efforts and set priorities.

3.0 Volcanic Hazards in New Zealand

3.1 Volcanism in New Zealand

The New Zealand region is characterised by both a high density of active volcanoes (Figure 3.1) and a high frequency of eruptions (Wilson *et al*. 1995). 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 of a volcano cannot yet be determined but its probable effects can reasonably be assessed.

We can subdivide New Zealand's volcanoes either by type or by status.

3.1.1 Status of New Zealand's Volcanoes

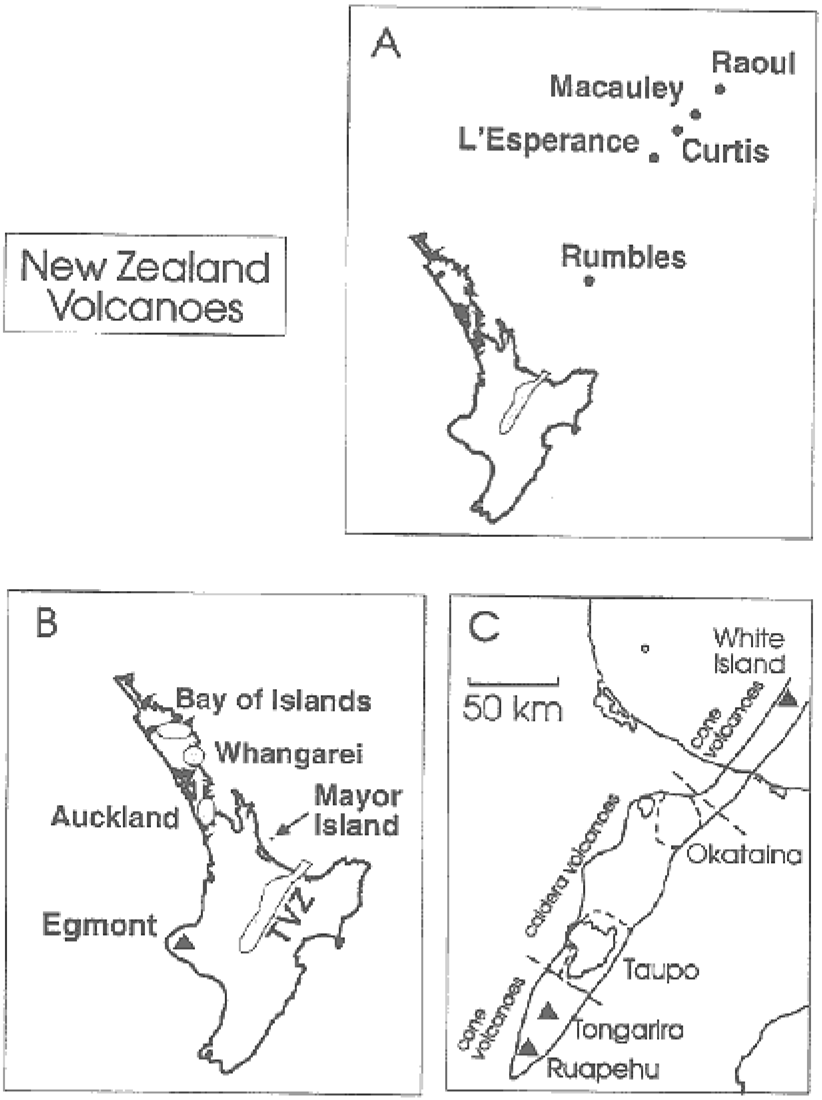
The National Civil Defence plan subdivides New Zealand's potentially active volcanoes into two classes: frequently active and re-awakening volcanoes.

The former are characterised by numerous often prolonged eruption episodes over the last 150 years; the latter have been less active in historical times but have had numerous eruptions in the last 15,000 years. Frequently active volcanoes include White Island, Tongariro-Ngauruhoe, and Ruapehu. Re-awaking volcanoes include the Auckland Volcanic field, Mayor Island, Mt Edgecumbe, Okataina, Rotorua, Maroa and Taupo volcanic centres, and Taranaki (Mt Egmont).

3.1.2 Our Types of Volcano

New Zealand's young volcanoes represent a cross-section of most of the types of volcanoes documented elsewhere in the world, the only type missing being an example of a modern basaltic shield volcano such as Kilauea or Mauna Loa in Hawai'i. In two respects, New Zealand's volcanoes are world-beaters: our cone volcanoes at Ruapehu, Ngauruhoe and White Island are among the most frequently active examples known; and Taupo and Okataina are the most productive and frequently active rhyolite caldera volcanoes on Earth (Wilson *et al.* 1995). The short time span for which the eruptive histories of New Zealand's volcanoes have been observed is inadequate to show the full extent of eruption styles and sizes that are recorded in the pyroclastic deposits and lavas generated by past activity. Thus lessons about the sizes, styles and associated hazards of future activity have to be learned from the prehistoric record as well as historic eruptions.

Figure 3.1 New Zealand's Volcanoes



Volcanic fields: Volcanic fields such as Auckland, are where small eruptions occur over a wide geographic area, and are spaced over long time intervals (thousands of years). Each eruption builds a single small volcano (e.g. Mount Eden, Rangitoto), which does not erupt again. The next eruption in the field occurs at a different location, and this site cannot be predicted until the eruption is imminent.

Composite cone volcanoes: Composite cone volcanoes such as Egmont and Ruapehu are characterised by a succession of small to moderate eruptions occurring from roughly the same point on the earth's surface. The products of successive eruptions accumulate close to the vents to form a large cone, which is the volcano itself. Over a long period of time several cones may form which overlap and are built up on top of each other. The same route to the surface is used repeatedly by the magma so sites of future eruptions can largely be predicted.

Caldera volcanoes: Caldera volcanoes such as Taupo and Okataina (which includes Tarawera) exhibit a history of moderate to large eruptions. Eruptions at these volcanoes are occasionally so large that the ground surface collapses into the "hole" (caldera) left behind by the emptying of the underground magma chamber. The pyroclastic products are usually spread so widely that no large cone forms, except where lava flows may pile up on top of each other to form a volcanic edifice (for example, Mt Tarawera). In the large caldera-forming eruptions, a lot of the erupted material accumulates within the caldera itself as it collapses, and the old land surface may be buried to several kilometres depth.

3.1.3 Distribution of New Zealand's Volcanoes

Volcanoes in New Zealand are not randomly scattered, but are grouped into areas of more intensive and long-lived activity, whose position (and the compositions of the magmas erupted) can be related to the large-scale movement of plates in the New Zealand region. Volcanic activity in New Zealand occurs in six areas (Fig. 3.1), five in the North Island and one offshore to the northeast in the Kermadec Islands.

Most New Zealand volcanism in the past 1.6 million years has occurred in the Taupo Volcanic Zone (Wilson *et al*. 1995), an elongate area from White Island to Ruapehu, which has been by far the most frequently active area, both in historic times and over the last 1.6 million years. Taupo Volcanic Zone (TVZ) is extremely active on a world scale; it includes three frequently active cone volcanoes (Ruapehu, Tongariro/Ngauruhoe, White Island) and the two most productive caldera volcanoes in the world (Taupo, Okataina).

Volcanic Fields

Northland and Auckland: Three volcanic fields occur in Northland and Auckland, where small individual eruptions occur at intervals of hundreds to thousands of years. The best known of these is the Auckland field, where around 50 small volcanoes have formed, Rangitoto being the youngest (600 years old) (Allen and Smith 1994). The magma is basaltic in composition, and eruptions tend to be small (typically 0.01 - 0.1 km3), and the areas affected are, at most, a few tens of km2; therefore hazards are very localised (Johnston *et al*. 1997). However, the growth of New Zealand's biggest commercial centre almost exactly on top of one of these fields has led to much greater awareness of the risks posed by a potential renewal of activity in this area.

Cone Volcanoes

Egmont: The modern cone of Egmont is only the latest in a series of cone volcanoes that stretches back in time for 1.7 million years (Neall and Alloway 1986). The older cones (1.7 - 0.13 million years) have now been eroded down to relics which form the Pouakai and Kaitake Ranges, and the Sugarloaf Rocks at New Plymouth. The main Egmont cone is about 130,000 years old, and has a complex history of multiple cone building episodes followed by cone collapse episodes when much of the cone was destroyed by huge debris avalanches. Most of the actual mountain that we see today is only about 10,000 years old and has rapidly built up since the last major collapse. The latest eruption where magma reached the surface is thought to have occurred in 1755 AD, so the volcano is considered to be dormant (Alloway *et al*. 1995). Eruptive products of Egmont are andesitic to dacitic in composition. They form domes and lava flows that, together with some pyroclastic material, have built up the modern cone itself. Comparable volumes of pumice, scoria and ash have spread as thin pyroclastic fall and flow deposits beyond the cone.

Tongariro/Ngauruhoe: Tongariro is a large (100 km3) cone volcano of which the youngest cone, Ngauruhoe, is the main active centre (Topping 1973). Tongariro, like Egmont, has been both built up by eruptions producing lava flows and pyroclastic material and has been partially destroyed on occasions in the past. However, the main destructive force at Tongariro does not appear to have been cone collapse, so much as erosion by ice during glacial periods. The oldest lavas from Tongariro are at least 340,000 years old, and occur in places that imply there was a substantial "Mt Tongariro" at that time. New work is showing that the modern cone has grown since 275,000 years ago, with intervals of cone building occupying a few thousand to tens of thousands of years (Ngauruhoe is only 2,500 years old) (Hobden *et al*.

1996). These cone-building periods are separated by times when either most activity was expressed as widespread pyroclastic deposits (which did not contribute much to cone building) or the volcano was much less active. In most eruptions the magma was andesite, but minor amount of dacite and basalt are also known here. The most prominent vent, Ngauruhoe, has been frequently active in recorded times, but has not erupted since 1975 and is now undergoing its longest break from activity in recorded history.

Ruapehu: Ruapehu is New Zealand's largest cone volcano and, like Tongariro and Egmont, has been built up and partially destroyed on several occasions during its history (Hackett and Houghton 1989). The oldest dated lavas are 230,000 years old, but there has probably been a "Ruapehu volcano" for at least 0.5 million years. Destructive influences at Ruapehu include both cone collapse and glacial erosion, the latter continuing to the present day. Like Tongariro, Ruapehu has erupted mostly andesite, and only minor amounts of basalt and dacite have been found. Ruapehu is unusual among the cone volcanoes in having a crater lake which, in historic times, has greatly modified eruptive behaviour such that even small eruptions are accompanied by potentially dangerous mudflows or lahars. With the exception of the 1945 eruption, the lake has acted as a trap for magmatic heat and volatiles, so making it warm and highly acidic. Ejection of lake water leads to the formation of lahars, one of which in 1953 led to New Zealand's worst volcanic disaster, at Tangiwai. Only in 1945 was the lake displaced, and lava extruded at the surface during the largest volcanic eruption in New Zealand this century (Johnston and Neall 1995).

White Island: White Island is the 320 m high emergent tip of a 17 km wide, 750 m high cone volcano largely submerged beneath the Bay of Plenty (Nairn *et al*. 1991). It is unusual in being one of the very few privately owned volcanoes in the world. White Island is currently New Zealand's most active volcano with three long cycles of eruption recorded between 1976 and 1994. Our knowledge of the earlier history of the volcano is severely limited by a lack of data on the age of prehistoric eruptions. This early history includes two major episodes of cone growth with both extrusion of lava flows and explosive eruptions. There are no recognisable products of primeval or historic activity preserved on the mainland. Historic activity included a small collapse of the west wall of the main crater in 1914, forming a debris avalanche which killed 11 sulphur miners. All subsequent events have been small explosive eruptions, linked to the formation of collapse craters through the 1914 deposits. Since 1976, White Island has erupted low-silica andesitic magma, whereas most early activity involved higher-silica andesite or dacite.

Kermadec Islands: Many oceanic volcanoes occur along a line from the North Island, trending north-northeast towards and including Tonga, and the Kermadec Islands which represent points where some of these volcanoes have constructed cones above the surface of the sea (Latter *et al*. 1992). Although shaped like their mainland counterparts, the three major cone volcanoes in the Kermadecs (Raoul, Macauley and Curtis) differ in two respects. The first respect is that they have erupted substantial amounts of both dacite and basalt, rather than andesite. The second is that the main processes causing destruction of the cones are marine erosion, and caldera collapse, the latter accompanying dacite eruptions. Many details of the volcanic histories of the Kermadec volcanoes are unknown, as the oldest rocks available on the islands are only a few thousand years old, whereas by analogue with similar-sized volcanoes on the mainland, the individual volcanoes would have taken several hundred thousand years to be constructed. Raoul Island has experienced several historic eruptions, the most recent in 1964. The size range of eruptions at the Kermadec volcanoes is higher than that usually considered the norm for cone volcanoes, and pyroclastic deposits (including ignimbrites) are prominent features of the young eruptive records.

Caldera Volcanoes

Below we describe only the youngest, and hence potentially active, calderas within New Zealand.

Taupo: Taupo is a large caldera volcano, whose shape reflects collapse following two large eruptions about 26 500 and 1 800 years ago (Wilson 1993), although the volcano itself first began erupting about 300,000 years ago. The modern Lake Taupo partly infills this caldera structure. Taupo has erupted mostly rhyolite, with only minor amounts of basalt, andesite and dacite, and is the most frequently active and productive rhyolite caldera in the world. The eruptions are notable for varying enormously in size, from <0.01 km3, up to the largest (26 500 years ago) which ejected about 800 km3 of pumice and ash (if expressed as dense rock, this would be similar to the volume of Ruapehu). There have been 28 eruptions at Taupo since 26 500 years ago, of very different sizes and spaced at different intervals. The variability in the sizes and repose periods makes it impossible to predict when the next eruption will occur and how big it will be. The latest major eruption from Taupo caldera volcano about 1,800 years ago was the most violent volcanic eruption in the world for the past 5000 years and has left marks on the landscape and vegetation patterns which are still visible today (Wilson and Walker 1985).

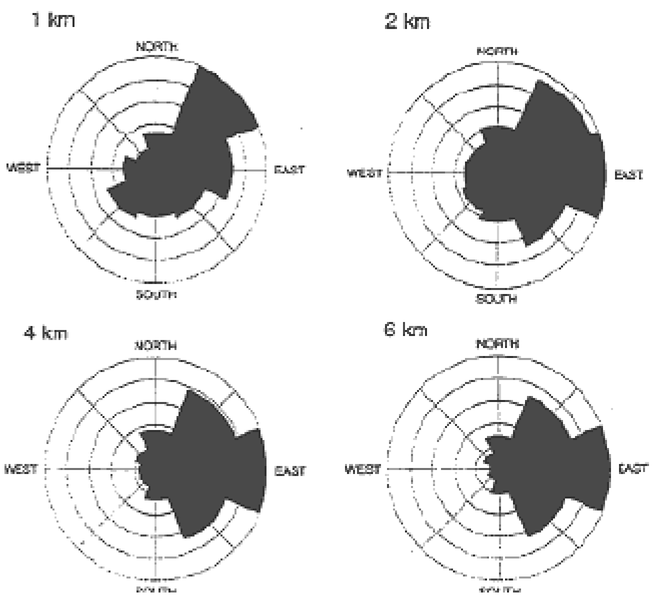
Okataina: Okataina is a large caldera volcano which has been erupting over a similar time span to Taupo, at similar rates of production, and involving the same types and proportions of magma (that is, almost entirely rhyolite) (Nairn 1991). However, the superficial appearance of the volcano and the styles of recent eruptions at Okataina are different. The last caldera collapse occurred about 64,000 years ago, and the many eruptions since then have largely infilled the hole left behind by the collapse. These young eruptions at Okataina have been fewer in number than at Taupo, but more uniform in size, so that the smallest rhyolite eruptions at Okataina were bigger than all but the four or five largest eruptions at Taupo in the same time period. Many eruptions at Okataina have produced large volumes of rhyolite lava; this lava has piled up over the vent areas to produce two large massifs, Haroharo and Tarawera. However, Okataina has also produced some unusual eruptions such as the basaltic eruption of Tarawera in 1886 AD which is not only New Zealand's largest historic eruption, but also the largest basaltic eruption known in the entire 1.6 million year history of the Taupo Volcanic Zone.

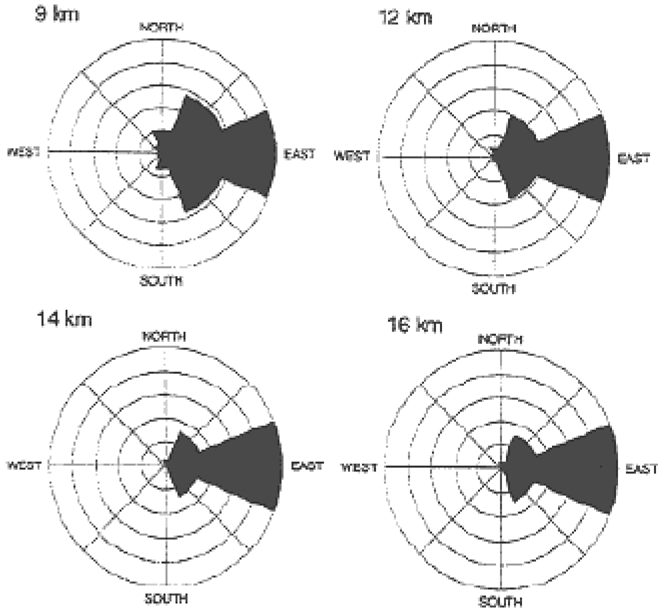
Mayor Island: Mayor Island (Tuhua) is the emergent summit, 4 km in diameter and 350 m high, of a caldera volcano which is roughly 15 km across and 750 m high (Houghton *et al*. 1992; Houghton *et al*. 1994). Our present understanding of the history of the volcano is therefore limited to what we can see on the island, the oldest portion of which is about 130,000 years old. Although Mayor Island erupts almost entirely rhyolite magma, this rhyolite is unusual in containing higher amounts of sodium and potassium than the more "normal" rhyolites at Okataina or Taupo, reducing the magma viscosity and therefore the degree of explosivity of many eruptions. The volcano has produced many explosive and effusive eruptions during its history above the water surface, punctuated by at least 3 occasions when caldera collapse occurred. The latest of these occurred about 6,300 years ago, following the largest eruption known in the history of the volcano, and later lavas have only partly filled in this caldera. The eruption 6,300 years ago was so large that substantial amounts of fall material fell on the North Island, and large pyroclastic flows entered the sea, building up fans that (temporarily) roughly doubled the area of the island.

Table 3.1: Summary of volcanoes, eruption sizes and frequency of occurrence

Volcano		Last known eruption	Future eruption size (km3)	Estimated frequency of occurrence
Auckland		~600 years B.P.	small - medium (0.1-2.0)	1000-2000 years
Mayor Island		6340 years B.P.	small - medium (0.1-1) large (>1.0)	?1000 years ?10 000 years
White Island		1998 AD	small (<0.01) medium (0.01-0.1) large (> 0.1)	1-5 years ?100 years ?10 000 years
Tongariro Volcanic Centre	Ruapehu	1996 AD	small (0.01-0.1) medium (0.1-1.0) large (>1)	20 years 100-500 years 10 000 years
	Ngauruhoe	1975 AD	small (< 0.01) medium (0.01-0.1)	10-20 years 100-200 years
	Tongariro	1896 AD	small (<0.01) medium (0.01-0.1) large (0.1-1)	100 years 1000 years 10 000 years
Egmont		1755 AD	small (<0.01) medium (0.01-0.1) large (<.1)	300-500 years 1300-1600 years 10 000 years
Taupo		181 AD	small (0.1-0.9) medium (1-10) large (10-100)	1300-1600 years 2500-5000 years 5000-10 000 years
Okataina		1886 AD	medium (1-10) large (10-20)	1500-2000 years 2000-5000 years

Figure 3.2: The frequency of wind directions at various heights above Auckland Airport derived from 1966 to 1979 data





Wind Frequency

The distribution of ash is highly dependent on wind direction. 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 above North Island because of the small difference in latitude between them (see Figure 3.2).

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. However, if 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.

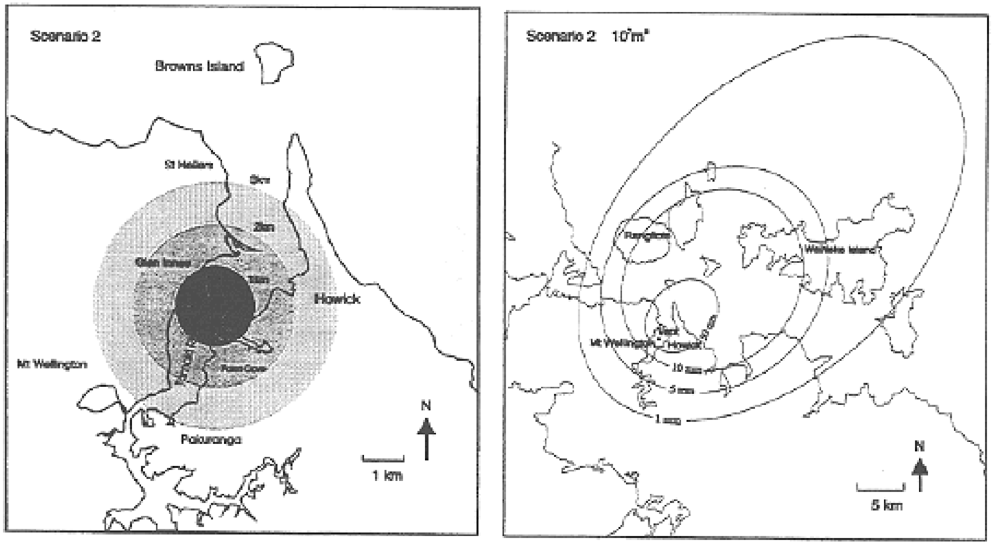
3.1.4 Possible Future Eruption Scenarios

An understanding of past eruptive activity is a key to assessing the location, size and nature of future eruptions. The following section illustrates the range of possible future volcanic hazards by presenting examples of past eruptions and scenarios. However, a future eruption at any volcano will not necessarily be the same as events described here.

Auckland Volcanic Field

Eruption scenarios for the Auckland Volcanic Field have been developed by Allen (1992), Smith and Allen (1993) and Johnston *et al*. (1997). Figure 3.3 shows a phreatomagmatic eruption scenario centred in the Tamaki Estuary (see Johnston *et al*. (1997) for a more detailed description). Surges travel out to 3 km and a total of 107m3 of tephra is erupted. Beyond a few kilometres only light ash falls occur.

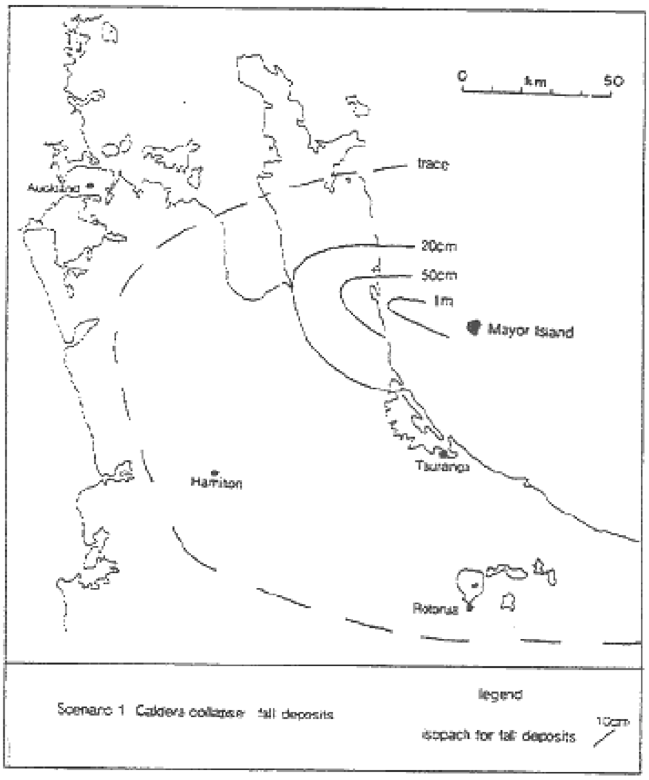
Figure 3.3 A: Vent location for the scenario eruption, extent of tuff cone, and the 1, 2, 3 km zones affected by base-surges and ballistic clasts. B: Tephra fall distribution pattern (107m3) for scenario eruption. Figure modified from Figures 1.12 and 1.13 of Johnston *et al* (1997)



Mayor Island

Eruption scenarios for Mayor Island are described by Houghton et al. (1994). Figure 3.4 illustrates a worst case scenario; a repeat of the 6340 year B.P. eruption. Pyroclastic flows, surges and ballistic blocks would devastated the entire island. Thick ash falls would cover a large area of South Auckland,Waikato and the Bay of Plenty. Since the Mayor Island magma is exceptionally rich in chlorine and fluorine (Houghton et al. 1992) the poisoning of stock in ash-affected areas may result from any eruption, even in areas where only minor amounts have fallen.

Figure 3.4: Distribution of fall deposits associated with a repeat of the 6340 year B.P. eruption assuming an easterly wind. The map is from Houghton *et al* (1994)



White Island

Figures 3.5 and 3.6 show the distribution of ash from scenarios developed by Nairn et al. (1991). The entire island is subject to debris avalanche, pyroclastic flow and surge and ballistic block hazards. A major eruption (or a very large debris avalanche entering the sea) could generate a tsunami affecting the Bay of Plenty coast, although the risk is thought to be extremely low.

Figure 3.5: Bay of Plenty map showing possible ash dispersal ellipses from White Island for a 100 year return period. The dispersal ellipses can be pivoted around White Island depending on the wind direction at the time of the eruption. The rose (compass) diagram shows the approximate percentage of time that wind blows in various directions

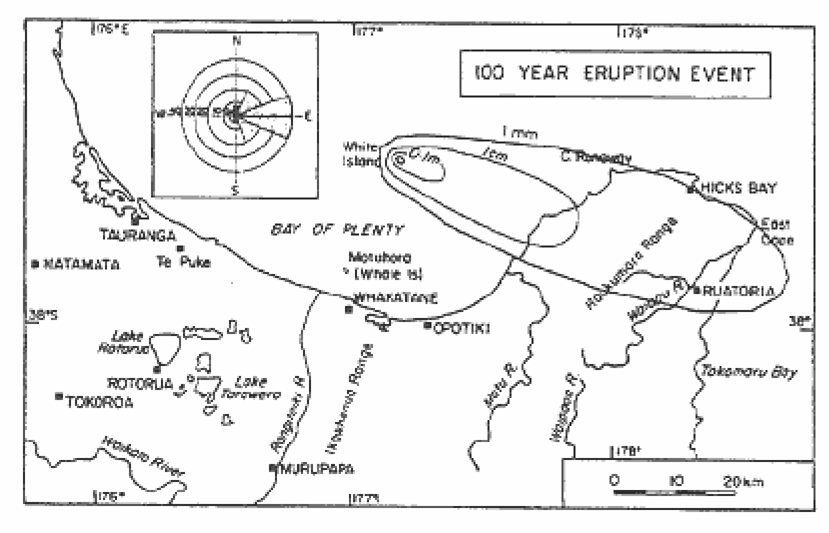
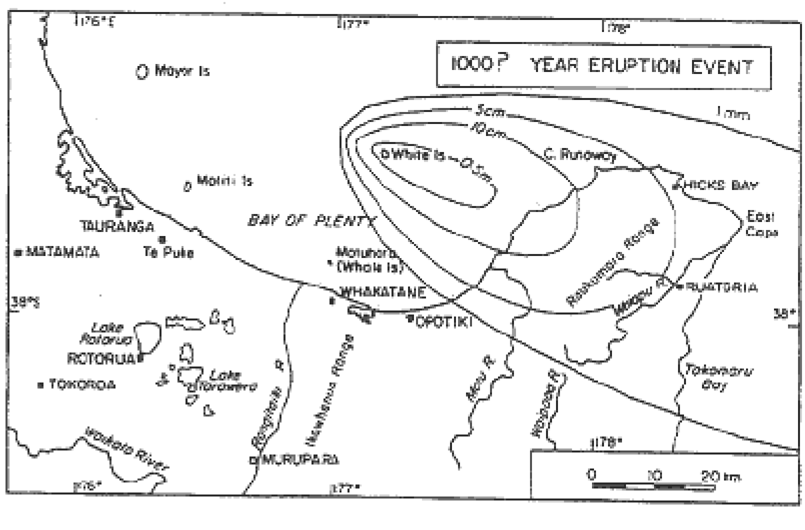


Figure 3.6: Possible ash dispersal map for a one per 1000 year return period eruption. See above caption



Okataina Volcanic Centre

Detailed eruption scenarios have been developed for the Okataina Volcanic Centre by Johnston and Nairn (1993). A future Okataina eruption is expected to resemble those that have occurred in the past (Nairn 1991). Figure 3.7 show the preserved deposits of an event that occurred 9000 year B.P. A rhyolite eruption will most probably occur from one of two vent lines. Hazard zones for the Okataina Volcanic Centre are shown in Figure 3.8.

Figure 3.7: Present day distribution and thickness of fall deposits erupted from the Okataina Volcanic Centre 9000 years ago. Thickness in centimetres. Figure from Nairn 1991

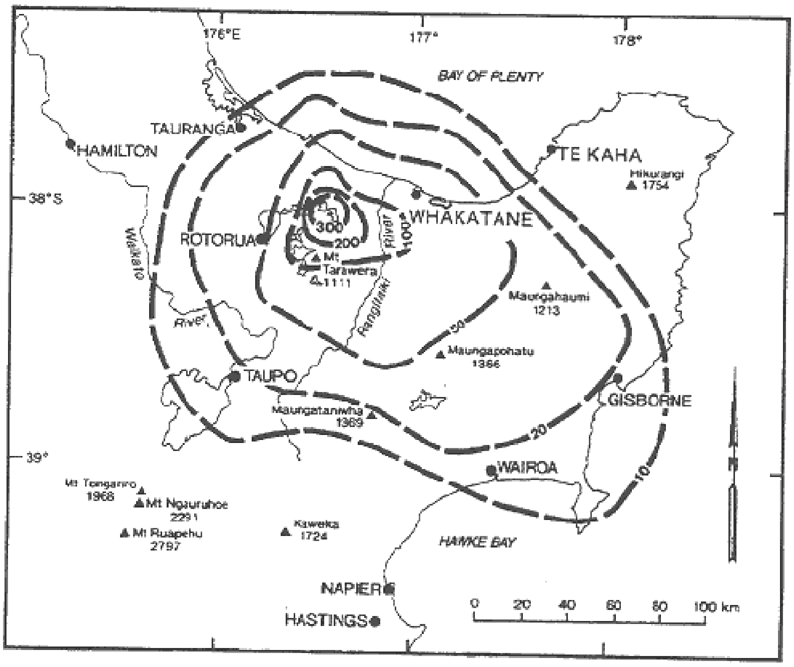
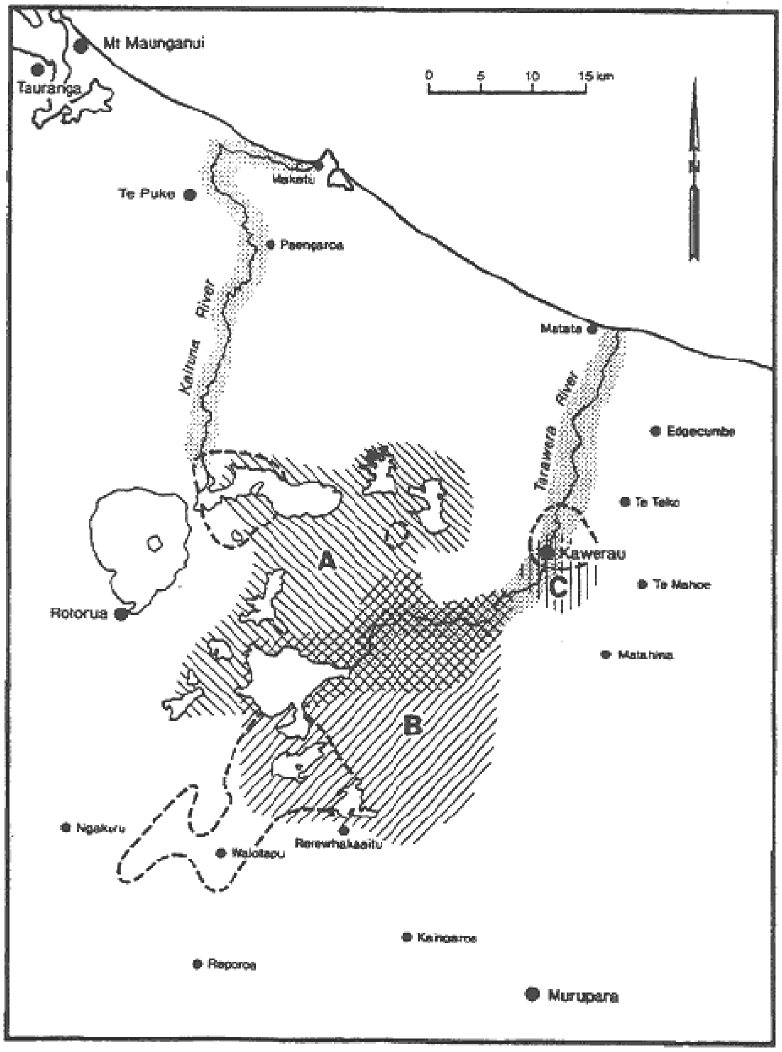


Figure 3.8: Hazard zones defined at Okataina Volcanic Centre based on effects of past eruptions. The hatching defines areas at risk of complete devastation as a result of eruptions at (A) Haroharo; (B) Tarawera; (C) Mt Edgecumbe. The dashed lines enclose areas at risk from hydrothermal eruptions. The dot pattern defines rivers at risk of eruption-induced flooding and lahars. The risk is greater for the Tarawera River than for the Kaituna. Figure from Nairn 1991.



Taupo Volcanic Centre

The range of sizes and types of eruptions likely to occur at Taupo Volcanic Centre in the future are difficult to forecast because of the chaotic nature of the volcanic systems (Wilson 1993). There is no simple pattern to past eruptions as shown in Figure 3.9 but the distribution of tephra from three past eruptions is shown to illustrate the range of possible future events (Figures 3.10-3.12).

Figure 3.9: The volume of tephra erupted in cubic kilometres plotted against the age of the eruptions

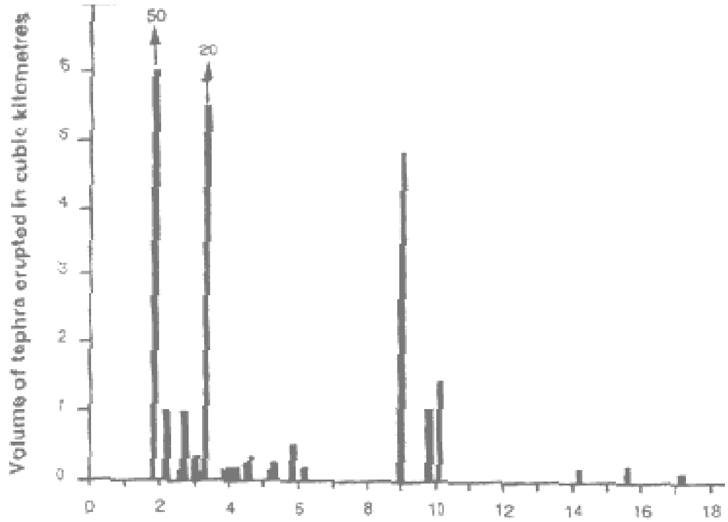


Figure 3.10: Distribution of the 1800 year old Taupo fall deposits (in centimetres) and the outer limit of the accompanying Taupo ignimbrite. There was total devastation within the zone of the ignimbrite. (map from Wilson 1993)

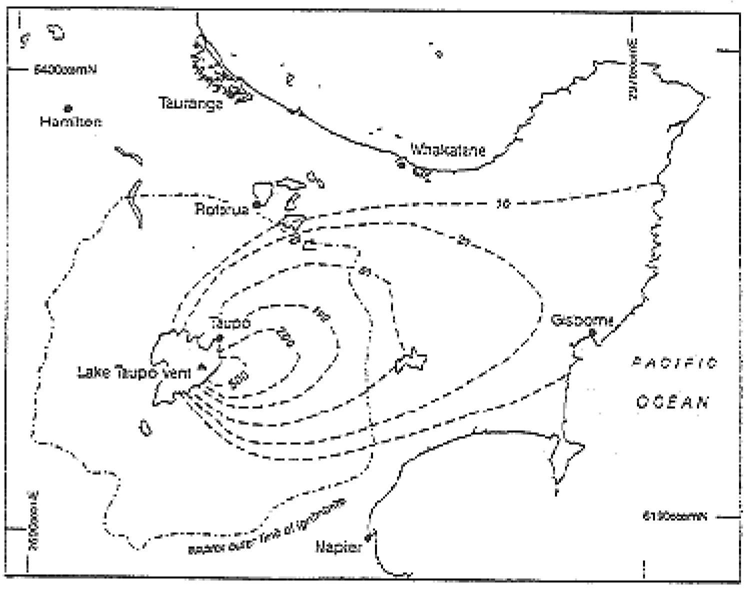


Figure 3.11 Isopach map of fall deposited erupted from the Motutaiko Island vent ~ 7000 years B.P. Map from Wilson (1993)

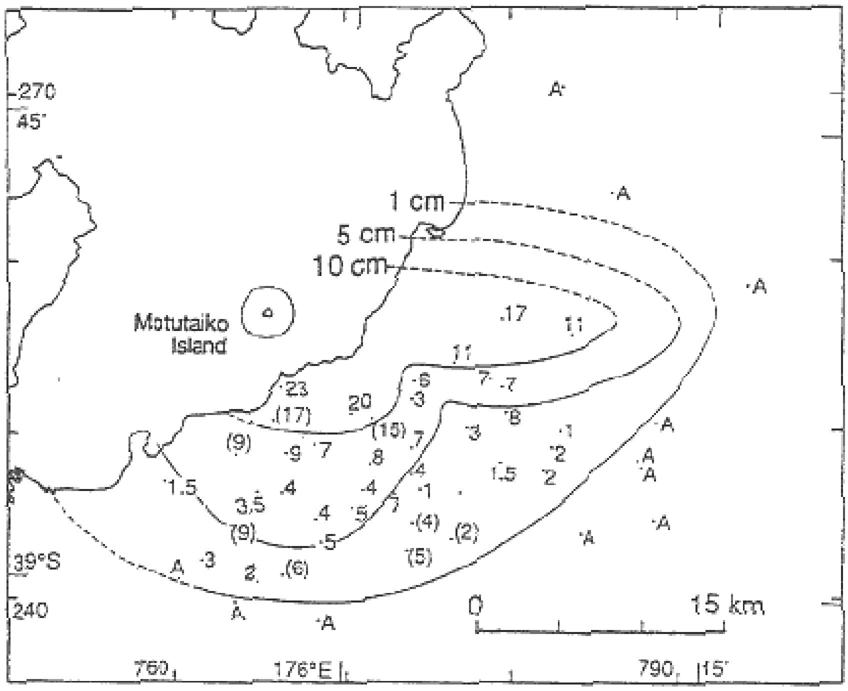
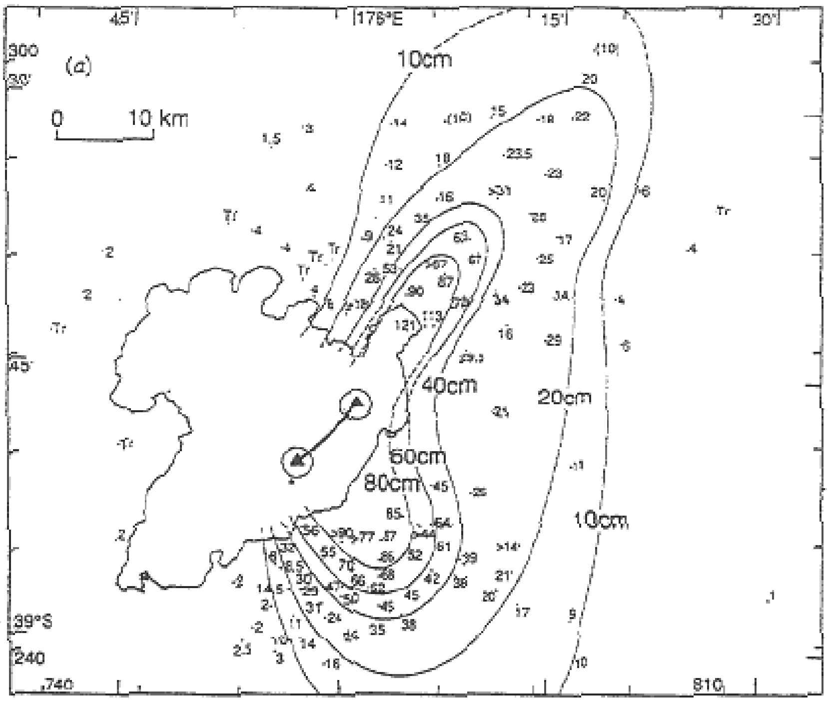


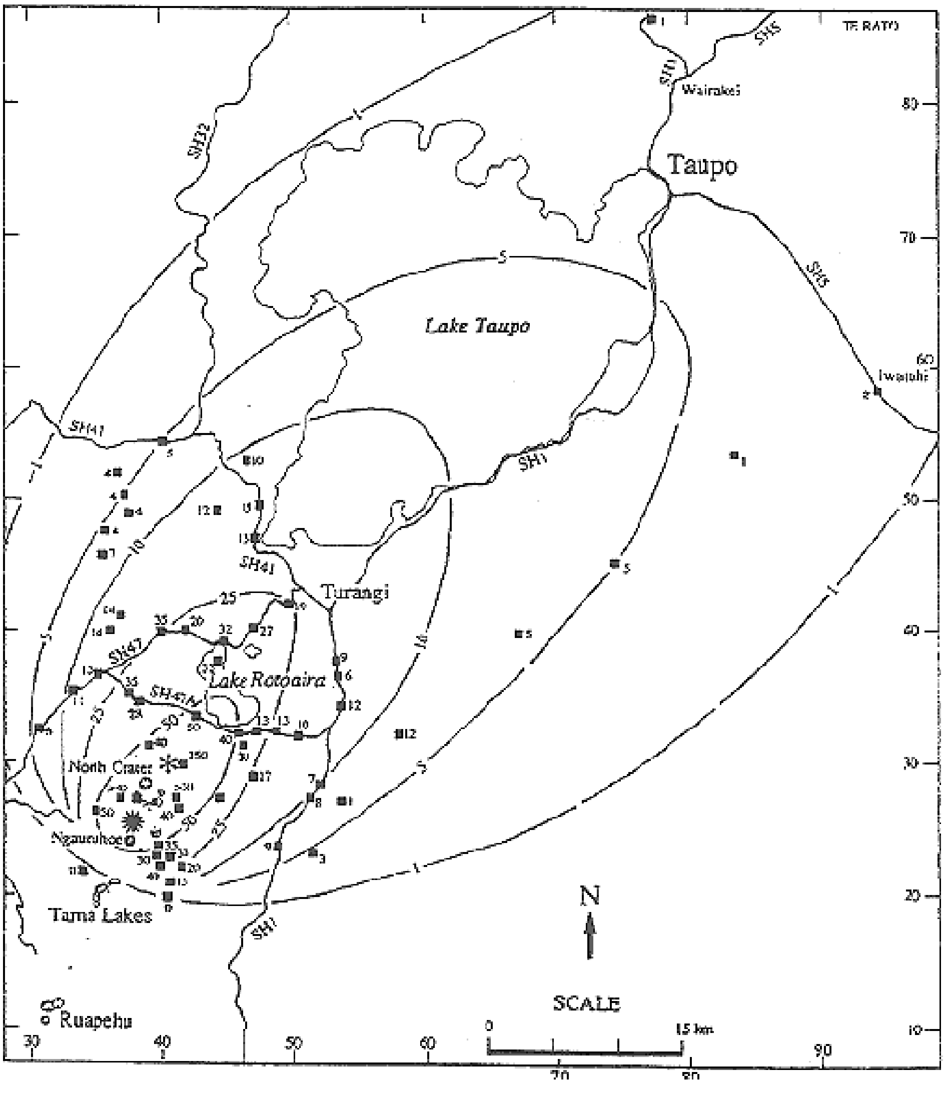
Figure 3.12: Isopach map of fall deposits erupted from multiple vents along a fissure with ends marked by filled triangles around 10 000 years B.P. Map from Wilson (1993)



Tongariro Ngauruhoe

The most likely eruption scenario from the Tongariro Volcanic Centre (which includes Ngauruhoe) is a small event similar to historic eruptions (e.g. Te Mari 1896, Ngauruhoe 1954, 1975). A worst case scenario is likely to be an event the size of the c. 10 000 year B.P. eruption that deposited the Te Rato Lapilli (Figure 3.13). The area potentially affected by pyroclastic flows and ballistic clasts from such an eruption would be within the Tongariro National Park.

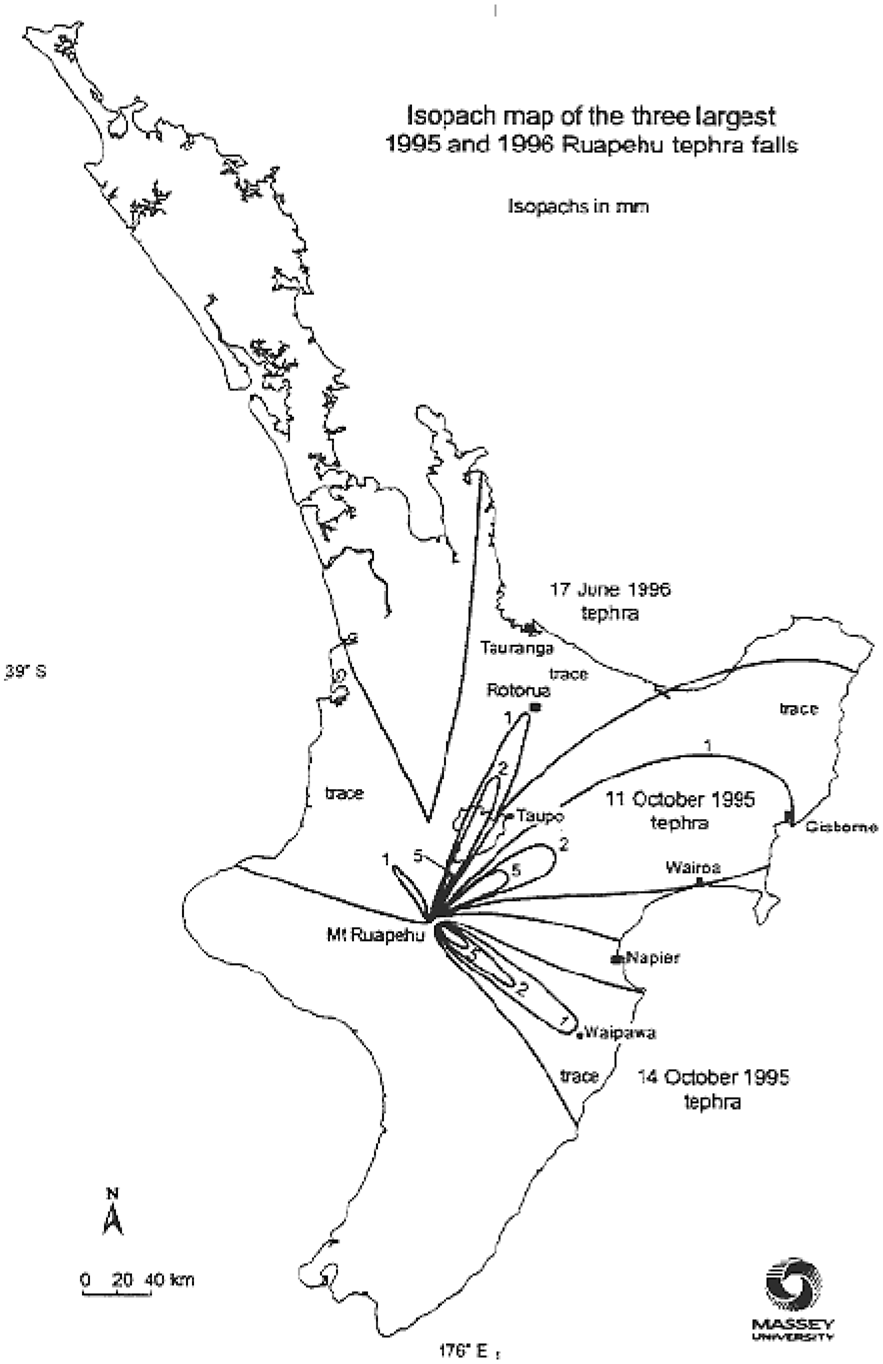
Figure 3.13: Isopach map (in centimetres) showing the distribution of Te Rato Lapilli erupted from a vent since buried under Ngauruhoe ~ 10 000 years B.P.



Ruapehu

A range of eruptions are possible from Ruapehu with a "worst case" event similar in size to that shown in Figure 3.13. The Crater Lake of Ruapehu also presents a significant lahar hazard (Neall et al. 1995) and a hazard map has been produced by Latter (1987). The 1995-1996 eruption illustrated the impacts of even small eruptions on agriculture in New Zealand. Similar events can be expected every 20 - 50 years. The distribution of ash is shown in Figure 3.14.

Figure 3.14: Isopach map of the three largest 1995 and 1996 Ruapehu tephra falls



Egmont

Eruptions from Egmont can be expected every few hundred years, with the last eruption around 250 years ago (Alloway *et al.* 1995). A range of near-vent hazards pose a significant hazard in Taranaki and are shown on the hazard map of Neall and Alloway (1996). An eruption scenario is shown in Figure 3.15 and the distribution of tephra from an event 3 600 years B.P., the Inglewood tephra is shown in Figure 3.16.

Figure 3.15: Tephra fall distribution pattern (108m3) for scenario eruption

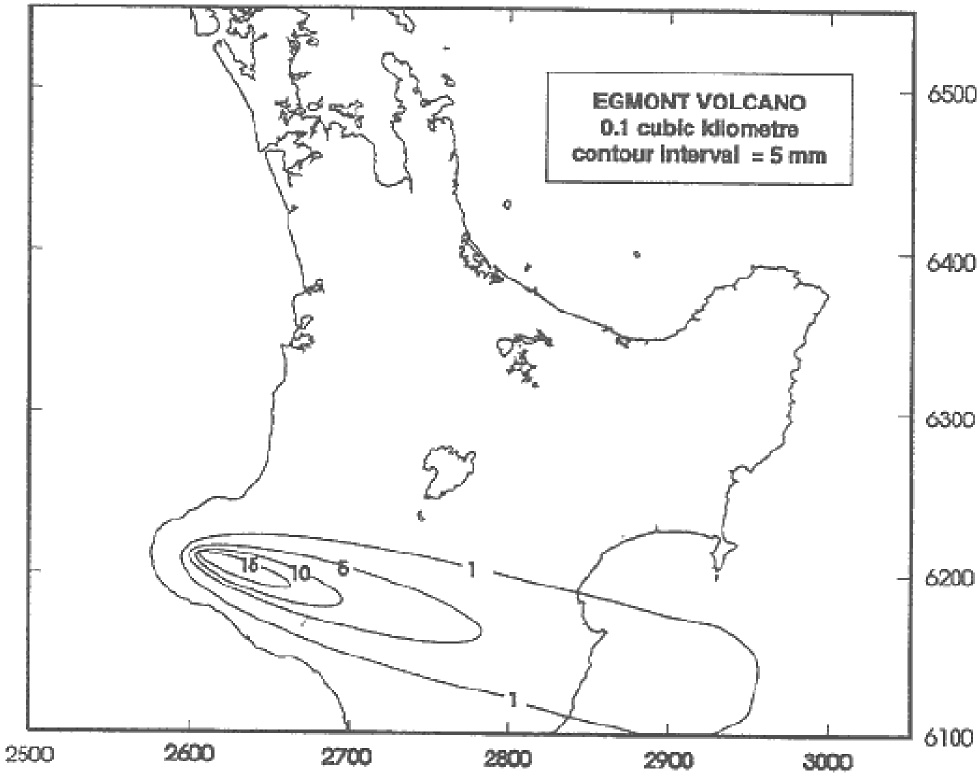
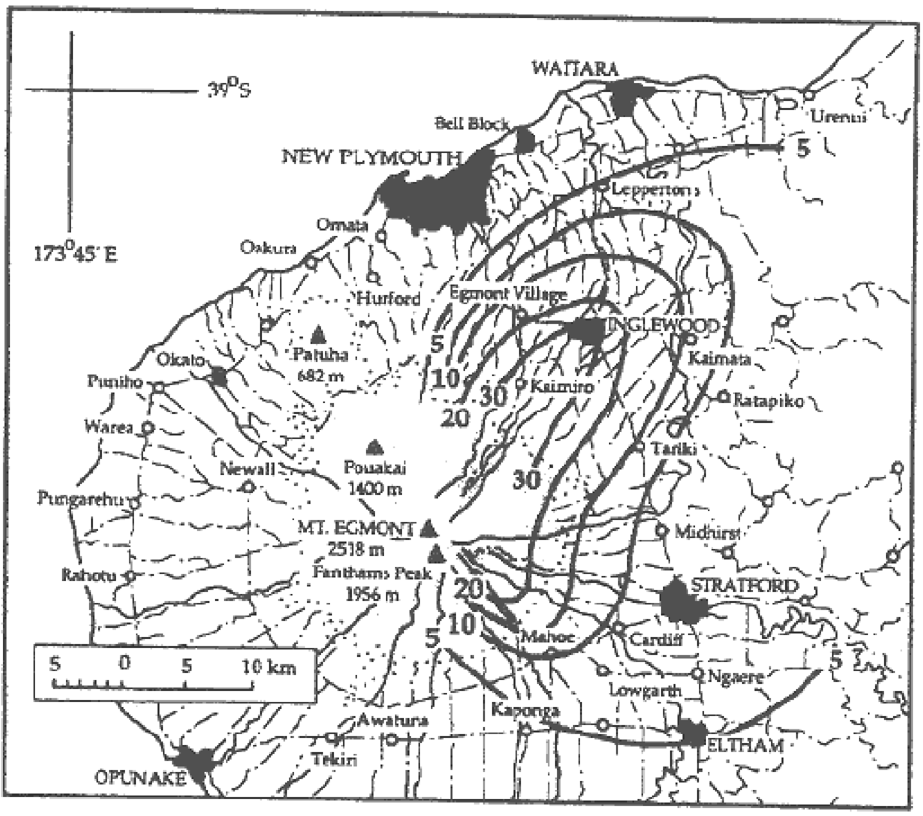


Figure 3.16: Isopach map (in centimetres) for the 3600 B.P. Inglewood Tephra. Map from Alloway *et al* 1995



3.2 Impacts of Volcanic Hazards

Typically a number of types of hazards will result from a volcanic eruption. The most threatening hazards include pyroclastic falls, pyroclastic density currents, lava (flows and domes), lahars and flooding, debris avalanches and volcanic gases. These hazards can be divided into two categories; near-vent destructive hazards and distal damaging and/or disruptive hazards.

3.2.1 Near-vent Destructive Hazards

Pyroclastic Falls

Large fragments (blocks and bombs > 64 mm) follow ballistic trajectories and are here termed projectiles. Large ballistic projectiles rarely land more than 1-2 kilometres from a vent in a brittle or molten state and are capable of starting fires. The impact of ballistic clasts will cause damage to buildings (including ignition), with the degree of damage dependent on projectile mass, temperature and velocity. Projectiles present a high risk of death or injury to people and animals.

Finer material (ash < 2 mm and lapilli 2-64 mm) is convected upwards in an eruption column (Self & Walker 1994) and dispersed by the wind (see distal hazards section). Finer material can form thick pyroclastic fall deposits capable of overloading roof strength causing collapse and possible death or injury to people or stock inside. 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). Deaths and injuries are also likely to result from falling branches or other accidents.

Pyroclastic Density Currents

Pyroclastic density currents (flows, blasts, and surges) often travel at speeds up to 200 km/h, and cause total destruction in the areas they cover. Surges and blasts are more dilute, turbulent, and widespread in their effects than flows (White 1996). Flows are more concentrated and are topographically controlled (Sparks 1976). Pyroclastic density currents from magmatic eruptions are usually very hot (several hundred oC) and can start fires. Pyroclastic surges from hydrothermal and phreatomagmatic eruptions are cooler (usually less than 300oC) and often deposit sticky wet mud. Pyroclastic flows and surges have been produced by many eruptions from New Zealand volcanoes and represent one of the most destructive manifestations of volcanic activity.

People or animals caught in the direct path of pyroclastic density currents are most unlikely to survive and any survivors will probably receive severe injuries. Buildings offer some protection on the periphery of the flow but will not guarantee survival as the building may be destroyed or severely damaged. The best protection is to evacuate the area prior to the event. Pyroclastic density currents will cause destruction of vegetation caught in its path, often removing the forest cover by uprooting and stripping foliage, branches and bark. Heat damage to plants may also occur Heat damages the hydrated tissues of plants. Damage to buildings and other structures depends on the temperature, duration of flows and amount of solid material it carries.

Lahars

Lahars are mudflows formed by mixing of volcanic particles and water. 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 or animals caught in the path of a lahar have a high risk of death from severe crush injuries, drowning or asphyxiation. Lahar events will cause destruction of buildings, installations and vegetation caught in their path. 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 by the lahar.

Lava

Lava flows are streams of molten rock that flow downslope from a volcano. The distance lava travels depends on the viscosity of the lava, output rates, volume erupted, steepness of the slope, topography and obstructions in the flow path (Cas and Wright 1987). Basalt flows have low viscosity (flow easily) and have been recorded to travel more than 50 km from a volcano but usually only flow 5-10 km. Andesite flows are more viscous and rarely travel more than 5 km. Dacite and rhyolite lavas have high viscosity and typically form short, thick flows or domes.

Lava flows will also cause complete destruction of vegetation, often igniting trees and shrubs. Lava flows will seldom threaten human life because of their slow rate of movement. The steep fronts of flows may became unstable and can collapse, causing small pyroclastic flows. Lava flows will also cause total destruction of buildings and other infrastructure in their path.

Sector Collapses and Debris Avalanches

A debris avalanche is a sudden and rapid movement of rock and associated materials due to gravity (Siebert 1984). Debris avalanches usually occur at larger over-steepened volcanoes and are one of the most hazardous of volcanic events. Debris avalanches can travel considerable distance from the summit area and destroy everything in their path. As debris avalanches 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.

Volcanic Gas Hazards

Magma generated at the base of the earth's crust attains buoyancy through density differences between the molten material and adjacent solid, or semi-solid crustal rock. Density differences are attributable to two factors. First, the liquid phase is of intrinsically lower density than the adjacent solid rock, and secondly, as the magma ascends through the crust, confining pressures decrease leading to exsolution of a discreet volatile phase from the magma. It is widely argued in the literature as to where in the crust exsolution occurs, but its contribution to magma buoyancy is tremendous, and results in accelerated ascent of the magma. As the magma approaches the surface, it is common for the volatile phase to decouple from the magma, and continue on to the surface independently of the molten material. Although the processes have been vastly simplified here, this illustrates how significant quantities of magmatic volatiles can be released from a volcano between, or even in the absence of, eruption events.

The magmatic gas stream typically consists of, in order of decreasing abundance, H2O, CO2, SO2, H2S, HCl, HF and a number of other minor species, including metal-bearing chloro-, fluoro- and sulfido- gas species. All of these gases enter into chemical equilibrium relationships with each other, and with the enclosing hydrothermal system. The various equilibrium relationships are discussed by Giggenbach (1996), Symonds and Reed (1993), and Christenson & Wood (1993).

Plume gases released from volcanoes such as Ruapehu and White Island contain acidic constituents from essentially two end-member sources, including those coming directly off the magma, and those derived from the hydrothermal system which typically envelops (and/or covers) the magma column. These end-member fluids become thoroughly mixed in the vigorous, high temperature environment within the eruption vent, and within the plume itself.

Chemical data for the major fumarolic gas species from Ruapehu and White Island are listed in Table 3.2. By virtue of the fact that these samples were collected during relatively quiescent periods from the respective volcanoes, they clearly show evidence of interaction with shallow surface waters, and therefore are not perfect analogues of the main vent gases. Never-the-less, the component ratios for the sample for Ruapehu sample site "B" are close to theoretical values derived for magmatic gas streams from other volcanoes (eg White Island Giggenbach and Sheppard, 1989; Table 3.2), suggesting that this particular discharge is representative of the carbon, chlorine and sulphur contents of the magmatic gas from this volcano.

There are three agricultural hazards associated with volcanic gases. The first, and usually most benign in an agricultural context, results from direct exposure to gases emanating from active volcanoes. Symptoms from such exposure are restricted to respiratory and eye irritation in humans and animals, and significant exposure is likely to be restricted to zones within about 5-7 km of the active vents. Although there have been instances where heavy gases released from active vents have flowed considerable distances down confined channel-ways (valleys) or slopes from volcanic vents, leading to suffocation and/or poisoning of humans and animals in the pathway, this is not expected to be a serious threat in the New Zealand context.

The second threat to livestock and crops stems from the interaction between volcanic gases and atmospheric environment adjacent to the volcano leading to the development of vog (volcanic fog) and/or acid rain. Under the appropriate atmospheric conditions, the soluble acidic components of the gases (SO2, H2S, HCl, HF) can be readily absorbed into aerosol droplets (condensed steam, cloud or rain), and subsequently dispersed downwind to rain out on livestock and crops. Whereas the effect on livestock is not considered to be a serious threat, acid rain and fog can cause considerable damage to crops and farm plant/machinery (ie. Corrosion).

The third threat posed by volcanic degassing results from the uptake of the water soluble plume gas species described above onto aerosol particles and ash, which subsequently falls out onto pastures and forests. As shown in the 1995 eruptions of Ruapehu, ash with even moderate soluble chemical burden proved lethal to sheep and deer. The characteristics of these leachable components are described below (Tables 3.2, 3.3).

Table 3.2: Fumarolic Discharge Chemistry. All values as mmol/mol total discharge. [1] Data from Christenson (1998). 2. Data from Giggenbach and Sheppard (1989)

Volcano	Date	Site	T(°C)	CO2	St	Sn	H2S	SO2	NH3	HF	HCl	He	H2	O2	N2	CH4	Ar	CO	H2O
Ruapehu[1]	6.12.95	A	281	16134	12274	3.00	2040	10234	2.5	32.9	611	0.14	184.5	0.82	108	-	0.12	-	970652
Ruapehu[1]	18.1.96	A	92	10950	3311	2.74	693	2618	0.2	0.8	30	0.11	123.8	0.49	80	-	0.10	-	985504
Ruapehu[1]	26.2.96	A	94	30816	1089	4.00	0	1095	2.8	0.5	61	0.35	38.08	0.00	667	0.174*	5.77	0.13*	967319
Ruapehu[1]	26.3.96	B	190	33135	15772	0.59	8964	6808	16.5	4.5	7456	0.25	18.28	599.27	3517	0.015*	39.46	0.10*	939443
Ruapehu[1]	26.3.96	C	215	18694	6465	1.92	2245	4220	58.7	73.8	1518	0.15	79.82	1.37	151	0.015*	0.15	0.42*	972958
Ruapehu[1]	10.5.96	A	92	9416	4300	-1.95	4266	34	0.6	0.4	29	0.06	109	0.00	74	0.390	0.20	-	986071
Ruapehu[1]	28.2.97	D	154	15469	5249	2.59	1236	4013	17.5	na	346	0.07	509.0	<.02	151	-	0.18	6.18	978252
White Is[2]	13.12.76	3	100	146300	14430	4.10	0	14430	10.3	16	2460	-	46	<0.8	763	1.0	<.5	1.3	983000
White Is[2]	21.5.81	3	396	268000	44560	2.70	9655	34905	10.0	37	4150	2.78	1040	6.7	1600	20.1	97.15	-	665000
White Is[2]	22.7.83	3	685	115200	23250	2.90	4263	18988	18.1	424	10460	.332	888	36.5	711	1.7	2.42	67.2	849000
White Is[2]	Magmatic Gas Phase			89000	18000						9000								885000

Table 3.3: Crater Lake Water Chemistry, 1995-1996. All values are mg/l.

Date	Tm(°C)	Ta(°C)	pH	Li	Na	K	Ca	Mg	Fe	Al	Cl	SO4	B	SiO2	H2S	F
15.8.95	29	16	0.67	0.51	432	202	906	584	666	1960	8154	26000	18.1	290	<0.05	420
20.9.95	48	21	0.63	0.62	467	196	1037	713	888	2000	8619	30300	20.3	430	<0.05	450
6.12.95	57.7	23	0.7	1.07	766	143	1944	903	556	1160	12536	11400	17.7	415	<0.05	380
20.12.95	60	23	1.04	0.86	582	124	1448	615	528	1030	8127	7070	13.9	471		260
18.1.96	49.6	23	1.06	0.54	332	61	1512	367	362	580	5664	5780	14.2	370	<0.05	240
26.2.96	55	17	1.2	0.26	173	26	1020	183	236	220	2684	5251	5	222		110
26.3.96	49.6	17	1.07	0.53	326	26	1120	378	318	377	4343	5483	17.7	261		90
10.5.96	65.6	20	0.99	0.86	655	52	1529	705	500	615	8103	12019	14.8	442		130

3.2.2 Distal Hazards

Pyroclastic Fall Deposits

Fine ash can be deposited hundreds to thousands of kilometres from its source, making volcanic ash the product most likely to affect the largest area and the most people during an eruption. The physical and chemical properties of volcanic ash are discussed in more detail in the following section of this report.

Sedimentary Response

The impact of ash fall on hydrologic systems depends on a number of factors, including: thickness of the deposits; grain-size distribution; nature of the substrate i.e. slope angle and degree of vegetation cover; and climate, in particular the intensity of precipitation. There are two main classes of impact: (1) hydrologic effects such as run-off, flashier stream discharges and higher flood peaks, due to enhanced surface run-off and reduced infiltration rates in catchments, and (2) erosion and resedimentation processes, which may be partly a function of the hydrologic effects and which act to remobilise and redistribute the ash.

3.3 Impacts of Ash Fall on Animals and Plants

3.3.1 Impacts on Animals

Mammals: Ash fall is unlikely to immediately kill animals except when deposition rates are exceptionally high and thickness is great. Tephra cover on pastures will result in lack of feed for animals. During the 1945 Ruapehu eruption pastures covered by ash were often described as being unpalatable to stock but no significant pasture damage occurred (Johnston & Neall 1995). No stock losses due to lack of feed were reported (Cunningham 1946). Following ash falls from Ruapehu in 1995 and 1996 farmers noted that animals were readily put off their feed by ash deposits of around 2-5 mm thickness. Ash from the 1980 Mount St Helens eruption had little impact on livestock as long as they had access to sufficient feed (Blong 1984). Trials on cows being fed ash at a rate of 1.5 kg per day showed no obvious effects on milk production.

Aquatic life is very susceptible to changes in water conditions such as increases in acidity, turbidity, temperature and concentrations of soluble elements.

Thick ash falls will have a dramatic impact on water conditions in affected areas. Rivers draining such areas will produce sustained high sediment yields due to the availability of readily erodible material as the river flows through the new deposits. Rivers flowing through barren areas that were previously vegetated will suffer from lack of shade, raising water temperatures beyond previous levels. After the 1980 Mt St Helens eruption, water temperatures soared beyond levels for growth and survival of salmon where the Toutle River flowed through the area devastated by the debris avalanche (Lucas 1986). Another problem for such rivers is the lack of leaf litter that is an important food source for aquatic invertebrates. Further away from the mountain little impact was noted on streams in areas with ash thicknesses of 2 cm (Gamblin *et al.* 1986).

In normal circumstances little sediment is added to rivers by tephra in areas away from stream or river channels, unless the stream channel lies directly below steep slopes. Only during severe rainstorms is tephra readily eroded from the land surface and deposited in streams or rivers. Such events are little different to the behaviour of soils on non-vegetated land during similar severe rainstorms. Keam (1988) notes Dr Hectors observation of the tephra deposits from the 1886 Tarawera eruption. "*While rain had certainly washed a great deal of mud off steep slopes, it was showing no tendency to slide .... the mud was there to stay, unless it was removed by normal erosional processes*."

The primary factors causing fish to die in the rivers around Ruapehu after the 1969, 1975 and 1995 lahars were suspended sediments, acidity and concentrations of fluoride. Minor fish kills were also reported in ash-affected rivers after the 1995 eruption but 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.

Aquatic floral and faunal invertebrate populations are susceptible to ash suspended in rivers and lakes. Reductions in primary production of planktonic and rooted plants will reduce secondary grazers important as fish food.

Birdlife: Ash may cause several problems for birds, with falls of fine ash preventing flight. Widespread ashfall may result in lack of food. Gases from the vent area can kill overflying birds. In the 1886 Tarawera eruption, pigeons, ducks and sparrows were killed in large numbers (Keam 1988). Surviving sparrows were blinded at least temporarily, with eyelids gummed together by the falling mud.

Other living things: Ash particles are especially destructive to insects largely due to abrasion of the epicuticular wax layer which causes rapid desiccation and death (Cook et al. 1981). One advantage noted in agricultural areas which received small amounts of Mount St Helens ash was the destruction of insect pests.

3.3.2 Impacts on Plants

Damage to small vegetation and the soils on which they depend will vary with tephra thickness and composition of the ash. The effects in Table 3.4 are based on observations from past eruptions described by Folsom (1986) and Blong (1984).

Table 3.4: Impacts on plants and soil from increasing ash thickness

Thin burial (< 5 mm tephra)

- No plant burial or breakage
- Ash is mechanically incorporated into the soil within one year
- Vegetation canopies recover within weeks

Moderate burial (5 - 25 mm tephra)

- Buried microphytes may survive and recover
- Larger grasses are damaged but not killed
- Tephra layer remains somewhat intact on the soil surface after one year
- Soil underneath remains viable and is not so deprived of oxygen or water that it ceases to act as a topsoil
- Vegetation canopies recover within next growing season

Thick burial (25 - 150 mm tephra)

- Completely buries and eliminates the microphytes
- Small mosses and annual plants will only be present again in the local ecosystem after recolonisation
- Generalised breakage and burial of grasses and other non-woody plants
- some macrophytes of plant cover do not recover from trauma
- Large proportion of plant cover eliminated for more than one year
- Buried soil is revitalised when plants extend roots and decaying organic matter from the surface of the tephra layer down to the top of the buried topsoil and affect an integration of the tephra and buried A horizon. Generally accomplished in 4 - 5 years
- Vegetation canopy recovery takes several decades

Very thick burial (> 150 mm tephra)

- All non-woody plants are buried
- Burial will sterilise soil profile by isolation from oxygen
- Soil burial is complete and there is no communication from the buried soil to the new tephra surface
- Soil formation must begin from this new "time zero"
- Several hundred (to a few thousand years) may pass before new equilibrium soil is established

Eruption impacts on trees are described by Rees (1970) below (Table 3.5).

Table 3.5: Impacts on trees of tephra

Tephra Thickness	Impact on Trees and Shrubs
150 - 500 mm	Slight damage and partial survival of shrubs
500 - 1500 mm	Tree damage, large branches were broken, heavy kill of shrubs
1500 mm	Total kill zone

Eggler (1948) noted pines surviving in tephra depths of 1240 mm and 1780 mm. Pine seedlings and small trees were killed as a result of excessive bending and burial while large mature trees suffered from branch breakage under the load of ash. Pines with basal diameters of 100 - 300 mm survived best because their stems were strong enough to resist excessive bending yet sufficiently flexible to dump part of the load and avoid breakage.

Crop damage will result from burial which can kill or damage plants depending on the thickness of the tephra. During the 1995 Ruapehu eruption major losses (~$250 000) to cauliflower crops were reported in Gisborne, 250 km downwind but market gardens were fortunate that many crops were not in the ground at the time of the ash falls. The following table (3.6) was prepared by the Ministry of Agriculture in 1995 following the Ruapehu eruption.

Table 3.6: Periods of high crop risk from tephra (from MAF 1995)

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 tissues, 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.

Damage to soils may result from the tephra fall affecting the productive potential of the area. Small amounts may improve soils. A positive impact of the 1995 - 1996 Ruapehu ash falls was to temporarily reduce the sulphur fertiliser requirement for all sheep, beef and dairy farmers within the ash fall area (Cronin *et al*. 1996). Contamination of water supplies may cause damage to plants and limit production.

Acid rain (and acidic ash) has been reported as causing a number of effects on plants. Blossom drop, poor fruit set, small almost seedless fruit have also been reported in horticultural areas. In most areas where ash fall has occurred, crop damage has only been sporadic. Minor acid burns were reported on some plants on Ruapehu and the Kaimanawa Ranges following the 1995 Ruapehu eruption but most had recovered by late 1996 (Keys 1996).

Plant recovery: Most detailed studies of plant growth after tephra fall result from the 1980 Mount St Helens eruption. Algal covers became established on most tephra surfaces within a few weeks, providing a protective surface skin against erosion, although the mat is easily disturbed.

Folsom (1986) showed that the recovery of plants from the trauma of tephra deposition will follow a sequence:

1. Recovery of surviving not completely buried plants
2. Emergence of surviving buried plants
3. Germination of local seed reserves
4. Colonisation from outside seed sources

with individual plant recovery dependent on:

1. Thickness of ash
2. Degree of continuing disturbance
3. Amount and reliability of rainfall

Chaplin *et al*. (1986) noted that certain species of plant do not suffer from mineral deficiencies when growing in the nutrient-poor volcanic soils. Such plants will obviously be better suited to recolonisation in areas where tephra or surge deposit thicknesses are great or on lava flows. The re-establishment of plants on barren areas influences the colonisation of subsequent plants by trapping seeds and changing the microclimate (Dale 1986). After five years specie richness had stabilised in areas where recolonisation had occurred (del Moral and Wood 1986). Sites far removed from seed sources were unlikely to be recolonised rapidly.

The recovery of the area devastated around Mount Tarawera in 1886 is well documented (Clarkson and Clarkson 1991). The devastated area remained barren for over 10 years. Where bush had only been partly buried it resprouted quickly. On the lower slopes of the mountain toetoe and tutu shrubs re-established within 20 years and a mat of daisies colonised the middle slopes. After 27 years post-eruption shrubs had established on the middle slopes and daisies and grasses were present high up the mountain. The summit area was still barren. By 42 years after the eruption a young forest was present at the base of the mountain. Higher up the slopes a tutu association was common. After 75 years the forest was dominated by tawa at low altitudes and kamahi at higher altitudes. Near the top of the mountain, shrubs were common and the crater and summit area had widespread grasses, mosses and daisies. In the past 20 years an influx of tutu and scattered introduced conifers has occurred on large areas of the upper part of the mountain.

3.4 Properties of Ash

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. These deposits are composed of various proportions of vitric, crystal or lithic particles. Vitric particles are glass shards or pumice derived from magma, while crystals are minerals derived from phenocrysts or mircolites developed in the magma. Different minerals reflect the composition of different magmas. The most common minerals are shown in Table 3.7.

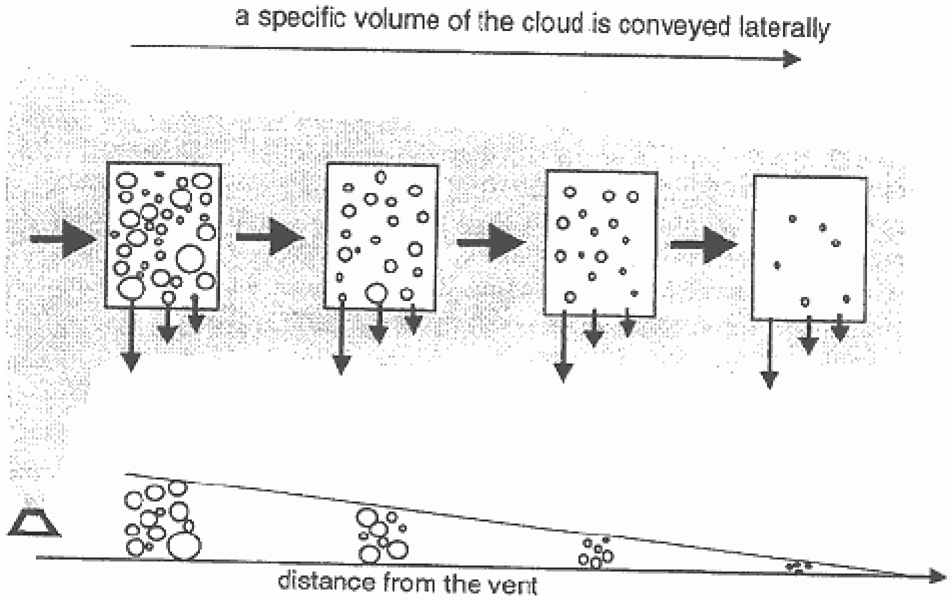
Table 3.7: Composition of major phenocryst phases in magma (from Thorpe & Brown 1985)

	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. 3.17) 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, Sparks et al. 1992).

Figure 3.17: 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 (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 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 3.8. Ash particles commonly have sharp broken edges which makes them a very abrasive material.

Table 3.8: 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		biotite (2.5-3)
			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)
				magnetite (H 7.5-8)
8	----	Topaz		
9	----	Corundum	Chromium	

3.4.1 Properties of Ash - Soluble Components

Reservoir fluids from volcanic hydrothermal systems can be an important source of chemical compounds in volcanic fallout which, if ingested, could be potentially hazardous to livestock. These fluids, once ejected from a volcano during eruption, are typically transported downwind from the vent as aerosols, or are adsorbed onto ash particles. For eruption columns that are restricted to the troposphere, these aerosols and ash particles ultimately fall out to the earth's surface, usually within 10's to 100's of km proximity to the volcanic edifice.

Excellent examples of these fluids are found in crater lakes sitting atop actively degassing volcanic vents such as that on Mt Ruapehu. As shown in Table 3.9, these fluids are highly acidic, consisting essentially of mixtures of sulphuric, hydrochloric and hydrofluoric acids, magmatic and meteoric waters, and dissolved rock components.

As described previously, soluble components on ash particles can also originate from sorption of magmatic gases (eg. SO2, HCl, HF) onto aerosols and ash particle surfaces during transport in the plume, and a third possible source of leachable material derives from hypersaline magmatic fluid which is resident in the magma chamber. The latter consists predominantly of chloro-salts of the typical alkali and alkaline earth rock constituents (eg. NaCl, KCl, CaCl2, MgCl2, etc.).

Examples of the fairly typical leachate compositions from Mt Ruapehu are listed in Table 3.9. The data are presented as mg of solute per litre of H2O; and can be readily converted to mass of soluble salt per unit mass of ash. Not only is the acidic nature of the leachate readily apparent from these data, but they also clearly demonstrate the ash leachate as the source of the F which was responsible for fluorosis fatalities associated with the 1995-96 eruptions of Ruapehu.

Time series trends in the leachate data point to a decrease in the total amount of leachable material during each eruption episode, and this trend is also apparent over the entire 1995/96 period of activity (Fig 3.18). This is interpreted as a result of decreasing content of the hydrothermal end-member aerosols in the plume through time, which is consistent with the observed early expulsion of these fluids from the lake and vent conduits during each event.

One of the interesting features of the ash deposits, particularly those erupted early in each episode, is the presence of particulate elemental sulphur (Fig. 3.19). Although this phase, which originates in the hydrothermal system, only slowly oxidizes to sulphuric acid under atmospheric conditions, the reaction can be catalyzed by bacteria and/or certain transition metals, and therefore has the potential to cause long term soil acidity and/or corrosion problems.

It is common for aerosols and ash particles to dehydrate as they are transported away from the volcano, or after they have settled onto the ground surface. This may result in the formation of very concentrated acid solutions within the aerosols or on the ash particle surfaces. It is possible to form nearly pure sulphuric acid in this way, whereas HCl tends to revolatilise to the gas phase during dehydration. Loss of HCl gas is indicated in several of the leachate samples from 1995-96 eruptions of Mt Ruapehu.

In terms of agricultural impact, the greatest chemical hazard posed by volcanic eruptions is that caused by ingestion of soluble (acidic) magmatic constituents on ash particles, followed by vog and acid rain. Volcanoes that have the highest potential to cause such problems will be those that 1) have large, long-lived hydrothermal systems associated with them, or 2) magmas that have large natural abundance of S and/or halogen constituents (F, Cl, Br). With regard to the former, the highest risk volcanoes in NZ would be those such as Ruapehu and White Island, whereas the high-F bearing lavas of Mayor Island make this a good example of the latter.

Table 3.9: Ash leachate analyses. All concentrations are as mg/l.

Sample No.	Locality	Eruption Date	Ash Wt	Wt H2O	pH	Li	Na	K	Ca	Mg	Fe	Al	F	Cl	Br	NO3	SO4
RuA 17069631	Kuratau Hydro. Rd.	17.6.96	9.965	108.36	4.93	<.05	39.0	3.50	258	27.0	0.74	4.6	2.71	42.3	1.25	2.56	784
RuA 17069634	Kinloch marina	17.6.96	9.317	100.00	4.47	<.05	30.0	0.14	343	30.0	1.90	5.8	1.43	29.4	0.24	0.91	1029
RuA 17069653	Opataka Hist Place	17.6.96	10.047	99.42	4.69	0.12	16.1	2.40	116	10.6	0.58	4.1	1.53	9.2		0.15	355
RuA 17069654	Rotopounamu car pk	17.6.96	10.770	98.68	4.66	<.05	18.4	2.80	121	11.4	0.38	4.1	2.24	9.8			377
RuA 17069655	Otara Road	17.6.96	10.076	99.84	5.01	<.05	16.6	6.40	112	9.6	0.21	4.0	4.32	10.0		0.16	355
RuA 17069656	Whangamata Road	17.6.96	10.318	99.32	4.70	<.05	30.3	2.60	193	24.4	0.81	4.1	2.38	27.1			613
RuA 18069613	Rotopounamu track	18.6.96	10.027	100.02	5.05	<.05	21.0	6.40	162	12.6	<.1	5.2	5.86	16.6	0.01	2.24	479
RuA 18069618	Otara Road	18.6.96	9.643	100.02	5.07	<.05	21.0	7.00	147	11.4	<.1	3.5	2.86	19.6	0.01	2.81	451
RuA 18069621	Rotoaira Farm	18.6.96	4.028	100.01	5.03	<.05	20.0	10.20	147	13.4	0.19	3.7	3.36	19.1	0.01	3.58	472
RuA 18069619	Top of the Bruce Road	18.6.96	9.982	100.01	4.72	<.05	23.0	3.90	146	19.7	0.33	4.3	2.58	19.3	0.38	2.15	481
RuA 18069625	Rotoaira fishing camp	18.6.96	10.060	100.22	4.15	<.05	37.0	0.44	269	45.0	2.80	4.3	0.76	84.3	0.18	2.23	833
RuA 18069630	Wairakei Nth.	18.6.96	9.942	100.01	4.11	0.08	68.0	2.70	388	66.0	3.90	3.5	1.18	79.9	0.07	3.37	1618
RuA 18069655	Rotorua	18.6.96	10.046	100.04	4.46	0.10	74.0	1.30	353	54.0	1.10	5.8	1.48	54.5		1.18	118
RuA 19069610	Mangatepopo Track	19.6.96	10.010	100.03	4.88	<.05	17.7	6.10	195	19.0	0.43	3.7	1.32	19.2		1.54	586
RuA 19069612	Top of the Bruce	19.6.96	9.986	100.04	4.45	<.05	37.6	3.70	189	36.0	0.96	3.3	2.67	116.5		1.64	518

RuA 19069652	Top of the Bruce	19.6.96	10.616	99.32	4.27	<.05	35.8	7.40	303	32.4	0.12	8.7	4.27	26.5	0.15	0.28	983
TOB-A	Top of the Bruce	8.7.96	10.283	99.25	4.91	<.05	14.6	7.00	101	9.4	0.10	2.2	2.42	11.0			319
TOB-B	Top of the Bruce	8.7.96	11.644	99.19	4.65	<.05	20.0	6.50	153	12.2	0.18	4.2	4.58	17.5			451
TOB-C	Top of the Bruce	8.7.96	10.469	100.00	4.62	<.05	14.9	6.00	118	9.5	0.12	2.9	3.84	12.0			338
Lochinvar	Lochinvar Station	12.10.95	10.223	99.20	3.70	<.05	85.0	0.39	276	124.0	8.40	120.0	8.13	61.8	0.72	0.57	2528
RuA 171095-01	Waipakahi Road	17.10.95	3.050	100.02	4.72	<.05	35.0	1.10	206	25.0	1.50	4.1	1.16	61.6		1.84	612
RuA 171095-05	Rangipo Intake	17.10.95	6.967	101.05	4.01	0.10	49.0	0.31	360	53.0	6.40	20.4	6.59	125.2		3.74	1154
RuA 171095-06	Whangaehu River ford	17.10.95	10.096	100.28	3.93	<.05	3.0	0.35	20	2.8	6.60	5.4	tr	12.3		3.56	89

Fig. 3.18: 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.

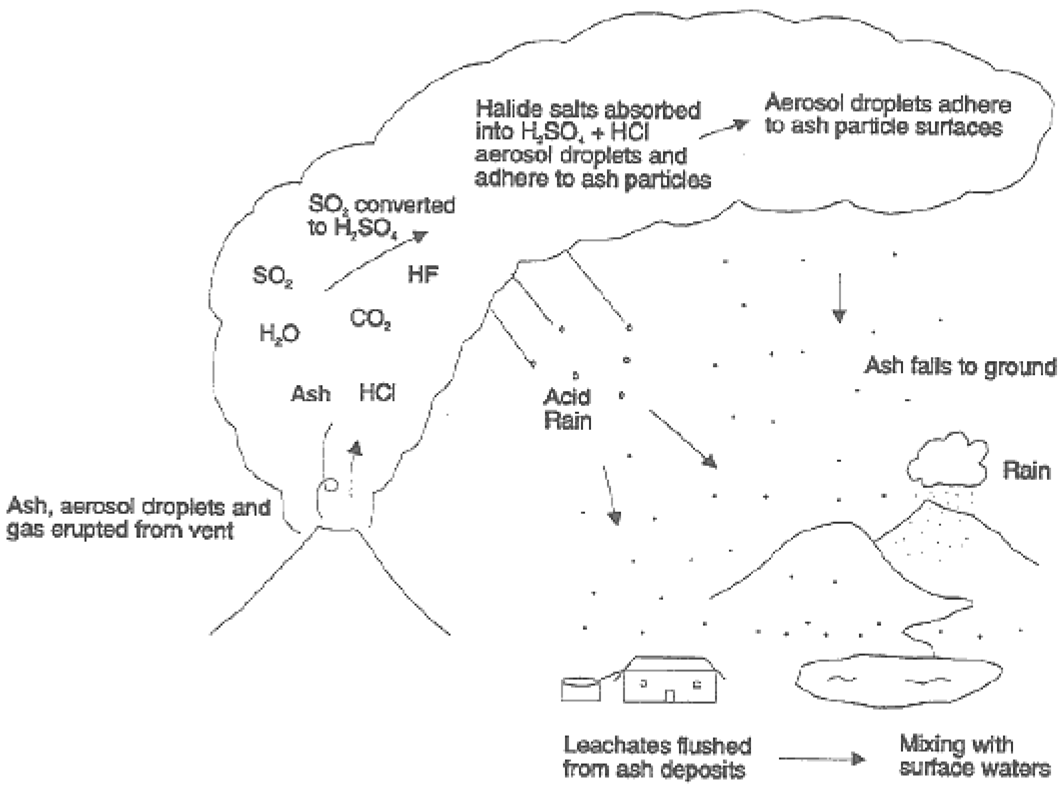
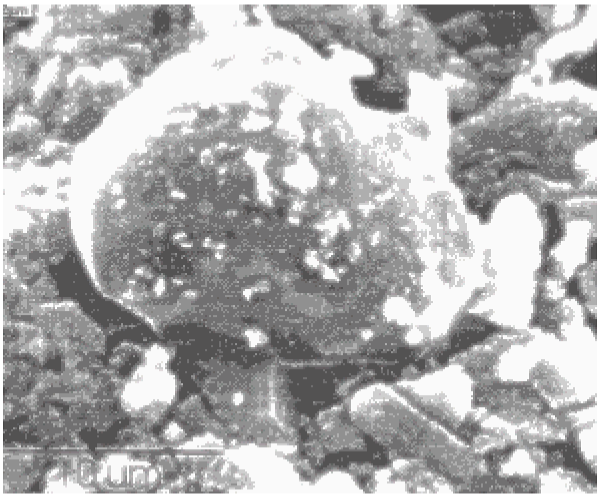


Fig: 3.19: Elemental sulphur grain in ash collected from Lochinver Station subsequent to the October 1995 eruptions of Ruapehu



3.5 Management

3.5.1 Volcano Surveillance in New Zealand

Volcano surveillance in New Zealand is carried out by the Institute of Geological and Nuclear Sciences (GNS) (Scott et al. 1995). Monitoring enables the background state of the volcano to be determined. Departures from this state may indicate the onset of an eruptive episode. 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 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** (e.g. Ruapehu, Ngaururhoe/Tongario) and the other for **reawakening volcanoes** (e.g. Taupo, Okataina, Egmont). GNS will adjust the alert level based on observations from the surveillance programmes at each volcano and notify Ministry of Civil Defence, councils, key organisations and the media (as per the National Civil Defence Plan - see appendix 1).

4.0 Impacts of Ash Fall on New Zealand Pastoral Agriculture and Arable Cropping

4.1 Background

Areas at risk from volcanic activity encompass large productive dairy, deer, sheep and beef and arable farms from Taranaki, south to Manawatu, across to the East Coast and up to Northland. The area affected by a volcanic eruption is dependent on the wind direction at the time of the eruption.

As intensive agricultural farming is young relative to volcanic activity, there is little historical data on the effects of ash showers on land farmed intensively for agricultural production. Although there have been several eruptions in the world that have affected agricultural land, the depths of ash on the land have all been less than 50mm in recent history. Consequently, much of the predicted impacts outlined in this report for the four depths of ash are conjecture and based on the impacts on plants and soil of various ash thicknesses as observed by Folsom (1986) and Blong (1984) and extrapolation of impacts from eruptions of lesser ash depths such as Mt St Helens, Mt Ruapehu and Hekla (Iceland). More research is required on simulating ash showers to determine the actual effects and methods for rehabilitating the land.

4.2 Near Vent Destructive Hazards

Pyroclastic Falls

As outlined in Section 3, pyroclastic falls 1-2 kilometres from a vent are very destructive and present a high risk to people and animals. Farm land and stock close to a vent would be destroyed by a significant eruption. Rehabilitation of this land would be very difficult and costly due to the coarse nature of the material and amount deposited. Farms at risk include land surrounding Taupo, Okataina and Taranaki vents.

Pyroclastic Density Currents

Pyroclastic flows or density currents can result in devastation up to 20 to 30 kms from the vent, destroying stock, buildings, pastures and crops. Restoration of land affected would be dependent on the nature of the material. Where the flow deposited wet sticky mud the land could take 10-20 years for vegetation to be re-established. Pyroclastic flows may occur from a major eruption of Mt Egmont, Okataina or Taupo.

Lava

Although lava flows are very destructive to land the damage to farm land is likely to be small as they generally only travel 5-10 km from a volcano with only a small area of farm land likely to be affected.

Lahars

Erosion and reworking of volcanic material can impact on land many kilometres from the original volcanic deposit. Alluvial deposits and mud flows may occur for many years after the eruption.

Ash covered watersheds (normally undisturbed tussock and pasture lands, bush and forests) will affect the supply or continuity of water to rivers and streams. Restricted infiltration in areas with significant ash deposition will disrupt the natural hydrology of the region. Water from rain and snowmelt will be shed more rapidly and will be high in sediment. This will increase the hazards of flooding and erosion. At this time , it appears that little can be done through management to modify the potential effects of ash on land at high ash depths or on steeper land with less ash deposits. Increased runoff and sediment laden water could persist for many years (RJ Cook et al 1981).

For example, a major eruption of Taupo or Okataina could result in the Rangitaiki Plains being unsuited for intensive agriculture for at least 10 years from on going flooding and alluvial deposits of volcanic origin (D Johnston pers comm). It was from alluvial deposits of volcanic material that the Rangitaiki Plains in the Bay of Plenty were originally formed.

4.3 Distal hazards

Pyroclastic Fall Deposits - (Ash)

4.3.1 Impact On Livestock

Ashfall is unlikely to immediately kill livestock, except when deposition rates are exceptionally high and thickness is great. From the experience at Mt St Helens, the majority of stock survived ashfalls up to 300 mm (MAF Volcanic Alert, 1995). However, survival of stock in the short term would be dependent on the availability of feed and good quality water, with ashfalls of 10 mm affecting pasture growth.

The actual effects on livestock depend on:

- consistency of the ash (tephra)
- amount of ash deposited
- poisonous aerosols attached to the ash
- amount of rainfall immediately following any ash deposit
- metabolic and nutritional demand of the livestock at the time
- age of livestock
- pasture length
- stocking rate.

Where the ashfall significantly destroyed pastures, stock survival in the short term would be dependent on the ability to feed up to 100% of their diet in supplement, until they could be evacuated out of the area, or slaughtered, or pasture species re-established. Restoring quality water supplies would also be essential for stock to stay on the land. Even with the evacuation to good quality feed and water, stock's long term productivity may still be effected by ash inhalation and fluorine poisoning. Some stock may not recover in the long term, with humane slaughtering being the best option.

Where ashfalls affect a large area, evacuation of stock would be extremely difficult due to the logistics of moving large numbers of stock and sourcing feed in areas unaffected by the ash. This may result in large losses of livestock through dehydration and starvation.

Where there is a significant ashfall, clean water would be in short supply, with natural water supplies and dams contaminated, and pump functions severely reduced by the abrasive nature of the ash. Following ashfalls from Ruapehu in 1995 and 1996, farmers noted that animals were readily put off their feed by 2-5 mm ash deposits. Hence, even with very light deposits of ash, supplementary feed would be required.

Young stock are more at risk than mature animals. Close grazing animals such as sheep and deer are more likely to be affected by light ash showers.

An eruption in early spring would have the greatest impact on both sheep and beef and dairy farms. On dairy farms, milk yields would be severely depressed in early lactation - an effect that would carry over for the whole lactation. On sheep and beef farms, lamb and calf survival/thrift would be poor as ewes and beef cows reduce/stop lactating. Livestock losses from the eruption of Ruapehu in 1995 were greatest in lactating ewes, grazing short pasture. Wool quality is likely to be severely effected where sheep are close to shearing.

Ashfalls may be poisonous to stock resulting in clinical diseases which include hypocalcaemia, fluorosis, forestomach and intestinal damage and secondary metabolic disorders. Nutritional and stress related diseases may also occur. The high sulphur concentration in the ash may also induce copper and cobalt deficiencies in the long term (DF Shanks, 1997).

Fluorine aerosols attached to fine tephra pose a significant threat to livestock (Gregory & Neil 1996). Poisoning occurs where the fluorine content of dry grass exceeds 250 ppm. Before death, the poisoning causes lesions in the nose and mouth and hair to fall out around the mouth. Fluorine poisoning of livestock has occurred a number of times in Iceland (Thorarinsson 1979). The eruption of Lakuggar in 1783 killed 50% of the island's horses and cattle and 79% of the sheep. In the 1947 eruption of Hekla, only sheep were effected with other animals (cattle, horses, cats, dogs and poultry) unaffected. In 1970 fluorine poisoning occurred in areas of Iceland which received only 1 mm of ash.

As a result of _ 5 mm ash fall on the Rangitaiki Plain (Taupo) during the 1995 Ruapehu eruption, approximately 2000 ewes and lambs (2.5% of the area's sheep population) were killed as a result of eating ash-affected pastures. Autopsies of the dead animals suggest fluorine poisoning or pregnancy toxaemia was the cause of death (Gregory & Neall 1996). Three Ayrshire dairy cows died at Atiamuri in June 1996 (*pers. comm.* MAF). It was reported that they stopped eating, showed signs of lethargy before dying after swallowing quantities of ash. Toxic levels of fluorine were found in the dead animals blood. The Department of Conservation also reported the death of a number of wild deer in Kaimanawa Ranges, downwind from Ruapehu, following the two largest October 1995 eruptions (possibly up to 5% of the sika deer population).

4.3.2 Impact on Pastures

Damage to small vegetation and the soils on which they depend will vary with tephra thickness and composition of the ash. The effects in Table 3.4 are based on observations from past eruptions described by Folsom (1986) and Blong (1984).

At light rates of ash, i.e. up to 50 mm, plant survival and regrowth will be dependent on :

- Chemical nature of the ash.
- Compaction of the ash after the eruption.
- Degree of continuing disturbance.
- Amount and reliability of rainfall.
- Length of feed at time of ashfall.

The ash would also affect insect populations, which would be severely checked with ashfalls greater than 25 mm. This may have a beneficial effect where pastoral and crop pest populations are reduced due to the ash. Highly mobile insects, many of which have a dense covering of body hairs which trap the dust such as honey and pollination bees are more susceptible to ash and their activity may be reduced (R J Cook et al 1981).

As outlined in Table 4.1, ashfalls greater than 150 mm result in complete burial of the pastures and soil. Where soil burial is complete, the soil is sterilised, as it is deprived of oxygen, resulting in death of all the existing pasture species and crops.

Survival of pastoral plants will be influenced by the timing of rainfall. With rain, the ash will compact to approximately one-third it's original depth. Where there is rain soon after an eruption (within 2-3 days) plant survival will be improved, with compaction of the ash.

On hill country, rain will wash ash into the gullies and low lying catchments, causing more damage. Wind erosion may also cause the ash to sand dune, where the ash is not consolidated or incorporated into the soil profile.

Where the ash results in complete burial of pastoral plants for 5-7 days, it is likely all plants will die, as occurs with heavy silting and flooding, e.g. Waimana floods July 1998.

Even where the ash could be removed within 5 days, plants may still die from burning if the ash is acidic.

The acidity and nature of the ash varies between volcanoes and eruptions. The chemicals in the ash from Mt St Helen's eruption did not have a significant detrimental effect on plants. In the Ruapehu eruption in 1996, ashfalls of 2mm on pastoral land elevated soil sulphur levels and were expected to lower soil pH by 0.2 - 0.3 units prior to pre-eruption values (Cronin et al 1996). Therefore, an ash layer 50 mm or greater, high in sulphur, could significantly reduce soil pH. In turn, this would reduce the availability of phosphate and other essential minerals and alter the soil's characteristics to such an extent, arable and pasture plants would not survive.

Where there is acid rain following an eruption, pastures will be scorched and die (N G Gregory *et al* 1996).

4.3.3 Impact on Arable Crops

As with pastures the type and depth of ash will influence crop survival and yield. Ash falls accompanied with acid rain would destroy crops.

The timing of the ash fall would affect the chances of survival of grain and cereal crops. Maize yields are not likely to be affected by light ash falls in the first two months of growth when the plant is in the vegetative period. Heavy ash falls burying much of the plant and changing the soil characteristics will result in crop failure.

The most critical period for maize yields are three weeks before tasselling to two weeks after pollination. Even light ash falls during this period could result in barren stalk and crop failure.

Although there is little information on the effects of ash, they could be similar to hail and frost damage. Table 4.2 below gives general guidelines on yield loss due to leaf defoliation. Yields may also be reduced by damaged stalks being more susceptible to disease.

Table 4.2

	% Leaf Defoliation in Maize			
	20%	50%	80%	100%
Growth Stage	% Yield Loss			
7 Leaf	0	2	6	9
9 Leaf	0	4	9	13
11 Leaf	1	7	14	22
13 Leaf	1	10	22	34
15 Leaf	2	15	34	51
17 Leaf	4	21	48	72
19 Leaf	6	27	64	96
Tassel	7	31	68	100

Maize requires many heat units for a crop to reach maturity. An eruption could delay crop maturity if sunshine hours were reduced during the eruptive period.

With most cereal crops being grown in the Manawatu, the likelihood of a 50mm ash shower or greater on these crops is low. An ash shower of this degree would effect these crops most over the pollination period.

Ash showers near crop maturity will make harvesting difficult and reduce the quality of grain. The weight of ash on crop leaves is likely to cause lodging, increasing harvesting costs and reducing yield. Ash collected within and among the spikes will cause some contamination of the harvested grain. Although from the Mt St Helens' experience 80% or more of ash was removed by cleaning procedures already used in flour mills, with the greatest loss to the farmer in reduced price (RJ Cook et al, 1981). However, this was at ash showers less than 50 mm.

Where ash depth was greater than 100mm, replanting of crops would only be possible where the ash could be incorporated to 20cm (deep ploughing).

Where it is possible to replant crops, yields would be depressed. The degree dependent on the change in the soil characteristics with the incorporation of the ash and amount of fertiliser applied.

The weight of the ash on leaves affects plant survival. Lucerne and pea crops regardless of stage of growth would either fail or have poor yields from ash falls of 10mm or greater as the plants have abundant delicate leaves and stems which are easily damaged, reducing the rate of photosynthesis and making the crop susceptible to lodging.

4.4 Ash Depths Scenarios

4.4.1 Greater than 500 mm

An ash deposit 500mm or greater would result in building collapse, destruction of services, limited to no access until there was consolidation of the ash with rain. Both livestock and humans would be killed, if not evacuated before the eruption. The land would be unsuitable for agriculture for a significant period as the ash sterilises the soil, with no organic matter or natural fertility to support plant growth. (Folsom 1986)

The environment after such an eruption would be very harsh and difficult for human survival until basic facilities were restored, such as water supply, power, access and shelter.

Reworking and erosion of the material would cause damage tens of kilometres away from the vent.

4.4.2 100 mm

Most plants would die immediately, including lucerne. Brassica and swede crops would fail if the ash fell before crops were well established. At 100mm a large proportion of the plant cover would be eliminated for more than one year (Folson, 1986 & Blong, 1984).

With feed supplies being decimated, productivity for the season would be severely checked. The long term impact is dependent on the ability to rehabilitate the land.

4.4.3 25-50 mm

The greatest impacts from a 25-50mm ash shower initially would be the loss of feed, due to burial and burning of pastures. Pastures and stock are more likely to be affected under a sheep and deer grazing regime as the feed is generally shorter in length.

On hill country, rain would result in ash being washed off hillsides, resulting in greater damage to gullies and land flooded with sediment laden water.

High amounts of supplementary feed would be required until pastures recovered or were re-established. The effect on production would be devastating for at least 3-6 months, until pastures were producing 70-80% of pre-eruption levels.

Where there is widespread reduction in stocking rate through slaughtering of breeding animals, increasing productivity to previous levels may be delayed due to the loss of high genetic merit stock.

Yields of maize and cereal crops would be reduced - the degree dependant on the time of the ash fall. The impact being the least in vegetative and late maturing stage.

4.4.4 5 mm - 25 mm

Although the initial impacts of 5-25 mm of ash would appear devastating, pastoral land should recover quickly,

- providing rain followed within 5-10 days of the ash fall,

- the ash was not acidic, and
- the ash did not contain poisonous gases.

The initial problems would be feeding livestock put off their feed by ash contaminated pastures. Once rain fell and the ash was reduced to 2-8 mm in depth pastures should start to recover. The effects being similar to a severe drought, e.g. summer 1998. A proportion of farms will require undersowing.

A 25mm ash shower would alter soil characteristics, both pH and permeability. This may reduce the productivity of the land for up to 5 years.

Animals may suffer ill-thrift, effects of fluorine poisoning and increased teeth wear, particularly deer and sheep.

Farm operations would be affected by the abrasive nature of the ash. Water pumps, cowshed plant and vehicles are all likely to need increased maintenance until the ash is consolidated and stabilised.

4.4.5 < 5 mm

The impacts of 5mm or less of ash will be minimal, unless the ash is high in fluorine. Even where the ash contained poisonous aerosols, the effects would be localised.

The biggest impact will be on farmer perceptions of the damage the ash may cause and the inconvenience of ash covered pastures, vehicles and buildings. This was borne out in the Ruapehu eruptions in 1995 and 1996 when lack of knowledge and fear of the impacts of ash created great uncertainty.

4.5 Rehabilitation Strategies for Pastoral/Arable Production Systems

4.5.1 >300mm

The devastation from 300mm of ash or more would be so great that the land would be rendered unfarmable for many generations and rehabilitation would be at an extreme cost. Bringing this land back into intensive agricultural production in the medium term (20 - 40 years) is unlikely to be economic. In the long term, alternative land uses would need to be explored, such as forestry.

The immediate requirement on land affected to this degree would be relocation of the affected residents and possible adjustment programmes to enable people to re-establish themselves elsewhere.

4.5.2 100 mm - 300 mm

Rehabilitation of the land with 100-300mm of ash would be extremely difficult, as the ash layer would have sterilised the soil below and would be too deep to be incorporated with conventional cultivation techniques - ploughing, discing, rotatilling etc. Rehabilitation on hill country would be dependent on the rate of erosion of the ash and the fertiliser and seed inputs.

Restoration of land is dependent on removal of the ash layer or a much longer time frame of recolonisation of the ash layer as organic matter and fertility builds up for plants to survive.

The time frame for restoration of the land back for pastoral farming could take generations. Initially species adapted to the harsh environment need to be established to start building up organic matter to support more productive species. The type of plant species suitable to recolonise the ash will be dependent on the climate. As the tephra has low permeability it is more prone to drought. This combined with the lack of fertility make species like Lupins and

Lotus species (that fix nitrogen) and possibly the Marran grasses as possible recolonising agents.

The process of re-establishing vegetation is likened to that of plant invasion and colonisation of sand dunes (RJ Cook et al, 1981).

Initially, just restoring basic facilities such as roading, water supply, power, effluent systems would be required before restoration of the land could be considered.

Farming the land as it was known before the eruption may not be an option, with a long term view to be taken in any restoration programme.

As with 300mm of ash or greater, relocation of affected residents and associated financial resources, compensation, counselling etc may be required for rural communities to re-establish themselves.

4.5.3 50 - 100 mm

Rehabilitation of the land will be influenced by contour, availability of suitable machinery, finance and human resources.

As the ash does not dissolve or percolate into the soil profile the ash needs to be incorporated with high inputs of fertiliser to provide a suitable medium for establishing ryegrass/white clover pastures. On land able to be cultivated, deep ploughing (to 20 cm) would give the best results as the ash layer would be buried.

Even with the incorporation of the ash, the soil characteristics change with:

- Reduced evaporation
- Lower fertility
- Lower permeability of the soil.

Any large scale cultivation would be expensive. Costs include regrassing, fertiliser and high machinery costs due to the abrasive nature of the ash increasing wear and tear.

Rehabilitation of land affected by ash is similar to development of sand country where the initial requirements are establishment of any species tolerant of the conditions to stabilise the ash and build up fertility.

Re-establishment of pastoral species is also dependent on the nature of the ash. Where it was very acidic, liming maybe required, along with high fertiliser inputs to create a soil medium, conducive to pastoral growth. Initially, acid tolerant species may need to be planted and species more tolerant of severe conditions, i.e. Marram grass, lupins, Yorkshire Fog and Lotus. These species tend to be lower yielding than the existing ryegrass and clover pastures. Once soil fertility and organic matter levels increase, more productive species may be established.

Where land cannot be cultivated, rehabilitation will be a slow process. Oversowing of low fertility species with fertiliser inputs may be required. It may be uneconomic to bring some land back into pastoral production and a change in land use may be the best solution.

Any rehabilitation programme will be very dependent on the financial resources of the farmer. With an ash shower of up to 100 mm, the short term impacts could be so severe on the financial viability of the business it is unlikely that the farmer will have the financial resources to stay on the land let alone implement a recovery programme. An eruption in winter/early spring would have the most devastating impact on cashflow.

Even a 100 mm ash fall may render some land uneconomic to be returned to it's original land use and alternative land uses such as forestry may be the best option.

As an ash shower of up to 100 mm may require de-stocking of the land for at least 6 months (until pastures can be re-established) any rehabilitation programme will require restocking. This may not be physically possible where the eruption devastated a large part of the country e.g. Taupo volcanic scenarios. The slaughtering of stock in the short term will result in a loss of valuable stock of high genetic merit. This will take many years to rebuild.

Until the ash settles, quality water for stock will be scarce, particularly when sourced from streams, rivers and dams. Extra expense will be incurred in maintaining water pumps as these are affected by the abrasive nature of the ash.

Ash will cause short circuits in electrical transformers and insulators although power lines are unlikely to collapse from the ash. There is greater danger from ash laden trees falling on power lines causing power failure.

Physical removal of the ash from buildings, yards, roadways etc will be difficult due to the large quantity. Where the ash is removed, dumping sites would be required (e.g. old quarries and existing land fills). To minimise wind reworking the ash dumps the surfaces of the disposal sites need to be stabilised with top soil and seeded with grass (Tilling *et al* 1990).

4.5.4 25 - 50 mm

Rehabilitation of the land will be greatly influenced by time of year of the ash fall and the nature of the ash. The most critical period for both dairy and sheep and beef would be the late winter early spring period when pasture covers are low and supplementary feed has largely been used up.

It will also be difficult to procure supplements from other areas or sufficient grazing to de-stock affected farms at this time of the year. Management options would be to mob stock up and move them through longer pasture areas of the farm to shake/remove ash off the plants. These areas could then be grazed with some supplementary feeding of bought in feed eg, meal, hay if available etc.

Other options would be to de-stock the farm as much as possible by sending stock to the works or for grazing in other parts of the country. This may involve moving stock a considerable distance eg from Central North Is to the South Is. The logistics of moving large numbers of stock is not considered feasible.

Paddocks that had been intended for cropping or pasture renewal could still be cultivated and sown in fast growing annual crops such as some of the annual rye grasses, feed oats and barley. Soil fertility is likely to decrease, requiring higher fertiliser inputs.

If the ash shower occurred in the summer/autumn period, management options would be eased by having the ability to de-stock lambs, prime cattle and cull dairy cows to the works before too much value was lost; reserves of hay/silage would be at their greatest and for those who traditionally put in a greenfeed crop such as maize, choumollier or swedes, these would be of sufficient maturity to supply a substantial amount of feed.

No matter when the ash shower occurs the provision of good quality water would be essential. Under most dairying situations this would require some increased water pump maintenance and cleaning of troughs once ash falls have ceased as most dairy farms would be on deep well bores and reticulated systems.

On farms (more likely to be sheep/beef/deer) taking supplies from streams or dams, provision of good quality water for both human and stock consumption would be more difficult. Outside assistance may be required in the short term i.e. until streams clear and dam water can be tested clear of toxic chemicals.

As with the 50-100 mm scenario rehabilitation of any farm will be dependent on the financial resources of the farmer and the robustness of the farm business as even a 50mm fall of ash will have serious financial implications in the year of the ash fall and following season due to lost production and increased costs.

4.5.5 5-25 mm

Rehabilitation of the land would follow similar lines to the 25-50mm scenarios, where pastures were destroyed through the burning of ash. Where the ash did not burn or scorch the pastures, rehabilitation would be similar to that after a severe dry period. Pastures would need to be re-established either through conventional cultivation or undersowing. The method chosen would be dependent on the ash depth. Where the ash was up to 25 mm deep, incorporation of the ash through ploughing would be best to return the land quickly to its pre-eruption productive value.

Rehabilitation of hill country would be slower as the material cannot be incorporated into the soil profile. Rainfall will improve the rate of recovery as the ash is eroded. Oversowing with fertiliser will be necessary where the pastures are weakened/destroyed by the ash and because of the inherent lower fertility of the soils.

Extra supplements would be required to maintain stock numbers until pastures recovered. Greenfeed crops and high producing annual ryegrasses could be established where the eruption occurred late summer, to provide increased feed in the winter until permanent pastures could be established.

Maintaining farm operations would be important after the eruption, especially providing good quality water and maintaining farm machinery.

Farms with high debt loading would struggle to meet their debt servicing commitments, due to reduced production in the short term (12-24 months) and the costs of re-establishing pastures after the eruption, the effects being similar to a severe drought.

4.5.6 0-5 mm

With the impacts of ash up to 5 mm being negligible, rehabilitation of the land would not be necessary. Increased supplementary feed may be required, while the stock were put off their feed. This should be a short term measure until the ash is washed and consolidates to 1-2mm.

4.6 Other Issues

Under any of the ash fall scenarios other industries and communities are going to be seriously affected.

Under 100 mm and 50 mm scenarios it might appear that rural communities would have to be self sufficient however, there are serious implications for industries such as New Zealand Dairy Group (NZDG) and Kiwi Dairy Co who are likely to lose a large proportion of their production volumes for at least one season if not three or four. This will see factory workers, tanker drivers etc all put at risk of job loss or at best reduced hours.

Small rural communities and businesses will also be put at risk as spending power of the farming communities are slashed. It would have to be expected that there would be a need for increased health care/rural support counselling in all areas directly affected by ash falls.

Because New Zealanders are such a small close knit community the flow on effects of any eruption are likely to have an impact on people and businesses far removed from the eruption site and ash fall affected area.

5.0 Impacts of Ash Fall on New Zealand Horticulture

5.1 Introduction

The impact on horticulture of a volcanic event could be severe. The most destructive events are likely to occur close to the volcanic vent, but cover a relatively small geographic area. The most significant effects in terms of affecting a wider range of crops over a larger area are from ash fall. Remobilisation of ash as it is eroded and distributed in water systems could also have a significant effect, particularly on plains areas. These areas are largely formed from alluvial material, often including ash from earlier eruptions. However, significant quantities of ash could render drainage systems ineffective and reduce usefulness of the land for long periods. This is discussed further under the effects on pastoral agriculture (section 4.2 on Lahars).

The severity of the impacts of ash fall would depend on the depth of ash, the particle size, the chemical composition and the area over which it was distributed. Distribution is very dependant on windfall on the day of the event. Even depths of ash as large as 1 metre (unconsolidated depth) would fall in a relatively short period of about 12 hours following each eruptive event. Because of the climate and weather variables, although there may be a significant warning of an eruption, prediction of where the ash fall is most likely would not be able to be assessed until close to the time the event was occurring. Where a series of eruptions occurred, as Mount Ruapehu in 1995, the ash fall distribution may be quite different from each eruption depending on the low and high level wind directions at the time. Thus growers over a wide geographic area would need to be aware of possible impacts, any steps to mitigate the effects of ash fall, and rehabilitation strategies. Major horticultural areas such as the Bay of Plenty, Auckland and Hawke's Bay are in volcanic risk areas. A wide range of annual and perennial crops are grown in these areas and are significant on a national scale.

There has been limited experience with ash fall on horticultural crops. Relevant examples are the effects of the Ruapehu ash in 1995, the Mount St Helens ash in the USA in 1980 (Cook et al, 1981; Folsom, 1986), Paricutin in Mexico (Luhr and Simkin), and studies on vegetation recovery from the Tarawera eruptions. (Keam, 1988). Some of the main impacts from these eruptions are summarised in the Table 4.1 and Table 3.5.

One of the significant effects of the Mount Pinatubo eruption was atmospheric dust reducing temperatures over a wide area. This reduced the summer temperatures in New Zealand by 1-2 degrees, with consequent retarded plant growth and reduced productivity. Lingering ash or repeated falls could have a similar effect over a more localised area. For example, after the Mount St Helens eruption, temperatures were reduced over 600 miles away in Canada. (C Van Eaton, personal communication).

During the 1995 Ruapehu eruptions one of the most significant effects was crop losses on cauliflower in Gisborne, 250km away, which received a trace level of ash. Broccoli crops were not similarly affected. The ash from this eruption was chemically fairly inert, so the main losses were due to the dark coloured ash on the white cauliflower curd detracting from curd appearance. This is a cosmetic effect but sufficient to downgrade the cauliflower crop causing economic losses. Other crops shed the ash before significant damage occurred.

5.2 Impacts from other natural events

Although experience with ash fall is modest, other natural events such as defoliation from frost and hail, indicate likely effects. Some of these are discussed below. Knowledge of these events, and a good understanding of crop husbandry and physiology provide guidance for rehabilitation strategies following the ash.

Cyclone Bola

This cyclone in 1988 caused widespread erosion and silting of plains areas in Gisborne. These observations are taken from discussion with horticultural consultants in the district at that time (G Loudon, S Scarrow personal communication). Cyclone Bola is relevant to this discussion of ash in terms of having a layer deposited on the soil surface, and resulting reduced soil aeration.

Silt, up to 1 metre deep, was washed through orchards and annual crops. The land was covered by silt and water for several days. The silt was difficult to handle initially as it was wet and muddy. Once dry, it was also fine and dusty until it had compacted.

Once the silt was dry it was not a great problem for growers to handle, and the fertility of the silt was good. Orchardists physically removed the silt from around the base of trees and vines to help prevent development of crown rot diseases that could ring bark the tree. Silt is still visible in piles in some orchards a decade later in areas where it was moved from around trees into the grassed area between rows. One of the main on-going effects on surviving plants was from lack of root zone aeration, caused by water logging, which led to diseases and reduced yields. There have been changes in orchard crops grown in the area, partly attributed to the effects of Cyclone Bola but also to crop economics. For example, kiwifruit orchards were replaced by apples, but the better profitability of apples at the time is the most important reason.

On annual crops, growers cultivated the silt into their soil and re sowed crops. Long term the effects were minimal, helped by the fertility of the silt.

Defoliation

Several examples of kiwifruit defoliation have occurred following events such as frost and hail and defoliation experiments. A severe hailstorm in late January of 1987 caused significant defoliation of kiwifruit vines, especially on Belk Road near Tauranga. An unseasonally late frost around the Bay of Plenty occurred in November 1994, which defoliated vines. Experimental defoliation of kiwifruit was carried out at various time of the 1986/87 growing season and the vines evaluated for the following two seasons. (Buwalda and Smith, 1990a)

The kiwifruit defoliation experiment was designed to investigate the role of the leaves in different zones of the vine. However, conclusions relevant to general effects of defoliation can fairly be drawn:

- The most severe effects occurred when a higher proportion of foliage was removed.
- The effects on the current seasons crop was a severely depressed marketable yield, due to fewer and smaller fruit.
- The effects continued into the next season, where return bloom was depressed by 29% to 100%. A higher proportion of leaves removed for more of the season caused the greatest reduction in return bloom.

Kiwifruit Hail

The effects of hail were a once-off partial defoliation. Leaves were either cut off, or severely reduced in effectiveness by tattering. Fruit were marked by the hail stones, rendering more of them unsuitable for sale. The effects of the hail reduced marketable yield significantly in the current season. Return bloom was also affected so the yields did not return to normal levels for a further 1-2 seasons. Fruit size was a little affected but the main impact was unsaleable fruit. There were few disease problems on the fruit because in late January the crop is not especially sensitive.

Kiwifruit Frost

A frost in November 1994 occurred just as kiwifruit were flowering. The frost defoliated vines, the extent depending on the site. Flowers were killed, and some surviving flowers were lost to disease following the physical damage. The damaged and dead leaf and flower tissue also created an innoculum source for disease. The current seasons yield was reduced by crop loss, higher proportions of reject (mainly deformed) fruit. Following the frost, the vines had a growth surge and replaced their foliage. This foliage subsequently proved to be fruitful despite being less mature than fruiting wood that had grown for a full season.

Of interest is that many growers initial reaction was to "tidy up the vines" by pruning which removed more foliage. The best vine recovery occurred where this was not done, and summer leaf area was preserved. Some of the frosted vines had a poor crop the following season - largely due to carrying an excessive cropload of small fruit, while the vine resources were depleted. Preserving the remaining and regenerating leaf area after the frost, and careful management of crop load in the following season were the most successful rehabilitation strategies. Good rehabilitation allowed some orchards to return to normal yields in the first full season following the frost.

Pipfruit Hail

Hail occurred on pipfruit in Hawkes Bay in October 1996, after flowering when the fruitlets were small. The main damage was marking of the fruit. The severity of damage was very dependant on wind direction. Growers were able to manage their losses to some extent by thinning off worst affected fruit. This both helped to overcome the effects of partial defoliation likely to lead to reduced fruit size, and the costs of picking reject fruit which provides little revenue. More recently, several hail events occurred in a single season on pipfruit in Hawkes Bay. As well as the reduced marketable yield from physical damage to fruit, fruit size of the remaining fruit was reduced, and the yield in the following season was also reduced. These latter two effects are largely due to the defoliation, and are a similar response as determined in the defoliation experiments on kiwifruit discussed above.

5.3 Ash Fall Effects on Horticulture

The effects of ash fall are discussed as either physical or chemical effects. Prompt determination of the physical (e.g. particle size) and chemical (composition and reactivity) of ash from an actual event will help to predict its effects and guide mitigation or rehabilitation strategies.

For annual crops, any periods of fallow or cover crops are the most tolerant period, which usually occurs during winter. For deciduous perennial crops, such as pipfruit, kiwifruit and grapes, the winter is their most tolerant time. For evergreen perennial crops, such as avocados and citrus, susceptibility is more uniform through the year due to their persistent foliage cover. These types of crops can be considered more at risk for this reason.

Physical Effects

These effects are most likely to be either physical effects or physiological effects. These are discussed together as they interact. The presence of ash on leaves is akin to the effects of dust. Dust, such as road dust, has been investigated and found to reduce photosynthesis with a subsequent decrease in plant dry weight, and other related effects such as fruit drop (Armbrust, 1986). This is caused by:

- Blockage of leaf pores by dust impeding transport of photosynthetic materials through the leaf.
- Reduced light and energy interception from having a layer of dust on the leaf surface.

- Reduced transpiration causing the leaf to heat up, respire more and impede supply of materials for photosynthesis and plant growth from the roots. The effects of dust on the leaves would be most significant with greater quantities of dust or ash, and longer duration of the leaf being covered. After the Mount St Helens eruption, apple leaves commonly had a 1mm layer of ash on their leaves for up to a week which reduced photosynthesis during the period by 90% (Cook et al, 1981).

Leaves shed dust over time from natural processes, particularly leaf expansion, and wind and rain removing the dust. Growth of new leaves dilutes the impact of the dust. Leaf characteristics affect the rate of this shedding. Smooth shiny leaves shed dust the fastest, and hairy, textured leaves the slowest (Cook et al, 1981) Plants whose leaves were wet at the time of ash fall will stick the dust more firmly, although subsequent water is more likely to wash the ash off leaves that were dry at the time of ash fall. Deciduous plants will of course shed the dust when they shed their leaves each autumn/winter. The least sensitive time for these dust effects is in the winter for deciduous plants. Spring could be the most significant time for ash fall because it is early in the growing season. However, as it is also the time of fastest plant growth, leaf expansion and new leaf development, it is also the time when plants will shed the dust faster. However, annual plants have few stored resources to support the plant during the period of reduced photosynthesis so will be most vulnerable at their seedling stage, usually in spring.

Perennial plants have greater resource to help overcome the period of reduced photosynthesis, so will be better able to withstand a spring ash fall. The Mount St Helens eruption occurred in spring (May of 1980), but after pollination of pipfruit had occurred. The pipfruit crop harvested from the affected areas by ash fall was higher overall than the previous year due to better growing conditions, and the effect of ash by harvest was estimated as a 10% yield reduction. On individual orchards, fruit drop occurred following the ash fall, but some of this was compensated by larger size of the remaining fruit that survived through to harvest (Cook et al, 1981).

Pollination is a particular time that is affected by dust. Transfer of pollen to the receptive parts of the flower is impeded by dust, with resulting reduced fruit set (i.e. fewer fruit), and smaller or deformed fruit. This is relevant to a wide range of fruit and vegetable crops such as pipfruit, kiwifruit, grapes, avocados, tomatoes, peas, sweetcorn, and squash. All these crops would be more sensitive to effects of ash fall dust at the time of flowering and pollination, which is usually in spring or early summer.

Dust may also have significant effects on fruit quality such as delayed fruit maturity, reduced sugar levels and impeded development of colour. (MAF, 1997).

Physical Damage

Physical damage may occur to produce from ash fall. This may be to the leaves or fruit. Surface blemishes may render the produce unsuitable for primary markets and result in lower marketable yield and reduced income. The stage of the crop development and the ash characteristics are important determinants of this effect. Following such physical damage, incidence of disease is likely to increase which will cause crop losses and reduced product shelf life.

Many crops have a period when the fruit surface is especially sensitive to physical damage, usually when the fruit is small. Physical damage then may result in extensive russet or blemishes that downgrade the fruit affected.

"Reworking" of the ash during harvest or post harvest handling of the produce may cause physical damage from abrasion even though the fruit was sound prior to harvest. Even where there is no physical damage, presence of ash on the fruit may be a quality issue either for cosmetic or phytosanitary reasons.

One kiwifruit packhouse near Te Puke was still packing kiwifruit after the Ruapehu ash falls in 1996. The ash was sufficient that people were using car headlights in Te Puke at midday, and there was visible fine dark dust on the ground. The fruit was put over the grader and then back into bins in the coolstore. The brushes on the grader brushed off most of the coarser ash particles. The fruit appeared a bit grey after packing. Fruit samples were sent for chemical analysis and they came back with no problems of residues of concern. Despite the fruit in the trays looking a bit grey, there was no further problem with the fruit. The greyness was sufficiently mild and even across the tray to not be a problem. The grower concerned said "it turned out to be a non-event."

Ecosystem Effects

Dust is generally tougher on predators than on pest species, due to their physical characteristics and greater mobility. (Phillips, 1986. Cook et al, 1981). Thus after ash fall, there may be a change in the pest dynamics and destruction of predator species, thus disrupting integrated pest management of commercial crops. These kinds of pest management programmes are increasing in use on major crops in New Zealand, so this impact is likely to increase in its significance over time.

Pollination will be further affected as ash fall is abrasive to bees, the main pollinating insects. Bees exposed to ash dusted plants following the Mount St Helens eruption died from the physical effects, mainly dehydration, and bee colony numbers were severely reduced (Cook et al, 1981). Moving hives into crops for pollination is a common practice with many horticultural crops, especially kiwifruit. The hives are vulnerable when in a particular crop, and also when in their other locations (especially locations around the central North Island). This could therefore severely impair pollination, as well as reducing production of other bee products such as honey, beeswax and Queen bees. During the 1995 Ruapehu eruptions, there were few bees in the area affected by ash fall. Only small numbers of hives are located in the Central Plateau, mainly during the summer. However, about 30% of New Zealand's hives are usually located in the wider Central North Island area covering the Waikato, Bay of Plenty, Coromandel, East Coast and Central Plateau (M Reid, Personal Communication).

Subsequent to ash fall there will be erosion effects as the ash is redistributed in water. This could affect integrity of drains, and alter natural and man made water courses with consequences of drainage and water logging. Most plants react poorly to water logging due to the consequently reduced aeration in the root zone. The most sensitive plants are affected by short periods. For example, kiwifruit is particularly sensitive, and irreversible effects may occur following four days of root anoxia (Buwalda and Smith, 1990b). Diseases can also follow periods of soil water logging, so are also likely to occur following soil anoxia due to ash smothering. Seedlings are especially vulnerable, as are more sensitive plants such as peas, beans, asparagus, avocados and kiwifruit.

Water logging causing reduced root zone aeration is especially common on poorly structured alluvial soils. These are both the soils more prone to this effect, and are found in the areas where flooding is more common. These kind of aluvial plains areas also tend to be flat and well suited to annual cropping because of their ease of cultivation. The effect of water logging is most significant during the peak of the growing season in summer.

Higher volumes of ash fall have more severe physical effects. Defoliation would be expected to occur due to leaf breakage from about 150mm unconsolidated ash depth. Some plants are more sensitive. For example, alfalfa, a fine leafed legume, was particularly prone to leaf breakage from ash in the area around Mount St Helens (Cook et al, 1981). Stems of non-woody plants may break, causing defoliation. Leaves may break off from the weight of dust on woody plants even when the branches remain intact. The general effects of defoliation are known from experiments, and natural events such as hail and frost as discussed above.

Large branches would be broken by falls of about 500 mm (unconsolidated) ash. The impact of this is far reaching as the branch framework of the tree has a major influence on productivity. It is established during the first few season for a perennial fruit tree. To re establish a branch framework may not be possible, or may result in an inferior tree structure and thus on going reduced productivity. The least sensitive time to branch breakage for a deciduous fruit crop would be in winter prior to pruning. The most sensitive time would be in the period just before harvest when the seasonal costs to grow the crop are almost fully invested, and marketable fruit would be lost with the breakages, and access to the orchard to harvest salvageable fruit may be impeded by broken branches.

Structures such as support structures for vines, greenhouses and crop covers would be broken by heavy ashfalls. The most sensitive time for this would be just prior to harvest, for the same reasons as for the branch breakage. Structures partially broken can be temporarily repaired. However, significant breakage of the structures would be coupled with significant breakage of the vines or trees being supported so the impact would be similar to that of broken branches on unsupported trees.

At thicker depths of ash, burial of plants would kill many small plants due to breakages, smothering and lack of photosynthesis. This would be severe at any time of year when there was actively growing foliage. Access for tending and rehabilitation is likely to be impeded which will further exacerbate the problem. Drifts, and distortion of the landscape by ash would create further problems, including access and safe trafficking problems.

Physical Effects on Soil

Even small depths of ash have physical effects on the soil. The ash tends to be of low fertility. It may crust on the surface, impeding water absorption. The pale colour typical of ash leads to cooler soils, which slows plant growth, and can lead to higher disease levels such as pythium (Cook et al, 1981).

After Mount St Helens, 99% of the ash was found to have reached the soil surface within a few days of each ashfall (Cook et al, 1981). An ash layer will cause reduced soil aeration especially where ash is deeper than 500 mm. This reduces suitability of the soil for plant growth until remedial action is taken. No recovery will occur unless the ash is removed, mixed with the underlying soil or organic matter added to help soil recovery (Luhr and Simkin). Ash will compact to 1/3 to ½ its unconsolidated depth with rainfall (Cook et al, 1981).

After even small quantities of ash have been added to soil, the rates for residual herbicides may need to be re calibrated (Cook et al, 1981). These chemicals are used at lower rates on coarser soils, or soils with low organic matter content, so lower rates would need to be used as a precaution, or alternative types of weedkillers used.

Chemical Effects

The chemical effects of the ash would depend on the ash characteristics, particularly acidity (pH), and any reactive chemicals. An acidic ash of say pH less than 3 (MAF, 1997) will cause burning of plant tissue. On leaves, this will have a similar effect to defoliation especially with dew or light rain, and may cause defoliation or even burning of leaf buds which would start to kill the plant. On fruit, acid may cause russet, delayed maturity, fruit drop, or impeded colour development similar to the physical effects of ash discussed above.

Acid rain may occur, causing defoliation and plant death depending on how acid and how prolonged the acid rain was.

Specific chemicals may be an issue for plants. Many plants are especially sensitive to volcanic gases such as fluorine. If gases were to occur during the dormant period for deciduous perennial plants then the effects would be modest. Root uptake of chemicals is regulated by the plant to some degree so would be less damaging than if significant quantities of gas were released into the air around sensitive plants.

Social/Infrastructure

Normal husbandry activities may be disrupted by ash fall. If power supplies are interrupted, rurally located coolstores may be significantly affected as few have standby generators. Power supply may also affect water supply which in turn will affect irrigation and crop spraying for pest control.

Where aviation is affected, aerial pest control may be disrupted. Helicopter spraying is a common means of chemical control for avocados and some field crops. Delays of a week or more may increase crop losses to pests and diseases.

If equipment failure occurs due to increased mechanical wear, the disruption to husbandry activities may cause further crop losses. These would be most severe at critical times of the season for pest control, or during harvest. Most orchard tractors are pretty robust machines. It is more likely that specialised equipment such as harvesting machines for process crops would be most at risk.

5.4 Mitigation

The alert period prior to a volcanic event provides some time to prevent or mitigate potential damage. This is made complex by the wide geographic area at risk from ash fall until specific wind directions are forecast. There are also a very limited number of strategies able to be used.

Strategies considered worthwhile are:

Beehives

Relocating beehives out of the areas likely to receive significant ash will assist hive survival. Bees are especially vulnerable to ash because the way they collect pollen on their bodies means they also readily collect dust. Bees are moved several times each season so beekeepers have the capacity to shift hives over a short time period. Hives would need to be taken well away from the expected eruption site to account for unknown effect of wind on ash distribution.

Cauliflower

Bending or breaking over a leaf on each plant will physically help to shelter the white curd from subsequent ash fall. This is a practice sometimes used on cauliflower in summer to reduce curd discoloration from sun exposure. It is done manually so has a certain cost. It would be most worthwhile on plants close to harvest where the curd is large and prominent, and close to its full value.

Other "readiness" activities would include maintenance of equipment and drains, checking portable irrigation equipment, stocking up on fungicide sprays or applying insect controls or protective fungicide treatments to crops if it is appropriate.

5.5 Ash Depth Scenarios

NB Depth refers to the unconsolidated depth

<5 mm

The impacts of this depth of ash will be minimal unless the ash has significant chemical reactivity. Crops will be set back during the time it takes for the ash to be shed. The degree of impact would be similar to the normal variation in plant performance due to seasonal climatic conditions. Particularly sensitive times would be pollination, or soon after planting or emergence for annual crops.

5 mm-25 mm

More significant effects are expected at this range of ash depths. However, the effects would be largely contained to the current crop unless the ash has significant chemical activity. Partial loss of the current crop is expected for both annual and perennial crops. The effects would be most severe at sensitive crop stages such as pollination and harvest. Significant defoliation is unlikely unless caused by chemical activity of the ash. However, plant burial and partial defoliation would occur towards the high end of the range, particularly for annual crops.

Soil characteristics would begin to be affected sufficiently to require extra attention to mixing and fertility.

25-50 mm

At this level of ash, annual crops would be largely buried and the crop lost. Impacts on the current crop will be severe. However, the subsequent crops will not be too greatly affected.

For perennial crops, partial plant defoliation is expected to occur which will mainly affect the current crop, but will also reduce the next crop. However, deciduous perennials such as pipfruit, grapes and kiwifruit would be little affected by this level of ash fall during their leafless dormant phase.

100 mm

Most annual crops would be lost due to smothering and burial. Perennial crops would suffer significant or complete defoliation, with the most significant consequence being loss of most of the current seasons crop. The effects of defoliation would extend into the next 1-3 seasons.

On perennial trees and vines, little branch breakage is expected so the basic productive framework would still be intact. If this depth of ash fell during the dormant period for deciduous perennial crops, the effects would be modest.

100 - 500 mm

This depth of ash would begin to break branches and destroy the productive framework for the most resistant of crops, so the effects would extend well into the future. Branches of 10-30cm diameter would be most likely to survive unbroken due to their flexibility. This means younger orchards would be more likely to recover. During the dormant season for deciduous perennial crops branch breakage would cause the most significant long term effects. Otherwise, these crops would still have a good prospect for survival and restored production in the future. Structure trained plants such as kiwifruit and grapes are less likely to shed ash but support from the structure will aid survival until sufficient ash cause the structure to collapse. Rain adding weight to ash is likely to cause breakages at slightly lower ash depths.

Over 500 mm

The impact of this ash depth will be severe and sustained. Significant plant burial, branch breakage and infrastructure effects such as building collapse and reduced access would occur. Suffocation of the previous soil under such a great depth of ash also extends the impact and duration of the effects.

Over 2 metres

The effect of 2 metres or more of ash will be severe. Perennial crops are unlikely to be rehabilitated. Annual crops may be re sown but will require high inputs for organic matter, fertiliser and create a demanding cultivation task. This depth of ash is getting beyond an individual's capacity to provide sufficient inputs for recovery. It is more likely growers may abandon their property or undertake only minimal remedial work. Personal "survival" issues will be a very high priority.

5.6 Rehabilitation

Lyons ("Agricultural Impact and Adjustment to the Mount St. Helens Ashfall: A search for Analogs") found degree and speed of recovery from ashfall was affected by general economic conditions at the time of impact, and availability of technology. He contrasts the more successful recovery from Mt St. Helens in a technological farming environment to the poorer recovery in Mexico where subsistence farmers lack of suitable equipment and fertilisers impeded recovery. New Zealand's horticultural culture and technology is more closely aligned to the American example so information from the Mt St. Helens eruption is more applicable. However, ability to finance recovery operations, in turn affected by the economic conditions for affected farmers at the time, will still have a major influence on how quickly or completely recovery is effected.

In general, rehabilitation strategies involve removing ash from leaves, and mixing ash into the soil. These processes occur naturally. Indeed, the soils in the geographic areas most likely to receive ash showers are often formed from ash fallen during previous volcanic events. These soils are typically physically good - well aerated and drained. Their disadvantages are low fertility and vulnerability to erosion due to weakly developed soil structure. Appropriate rehabilitation strategies will hasten soil mixing processes, or otherwise enhance plant health and growth to compensate for setbacks due to the ashfall. Where the plants survive, practices should aim to encourage plant growth. Additional fertiliser, or closer attention to irrigation and weed control should be considered. However, these are normal husbandry practices, and simply an extra degree of attention is recommended.

The more that is known about the chemical composition and reactivity of the ash the better in terms of choosing and prioritising appropriate rehabilitation strategies. Rehabilitation strategies are discussed for different ash levels in turn, with comments for both annual and perennial crops. These strategies are not prescriptive, but outline a range of options to consider. What actions are appropriate will depend on the ash fall depth, the time of year, local climatic and weather conditions. Also, implementation of strategies should be closely monitored to check they are achieving the desired outcome. In some instances, rehabilitation techniques that sound sensible may prove counterproductive. For example, irrigating to wash the ash off leaves may actually cause more problems such as lodging from the weight of the ash plus irrigation water.

Trace Ash Level

A chemically inert ash could be left for natural processes to shed and mix into the soil. Washing ash off the foliage is recommended where the ash has undesirable chemical activity such as strong acidity. This is more likely to be practical on annual crops where portable overhead-sprinkler irrigation systems are more likely to be available. Orchards that have overhead sprinklers as frost protection, could use these to wash off ash, but it is not common to have these sprinklers.

Soil testing is recommended to detect any significant effects on soil pH and to guide any additional lime inputs.

Only minor effects from the ashfall are expected at the trace level and recovery should be swift from natural processes and normal husbandry practices on both annual and perennial crops. Thus, damage to annual and perennial crops should be contained to the current crop.

Ash level Trace to 5 mm (Unconsolidated)

This ash is also expected to be shed from the plants fairly quickly. Some annual and perennial crops routinely have a post harvest wash of some kind. This should help to remove ash. However, problems with abrasion may arise due to the ash in the water, which will reduce quality and shelf life of the produce. More frequent water changes, and filter cleaning will help reduce any problem. Trials such as assessing washed samples of produce for abrasions after standing for a suitable period will help assess abrasions. Both annual and perennial crops should recover with the next crop, i.e. within one full season.

Annual Crops

At the top end of the range, the ash could cause problems for young seedlings of annual crops due to the dust reducing growth, and possibly lodging of seedlings from the weight of ash, especially when wet. Overhead irrigation should be considered to hasten movement of the ash off the leaves, as discussed previously. A check that irrigation is not increasing lodging is recommended.

Mixing the ash into the topsoil is a key rehabilitation strategy well suited to annual crops because regular cultivation is a normal practice. Processes that aid topsoil development and mixing are also recommended. These include adding organic matter, adding fertiliser to encourage plant and root growth which improves the soil organic matter and structure, adding worms, or encouraging worms by appropriate practices such as applying lime and organic matter. Where the ash is chemically active, mixing will dilute these effects. Adding lime before cultivation will help to combat acidic ash.

The deeper the ash layer, the deeper the cultivation required for successful mixing into the topsoil. Timing cultivation after rainfall or irrigation have consolidated the ash will help to mix it into the soil, and avoid the very dusty conditions that could otherwise arise.

Perennial Crops

Natural process will help to shed the ash. Chemically active ash may need to be washed off foliage. This could be done with crop sprayers at a high water volume. However, the water volume could still be insufficient and low water volumes could actually increase risk of chemical burning by making an acidic solution. Thus if a sprayer is used, leaf wetness should be monitored, and aim for wetting until water runs off leaves. Otherwise, it would be better to wait for rain. If it is a dewy time of year, this could cause problems with acidic ash.

Normal management practices will help to contain the financial impact of losses. Such activities as thinning off blemished or poorly pollinated fruit caused by ashfall may assist, but these actions will not be appropriate for some time after the ash.

Adding organic manure, cultivation to help mix the ash, liming to counteract an acidic ash and introduction of worms are all strategies that can be used for both annual and perennial crops. The main difference with perennial crops is the need to minimise root disturbance around growing plants, so mixing is slower because treatments are mainly restricted to application to the soil surface. Light cultivation is possible, especially in the inter row space. Equipment such as the "shakeaerator" that lifts and vibrates soil, corers or spikes as used for turf may be suitable equipment. Any such cultivation must be done with care and monitoring to check that few plant roots are being disturbed and that soil mixing is being enhanced.

Ash level 5-25 mm (Unconsolidated)

In this range, the expected effects of the ash start to increase markedly. However, the same rehabilitation strategies discussed above should be considered, and the additional strategies below. With appropriate rehabilitation strategies, both annual and perennial crops should recover within 1-2 seasons. Recovery will be slower where the ash is significantly chemically active, and with deeper ash.

Annual Crops

Therapeutic chemicals should be considered where surviving plants have been physically damaged which could provide entry points for disease. Chemical application may need to be delayed until some ash is shed from leaves so a close watch should be kept on both plant health and ash retention.

Where annual crops fail, the ash should be cultivated into the soil with lime added if appropriate to neutralise an acidic ash. A new crop can then be resown, or a cover crop to provide additional organic matter if the land is not intended for immediate replanting.

Perennial Crops

At this depth of ash, clearing the ash from the base of trees should be considered. If trees are in leaf at the time of ash fall, this may not be necessary as there will be less ash fallen directly onto the ground around the tree trunks because of the foliage intercepting ash. If deciduous trees are leafless at the time of ash fall, clearing ash from the base of trunks should be completed before active growth recommences. This strategy is more important as the depth of ash increases. The ash moved from around the base of trees or vines could simply be moved into the space between rows. Moving it would help prevent plant disease or death from crown rots fostered by the contact of damp ash with the trunk, as well as provide improved soil aeration in at least part of the root zone. This was done with the silt in Gisborne after cyclone Bola with good results.

For higher volumes of ash, a grader blade could be used to push ash out of rows, preferably once the ash has consolidated and is less dusty. This would then create room for ash to be manually cleared from around trees into the between row space. A problem could arise of where to put large quantities of ash removed from within rows. Options include to pile it up and stabilise the pile by sowing cover crops, to create "silage-pit" type repositories, or to spread it onto wasteland in appropriate landforms. It would be necessary to have very localised places to put the ash to contain costs. In Gisborne, the silt deposited by Cyclone Bola is still apparent where it was left in the inter row space in orchards and it has not greatly hindered orchard operations since.

Under evergreen trees, such as citrus and avocados, there is likely to be a "shadow" effect of less ash fallen directly under trees. If this occurs, it may be worthwhile to spread out the ash to a thinner layer by pushing some under the trees.

Defoliated trees will probably drop fruit anyway. However, where there is partial defoliation, thinning off fruit to better align leaf resource to fruit numbers should be considered. Adding some extra fertiliser to support new leaf growth should also be considered.

Where the depth of ash is significant and vegetation in the space between rows has been killed, growers should consider sowing cover crops to stabilise the ash and add organic matter to help hasten its integration into the soil. Lupins, or other legumes, especially crops tolerant of dry or fluctuating water conditions, are preferred plant types.

Ash Depth 25-100mm (Unconsolidated)

The strategies discussed previously are all still recommended. At this depth of ash, more annual crops will fail, and it will be more important to clear ash from around the bases of perennial plants. It will also be increasingly appropriate to quickly sow cover crops either in the space between rows for perennial crops, or across land used for annual cropping to stabilise the ash.

Even at this depth of ash, annual crops should recover within 1-2 seasons and perennial crops within 1-3 seasons with appropriate rehabilitation strategies.

Ash depth >150mm (Unconsolidated)

At great depths of ash, the rehabilitation techniques used become less crop related as crop survival is expected to be low. Techniques similar to those used for soil conservation in hostile environments such as sand country should be used. These would include those methods discussed above, but with the emphasis moving more onto stabilisation of the ash with cover crops, even including tree species.

Technology such as that used to vegetate roadside cuttings could be considered.

6.0 Impacts of Ash Fall on New Zealand Production Forestry

6.1 Introduction

Production forests in New Zealand are almost entirely exotic plantation forests. This simplifies the assessment of likely impact from volcanic eruption, because the factors that must be considered are fewer and less complex than those that would be needed for assessing the impact on natural forest. In addition, the production forests tend to be concentrated in large contiguous blocks which makes impact assessment from various scenarios more straightforward than might be the case with a more scattered resource.

No attempt has been made to quantify impacts in statistically valid terms because the level of precision of the data is not sufficient to make this possible. Description of likely impacts is therefore the main focus of this report, this being based on a small number of international studies and a large amount of personal observation and discussion with New Zealand forest industry personnel.

A more complete assessment, including sound numerical data on likely impacts and recovery action plans, is probably needed by New Zealand, but would require devotion of significant resources. This could be done as a follow up study.

6.2 Forest Impacts

Damage to forests is related to the type and quantity of material being produced by volcanic activity, and the proximity of the forest to the volcano. Few if any forests will be impacted by lava flows, while for most eruption scenarios, lahars will have only isolated impact in forests that are adjacent to volcanos or to affected streams. After large events, there could be ongoing problems from lahars during heavy rain on areas more distant from the eruption centre.

Pyroclastic effects can extend for large distances from volcanic activity, although the impact will depend on the severity of the event and the proximity of the forest to it. Pyroclastic falls are the most likely cause of manageable damage. Pyroclastic density currents from a large event will undoubtedly bring catastrophic damage, including burial, breakage, fire and impact on fertility

6.3 Burial

Indigenous podocarp forest was buried by the last major Taupo eruption 1800 years ago. Visitors to Pureora Forest, 30 km from Lake Taupo, can view preserved logs buried under a metre of pumice. A large event such as this, involving ash fall several metres deep or pyroclastic density currents, would destroy production forests in its path. Re-establishment of a forest could be undertaken after the ash has consolidated, although much would depend on the parent material.

Where burial of forest or other land has taken place, the question of re-establishment is important. Basaltic material such as arose from the 1886 Tarawera eruption, can readily be re-established in production forest. However, it has physical properties that can damage the bark and roots of young trees. This makes the task of establishing a forest more expensive and increases the risk of seedling mortality. The rhyolitic material that is prevalent in both the Okataina and Taupo calderas is capable of being established in production forest but nutrient issues such as nitrogen and magnesium deficiency, must be addressed.

Forests can also be buried by lava flows and lahars. The likely initial impacts of these phenomena are more isolated than those caused by pyroclastic events because such flows occur closer to the source of the volcanic eruption or along drainage channels. These flows will be more limited in impact on production forest, but will have a more permanent impact within the limits of the area. Lava in particular solidifies into material that is difficult to replant in forest and damaged forest is not able to be salvaged.

Young forests will be buried by pyroclastic fall out, with stands aged less than 2 years old most at risk. Where the ash depth is much greater than 100 mm, burial or death of such trees is likely to occur. This is most likely to impact widely from a large event based on the Taupo or Okataina calderas, but could impact on a local scale from cone volcanoes including Ruapehu, Tongariro / Ngauruhoe, and White Island. Mayor Island's isolation, easterly location and lower explosivity reduces the likelihood of burial of forests by ash fall from this source.

For ash falls greater than 100 mm, there is a likelihood of survival of larger trees but the point at which the damage becomes commercially significant is very difficult to determine. Published international experience does not extend to planted production forests so, an informed estimate is all that is possible. Experience in the Philippines with the aftermath of Mount Pinatubo suggests that it is the combined effect of burial through ash fall plus burial by rain induced lahar flows that cause ongoing problems. It is likely that forests planted on rolling or hilly country (which includes the majority of New Zealand production forests) may have ongoing problems resulting from instability of the new soil base until managed soil stabilisation is carried out.

However, the same factors mean that ash may not remain for long on the hills and steeper slopes. It can be expected to be washed off to accumulate in lower lying areas and from there to provide a threat to flatter land downstream.

6.4 Breakage

The worst breakage will occur as a result of pyroclastic density currents. Much of this broken material will be partially or completely buried. Other than this, breakage of tree tops and branches will predominantly occur from heavy pyroclastic falls, comprising large fragments (> 60 mm) that fall within 1-2 km of the vent, and finer material that may be deposited hundreds of kilometres from the source of the event. Breakage of trees will depend on several factors including the amount and type of material deposited, age of the forest and species of trees involved.

It is expected that ash fallout could have a similar impact to snow. This causes bending and breakage of branches and tree tops through the weight of material on branches. Snow is more adhesive, but it melts naturally in time as temperatures rise. Ash which fell on plants during the recent Ruapehu eruption discoloured leaves and branches, but did not build up into a mass on the plants concerned. Where flatter surfaces such as roofs experienced a build up of up to 2 mm of ash in Rotorua, leaves had no more than dust on the surface. Unless wet, small particles of ash tend to fall off the small needles that characterise the conifers that dominate the New Zealand production forest resource. New Zealand's geographical position within South Pacific leads to more wind than elsewhere, with the constant motion of leaves, branches and tree tops, decreasing the stability of the ash on plant surfaces. Heavier falls however, can be expected to build up to a greater extent and therefore have a greater impact.
Larger material, 2 - 60 mm in diameter, will be more localised but may pose greater risk for conifers. The upward character of radiata pine needles may hold a greater volume of these particles than finer ash, increasing the burden on branches, and the consequent risk of distortion and breakage from ash accumulation. Douglas fir has a drooping branch habit that allows material, including snow, to slide off when under load. Douglas fir will be less prone to breakage than radiata pine during a volcanic event.

Evidence from ash falls in Mexico, greater than 1.2 metres deep, suggests that pine 125 - 300 mm in diameter will survive with the least damage. Smaller trees will be buried while older trees may resist bending to the point of branches and tops being broken.

Interaction with the impact of wind could reduce the build up and subsequent impact of ash loads on forests in New Zealand. Ash fall greater than 500 mm deep could extend up to 100 km from a large caldera event and could cause serious damage in New Zealand forests, with survival of only some of the trees. This level of impact could extend over a major part of the Central North Island resource.

6.5 Fire

Forest fire danger is comprised of two related components. Essentially, incipient weather influences the chance of fire spreading. The index that measures this, the "fire weather index", is quite volatile, responding to wind, rainfall, temperature and humidity on a daily basis. Long term weather patterns influence the status of forests regarding the likelihood of a forest fire beginning from any source. Over a long drought the ground cover becomes drier and more likely to reach combustion point from several possible starter mechanisms. The "build up index" which measures this, is less volatile because it estimates fuel factors such as the dryness of vegetation and its response to humidity, rainfall, wind, and wind direction during a fire season.

Volcanic activity, by nature, has the potential to start fires. The explosion of super heated rock and ash carries a threat to forests exposed to this phenomenon. Pyroclastic density currents are usually very hot and can be expected to start fires. The fact that such currents would first destroy the forest reduces the relevance of these to the issue of forest fire danger, except for fires started on the periphery of the current. The fire weather index and the build up index at the time of the event will determine the degree of impact of these fires.

At the other extreme ash deposits (< 2mm diameter) resulting from volcanic activity are generally cooled by the time they are deposited. Little fire risk is perceived from this material. Lahar activity also fits this category because the moisture content of lahars reduces the fire potential.

Graphic pictures of lava flows from Kilauea and other active volcanoes depict the fire danger present from lava flows. While lava flows are limited to close proximity to volcanic events, the fire weather index will determine the risk of fire spread. If the forest has a high fire danger, and the wind direction is away from the lava flow, then the risk of fire spread is extreme. This could have a much greater impact than the initial volcanic event partly because of the likelihood that firefighting will be severely constrained by other eruption related factors.

6.6 Fertility

Production forests have lower nutrient requirements than agricultural land use, but ash fall will impact on the fertility of the forest. During the 1995 Ruapehu eruption the ash fall included levels of magnesium, aluminium and sulphur that were actually beneficial to trees. For the central north island, magnesium deficiency is not uncommon, particularly in water sorted pumice areas, and nitrogen levels are often low. Changes (usually lowering) of soil acidity can also be expected to impact on fertility through impact on soil bacteria activity and nitrogen fixing in particular. Chemical effects on the availability of nutrients could be another problem.

6.7 Infrastructure

The nature and history of production forest as a land use means that isolation, access and topography are issues when considering the impact of a volcanic event. Volcanic activity itself will impact on infrastructure, complicating the response to forest damage during the event.

6.7.1 Fire Fighting

Of most immediate concern following volcanic activity are fires, which require a rapid suppression response in order to limit fire spread and fire intensity. Aerial ash will limit the ability of aircraft to operate, as was experienced by air travellers during the 1995 Ruapehu eruptions. Modern forest fire fighting utilises the precision and effectiveness of helicopters to fight forest fires rapidly and safely. Any lack in air support will therefore reduce fire fighting effectiveness and mean that the techniques and machinery used will need to be those that pre-date helicopter availability. However, ground access is also likely to be impeded by ash on roads, and this combined with reduced visibility may well severely limit the effectiveness of ground based fire fighting operations.

Fire fighting also uses water as the only readily available, cost effective and reliable fire retardant. Waterways and water sources are likely to be severely affected by volcanic activity, including lahar and pyroclastic fallout. Small pumps used in rural fire fighting have wooden components in the pump systems that require clean water, in order to reduce the likelihood of damage to the pump system. The presence of ash in the water would undoubtedly affect these pumps, destroying the pump action by `sanding' the internal components.

Without water, alternative fire suppression plans would need to focus on limiting the spread of fires rather than extinguishing fires. Fire firefighting would focus on creating fire breaks using bulldozers, excavators, and available manpower.

6.7.2 Access

Burial of forest by ash would also result in burial of roads and machines, limiting the effective response to the situation by emergency services. People caught by the event may survive by sheltering in machines or buildings, but may then face the prospect of having to seek safety for themselves rather than rely on being rescued. Communication links would be important in activating rescue procedures, especially because available resources will be stretched in several different directions.

Limitations on access would reduce opportunities to rapidly activate fire fighting resources. Bulldozers and heavy machinery need to be transported to fire fighting action rather than having to crawl to the fire itself. This would reduce fire fighting capability to four wheel drive based and manual methods of fire fighting. Because of the demands at such a time on all available machinery and manpower for essential public infrastructure recovery, it is unlikely that there would be many resources available for forestry use except where life was at risk.

In any large event where forest rehabilitation will be required, infrastructure damage is likely to limit any remedial action being taken for some time.

6.8 Other

Even small quantities of ash can have unexpected effects. After the 1996 Ruapehu eruption, it was found on land near Rangitaiki that soil applied herbicide did not work. Investigation revealed that the cause was a thin layer of very low pH ash at the soil surface. There are certain to be other similar issues relating to the chemical composition of specific ash types.

On the other hand, larger amounts of ash may have a beneficial effect by suppressing weed species as a result of burial of their seeds. This, combined with possible introduction of additional nutrients to the site could ultimately result in increased growth on the surviving trees.

6.9 Scenarios

6.9.1 General

The differing ash depth scenarios have been considered first in a general sense with the detail for individual eruption centres following. The sections on individual eruption centres gives an outline of the main forests that are likely to be affected by each of the eruption scenarios.

Less than 5mm

Ash fall of this depth would not be significant from a forestry perspective. Physical problems would range from minimal to non-existent, while chemical problems could mostly be expected to be a non-issue. Increased soil acidity level would be transient and with the natural soil pH under most New Zealand production forests being acidic, no effect on the forests would be anticipated. Because of this, this ash depth has not been covered in the individual scenario descriptions for forestry.

5mm - 25mm

Ash fall of up to 25 mm would be more significant in terms of nuisance value, but would not be regarded as anything other than a short term inconvenience. It is not anticipated that forest crop damage would occur at all. Operations would have to be stopped while the ash was falling, but in most cases would restart immediately the air had cleared.

In some places, where the ash was blown into drifts, there could be a need to remove it or stabilise it with vegetation. This is not expected to be a big task, nor would it be expensive.

Ash on roads can be expected to create a traffic hazard through excessive dust for some time, but this will be reduced by the regular rainfall common in most New Zealand forestry growing areas. People employed in forestry are used to roads that are unsealed and are therefore experienced in safe use of dusty roads. The addition of the volcanic ash could make the problem worse than normal, but the greatest impact may be on the need to clean vehicles more thoroughly because of the abrasive and corrosively acidic nature of the dust.

25mm - 50 mm

Even at 50mm, ash fall is not likely to impact very heavily on the forest crop itself. In extreme cases, small trees may be buried, particularly by drifts. However in general, ash is likely to be shed from trees by wind action with no subsequent problem to the trees. There may indeed be a beneficial effect from the introduction of new nutrients to the site and there could be an additional benefit through the suppression of germinating weed seeds.

Ash on roads will be a greater problem but access is unlikely to be seriously impeded once ash fall ceases. The issues relating to dust will certainly be evident and can be expected to remain a problem somewhat longer.

Forest operations can again be expected to resume as soon as the ash fall ceases.

50 mm - 100 mm

At 100 mm, the ash problem becomes a little more serious from the forestry perspective. The forest crop will be affected to some extent, with localised burial of newly planted seedlings in some places, particularly lower lying collection points. Very small trees will also be buried by ash drifts. However, in both these cases, there is every likelihood that a proportion, perhaps a large proportion, of the buried trees will emerge essentially unscathed from the ash, particularly if the ash fall occurs during the spring or early summer.

In places, there may be bending and distortion of branches (and perhaps a few tops) but this is not likely to be significant enough to be of concern to forest managers.

Roads will have enough ash on them to make access a problem for a while and an active road maintenance programme will be required. Many forest operations will restart immediately after the end of the ash fall. For others, particularly harvesting, it is not expected that this depth of ash will serious limit operations for much more than a week or two at the most, from the end of the ash fall.

100 mm - 500 mm

With an ash fall of up to 500 mm, the impact becomes significant. Trees up to perhaps eighteen months old will be buried while older trees up to around 12 years could have significant branch damage. The youngest trees will have to be written off while the approach in relation to older stands will involve a "wait and see" philosophy. Damage can be expected to look severe but forestry experience has shown that in many cases, the effect on the trees that will be selected as residual crop trees is not as bad as the visual impact appears. The presence of wind may well be a deciding factor in the degree of meaningful damage experienced.

Damage to roading infrastructure will in any event prevent any rapid ameliorative action being taken. Many, if not most, roads will need to be reformed on the new ash level as there will be far too much material to contemplate its removal. The rate of natural consolidation of the ash will therefore be an important factor in how soon any forest operations can restart. It can be expected that apart from access for damage assessment, many of the areas with this depth of ash will simply be left for a time with operational activity being moved to less affected areas.

The impact will therefore be serious in economic and social terms and it is likely that it will be a year before things will be considered to have returned substantially to normal.

Greater than 500 mm

If the ash fall significantly exceeds 500 mm, the impact will become proportionately greater. Older trees will be buried and breakage will become more common. However, being a pioneer species, radiata pine is remarkably resilient and providing there is wind at the time of the ash fall, it could be envisaged that branch and top breakage may be kept to a minimum. It is certain that with a fall of this magnitude, the whole visual aspect will be negative. Trees will be buried, branches will be bent and ash will probably form wind drifts.

Access will be impeded for some time. Air access will depend on the presence of aerial ash and landing will not be feasible because of dust problems until the ash has consolidated or is wet. Ground access will be very difficult and can be expected to take place initially only for inspection purposes. There will need to be major revisions of forest plans of operations with the most likely initial scenario being the diversion of all operational activities away from these areas for the foreseeable future.

Roading infrastructure will need to be completely reformed before any heavy traffic can use it. Initial plans will need to involve soil stabilisation in areas that will require replanting and also alongside all reformed roads. Silvicultural activity will be delayed indefinitely as other work takes priority. Harvesting will cease until access for logging trucks is possible, although if salvage proves to be economically feasible, this may be done in the first instance by the use of six wheel drive forwarders.

It is extremely unlikely that there will be any forest operational activity in these areas for weeks or perhaps months. Because of the burial of young trees, the whole forest operating environment will be altered for some years. Recovery will be possible however, and with the likelihood that areas formerly in agriculture may have become unsuitable for reinstatement for agriculture, the potential for profitable forestry expansion may ultimately prove to have increased significantly.

6.9.2 Auckland

The Auckland volcanic field, where small volcanoes develop but do not erupt again, will only have isolated minor impact on localised forests such as Riverhead, Woodhill and the catchment forests of the Hunua area if an unusually large event took place. These forests are important to the local timber supply of Auckland, but are not a large resource by NZ standards.

For the scenario[1] given, impacts would be as set out below.

Greater than 500 mm

No effect on forestry.

100 mm

This would be entirely within the urban area or the sea, so no commercial plantation forests would be affected.

Less than 50 mm

Scattered woodlots are the only forestry assets that would be affected under this scenario.

6.9.3 Mayor Island

Mayor Island has the potential to impact on the mainland via pyroclastic fall material. Much would depend on wind direction. The eastern location of Mayor Island reduces the risk of fall out because of the predominance of the westerly wind in New Zealand.

1 Refer Fig 3.3

For the scenario[2] given, impacts would be as set out below.

Greater than 500 mm

No effect on forestry

500 mm

Possibility of some impact on Carter Holt Harvey forests at Whangamata and perhaps part of Tairua forest.

100 mm

This would impact on Athenree forest, Environment Waikato blocks and other blocks on the western Kaimais, plus Kopu forest

Less than 50 mm

This would cover Coroglen, Patetonga, Te Matai, Omana and part of Mamaku forest, and perhaps parts of Rotoehu and the Paengaroa area forests predominantly owned by Fletcher Challenge Forests Limited.

6.9.4 White Island

White Island is New Zealand's most active volcano, with long cycles of activity evident between 1976 and 1994. None of these episodes resulted in any impact on forestry. Recorded history presents no products of the activity on the mainland in any quantity of significance to forestry. The only likely impact is light ash fall on those forests located between Opotiki and Cape Runaway. Such ash fall is only likely to be greater than a trace during a 1,000 year event. White Island is unlikely to have a significant impact on production forests.

For the scenario[3] given, impacts would be as set out below.

Greater than 5 mm

No real impact under the 100 year event.

Under the 1,000 year event scenario, 100 mm could possibly affect parts of some of the Caxton leases on Maori land near the coast, east of Opotiki. 50 mm would also fall on most of the rest of the Caxton lease forests and perhaps on part of the Ngati Porou Whanui forests Limited estate near Hicks Bay. 25 mm could fall on the forests of the East Coast.

6.9.5 Okataina

Okataina has had more uniform eruptions than the variable sized eruptions from the Taupo caldera. This means that the smallest eruption from Okataina was larger than all but four or five of the largest eruptions from Taupo in the same period. Many Okataina eruptions have produced rhyolite lava which determines the soil types and parent material within the region.

Okataina is located to the north and west of significant areas of the plantation resource within the Bay of Plenty, allowing the predominant westerly wind to carry ash fall onto the forested area. Any significant event will result in a large proportion of the forest estate of Fletcher Challenge Forests, comprising Kaingaroa, Kawerau, and Rotoehu Forests, being subjected to

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[2] Refer Fig 3.4

[3] Refer Figs 3.5, 3.6

ash fall from 100 mm to 3.0 metres depth. The impact close to the epicentre would cause burial of small trees while older forest would suffer some damage, depending on the age and impact of fallout material. Any major Okataina eruption could be expected to produce a significant area of total devastation as a result of pyroclastic density currents.

Salvage of damaged forest may be a possible outcome of an Okataina eruption. Any salvage efforts would have to be preceded by redevelopment of roads that had been buried by ash fall. Many younger stands would be buried by the levels of ash expected from an Okataina eruption, especially within the Kawerau, Rotoehu and northern Kaingaroa Forests.

For the scenario[4] given, impacts would be as set out below.

Total devastation

Complete devastation would be likely to occur close to eruption centres. Depending on the precise location of the eruption centre, this could include Tarawera Forest, forests in the Rotoehu and Rotoma area, Crater block and the northern part of Kaingaroa Forest and part of the Fletcher Challenge Forests Limited Forest near Kawerau.

Greater than 500 mm

Forests affected would be The Fletcher Challenge Forests Limited Forests near Kawerau plus Rotoehu Forest.

500 mm

Impact would extend to Northern Kaingaroa and Whakarewarewa Forests.

100 mm

This would cover the balance of Kaingaroa, Whirinaki, and Lake Taupo Forests, part of Kinleith Forest, the southern Kaimai Forests, and Mamaku, Mangatu, Wharerata, Hikurangi Forest Farms and many of the Forest Enterprise's Gisborne Forests

Less than 50 mm

Impact would be likely to extend to the balance of Kinleith, Rotoaira, Waimihia, Kaweka, Mohaka, Esk, most of the remaining Crown lease forests on Maori land in the Bay of Plenty and Poverty Bay areas and all the remaining Hawkes Bay forests.

6.9.6 Taupo

The Taupo volcanic zone includes the largest and most mature area of production forest within NZ, parts of which are now carrying a fourth rotation of radiata pine. Exotic forests have been managed within the Central North Island since prior to the 1920s and now include a total estate of approximately 535,000 hectares including corporate, Maori and farm forest owners. This estate is approximately one third of the NZ production forest area, and provides the region with significant economic benefits. Any major impact on the forest estate by volcanic activity will have proportionate downstream effects on business, employment, and the future well being of the region.

The Taupo caldera is more variable than the Okataina center. At one extreme is the small event, that would have very little impact on forests within the region. A larger event would

[4] Refer Fig 3.7 and Fig 3.8

deposit up to a metre fallout on parts of Lake Taupo Forest, while depositing up to 200 mm ash on southern Kaingaroa Forest.

A really large event would also include a pyroclastic density current, defined in its extent by topography rather than wind. A pyroclastic density current could extend over 60 km, destroying many of the forests within the region. In any major Taupo volcanic event, the economic impact on forestry is likely to be long lasting, extending into years.

This type of event could completely devastate over 270,000 hectares of forest. Economic recovery from this would require at least a complete rotation of approximately 30 years. It would encompass several billion dollars of direct business activity, as well as related downstream business impacts.

For the scenario given, impacts would be as set out below.

Total devastation

A very large event could cause extensive total devastation. The forests affected could include Lake Taupo, Rotoaira, the western bays forests, south and western Kaingaroa, much of northern Kaingaroa and Waimihia Forests, the Bay of Plenty Crown lease forests, plus Kinleith, Esk, Mohaka, Tauhara, Tahorakuri and part of Whakarewarewa Forests.

Greater than 500 mm

For scenario 1[5], this level of ash fall would cover part of Lake Taupo and part of Kaingaroa Forests, but this would already be totally devastated by pyroclastic density current.

For scenarios 2 5 and 3 5 , there would be little impact if any.

500 mm

For scenario 1, most of the area that would receive this level of ash fall would already be totally devastated by pyroclastic density current. The forest affected would be the balance of Kaingaroa.

For scenario 2, there would be very little forest affected, while for scenario 3, about 50% of Lake Taupo Forest would be covered.

100 mm

For scenario 1, this level of impact would extend well beyond the area of complete devastation to cover much of the lower part of the East Coast. Forests impacted would include the Fletcher Challenge Forests Limited forests at Kawerau, plus Mangatu, Ruatoria, Hikurangi Forest Farms, the Crown lease forests on the East Coast, many of the Ngati Porou Whanui Limited forests, Wharerata and many of the East Coast Forestry Scheme forests.
For scenario 2, part of Lake Taupo Forest would be affected.

For scenario 3, most of the balance of Lake Taupo Forest, south west Kaingaroa, and the Fletcher Challenge Forests Limited forests at Taupo, including Tauhara and Tahorakuri Forests

[5] Scenario 1 - refer Fig 3.10
Scenario 2 - refer Fig 3.11
Scenario 3 - refer Fig 3.12

Less than 50 mm

For scenario 1, impact at this level would extend to the balance of the Ngati Porou Forests, plus the Caxton leases and Fletcher Challenge Forests Limited forests east of Opotiki

For scenario 2, most of the balance of Lake Taupo Forest would be included.

For scenario 3, impact would extend to southern Kaingaroa, the Justland Forests and perhaps the southern part of Kinleith Forest.

6.9.7 Tongariro

Tongariro is a frequently active volcano with most action emanating from Ngauruhoe. Ash fall from volcanic events is expected to impact on Rotoaira Forest to depths of between 100 and 500 mm, while Lake Taupo Forest could generally expect less than 100 mm of ash. Ash fall of this level is expected to be frustrating rather than serious, although fires could occur. Fires were not started by eruptions from Ruapehu but weather and season variation could increase the risk of fires being started by such an event.

For the scenario[6] given, impacts would be as set out below.

Greater than 500 mm

No impact on forests.

500 mm

Part of Rotoaira Forest would be affected.

100 mm

The balance of Rotoaira and the southern part of Lake Taupo Forests would be affected.

Less than 50 mm

Most of the balance of Lake Taupo and some of the Western Bays forests would be affected.

6.9.8 Ruapehu

The proximity of Karioi Forest to Mount Ruapehu means that it has special risk attached to it. It is the forest most likely to be affected by lava flow from Ruapehu and the associated fire risk has to be considered.

Apart from this, the size of Ruapehu eruptions and the direction of the prevailing wind means that any impact on production forestry is expected to be minor. The most significant impact could be from an eruption during the height of the fire season, putting sufficient ash into the air in the region to limit the use of aircraft for routine regional fire surveillance and any normal fire suppression.

For the scenario[7] given, impacts would be as set out below.

Greater than 25 mm

No impact on plantation forests

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[6] Refer Fig 3.13

[7] Refer Fig 3.14

6.9.9 Taranaki

Mount Taranaki has a similar uniqueness because when expected eruption size is taken into account, there are no significant production forests in the zone where 25 mm of ash or more is expected to fall.

For the scenario[8] given, impacts would be as set out below.

Greater than 25 mm

No impact on plantation forests

6.10 Rehabilitation

5 - 25 mm

With this depth of ash there is no rehabilitation required for forestry purposes. The main problem is likely to be a temporary dust nuisance, particularly on roads. The ash can be expected to be incorporated into the forest soils quite quickly. Wind will assist in removing most ash from vegetation but some problems with dust being stirred up by wind in forest stands may persist until the ash consolidates.

50 mm

The main rehabilitation requirements for ash of this depth would be reinstatement of infrastructure. This is very weather dependent because the rehabilitation of ash covered roads during dry weather would pose different problems to the rehabilitation during wet weather.

It could be expected that road rehabilitation with this depth of ash would be regarded as simply a rather extensive road maintenance exercise and costs would be manageable.
The rehabilitation requirements of trees at this ash level would also be minimal. Small trees that may be buried in drifts would probably be a minority of any crop and normal stocking rates should be able to absorb any impact. It is not envisaged that any operational rehabilitation work would be undertaken at all. In fact, the main effect of such a level of ash could well be to significantly reduce the weed problem for recently established trees.

Stem abrasion of very young trees when the trees are moved by the wind, can be a problem in some of the Tarawera ash soils, but ash fall of this magnitude post planting, would be no worse than the current soils and may cause less of a problem, as a result of being less compacted.

On older trees - between 3 and 12 years of age - although branch distortion may occur in isolated places due to the weight of ash deposited, it is unlikely to be considered to be a serious or long term problem and no action would be required by the forest owner.

It is not expected that there will be any rehabilitation required in relation to trees older than this for an ash fall as small as 50 mm.

100 mm

Rehabilitation from this level of ash fall is likely to be required.

Road rehabilitation would be a more major operation, but would in most cases still be able to be done as a road maintenance job. With a greater volume of material to be moved in order to uncover the original road surface (900 m3 per kilometre of 9m wide road surface), the

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[8] Refer Fig 3.15, and Fig 3.16

rehabilitation work would be a lot slower. Priority areas for purposes of safety, fire protection and salvage would have to be done first.

It is likely that such rehabilitation would tie up a large proportion of the available roading contract work force and forest road rehabilitation would have to be prioritised along with other road rehabilitation needs.

A 100 mm ash fall immediately after planting will bury a number of the smaller seedlings. Each case will need to be considered individually, but there could be a requirement for replanting on some sites. Again much depends on weather conditions, with wet ash giving a greater rehabilitation requirement than dry ash.

For trees aged 3 - 12 years, the more serious branch distortion that will result from the extra load of ash, is again of little consequence. For the younger ages, many of these branches will eventually be pruned off, while for the older trees, these branches will eventually be suppressed. No rehabilitation action is anticipated, although pruning may be brought forward in some cases, simply to tidy up damaged stands for aesthetic reasons.

For older trees, branch distortion is again not important. It is only if actual breaking of branches occurs that quality degrade may become an issue. If this was the case, then the only rehabilitation possible would be the option of early felling of the affected stand. Value loss would be an inevitable result. It is however, unlikely that breakage would occur on any scale.

500 mm

This depth of ash produces a completely different picture. With the impact becoming major, the rehabilitation requirements rise significantly.

To begin with, the loss of infrastructure would require major and expensive capital work before any other forestry activity could take place. Road lines would still exist, but formation of roads on these lines would have to start as if from scratch. This would be slow, and access would not be provided to anything other than absolutely essential sites for quite some time.

The use of roading machinery for other, higher priority, non-forestry work would mean that it is likely there would initially be limited machinery available for forest infrastructure rehabilitation.

No rehabilitation would be possible for areas of young trees. Burial would be complete and replanting would be the most feasible option once the ash had consolidated sufficiently. Virtually all trees younger than 18 months would be completely buried and trees up to perhaps three years would probably be seriously threatened through deep burial of root systems and bending or breakage of the tops. Recovery from this would almost certainly involve replanting in most cases. This would not be able to proceed immediately after the ash fall, because of infrastructure limitations and because of a need to wait for the ash to consolidate somewhat. Experience from the Philippines suggests that instability of the resulting ash surface, particularly in times of high rain, will mean that many sites will require soil stabilisation techniques to be practised before re-establishment can take place. The techniques for this have been perfected stabilising mobile sand dunes in New Zealand.

For trees aged 3 - 12 years, rehabilitation is again doubtful. The damage levels may be severe although there is likely to be survival of a large proportion of the trees albeit in a damaged condition. The most likely scenario to be taken by forest managers would be a "wait and see" approach because the passage of a little time would quite quickly sort out which stands needed to be cleared and replanted and which would have sufficient quality and quantity of trees to provide a salvageable crop. In most cases, there would also be little choice other than to wait, because resources to implement any rehabilitation will initially be required for other public rehabilitation work. Soil stability would again be a problem, in some of these areas.

Stands that had been unthinned or lightly thinned at the time of the ash fall, would be more likely to have sufficient acceptable trees left to provide a commercial crop, if for no other reason than that there were more trees to choose from. Thinning out of damaged and dying trees would then be done so that the remaining stand was of suitable stocking and form. This would also assist in providing some physical protection to the new soil surface and would add an initial layer of new organic matter to the soil. Loss of at least one to two years growth could be expected because of the ash effect (surface coating reducing light, clogging of stomata, etc.) and the burial of part of the butt log.

Greater than 500 mm

With this level of ash fall, burial of all infrastructure and young trees would be complete. Rehabilitation of the infrastructure would require starting from scratch and would take considerable time and money for complete reinstatement. In most cases, soil stabilisation techniques would be required prior to any meaningful development taking place.

Larger trees could suffer significant breakage which, even if salvage logging was economically feasible, would cause degrade of the timber through invasion of sap stain fungi.

Most areas where a 2m ash fall had taken place, would predominantly have to be written off, cleared up as well as possible, stabilised where necessary and then replanted.

6.11 Salvage of Buried Forest

Salvage from wind damaged forest has been carried out on more than one occasion within the Central North Island forest resource, including more than 800,000m3 following Cyclone Bola. Logs can only be salvaged if large enough to enter the market, so a minimum age of 20 years limits the salvage from the damaged forest. Salvage of damaged forest is more dangerous and expensive than conventional harvesting, with trees under stress from confused fall patterns. Logs also degrade as sap-stain enters through damaged bark. These factors would also impact on salvage operations within forests damaged by volcanic events. The presence of ash and its effects on both the machinery and the people working in the salvage operation would compound the problems of salvage.

Salvage after a volcanic eruption would be further compounded by partial burial of some of the material together with both the abrasive and corrosive effects of ash. It is very likely that any material salvaged would have a significant discount applied to the sale price. As a result, it is likely that in most situations where trees in a forest had been broken or uprooted by volcanic eruption, salvage would not be economically viable, other than as a site clearance operation prior to replanting.

7.0 Policy Implications

7.1 Introduction

This chapter of the report briefly describes the Government's current direction in emergency management, the issues for primary production that may necessitate a policy response and then describes the requirements for an institutional framework that can co-ordinate efforts and priorities in response to an emergency initiated by a volcanic eruption.

7.2 New Zealand's Direction in Emergency Management

New Zealand is taking a new direction in emergency management following reviews of the current arrangements which have tended to focus on responding to emergencies as they happen.

The key concepts of the new approach are:

- Assessing the risks of the emergency happening;
- Reducing those risks and minimising the impact of events should they occur;
- Improving co-ordination and effectiveness of response to routine incidents;
- Operating an effective network that copes with emergencies when they happen; and
- Helping communities recover as quickly as possible.

Once the risk is understood, systems can be developed to limit the effects of the hazards, or even prevent them from becoming an emergency at all. The Government suggests that communities can do this by:

- Determining how much disruption is acceptable in the event of an emergency;
- Developing ways to minimise any damage or disruption
- Ensuring that they have the resources in place to keep the risk of it happening to a minimum.

Comprehensive emergency management has four areas for action.

Reduction: Identifying and analysing long term risks and developing plans and systems to reduce risks, eg land use planning, building and safety codes.

Readiness: Developing early warning systems, operational plans and emergency operational centres, emergency public information training programmes and exercise schedules.

Response: Given an alert warning, this includes actions before, during and directly afterwards to save lives and property as well as help communities recover.

Recovery: Recovery programmes extend to rehabilitating and restoring the community - clearing ash, counselling programmes, financial support and help, disaster unemployment assistance, temporary housing etc.

The Secretary for Civil Defence has described three levels of emergency management based on the resources required to cope with the emergency.

Emergency Management Level 1

These include everyday incidents - house fires, car accidents etc which are managed by local agencies such as Police, Fire Service and Ambulance. These are not "declared emergencies".

Emergency Management Level 2

There are local emergencies declared by a person authorised by the Emergency Management Policy Committee (elected representatives from local authorities). Events are "declared" when they are beyond the resources of the "111" organisations. These "declared" emergencies will give similar powers to current civil defence declarations.

Emergency Management Level 3

These are national emergencies such as the Edgecumbe Earthquake or Cyclone Bola and are "declared" by the Governor General or Minister of Civil Defence.

Declared events under the old Civil Defence emergency legislation were generally only declared where human life was endangered and a Recovery Co-ordinator could be appointed with wide powers under the Civil Defence Act.

Many of the events which have significant impact on agriculture and rural communities such as the 1998 droughts, the early 1990 snowfalls in the South Island and probably those volcanic events that result in less than 25mm of dust often do not have any implications for a significant loss of human life. Therefore they have not required a declaration of a civil defence. However, the impact upon rural communities has been significant and generally beyond the resources, both financial and human, of the local community.

Consequently, there has been provision for the triggering of a central Government response if the local agricultural community formally request assistance via MAF Policy to the Prime Minister's Department who can declare an Agricultural Disaster of National Significance and appoint an Agricultural Rescue Co-ordinator to co-ordinate the assistance measures provided by central Government to support the local initiatives.

7.3 Volcanic Eruption and New Zealand's Direction in Emergency Management

Given the brief summation in Section 7.2 of New Zealand's current direction in emergency Management, it is appropriate to ask how effective this approach is to manage the risks and impacts associated with active volcanoes.

Lyons suggests that volcanoes have particular characteristics that differ from other emergency events. He suggests that "the gap that exists between our understanding of the vulnerability of human systems to volcanic events and our knowledge of the events themselves can be narrowed, but the difficulties should not be underestimated".

This gap is a function of:

- most of the study of volcanic events has been done by earth scientists with less interest in the impact on human systems
- the low frequency of the event - the median active volcano has an eruption rate of 0.45 times per century
- volcanoes tend to be rare and catastrophic rather than an ongoing part of human existence
- they tend to be dissimilar in nature and impact, and it is difficult to generalise in principle - most studies are specific
- there are only partial records of past events

Lyons proposed the following framework:

Event Sectorial Impacts Societal Impacts

Modify Limit Prevent or mitigate

Physical Vulnerability impact Event (only options for volcanoes)

Lyons suggests that modifying the physical event or limiting the vulnerability is not realistic, but that improving our ability to react effectively is the important factor in lessening vulnerability.

i.e. The Government's four R's of Reduction, Reaction, Response and Recovery can be reduced to two: Response and Recovery. Volcanic impacts are widespread - reduction is unlikely to be an option. Volcanic events are rare - Readiness is a limited option apart from a general readiness for emergencies. How ready can one be for an event that has a median of once in 220 years?

Anecdotal evidence from a survey among agencies involved in emergency management of the 1995 and 1996 Ruapehu eruptions suggested a number of issues arose that were difficult to deal with given that the eruptions did not warrant declaration as a civil defence event.

- The event covered more than one local authority and consequently there was duplication of effort particularly in the provision of information, i.e. most volcanic eruptions should be treated as a national event because they tend to be widespread across territorial boundaries and can escalate to a significant event.

- A change of wind direction can change the local authority area of impact. A nationally co-ordinated effort can reduce duplication. This is particularly true for providing information to the public and media.
- There is difficulty for local authorities to maintain readiness for these extremely rare events and maintaining institutional memory particularly given staff turnover in emergency management policy committees. This is quite different from local disasters such as floods where Councils have significant monitoring equipment on rivers, and recent experience to predict and manage the impacts. There was evidence that the second volcanic eruption was better managed because of the experiences of the first one.
- A nationally co-ordinated effort would certainly place less demands on national resources such as the Crown Research Institute IGNS who provide the technical expertise to local emergency management organisations.
- Funding is a major issue for territorial authorities. The costs associated with low level events that are not declared can be very high relative to annual rateable income.

7.4 New Zealand Experience

7.4.1 Literature Review

Paton, Johnston and Houghton (1998) reported the results of their survey of 42 organisations involved in responding to the 1995 Ruapehu eruptions.

The most significant issue was "the lack of clear responsibility for co-ordination" mentioned by 45% of respondents. The eruption covered a wide area and generated demands beyond the expertise and local jurisdiction of any one organisation.

There appeared to be several common indicators of team breakdown:

- Inadequately defined and co-ordinated roles.
- Poor communication between agencies who normally have little contact with one another. Differences in operating structures, procedures, terminology and technology compounds this difficulty.
- Resource constraints. The decision not to declare a state of civil defence emergency reduced the available financial resources.
- Plans based on untested assumptions - i.e. some organisations expected the Ministry of Civil Defence to co-ordinate the event but the lack of declaration resulted in inconsistency between their planning and the real event.

The issue of communication resulted in 50% of respondents identifying that there was either insufficient information and/or information was difficult to get hold of.

The lack of trained personnel was also cited as an issue by over a third of respondents. Training is seldom a high priority given the low frequency of event.

Management was also an issue, particularly relying on established decision making structures used for routine activities that may not be suitable for crisis management.

Media problems were reported by 43% of organisations. World wide media interest created significant demands.

This highlighted the need for:

- Better networks among the "players" with more simulations, and exercises to identify and resolve co-ordination problems should be a priority with readiness programmes.
- Groups working together in the planning stage to develop their capability to operate as an integrated team.
- Including a media management component in training programmes.

7.4.2 Survey Results

A survey was conducted of local and regional Government and other involved organisations in the Bay of Plenty/Waikato Region to ascertain:

- The response to the 1995 and 96 Ruapehu eruptions
- How they saw their roles and responsibilities, and
- How organisations perceived the role of Central Government.
- Response to Ruapehu eruptions 1995 and 1996

The eruption in 1995 highlighted deficiencies in the Emergency Response Procedures for most of the organisations surveyed. The main areas requiring improvement were communication and liaison between affected organisations and management of the media and public.

In 1996, organisations responded quickly and more effectively due to improved liaison, particularly between IGNS, DOC and local district councils.

Emergency response plans

Most of the organisations surveyed, including the public health sector and power providers, have an emergency response plan. Plans are regularly updated and as a result of the experience gained in 1995, have specific reference to volcanic activity.

Role of central government

Of the organisations surveyed, they saw the role of Central Government as follows:

- To co-ordinate an event which crosses districts/territories, including media liaison, and appointment of a central co-ordinator.
- Funding of extra activities outside their budget allowance, even where a state of emergency is not declared.
- To set priorities for assistance, directing equipment and resources for maximum benefit to most vital place.
- To co-ordinate with the army, if and when required.

Response to rural community

Of the organisations surveyed, all would respond to the area of greatest need and the best use of resources. In most emergencies, this would result in a focus on urban areas with the rural community being self-dependent.

Organisations with a strong rural base, such as Opotiki and Ruapehu District Council, tend to look after the rural needs more than urban based. This extends to ensuring power supplies are restored to communities where there are animal health issues, e.g. restoring power to dairy sheds to enable cows to be milked.

Areas for improvement

- The Ruapehu eruptions required activities to be funded from the local budgets, as they could not secure Central Government assistance as a state of emergency was not declared. Respondents suggested that this highlighted the need for Central Government funding outside of the state of emergency criteria.
- The preparedness of a district is dependent on past experiences. Institutional memory is important to ensure lessons learnt in past events are passed on to new staff in the respective organisations.
- The experience gained from local events needs to be dispersed to the wider community. This may require key personnel travelling overseas to gain experience from volcanic eruptions in other countries. For example, the Civil Defence Controller in Rotorua has been sent to view the impact of the eruption in Rabul.
- There is no co-ordinated approach to animal health, with any issues being managed at a local level by individual veterinarians. This situation is likely to be more confused with MAF Quality Management being split off into two SOE's.
- Federated Farmers offer support to local events such as flooding. However, assistance is member-focused and often the co-ordinators are personally affected. With the centralisation of Federated Farmers, management of a local event may be more difficult.
- Concern was expressed how Emergency Management Groups would function without local knowledge when run from an outside centre.

7.5 Institutional Framework

The institutional framework required to meet the unique features of preparing for and managing a volcanic emergency event will need to meet the following traits associated with these events:

Low Frequency:

It is hard to maintain readiness for an event unlikely to occur but perhaps very devastating if it does and institutional memory is almost impossible to maintain.

Widespread Impact:

Requires co-ordination of response across jurisdictional geographical boundaries where there is little history of co-ordination and networking.

Significant Damage Potential:

The potential size of the impact creates uncertainty for both landowners and the general public who will require information and reassurance as an event starts to begin. Furthermore the media, including the international media, will show intense interest and require managing to keep the demand for information within reasonable limits, ensure good quality information rather than misinformation and opinion to maintain good perceptions about food quality and animal welfare issues among our international customers.

Response:

- Given that most effort of local responses will be to respond to urban needs, there will be minimum response to rural people.
- Rural people are likely to have to rely on their own resources but they will need information of what is likely to happen and what options they have to minimise the impact. The institutional framework needs to consider what information rural people

and producers in particular will require (especially what to do for livestock that will enhance their welfare).

- Evacuation for livestock is unlikely to be an option except for those properties in the direct path of near vent impacts (Lahars, Lava etc).
- Maintenance where possible of essential services - access, power, telecommunications, water are high priorities for rural people.

Restoration:

- The priorities for rural communities following a volcanic eruption are likely to include:

All Events

- Restoration of basic services - water, power, access and telecommunications.
- Basic information on what should/could be done to minimise the impact.
- Advice on livestock welfare - this could include issues such as humane livestock slaughtering and disposal of dead stock in the event of significant deaths.
- Access to clean feed, e.g. the organisation of relief feed supplies.
- Testing of ash for contaminants (especially toxins) and for mineral requirements.
- Co-ordination of registrations for scarce supplies
    - feed
    - labour
    - machinery
    - contractors.

For Modest Events:

More assistance is likely to be required.

- Fast tracking of resource consents
    - disposal of livestock
    - dumping of ash
    - dumping of milk that can't be picked up
- More information for business recovery including technology transfer programmes that can assist producers to assess their options and re-establish their farm policies and systems.
- Restoration of the integrity of the farm - internal access, fencing, water supply, drainage, supplementary feed.
- Access to labour (Task Force Green).
- Integrity of Infrastructure - river and drainage schemes.
- Counselling and support both for those directly affected by the impact and for those in supportive roles.
- Social Welfare assistance and IRD tax relief appropriate (as provided in the 1997/98 drought assistance programmes).

For More Significant Events:

There will be a challenge for the Government to determine appropriate responses given the current non-market intervention approach.

- Many producers are going to be non viable and asset values are likely to fall. Government will be faced with making decisions on adjustment programmes such as those implemented in the droughts of the late 1980s when loan guarantees, new start grants and social welfare assistance was provided. Earlier adverse events included mortgage discounting.
- Some physical rehabilitation issues of land discussed in Chapters 4- 6 involve considerable speculation and probably do not allow for human ingenuity and inventiveness at overcoming technical difficulties.

The key organisations that have the critical role of emergency management for rural areas are:

Central Government

- Ministry of Agriculture and Forestry.

  MAF Policy is still probably the lead agency in co-ordinating response procedures in rural areas. In any significant emergency, rural areas will be of relative low priority for local Emergency Management Groups who will have urban areas as priorities.

  MAF Policy still has a field network with rural groups and communities. In a significant Level 3 emergency, it can network with the Ministry of Civil Defence while for lesser events, it remains the channel for Agricultural Adverse Events of National Significance which are resourced through the Prime Minister's Department.

  Even for an Event of Level 2, MAF can be a more appropriate lead agency in co-ordinating the preparation and distribution of information to meet the needs of producers.

  MAF Quality Management, currently having responsibility for animal welfare, has a significant field presence and emergency response capabilities (established for the management of exotic disease response procedures). This capability is contracted back to MAF following the split from MAF. They also have a significant database on land holdings, people and resources.
- Other central Government agencies such as Ministry of Health, Labour (Taskforce Green), Department of Social Welfare and Inland Revenue are involved in recovery programmes. The involvement of these agencies in recovery programmes is usually initiated by MAF Policy.

Emergency Management Groups who have the network of representatives of local government, emergency '111' services, private sectors and professional organisations, utilities and voluntary agencies. In any significant event their efforts are likely to be focused on the needs of the urban population as a priority. Any organisation responsible for the management of response and recovery programmes in the rural area would need to liaise with the emergency management group to get access to Police, utilities or roading services to meet rural priorities.

Producer Organisations

Traditionally Federated Farmers and grower organisations have been involved in emergency response issues. However, the ability of these organisations to contribute has probably diminished. Firstly, Federated Farmers is now funded by members only rather than all farmers (through levies) and so seeks to serve members rather than all farmers. Secondly, it has centralised many functions and has less resources in each region. Thirdly, at the local level, leaders are often directly affected by the event and must look to their own property and family.

Agribusiness including dairy companies, stock and station companies, veterinary practitioners and consulting firms. Agribusinesses will vary in their ability to play a role but most will have a good knowledge of the areas and people and can access resources. Many have networks suitable for information distribution.

Insurance Cover

In the event of an eruption, the Earthquake Commission (EQC), under the provisions of the Earthquake Commission Act 1993, will cover the cost of damage to the domestic dwelling and associated outbuildings such as garage, water tank stand and pump shed so long as it is in close proximity to the house. EQC will also cover damage to the land within 8 metres of the house and damage to the main access way from the domestic dwelling for up to 60 metres, i.e. EQC will pay to remove ash or debris from a mudflow but it won't pay for any damage to the artificial surface on the access way, e.g. concrete, asphalt. Under the Act there are specified limits to the cost of damage EQC will cover, plus EQC will not cover consequential or productive losses. (Rod Smith EQC pers comm).

Farmers, growers and foresters need to access insurance cover which includes natural disaster coverage, if available, from the private sector if they wish to insure their farm/orchard buildings, machinery, stock and/or for any production losses.

Rural Community

Various community organisations such as churches and social agencies can have a role but the local school is still the dominant community organisation for rural communities.

Radio Communications

Rural communities will be very reliant on radio/telephone communications for accessing information before, during and after an eruption. However, during an eruption and for a period thereafter, communication problems are likely to occur as the electro-magnetic forces set up during an eruption will affect any transmissions via radiowaves. Radio links failed during the 1996 Ruapehu eruptions (Malcolm Breadmore Civil Defence Rotorua pers comm).

Initially these electromagnetic fields will seriously hamper the ability of Civil Defence and other emergency services to communicate with one another let alone isolated rural communities. However high frequency radio transmissions as used by "Ham radio enthusiasts" are not affected, as the HF radiowaves are bounced off the ionosphere and are not reliant on repeater stations. Hence ham radio clubs could be an important network for passing information during an eruption.

Compounding the communication problem is the reliance of cellphones, phones and radio transmissions on a network of repeater stations to transmit the message across the country. These repeater stations may be put out of action by ashfalls affecting the transmitting disk, by earthquakes shaking the repeater station out of alignment as occurred during the Edgecumbe earthquake in 1987 (Malcolm Breadmore pers comm) or by the total destruction of the site as many of the repeater stations are situated on the top of volcanoes which may be the one erupting e.g. Mt Edgecumbe and Mt Ngongotaha.

Civil Defence does have some portable repeater stations which can be moved into an area to restore/improve the lines of communication but this would take time (possibly 12-24 hours).

Crown Research Organisations

In generating information on the impact of the event, mitigation and recovery options, CRIs are the major provider.

There would appear to be knowledge gaps on the recovery from volcanic events that should receive funding from the Public Good Science Fund and there is probably information that could be made available to those responsible for emergency management. This updating would need to be ongoing due to staff turnover and change.

Annexe c - National Contingency Plan for Volcanic Eruption

Introduction

1. New Zealand has a number of volcanoes, each with its own eruptive characteristics. Scientific study indicates that the majority must be considered as dormant, rather than extinct, and will produce eruptions at some indeterminate time in the future. Prior to any eruption, physical precursors are expected to be identifiable; these may develop over time frames of days for the basaltic sites, over months for andesitic sites, and over years for the rhyolitic sites. Such precursors provide the basis for the formulation and issue of warning information.

2. A volcanic eruption will produce a number of hazards, some of which may make their effects felt at distances of hundreds of kilometres. In this and other respects, volcanic planning differs from that undertaken for most other natural hazards. Weather events and floods may be generally predictable in their extent, have a short-term warning period, and be of short duration, but a volcanic event may build up over weeks to years and be unpredictable in its probable course and timing.

3. There is therefore a need for inherent flexibility when undertaking volcanic planning. This will extend to such issues as public information and the point at which declarations are made. How these issues are managed will depend upon the known characteristics of each volcano and the circumstances pertaining at the time decisions are made.

4. This Plan outlines a framework of actions to be taken by Government, regional councils, territorial authorities, and other agencies with civil defence responsibilities, in preparation for and response to volcanic events. Because smaller events will occur with a greater frequency than large eruptions, the Plan allows for appropriate response according to predicted scale or expected impact.

5. This Plan does not detail the likely effects of eruption at specific volcanoes, nor the possible extent of the threat. Such information is available elsewhere and is summarised in the Volcanic Hazard Information booklets written for the Ministry of Civil Defence (MOCD) by members of the Scientific Advisory Committee, university research scientists and educators, and volcanologists from Institute of Geological and Nuclear Sciences (GNS).

Objectives

6. The objectives of this Plan are to detail the Scientific Alert Levels used in the formulation of volcanic warnings; detail responsibilities for the issue of volcanic warning information; outline the responsibilities of territorial authorities, regional councils, Ministry of Civil Defence, and other agencies in managing volcanic emergencies.

Scientific Alert Levels

7. Ongoing volcano surveillance enables the background or normal status of a volcano or volcanic field to be determined. Variations and/or departures of monitored parameters may indicate a change of status and the onset of an eruptive episode. The *status* of a volcano at any time is defined by an assigned `Scientific Alert Level'.

8. Scientific Alert Levels are based on a 6-level system, with each level defining a change of status at the volcano or field. The lowest level *(dormancy) is* signified by `O' and the highest (large hazardous eruption) by `5' (Scientific Alert Levels are detailed at Appendix 1).

The scale or size of an event will vary from volcano to volcano, ie a Level `3' event at Ruapehu will be larger than a Level `3' at Ngauruhoe.

9. Where information from the volcano surveillance programme indicates a change in a volcano's status (either up or down), GNS will adjust the Scientific Alert Level by issuing a `Science Alert Bulletin'.

10. In the case of a volcano in the 're-awakening' category, a move from Level `O' to Level `1' does not necessarily signal imminent volcanic activity. Historically, seismic and deformation episodes have occurred at Taupo, Auckland, Rotorua, Okataina, and Raoul Island, which would have resulted in an adjustment to a level `1' alert with no accompanying eruption threat. Similar episodes leading to Level `1' alerts at volcanoes in the `re-awakening' category may be expected every 5 - 10 years.

11. The Scientific Alert Levels act as a trigger for the issue of warnings, as outlined in the National Civil Defence Plan (NCDP) Part Three Civil Defence Warning, Systems. The warning will take the form of a 'Volcanic Information Notice', which will specify the hazard or hazards which exist or may develop, and the actions which may be expected.

12. Whilst Scientific Alert Levels will be based on physical observations made by practising volcanologists, advice as to the probable course or extent of a predicted or actual eruption cannot be expected to be precise. Volcanic Information Notices will therefore be issued on a 'best advice' basis.

Responsibilities

13. This Section defines responsibilities in three distinct phases, pre-eruption, eruption, and post-eruption. 'Pre-eruption' should be considered as including mitigation and preparation; the 'eruption' phase includes imminence, event, and on-going activity; 'post-eruption' covers the period when volcanic activity has waned to the point where recovery and rehabilitation measures take precedence.

Institute of Geological & Nuclear Sciences (GNS)

14. GNS plays a major role in the surveillance and monitoring of New Zealand's volcanoes, and in the warning process. For the purposes of this contingency plan, GNS contribute as follows:

(1) *Pre-Eruption*

The Volcanology Programme of GNS, based at Wairakei Research Centre, maintains as part of its Public Good Science Fund (PGSF) function a volcano surveillance capability. This surveillance capability covers all known New Zealand volcanoes and, in part, is conducted in conjunction with regional councils and universities. Routine information from the programme is passed to civil defence organisations and other agencies in the form of 'Surveillance Reports and Science Alert Bulletins'.

GNS will have the prime responsibility to interpret and assess the significance of the gathered information in terms of a volcano's status. They will allocate the appropriate Scientific Alert Level to the volcano or field and incorporate that level in Surveillance Reports and Science Alert Bulletins.

The prevailing Scientific Alert Level will largely dictate subsequent actions by civil defence authorities, departments, organisations, stateowned enterprises (SOE's), and utility providers. Changes will therefore be signalled as quickly as practicable and as widely as possible.

(2) *Eruption*
GNS will coordinate on-going surveillance and hazard assessments of all eruptions as permitted by PGSF funding and the MoCD/GNS Memorandum of Agreement. They will be responsible for setting the Scientific Alert Level according to information on the status of the volcano or field and its associated threats. GNS will issue regular Science Alert Bulletins regarding the status of the volcano or field, and on volcanic products eg hazard maps, ashfall predictions, lahar paths.

(3) *Post-Eruption*
GNS will coordinate on-going surveillance and hazard assessment as permitted by PGSF funding and the MoCD/GNS Memorandum of Agreement. GNS will issue regular Science Alert Bulletins outlining volcano status and post-eruption hazards eg secondary lahars, cone stability.

Territorial Authorities

15. 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 ashfall.
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.

Regional Councils

16. Regional councils encompassing volcanic areas are to undertake appropriate hazard analyses and determine the extent to which volcanic activity might impact on the region. Those outside the volcanic areas should take into account the likely effects of volcanic products eg lahar in river valleys or ashfall, on the region, a probable increased demand on facilities resulting from an influx of displaced people, and the probable requirement to assist a directly affected region.

17. 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.
Co-ordinate 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.

Ministry of Civil Defence (MOCD)

18. MOCD will carry out its functions as defined by the Civil Defence Act and the National Civil Defence Plan. For the purposes of this Contingency Plan MOCD will:

(1) *Pre-eruption*
Maintain this 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, ashfall 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 and 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, ashfall 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, ashfall 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.

Departments, Organisations, SOEs, and Utility Providers

19. A major volcanic emergency has the potential to require government intervention in response management. In such a case, the Civil Defence Emergency Steering Committee (CDESC) may be convened by the Director of Civil Defence for the purpose of advising Ministers on appropriate response measures.

20. Departments, organisations, SOE'S, and utility providers should determine the potential effects of eruption on the services which they provide and the probable extent to which those services will be disrupted or otherwise impaired, and prepare appropriate mitigation, response, and recovery plans.

21. A volcanic eruption will bring about demands for public information in specific spheres of interest eg health, agriculture, transportation, and energy, which will need to be addressed responsibly. Respective agencies should formulate appropriate plans for dealing with such demands, giving particular attention to the need for rapid collection and analysis of ash, air, and water samples for specific purposes eg public health, animal health, effects on food crops, implications for all forms of transport, continuation of energy.

22. Departments, organisations, SOE'S, and utility providers should:

(1) *Pre - Eruption*
Identify the probable impact of volcanic activity on prime functions. Prepare plans in accordance with responsibilities and functions imposed by the Civil Defence Act and the National Civil Defence Plan.
Participate in civil defence training and exercises.
Prepare and provide public information material in respect of their particular spheres of

interest.
Co-ordinate planning procedures with MOCD.
Identify resources which could be made available for civil defence purposes.

(2) *Eruption*
Implement response plans
Ensure continuation of essential functions to the best possible level. Coordinate, with MOCD, the issue of public information material in respect of their particular sphere of interest.
Respond to requests for specific information.
Respond to specific requests for assistance made by civil defence organisations.
Initiate recovery plans where feasible and appropriate.

(3) *Post Eruption*
Continue implementation of recovery plans.
Analyse event responses and effect necessary revisions to plans. Restore prime functions to pre-eruption level.

Recovery

23. In general, the principles of recovery as addressed in the National Civil Defence Plan Part Two Disaster Recovery will apply, and should suffice for the planning and undertaking of recovery measures necessitated by the majority of lesser eruptions. Exceptions to the above may include large-scale rhyolitic events, or lesser events impacting directly onto a heavily populated urban area such as Auckland. In the former case, large land areas may be made uninhabitable and unworkable for periods of years; in the latter, tens of thousands of people may be made homeless for extended periods of time, with perhaps thousands being unable to ever re-occupy their properties. In both these cases, recovery will require policy direction by central government.

24. In this respect the Officials Committee for Domestic and External Security Coordination (ODESC) has responsibility for recovery issues, and will coordinate central government recovery procedures.

25. National Civil Defence Plan Part Two paragraph 16(h) addresses in part the role of central government in the recovery process. However, regional councils, territorial authorities, departments, organisations, SOE'S, and other agencies should also address identified long term issues prior to any volcanic emergency.

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