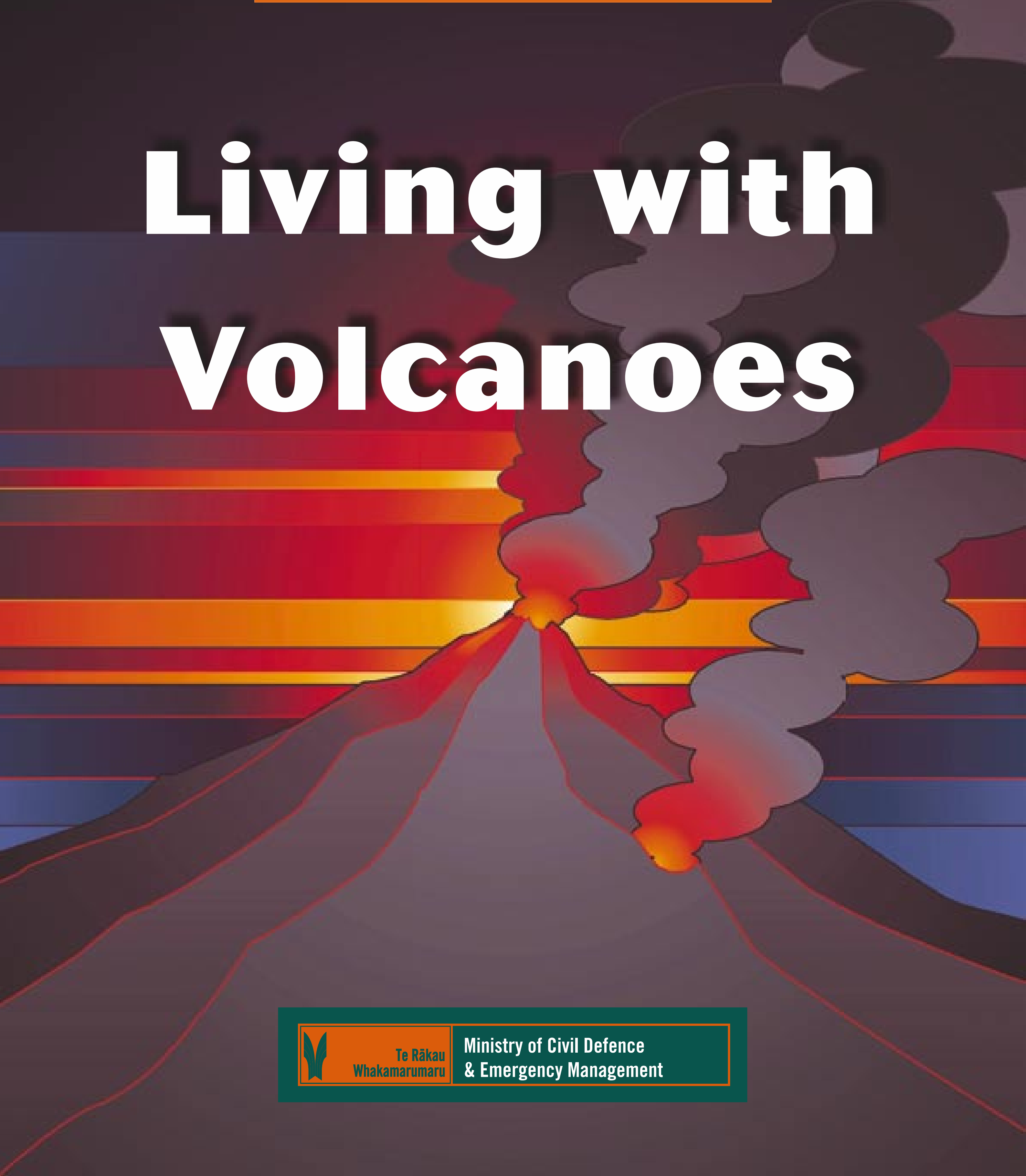
TEPHRA
KIA TAKATU TAHI TATOU September 2004 • Volume 21

Living with Volcanoes



Te Rākau Whakamarumaru
Ministry of Civil Defence & Emergency Management

From the Editor

Living with Volcanoes

Over the last few issues, Tephra has sought to provide scientific and educational information to help us better understand the hazards that we face. The journal aims to bring together relevant information on the work that is being done by scientists and researchers, and illustrate how that knowledge is applied in New Zealand.

The case studies from local authority emergency managers on the work that is being done to plan for, and reduce the potential impact of these hazards in their communities, are aimed at providing practical information for those involved in the civil defence emergency management sector.

This issue of Tephra explores the exciting world of New Zealand's volcanoes. While many of us are quite fascinated with the phenomena, it is potentially one of the country's most underrated hazards.

What causes them, what do we know about their past and what can we expect them to do in the future. Where and when are they most likely to occur? Can we predict them? With reference to specific events, the articles in this issue address these questions and describe the relevant research that is currently being done in New Zealand.

How prepared though are our communities to cope with a volcanic eruption in New Zealand WHEN, NOT IF, it happens. A consistent theme in many of the articles is the concern over the low level of individual and community awareness and preparedness for volcanic events. Why aren't our communities not taking the hazard more seriously? Is it because the potential scale and the unpredictability of volcanic eruptions defies imagination and is therefore seen as being beyond our realm of control? That it won't happen in our lifetime?

For those tasked with planning for emergency management, it is not an option to do nothing or to deal with it when it happens. In the regions most at risk, a great deal of work is being done to understand the potential impact of volcanic hazards and to plan for their mitigation. Articles in this issue explore the work being done for the areas of Auckland, Taranaki, Taupo, and Bay of Plenty.

We also explore some of the barriers to raising community awareness and preparedness. Communities need to fully understand the degree of volcanic risk they face and to build their own capacity to be resilient. At a national and local level, emergency managers tasked with public education acknowledge that a great deal more needs to be done to effectively get the message across and to bring about change.

Publications such as Tephra will hopefully improve understanding of the hazard and encourage individuals and communities to be better prepared. Tephra is a non-profit publication that is distributed widely within New Zealand to central and local government, commercial organisations, libraries and educational institutions. It is also distributed internationally to agencies with an interest in emergency management.

The Ministry gratefully acknowledges the contributions of the various authors, in particular from the science and research community - the Institute of Geological and Nuclear Sciences, University of Canterbury, and Massey University for their contributions and ongoing support for the publication. The case studies from emergency managers are gratefully acknowledged as they provide readers with an understanding of what's being done around the country to plan for managing volcanic hazards.

Chandrika Kumaran

Te Rākau Whakamarumaru | Ministry of Civil Defence & Emergency Management

TEPHRA n. fragmented rock, ash etc ejected by a volcanic eruption [from the Greek word for ash]. Concise Oxford Dictionary.

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Living with Volcanoes

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Cover illustration: An artist's impression of volcanoes in New Zealand. Stephen Crowe, Wellington.

Back cover: Looking out to Mt Tarawera with Lake Okareka in the foreground, Landscape shows the lava domes from the 1315 Kaharoa eruption. Photo courtesy of Tourism Rotorua.

Living with Volcanoes

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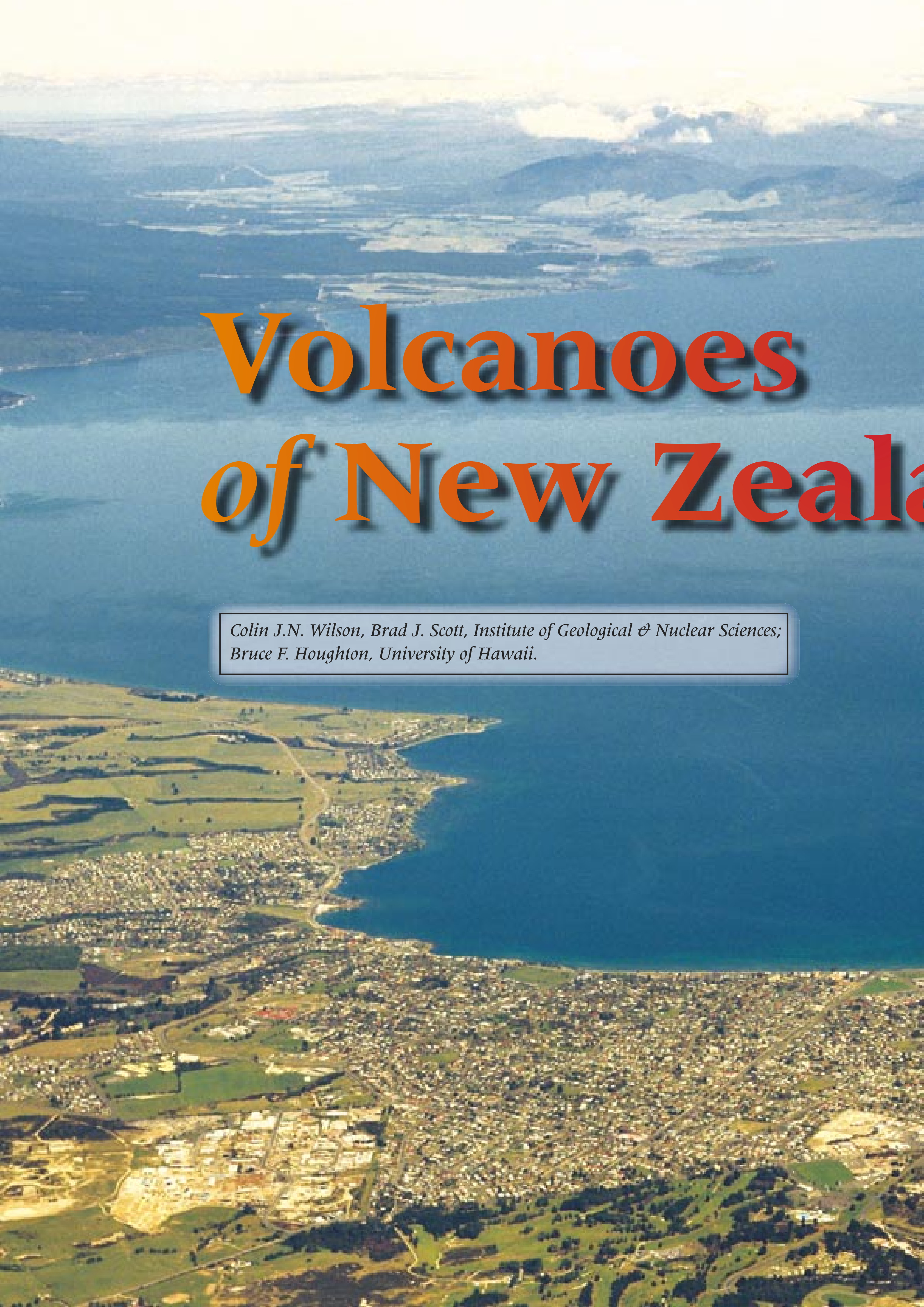
Volcanoes of New Zeala

Colin J.N. Wilson, Brad J. Scott, Institute of Geological & Nuclear Sciences; Bruce F. Houghton, University of Hawaii.



and

Volcanism has played an important role in shaping New Zealand, with the greatest impacts on the present-day landscape and environment occurring during the last 1.6 million years. Much of the spectacular landscape of the central North Island (recently starring in several settings for the 'Lord of the Rings' trilogy) owes its shape to volcanism. Volcanic soils support large parts of the farming and forestry sectors of the economy, and much of the electricity-generating capacity in the North Island is from power stations built on volcanic rocks and utilising geothermal energy. However, volcanism has its disadvantages. Deaths due directly or indirectly to volcanism (and associated hydrothermal explosions) represent the biggest single source of fatalities from natural disasters in New Zealand during the last 150 years (Table 1). Past economic losses due to volcanism were trivial up until the Ruapehu 1995/1996 eruptions, but this eruptive episode has shown that the economic losses due to volcanism can greatly exceed the losses due to physical damage. In addition, the volcanic eruptions that have been observed during the human settlement of New Zealand show only a fraction of the types and sizes of volcanic events that have occurred in the past, and will occur again in the future. Contingency plans for our volcanoes must include scenarios based on their prehistoric records as well as the short recorded history.

TYPES OF VOLCANIC ACTIVITY

TYPES OF MAGMA (MOLTEN ROCK)

The biggest single contributor to the behaviour of magma (natural molten rock) is its content of silica (SiO_2), which controls its viscosity (stickiness) and hence influences the eruptive style. The most silica-poor (47-52% SiO_2) and fluid magmas are basalts, then come the moderately viscous intermediate compositions termed andesites and dacites. The most silica-rich, viscous magmas (72-78% SiO_2) are rhyolites. The next most important contributor to the behaviour of magmas are the gases dissolved in the molten rock. These are mostly water (H_2O) but also with lesser amounts of noxious or toxic gases such as carbon dioxide (CO_2), sulphur compounds (H_2S, SO_2), fluorine (F) and chlorine (Cl).

TYPES OF ERUPTION

There are two major types of eruption: effusive, where liquid magma emerges quietly at the earth's surface to form a lava flow or dome; and explosive, where escaping gases tear the magma apart into fragments. The fragments are termed pyroclasts (fiery and broken) and explosive eruptions form pyroclastic deposits. In any magma, if the gas content is low, or the viscosity is low so that gases can easily escape during ascent of the magma to the Earth's surface, then a lava flow is the likely end product. Thus basalts often erupt as lava flows. Conversely, high viscosity, gas-rich rhyolites tend to erupt explosively and violently, and most rhyolite eruptions form pyroclastic deposits.

TYPES OF EXPLOSIVE ERUPTION

Volcanic explosions occur in two different ways. In 'dry' explosive activity, gases dissolved in the magma come out of solution, froth the magma up and then tear it apart to form the pyroclasts. 'Wet' activity occurs where the hot magma meets a supply of water (eg. a lake, or a hydrothermal system), flashing the water to steam and making the eruption violently explosive. There are also two types of product. Fall deposits result when pyroclasts and fragments of old rocks surrounding the vent are carried up into an eruption plume. The plume is blown sideways by the wind and the fragments fall from the plume to the ground, the resulting fall deposits blanketing the old land surface like a snowfall. Flow deposits are laid down by ground-hugging rapidly moving mixtures of ash, pumice and hot gases sweeping outwards from the vent. Flow deposits tend to accumulate in valleys, and form a rock called ignimbrite.

VOLCANISM IN NEW ZEALAND

The New Zealand region is characterised by both a high density of active volcanoes and a high frequency of eruptions. Surface volcanic activity in New Zealand occurs in six areas (Fig. 1), five in the North Island and one offshore to the northeast in the Kermadec Islands. However, work in the last decade has established that there are at least 30 other submerged volcanoes, some active enough to be giving off plumes of fluids (analogous to fumaroles seen in subaerial volcanoes), between White Island and the Kermadec Islands.

There are three major types of subaerial volcanoes in New Zealand: volcanic fields; cone volcanoes; and caldera 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 (eg. Mount Eden, Rangitoto), which does not erupt again. Each succeeding eruption in the field occurs at a different location, and this site cannot be predicted until the eruption is imminent.

CONE VOLCANOES

Cone volcanoes such as Egmont and Ruapehu are characterised by a succession of small to large 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 cone shape can be modified by partial collapse due to oversteepening (as has happened several times at Taranaki volcano in its history), or

Table 1: Summary of deaths in volcanic areas of New Zealand during the past 150 years

Year	Location (eruption)	Cause - hazard	Fatalities
1846	Waihi (Lake Taupo)	debris avalanche/mudflow from thermal area	c.60
1886	Tarawera Rift	large volcanic eruption	>108
1903	Waimangu (Tarawera)	hydrothermal explosion	4
1910	Waihi (Lake Taupo)	debris avalanche from crater wall	1
1914	White Island	debris avalanche/mudflow from thermal area	11
1917	Waimangu (Tarawera)	hydrothermal explosion	2
1953	Tangiwai (Ruapehu)	lahar and flood from crater lake	151
			Total > 337

Page 2 Photo: Aerial view of Taupo looking towards Mt. Ruapehu. Photo: GNS Lloyd Homer.

by collapse of the summit area to form a caldera (as has happened at least twice at Raoul Island volcano). Roughly the same route to the surface is used each time by the magma and therefore, 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 very large eruptions. Eruptions at these locations 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 each other (eg. 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.

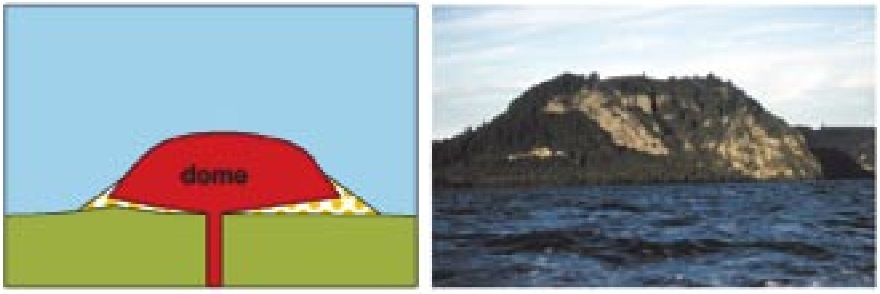
Locations of the young volcanoes in New Zealand.

Fig. 1

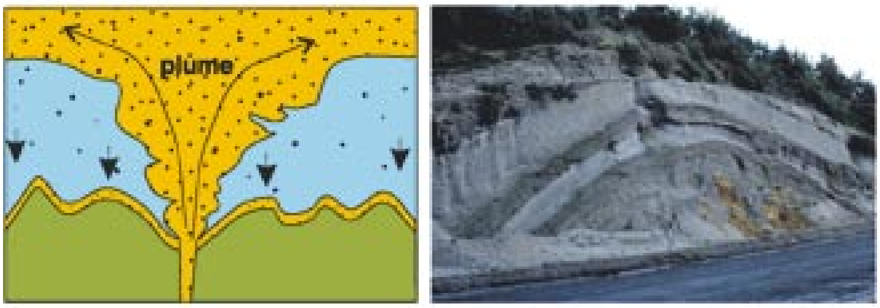
A The positions of the Kermadec Islands (Raoul, McCauley, Curtis, L'Esperance) relative to the North and South Islands.

B Enlargement of TVZ to show the segments dominated by cone volcanoes (White Island, Tongariro/Ngauruhoe, Ruapehu) and caldera volcanoes (Okataina and Taupo). Note that the north-northeast continuation of the TVZ trend beyond White Island links up with (and continues beyond) the volcanoes of the Kermadec Islands.

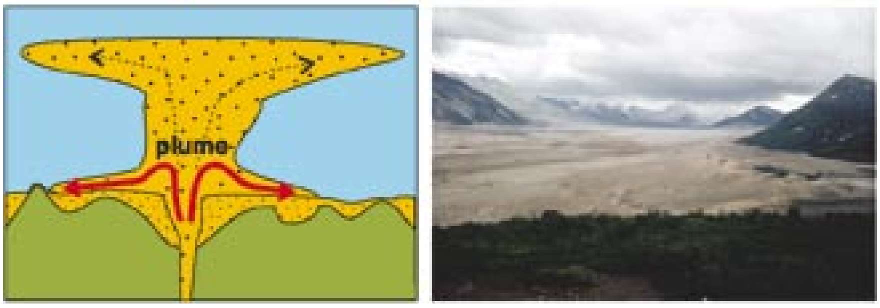
C Location of volcano fields in Northland and Auckland (grey ovals), the cone volcano of Egmont, caldera volcano of Mayor Island, and the Taupo Volcanic Zone (TVZ)



Lava dome: Lava domes form where magma is squeezed out on the surface like paste from a tube.



Fall deposits: Gas-rich magma erupts explosively, forming high plumes that rain pumice and ash over the surrounding landscape, The deposits drape the landscape like a snow-fall.



Ignimbrite: Large eruptions often have unstable eruption columns that collapse to form pyroclastic flows: ground-hugging mixtures of gas, pumice and ash. These fill in valleys to form a new landscape.

Illustration of volcanic eruption processes and products.

NEW ZEALAND VOLCANOES

DISTRIBUTION

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 tectonic plates in the New Zealand region. Most New Zealand volcanism in the past 1.6 million years has occurred in the Taupo Volcanic Zone (Fig.1), 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 contains three frequently active cone volcanoes (Ruapehu, Tongariro/Ngauruhoe, White Island) and the two most productive caldera volcanoes in the world (Taupo, Okataina)

INDIVIDUAL AREAS AND VOLCANOES

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 fifty small volcanoes have formed, Rangitoto being the youngest (~700 years old). The magma is basaltic in composition, and eruptions tend to be small (typically 0.1-1.0 km^3), and the areas significantly affected are, at most, a few tens of km^2; therefore hazards are very localised. However, the growth of New Zealand's biggest city and 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

Taranaki

The modern cone of Taranaki is only the latest in a series of cone volcanoes that stretches back in time to 1.7 million years. The older cones (1.7-0.13 million years old) 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


Dominating the central North Island landscape, the stunning Mt. Ngauruhoe with Mt. Tongariro on the right. Photo: GNS Lloyd Homer.

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 has reached the surface is thought to have occurred in 1755 AD, so the volcano is considered to be dormant. Eruptive products from 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, together with comparable volumes of pumice, scoria and ash that have spread as thin pyroclastic fall and flow deposits beyond the cone.

Tongariro/Ngauruhoe

Tongariro is a large (100 km^3) cone volcano of which the youngest cone, Ngauruhoe, is the main active centre. Tongariro, like Egmont, has been both built up by eruptions of lava flow and pyroclastic material as well as 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. 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). 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 some minor amounts 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. The oldest dated lavas are ~230,000 years old, but there has probably been a volcano in the Ruapehu area for at least 0.8 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. The four largest eruptions have been in 1945, when a lava dome partly displaced the Crater Lake, 1969 and 1975, when large explosions through the lake generated destructive lahars, and in 1995-1996 (see inset article).

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. 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 2000. Our knowledge of the earlier history of the island 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 from White Island preserved on the mainland. Historic activity included a small collapse of the west wall of the

Spectacular image of the 1995 Mt. Ruapehu eruptions. Photo: GNS Lloyd Homer

RUAPEHU 1995/1996

The 1995/1996 eruptions of Ruapehu began just as the previous Volcano issue of 'Tephra' came out, in itself fortuitously timed to celebrate 'Volcanic Awareness Week'. The eruptions represented the largest volcanic event in this country for 50 years and were the first volcanic events to affect a New Zealand society where electronic communications, television and air travel were the norms.

Eruptive activity occurred in a number of events spaced between September 1995 and August 1996. Eruptions in September 1995 took place through the Crater Lake, generating lahars in four rivers draining the volcano and accompanying ash-fall deposits that reached to >100 km from vent. About 90 % of the volume of lahars (~107 m^3) travelled in multiple events down the Whangaehu River. During October 1995, the eruptions became 'drier' as the Crater Lake began to disappear and were both larger and more sustained, depositing ash to >250 km from the volcano. During late October and November 1995 there were no major explosive events, but there were large-scale discharges of sulphur gases, generating volcanic smog ('vog'). From October to the following May, the volcano itself was relatively inactive, but more lahars were created as rain and snowmelt remobilised the fall deposits laid down on the upper slopes of the volcano, impacting catchments like the Tongariro River that were previously unaffected.

On 15 June 1996, volcanic tremors recommenced at the volcano, and the second part of the eruption began on the morning of 17 June with a 12-km-high eruption column that deposited a widespread but thin fall deposit over a narrow sector north-northeast of the volcano. Smaller eruptions continued into August, with the last eruption of new magma on 1 September. Since then, the volcano has been quiescent and the Crater Lake has re-formed almost to overflow level, although its temperature and composition indicate that considerable amounts of heat and gases are continuing to flow into the lake.

The 1995-1996 eruptions had the most severe economic impact of any volcanic event in modern times. Direct and indirect losses amounted to about $130 million, most of which was due to loss of skiing and other tourist activities on the volcano itself. The eruptions emphasised how vulnerable certain sectors (especially tourism and aviation) in modern New Zealand society are to what, geologically speaking, was very minor activity of which virtually no trace will be seen in the longer-term geological record.

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 earlier activity involved higher-silica andesite or dacite. For many years, a plume of acidic steam has risen from fumaroles on the island, even during periods when the volcano was not actively erupting. However, from March-April 2003 onwards a lake has formed in the vent area, drowning the fumaroles.

Submarine volcanoes and the Kermadec Islands

Many large volcanoes occur along a north-northeast-trending line from the North Island linking with and including Tonga. Nearly all of these volcanoes are submerged beneath hundreds to thousands of metres of water, but the Kermadec Islands are where some of these volcanoes have constructed cones above the surface of the sea (Fig. 1). Work is still continuing to discover just how many volcanoes there are in this line, and little is known about their eruptive histories. The three major volcanoes in the Kermadecs (Raoul, Macauley and Curtis) and others of the largest cones are similar in size to Ruapehu.

Although these volcanoes are broadly cone-shaped like their mainland counterparts, they differ in two respects. Firstly they have erupted substantial amounts of both dacite and basalt, rather than being dominated by andesite. Secondly the main processes causing destruction of the cones are marine erosion and caldera collapse, the latter accompanying the most silica-rich (dacite) eruptions. Unlike in the mainland caldera volcanoes however, the caldera collapse only truncates the top of the cone, rather than engulfing it entirely. Raoul Island in the Kermadecs has experienced several historic eruptions, the most recent in 1964, and other volcanoes show strong fumarolic activity, indicative of magma at shallow depths. The size range of eruptions in the offshore volcanoes is greater than that usually considered the norm for cone volcanoes, and pyroclastic deposits (including ignimbrites) are prominent features of the young eruptive records.

CALDERA VOLCANOES

Taupo

Taupo is a large caldera volcano, whose shape reflects collapse following two large eruptions about 26,500 and 1,800 years ago, although the volcano itself first starting 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 km^3, up to the largest (26,500 years ago) which involved about 530 km^3 of magma (that is,

White Island, one of the few privately owned volcanoes in the world, is New Zealand's most active cone volcano with three long cycles of eruptions recorded between 1976 and 2000. Photo: GNS Lloyd Homer.

Three volcanic fields occur in Northland and Auckland. Mt. Mangere (pictured above) is one of fifty volcanoes in the Auckland Volcanic Field.
Photo: GNS Lloyd Homer

about 2-3 times the volume of Ruapehu). There have been 28 eruptions at Taupo since 26,500 years ago, of very different sizes and spaced at very 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 5,000 years and has left marks on the landscape and on vegetation patterns which are still visible today.

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). 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 that 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 mountains, Haroharo and Tarawera. However, Okataina has also seen some unusual events, such as the basaltic eruption of Tarawera in 1886 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. 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 over 100,000 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 three 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.

CONCLUSIONS

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 gently-sloping shield volcano such as Kilauea or Mauna Loa in Hawaii (and such volcanoes may be present in the offshore realm). Volcanism in New Zealand is unusually frequent and productive on a world scale. 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 eruptive sizes and styles that are possible even on a human timescale.

Mayor Island, the smallest caldera volcano in New Zealand has produced many explosive and effusive eruptions, the latest of which occurred 6,300 years ago. Photo: GNS Lloyd Homer.

Looking across Mt. Tarawera to the north-east, with Mt. Edgecumbe top right. Photo shows the three vents of the 1886 eruptions.

Monitoring New Zealand Volcanoes

Tony Hurst, Brad Scott, Cindy Werner, Nicki Stevens & Hugh Cowan, GNS

The Crater Lake of Ruapehu is currently in the news in 2004, over concerns that it may produce a damaging lahar as it fills past its previous outflow level. This is tending to obscure the fact that the main hazard from Ruapehu is still a volcanic eruption, and New Zealand also has a number of other active volcanoes which could erupt and produce a wide range of damaging consequences.

Volcanic eruptions occur when magma (liquid rock) rises up towards the surface. If we can detect that magma is rising, or that a pre-existing body of shallow magma is becoming disturbed, then we would expect that an eruption is about to occur. Common indicators of volcanic unrest are volcanic earthquakes or continuing volcanic tremor, deformation of the ground around an active crater, the detection of gases evolved from magma bodies, and temperature measurements to detect the thermal effects of the magma. The most appropriate techniques will differ depending on whether we are looking at a frequently active volcano, such as Ruapehu or White Island, or volcanoes like Mt. Egmont/Taranaki, Taupo, or those of the Auckland area, which have not erupted for hundreds of years.

At the time of the 1995 and 1996 Ruapehu eruptions, the Institute of Geological & Nuclear Sciences (GNS) had inherited from the former DSIR the role of monitoring New Zealand volcanoes, but there was no funding tied to this responsibility. The volcano research programme was funded within a contestable science funding system, which emphasized new projects, and gave a low weighting to monitoring. It was not surprising therefore, that there were difficulties in responding to those eruptions, because of inadequate equipment (most of the seismic network dated from

1976) and conflicts over staff priorities between research and monitoring requirements.

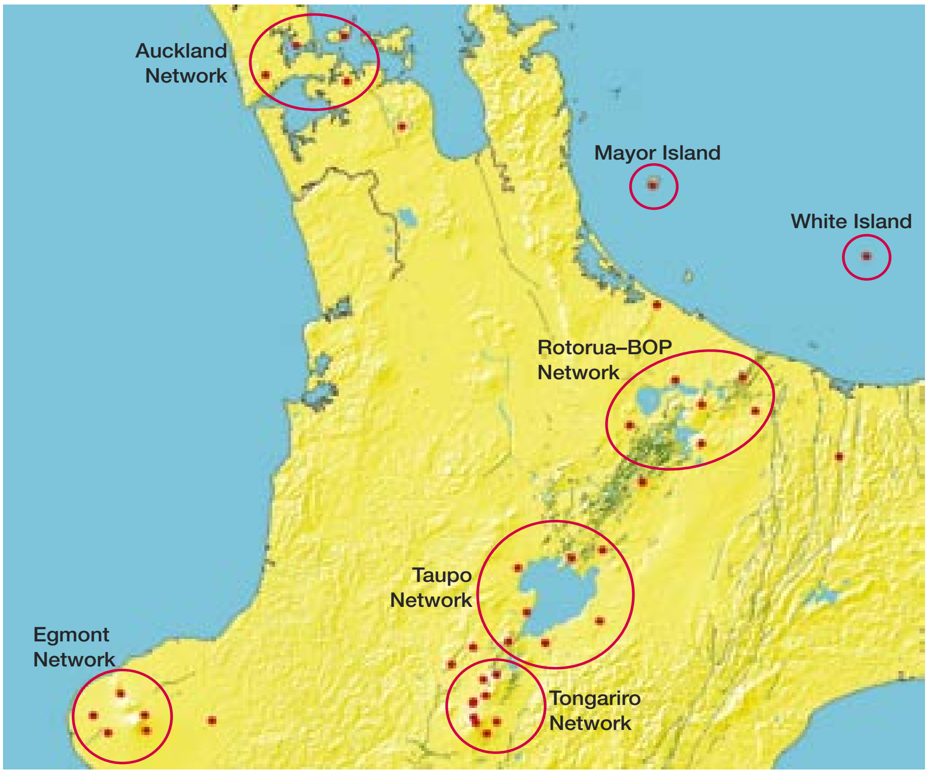
In February 1995, there was a major offshore earthquake on Waitangi Day, and GNS had difficulty in providing accurate information with the minimal network of real-time seismometers available. GNS therefore initiated a review of capability requirements while simultaneously seeking funding for such a system. Leadership and funding for this purpose were eventually provided by the Earthquake Commission and in 2001 the GeoNet Project was launched. Almost three years on, GeoNet is improving the detection, data gathering, and rapid response related to New Zealand earthquakes, volcanic activity, large landslides and the slow deformation that precedes large earthquakes. GeoNet will enable responding agencies to provide a much better service to the community during earthquake and volcanic crises, and provide the high quality data needed for modern research to advance societies' understanding of geological hazards.

VOLCANO-SEISMIC NETWORKS

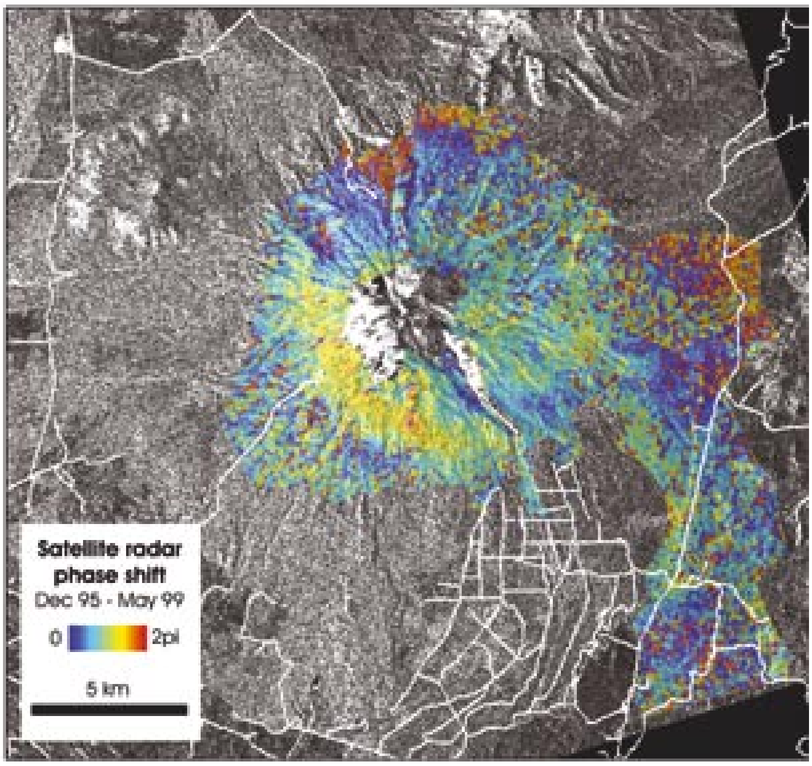
Cracking of rocks under stress from magma produces small earthquakes, similar to those seen in non-volcanic areas. But particularly indicative of impending volcanic activity are volcanic earthquakes and tremors. A normal small earthquake will have a vibration frequency of about 10 times a second (10 Hz), but volcanic earthquakes are much slower, about 1 or 2 Hz. Some volcanic earthquakes are single events, but at many volcanoes there is continuing low-frequency vibration, known as volcanic tremor. Scientific debate continues about the actual cause of these events, but they definitely seem to be related to fluids, especially fluids moving underground. At most volcanoes, an increase in the energy of volcanic earthquakes and/or tremor precedes eruptions. The Ruapehu volcano is a little anomalous in having long periods of tremor that do not precede eruptions, which makes it harder to use the tremor level by itself as an indication that an eruption is near. At some overseas volcanoes, another variety of seismic event, called a "tornillo" (Spanish for screw), with a sharp onset and regular slow decay, is noted as occurring before eruptions. We began to observe them under Tongariro in 2000, but so far there have been no eruptions.

Seismic networks have now been established for all the major volcanoes in New Zealand. The networks that extend from the Tongariro National Park volcanoes, through Taupo and Rotorua to the Bay of Plenty, together with a station on White Island volcano are operated by GNS, while networks on Mt. Taranaki/ Mt. Egmont and the Auckland volcanoes are operated by the Taranaki and Auckland regional councils. All these networks are linked for real-time analysis of the recorded signals by GNS staff at the GeoNet data centres.

Any earthquakes near an active or dormant volcano will be looked at in terms of their possible connection with volcanism. At the frequently active volcanoes, seismicity can rapidly develop into an eruption. For instance, both the 1969 and 1975 eruptions of Ruapehu were preceded by volcanic earthquakes of increasing size during the space of less than half an hour. The 1996 Ruapehu eruption commenced several days after strong anomalous tremors that resulted in warnings being issued. For the volcanoes and calderas that have been quiet for hundreds of years or longer, it is likely that there would be a longer period of warning. A particularly worrying pattern would be seismicity that got shallower over weeks or months, as magma rose. It is also necessary not to over-react to seismic events. For instance, the Rotorua area frequently has swarms of 50



Volcano-Seismic Networks for major New Zealand volcanoes.



ERS radar interferogram of Ruapehu (in colour) draped over a radar image for orientation, with local roads shown in white. The colours represent a radar phase shift between 1995 and 1999, which can be due either to surface deformation or atmospheric noise. In this case, the observed small phase shift is due to atmospheric noise, and no significant deformation occurred at Ruapehu during this period. This result is confirmed by field measurements. Data was supplied under a Eurimage Research Club contract.

to 200 earthquakes, lasting one or a few days. They are usually of small magnitude, but are very shallow and therefore frequently felt. These swarms are part of the normal "restlessness" of a comparatively young volcanic area.

ERUPTION DETECTION SYSTEM (EDS)

There is one volcanic hazard in New Zealand where the required response time is so short that a standalone automatic system is necessary. This is for the Whakapapa skifield on Ruapehu, where a significant eruption under Crater Lake could produce a damaging lahar into the ski area, and it is necessary to stop loading the chairlifts within a few minutes of detecting a possible eruption. The Eruption Detection System (EDS) is operated by the Department of Conservation for the skifield operators, using parameters developed by GNS. A dedicated computer system is used to identify any significant earthquakes that could be under Crater Lake, and large enough to cause a significant lahar. By comparing the amplitude of earthquake signals on and off the mountain it is possible to quickly confirm that the earthquake is under Crater Lake and estimate the size. The noise (airwave) made by the eruption is used to confirm an actual eruption is in progress, especially for smaller events.

DEFORMATION

Some volcanic eruptions are preceded by large surface deformations. Some points on Mt. St. Helens in the US had moved more than 150 metres before its catastrophic 18 May 1980 eruption. On a much smaller scale, level changes of a few centimetres within the crater have been found to precede eruptions of White Island. Deformation monitoring through GeoNet is aiming to monitor very small movements on both cone volcanoes and in the calderas where large eruptions have occurred in the past.

Direct measurement of position changes has become much more practicable with the establishment of the Global Positioning System (GPS), which makes routine precision position measurements possible. With GPS, we can reasonably expect to see horizontal movements of a centimetre, and vertical changes of several centimetres. GNS has been establishing a baseline GPS network around New Zealand for Land Information New Zealand, with extra stations in areas where tectonic plate movement is causing rapid deformation. The same type of GPS station is now being installed on active volcanoes, with three sites already on Ruapehu. The other priority volcanic areas are the Okataina and Taupo calderas.

Whereas GPS measurements record the position of one point at frequent time intervals, differential radar interferometry (DInSAR) offers the ability to see movements over the whole volcano surface, but only at infrequent intervals.

This technique uses radar images from the Earth Resource Satellite (ERS) and Envisat satellites which orbit about 800 km above the surface of the Earth. By comparing data acquired at different times, once they are matched exactly, it is possible to measure centimetre-scale surface deformation between those times, to a spatial resolution of several tens of metres. The use of DInSAR in the New Zealand environment is not straightforward, however, as the technique works best in arid, flat, unvegetated terrain.

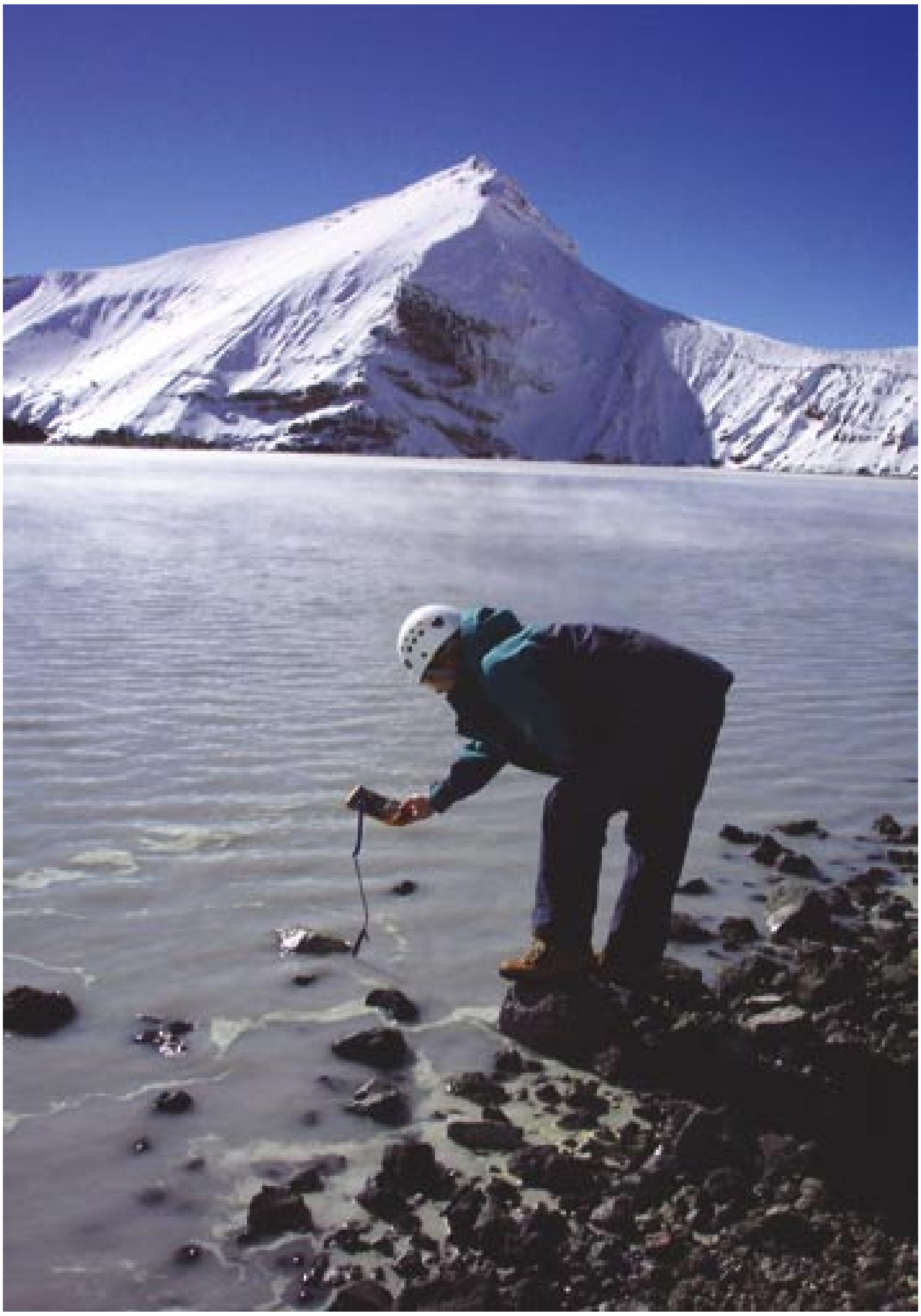
The feasibility of using DInSAR for volcano monitoring in New Zealand was tested at all active volcanic centres, including the Auckland Volcanic Field, Taranaki, Tongariro Volcanic Centre, the Taupo Volcanic Zone and White Island. Successful results were achieved at Auckland and Tongariro, and a fledgling near-real-time DInSAR monitoring capability has now been developed within GeoNet. Better results may be obtained in the future with the launch of a Japanese satellite, ALOS, which will carry an L-band sensor, which is less sensitive to moisture and vegetation cover.

Vertical deformation in the caldera volcanoes is monitored using a lake-levelling technique, in which the whole lake acts as a level. Nearly 30 years of record from Lake Tarawera and Lake Taupo have shown regional deformation of several millimetres per year, analogous to deep sighing of these volcanoes.

CHEMICAL MEASUREMENTS

Volcanic regions emit gases both during and between eruptions, and changes in emission rates and chemistry of volcanic gases can help us to predict changes in volcanic activity. Volcanic gases emit through the main volcanic conduits to form fumaroles and volcanic plumes, and also diffuse through soils. Some components of the gas stream react with groundwater and are essentially scrubbed when passing through crater lakes or shallow aquifers. Thus, when monitoring the volcano chemistry, it is important to consider the different emission pathways, and monitor both the gas and fluid phases.

The two most abundant gases emitting from volcanoes following water vapour are carbon dioxide (CO_2) and sulphur dioxide (SO_2). These two volcanic gases behave differently in magmas, and thus, each gas provides information about activity at different depths. Carbon dioxide, for instance, has a relatively low solubility in magma compared to sulphur dioxide and water vapour. Thus, as magma starts to move from deep (~35 km) in the crust toward the surface, CO_2 will become progressively supersaturated in the magma and be released before other gases. When monitored periodically using airborne or ground-based techniques, increases in CO_2 emissions will provide the first indication that there is magma movement at depth. For example, in 2000 at Usu Volcano in Japan, a group of scientists observed a tenfold increase over typical background levels in diffuse soil emissions prior to an eruption. The techniques for measuring CO_2 through soils and in volcanic plumes have improved dramatically over the last 10 years, and are being utilised to provide more insight about the behaviour of CO_2 emissions preceding volcanic eruptions in New Zealand.



Measuring temperatures at the Mt. Ruapehu Crater Lake. Photo: GNS.

Sulphur dioxide emissions are easy to measure using remote techniques (COSPEC) from airborne platforms. SO_2 is released from magmas at shallower depths and can also be used to detect magma movement toward the surface (within a few km of the surface). For instance, preceding the 1995 eruption of Ruapehu there was an 18% increase in the concentration of sulphate ions in the crater lake over a period of 5-6 weeks, suggesting an increase of at least one thousand tonnes/day of SO_2 over this time period.

Changes in the ratio of gas abundances can also be used to detect changes within the volcanic system. Sampling and chemical analysis of gases from individual fumaroles as well as crater lakes can provide detailed information about the trace abundance of gases emitting from the volcano. For example, for the six months prior to the eruption at Ruapehu in 1995, scientists observed

Preparing to collect water samples from Mt. Ruapehu's Crater Lake. Photo: GNS.

a gradual increase in the magnesium to chloride (Mg/Cl) ratio in lake waters which suggests that there was interaction between lake waters and fresh magma during this period.

THERMAL AND MAGNETIC MONITORING

Any eruption is likely to be preceded by increases in the underground temperature, but heat moves slowly, so eruptions often occur before any surface temperature changes are observed. Fumarole temperatures, or analysis of the heating of crater lakes, can give an indication of the temperature at depth. Another technique is to use the fact that volcanic rocks become demagnetised at temperatures of about 500 °C. This means that increases in the underground temperature are likely to produce decreases in the total magnetic field at the surface. White Island volcano has been found to produce large magnetic changes as a result of changing underground temperatures.

All of the above techniques, coupled with changes in deformation and seismicity provide a comprehensive diagnostic set of information for predicting changes in volcanic activity, and assessing volcanic hazard.

EVENT RESPONSE

The natural response of a volcanologist to an eruption (or a seismologist to an earthquake) is to head towards its source. This used to be the only possible response, as the monitoring instruments we had were not connected to data centres and data had to be retrieved on site. In 1993 the seismometers monitoring the Tongariro National Park volcanoes and the Rotorua/Taupo area were connected by leased telephone lines to the GNS Wairakei Research Centre near Taupo, so they could be recorded there. However they were only properly monitored if someone watched the recording drums, so during volcanic crises it was necessary to have staff in the office 24 hours/day for this purpose.

The new GeoNet response system is based on duplicated data centres, at the GNS Gracefield (Lower Hutt) and Wairakei sites, with data paths arranged so that all data is available at either centre, even if the other centre is out of action. By then putting processed data on web servers, it can be accessed by staff from any Internet connection. Two Geohazards Duty Officers are on duty at any time, one in the Wellington area and one in the Central North Island. They are alerted by pager when seismicity levels increase at any of the active volcanoes, as well as by significant earthquakes anywhere in New Zealand. With Broadband internet connections to the Duty Officers' homes, and laptops equipped with high speed data modems, they can readily check the condition of the volcanoes and the monitoring equipment at any time, and provide responding agencies with information to assist decision-making.

Another aid to the Duty Officers are the volcano cameras which have been installed since 2000. Their pictures have become one of the most visited parts of the GeoNet website at http://www.geonet.org/volcanocam.htm. They normally take photos every 30 minutes at five sites, giving general views of Ruapehu, Ngauruhoe, White Island and Mt. Taranaki volcanoes, together with a view within the White Island crater. This last view requires a short radio link to a ridge above the crater, and then an 80 km radio link, to provide communication between the camera and a computer in the Whakatane office of Environment Bay of Plenty. In times of high volcanic activity, the time between pictures can be reduced to a few minutes. If bandwidth is available, we are hoping to move towards some kind of video system to supplement or replace these cameras.

GNS allocates an Alert Level to each of the recently active volcanoes, depending on their level of activity. In normal situations, changes in the Alert

Level are made by an event coordination meeting of surveillance staff, where the implications of the available data are discussed. Science Alert Bulletins will be issued to Emergency Management organisations and the news media in response to any significant change in activity, whether or not the Alert Level is changed. However if a significant ash eruption occurs, the Duty Volcanologist will immediately raise the Alert Level and issue a Science Alert Bulletin, then call together other scientists to plan the broader response to the eruption.

MONITORING EFFECTS OF ERUPTIONS

Volcanic ash clouds are a severe aviation hazard. GNS works with MetService to provide information on possible ash plume dangers downwind from volcanoes. The role of GNS is to give the best estimates of the quantity of ash, and the height of the eruption column, so MetService can provide Volcanic Ash Advisories for the areas and heights for which ash could be a hazard. This system was introduced in the wake of the Ruapehu eruptions of 1995-96, when flights over the North Island were severely disrupted and it was realised formal arrangements for informing pilots of potential dangers were lacking.

For larger ash eruptions, for which we are concerned about ash landing on the ground, GNS has the Ashfall programme which calculates the thickness of ash based on eruption characteristics and the forecast wind. The GNS website (www.gns.cri.nz) has daily ashfall forecasts, based on a typical minor eruption from a selected volcano with the day's forecast winds.

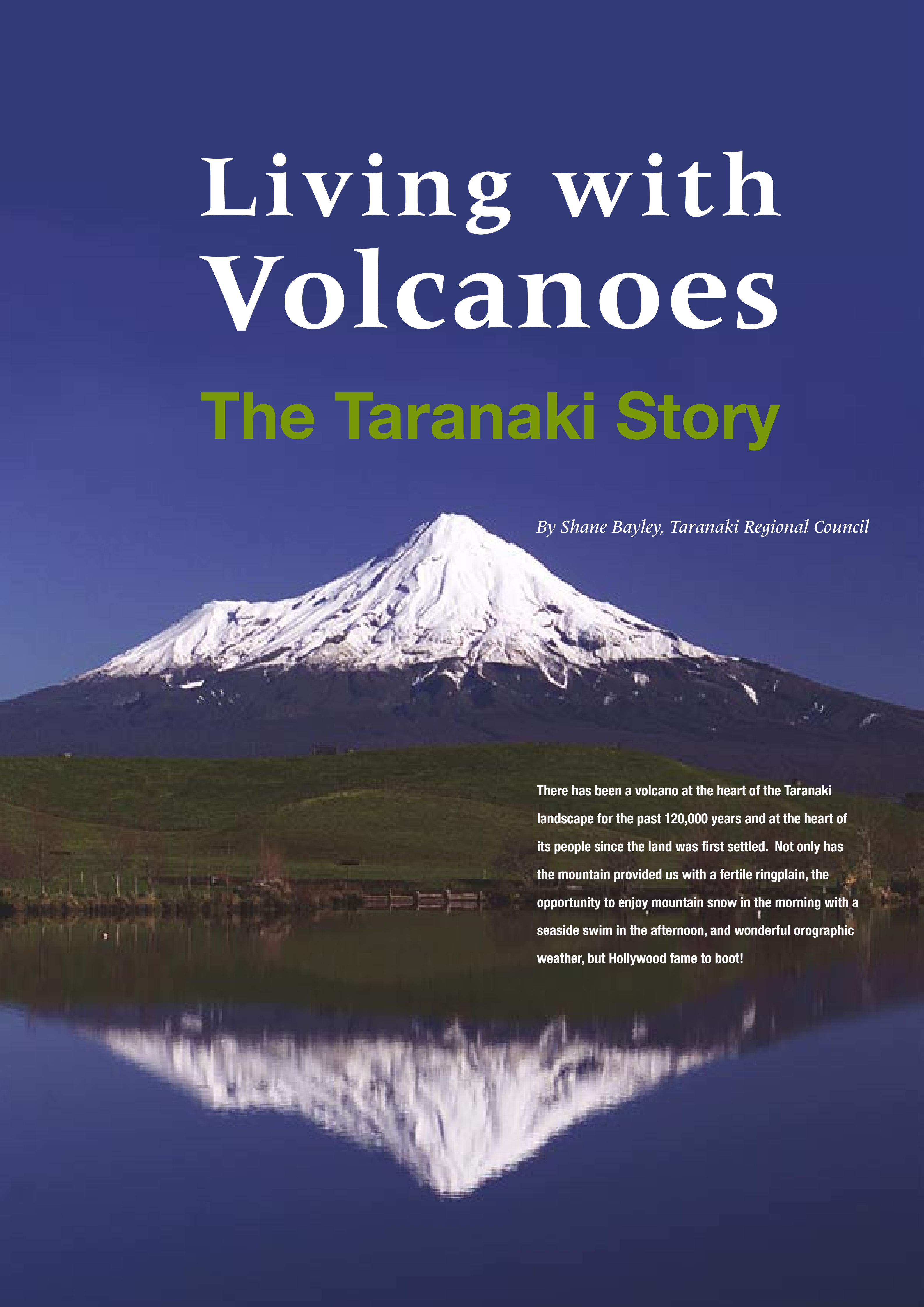
Servicing the seismic monitoring installation at White Island. Photo: GNS.

Soil gas sampling on Mt. Ngauruhoe. Photo: GNS.

Living with Volcanoes

The Taranaki Story

By Shane Bayley, Taranaki Regional Council



There has been a volcano at the heart of the Taranaki landscape for the past 120,000 years and at the heart of its people since the land was first settled. Not only has the mountain provided us with a fertile ringplain, the opportunity to enjoy mountain snow in the morning with a seaside swim in the afternoon, and wonderful orographic weather, but Hollywood fame to boot!

So what do we call this magnificent feature that dominates not only our landscape but our sense of home? According to the New Zealand Geographic Board, we can call it Mount Taranaki or Mount Egmont. In our regional planning work we prefer Mt. Taranaki/ Egmont and yet others would prefer the not so subtle reminder Egmont Volcano. The choice is yours.

It is no coincidence that the distance from the crater to the western coast is around 26km. The coastal ringplain was formed by eruption episodes from this site – earlier volcanic centres to the northwest are extinct. Many of these eruptions are small allowing the classical cone shaped volcano to build up to what we see today. In the past 1000 years alone there is evidence of some nine eruption episodes. Unfortunately, from time to time significantly larger eruptions have seen large scale collapses of the upper slopes of the mountain. These collapses have laid down the region as we know it today. Vast expanses of debris field are still clearly visible today particularly in coastal Taranaki, even though these events took place tens of thousands of years ago.

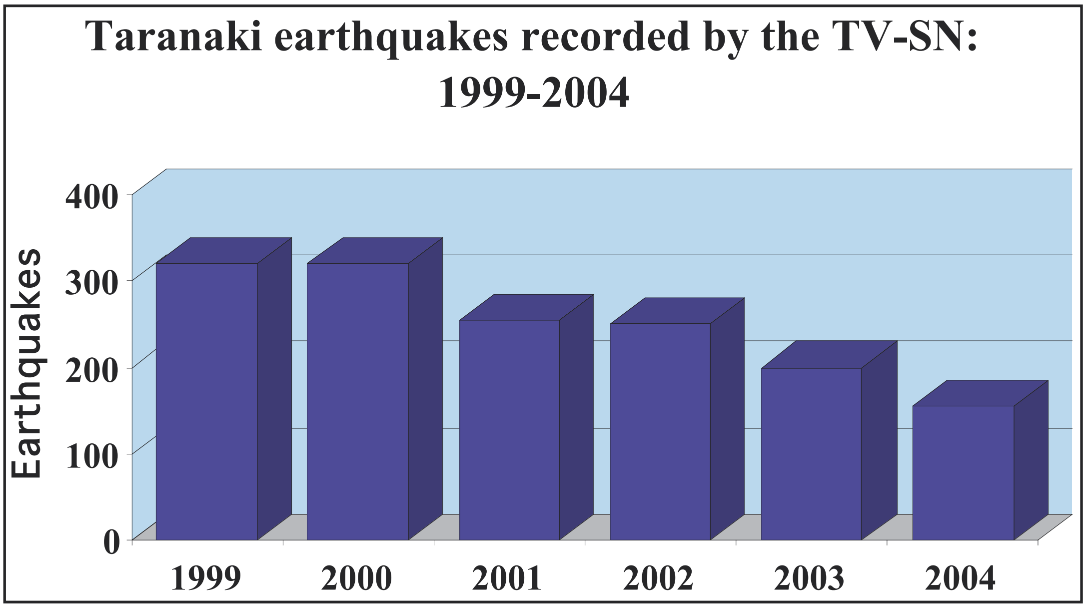
This story really begins in 1989 when two eminent scientists, Dr Ian Smith (University of Auckland) and Dr Richard Price (Latrobe University), became 'hut-bound' during a visit to the mountain. Their thoughts turned to the potential for an eruption and what that would mean for the 100,000 or so people who live nearby. They were keenly aware of the potential threat and that no concerted effort was being made to keep a watchful eye on what is an active volcano. The good doctors were on a mission – find out who the local 'mover and shaker' is for all things disaster! It was only a matter of time before they would meet the media crowned 'Duchess of Disaster' Bev Raine from the Taranaki Regional Council. A project was born.

The first step in the project, in true Kiwi style, was to form a committee. Well, it was really a small working group which comprised Dr Ian Smith, Dr Euan Smith (DSIR), Associate Professor Vince Neall (Massey University), Civil Defence Commissioner Barrie Sinclair (Ministry of Civil Defence) and Bev Raine. This group considered the technical issues, such as network design and cost, as well as the political issues and getting local support for the project. Ultimately a five-station seismometer network was funded jointly by the Taranaki Regional Council, Ministry of Civil Defence, and Shell BP Todd (as a part of their development levies).

By 1992 work was underway to establish the Taranaki Volcano – Seismic Network (TV-SN). A seismic monitoring network was chosen as this would detect earthquake activity which is almost guaranteed to be one of the precursors to eruption. An added benefit of a seismic monitoring network is that regional earthquake activity unrelated to the volcano would also be recorded. The network was designed to provide coverage around the mountain and at various altitudes. One of the stations is around 29km east of the mountain. This particular station is the first to detect earthquakes coming into the region from the east. It also assists by providing for better triangulation of earthquake arrival times from within the region.

As far as network design goes, the field sites are radio telemetered to the Emergency Management Office in New Plymouth. Traditionally, information was posted to GNS once a week for analysis. In recent times however the data from the network is transmitted to GNS electronically in near-real time. This development has been made possible by the GeoNet programme and has also allowed data to be displayed at Puke Ariki (the region's world class learning centre) as well as more detailed information for Taranaki Regional Council managers.

A sixth site was added to the network and some re-configuration has also taken place but useful data has now been received by the TV-SN since 1994. Data over the past five years suggests a slight drop in the number of earthquakes being detected. On average since the TV-



Mt. Taranaki/Egmont from Lake Ratapiko. Photo: Rob Tucker

Image STS110-726-6 of Egmont National Park, was taken by Space Shuttle crewmembers on 9 April 2002 using a Hasselblad film camera. This image was provided by the Earth Sciences and Image Analysis Laboratory at Johnson Space Center. Additional images taken by astronauts and cosmonauts can be viewed at the NASA-JSC Gateway to Astronaut Photography of Earth. (earth.jsc.nasa.gov)

SN began recording, 310 earthquakes have been detected per year within the Taranaki region.

One of the notable changes since the installation of the network is the location of a typical cluster of earthquakes recorded off-shore to the northwest. The introduction of the network has refined the locations of these events and it is now believed that this typical cluster activity is located in the upper Okato area, between the coast and the volcano.

Once work was underway in establishing the network, the working group was formally established as the Egmont Volcano Advisory Group. This Group meets once a year to consider reports on the TV-SN and any other scientific programmes that may be of interest to the region. The Group has recently been reviewed and now sits at the advisory group level to the Taranaki Civil Defence Emergency Management (CDEM) Coordinating Executive Group. The Egmont Volcano Advisory Group comprises representatives from Massey University, University of Auckland, Institute of Geological and Nuclear Sciences (GNS), Department of Conservation and the Taranaki Regional Council.

Well, to many it would appear that the project was a success – and it is. But let's face it, it's all well and good knowing if or when there will be an eruption but that certainly doesn't help in being ready for it.

In 1995 work began on the readiness phase. What will we do as local government, industry, departments, organisations and individuals? A public awareness survey was undertaken to establish some baseline data on what the community thought were hazards and where they get information about what to do in an emergency. A mere 37% of the Taranaki community considered volcanic activity as a potential threat, but we knew better!

VOLCANIC CONTINGENCY PLAN

The Taranaki Regional Council in partnership with the major players in emergency response set about developing a plan. By 1996 the plan had identified the basic 'rules' for responding to a volcanic emergency in Taranaki. This early work formed the basis for an intensive 17-month public awareness campaign.

In 1998, the original plan was reviewed and whilst the basic rules remained the same a more strategic approach was taken. The Taranaki Regional Volcanic Strategy places emphasis on the framework for response – who is responsible for what. The Strategy is more encouraging to industry to prepare their own contingency level plans based on the regional strategy. The Volcanic Strategy has been reviewed in anticipation of the Taranaki CDEM Group incorporating this document into the CDEM Group Plan.

One of the byproducts of this approach has been more consistent planning between players. The civil defence emergency management response to volcanic activity was also highlighted as an area that required specific planning. In 2000, the Taranaki Regional Volcanic Contingency Plan was completed. The Contingency Plan addresses the emergency management issues such as response coordination and emergency welfare. The Contingency Plan will be reviewed in due course to bring it more into line with recent response documents.

For those in the game of strategic and contingency planning, the Strategy is quite high level


Coastal ring plain showing volcanic debris avalanche mounds. Photo: Rob Tucker

and addresses the framework of Scientific Alert Levels and principal emergency management activities – what we do when the scientists tell us it's getting worse. Of course we have the little quandary that the scientists will be very cautious about telling us it's getting worse until they actually have evidence – no Pierce Brosnan's in that lot telling us to evacuate the town.

We identify the hazard zones. These are based on the scientific research on what has happened before. Our zones are colour coded – red, blue, orange and yellow. This makes the mapped zones easier to relate to than using numbers. The levels of alert are numbers (0-5). We talk about essential services and spell out that each of the services is responsible for keeping their service going. In addition we state exactly what it is they are responsible for in a volcanic response environment.

In the next section of the Strategy, we discuss the hazards – what can go wrong. Particular emphasis is placed on the life-threatening hazards, the ground hugging flows. Finally, we discuss monitoring of the volcano.

In the Contingency Plan, we discuss emergency management issues. This is divided into media management, coordination and control, evacuation, resources, communications and welfare. Such matters as identifying fastest evacuation routes, possible signage, emergency management facilities (Emergency Operations Centres), pre-event public awareness and the availability of information.

Of course, the Contingency Plan is only good for a short period and is not intended to be the response bible. The Plan provides a few ideas to support the huge amount of planning that will go into response when an eruption is imminent. Even the plans that are developed closer to the time will only be good for the first eruption. After that I guess it will be rescue and recovery, and without actually knowing where the rescues are required and what resources have actually survived that is just a guessing game.

Although only developed in 2000, a review of the Contingency Plan will soon bring this into line with plans developed on an inter-service basis (such as our Waitara Flood Plan, Naphtha Plan and Well-head Blowout Plan). This will then address lead agency, objectives, plan of action, critical elements, resourcing, information flow and communications for both the

New Plymouth power station with Mt. Taranaki in the background. Photo: GNS Lloyd Homer.

CDEM Group Controller and the CDEM Group's Welfare Manager. These are two clear and distinct functions in Taranaki.

PUBLIC AWARENESS CAMPAIGN

The campaign to raise public awareness began in earnest in February 1996. What had been identified in the plan was who was at risk and at what stages action would be taken. The aim of the Taranaki Eruption (T.E.) campaign was to teach people about the potential hazard and what our response was going to be. In this way, individuals could plan their own responses.

In preparation, the following work had been carried out:

- Display material was made suitable for dynamic or static displays,
- a presentation was prepared, including a video from UNESCO 'Understanding Volcanic Hazards' (the descriptive language from the video was used in all promotional material, eg. mudflow)
- a UNESCO companion video 'Reducing Volcanic Risk' was also used
- bookmarks and brochures were designed and printed
- radio, newspaper and magazine advertising was developed
- screen vistas cinema advertising was prepared
- letters were sent to organisations, clubs and groups advertising our availability as guest speakers.

Given that it was a long-term project and that we only had four staff, the delivery was targeted in order of priority. Those residents most at risk were invited to hear our presentation first. As we moved on to the next zone, brochures were delivered to residents. The programme has never really stopped and even now we get asked to talk about what will happen when the volcano erupts.

Eruptions at Ruapehu certainly helped to highlight the possibility of an eruption in New Zealand. However these eruptions proved to be a double edged sword. On the one hand people could actually see the eruptions and some in Taranaki were affected by them. On the other hand what they saw was far from the destructive nature we might expect to see during a future eruption at Mount

Egmont/Taranaki. The real truth is that an eruption at Egmont Volcano, even of a magnitude similar to those at Ruapehu in 1995-96, will have real consequences to a much wider audience than Ruapehu had.

During the course of the T.E. campaign, staff had direct contact with some 5,324 people through presentations to community groups. A further estimated 2,634 people received information at dynamic trade show displays, A & P shows etc. Some 50,000 brochures were distributed along with 30,000 bookmarks.

Schools were also a significant target group. The development of a schools education kit and a 'teach the teachers' approach to volcanic hazards was adopted. Along with the schools education kit for volcanic hazards, teacher notes were prepared and Dr Brent Alloway (GNS) has conducted numerous field trips for teachers. This allowed teachers to learn about the hazard and also provided them with sites and information they could use for class trips. These field trips prove to be very popular and each time this has been run a bus full of teachers are treated to a view of Taranaki they will not soon forget.

More recently, the T.E. kit was enhanced by the introduction of a young teens novel. Well known local author David Hill was commissioned by the Taranaki Regional Council to write a story around an eruption at Egmont Volcano. 'The Sleeper Wakes' was provided to schools courtesy of the Council along with teacher notes to accompany each class set. The Sleeper Wakes was published by Puffin Books (ISBN 0 14 131324 2) and has received many accolades.

Even with an intensive campaign and eruptions at Ruapehu over two years, the next Taranaki survey only resulted in 58% of people recognizing Egmont Volcano as a hazard. Some even went out of their way to say 'not the mountain'! As professionals we may wonder are these people blind? What it proves is that not only do our plans need to be robust, but the public awareness material also needs to be robust for when it wakes up. I'm certain that an awakening volcano in the backyard will perk up their interest.

So what about living with a volcano? There have to be benefits. Is it the adventure playground on the back doorstep, with its steep rivers, bush clad and montane environment? Is it the pastures that make this a most productive dairy region? Or is it just the fact that we can wake up to spectacular views of a pristine mountain in wonderful pastoral New Zealand. We all have our reasons.

Dairy farms with the ever present Mt. Taranaki in the background. Photo: GNS Lloyd Homer.

NATIONAL CONTINGENCY PLAN FOR VOLCANIC ERUPTION

David Coetzee, Ministry of Civil Defence & Emergency Management

The National Contingency Plan for Volcanic Eruption is part of the National Civil Defence Plan (Annex B2 to Part 1). The Plan outlines a framework of actions to be taken by Government, local authorities and other agencies with civil defence emergency management (CDEM) 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.

VOLCANO ALERT LEVELS

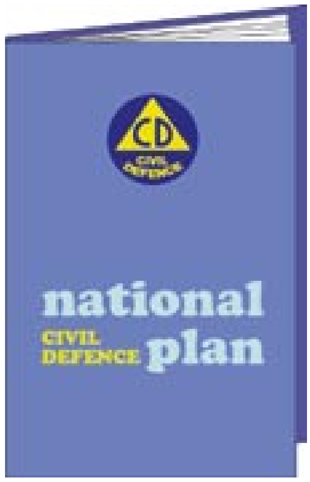
Ongoing volcano surveillance enables the background or normal status of a volcano or volcanic field to be determined. Variations and departures from monitored parameters may indicate a change of status and the onset of an eruptive episode. The status of a volcano at any time is defined by an assigned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

Volcano 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 '0' and the highest (large hazardous eruption) by '5'. The scale or size of an event will vary from volcano to volcano, ie. a Level '3' event at Ruapehu may be larger than a Level '3' at Ngauruhoe.

The Institute of Geological and Nuclear Sciences (GNS) is responsible for setting levels and issuing 'Science Alert Bulletins' to CDEM organisations and other agencies via its GeoNet Project whenever a status change occurs. GNS also advises the Ministry of Civil Defence & Emergency Management (MCDEM) when a Science Alert Bulletin is issued.

WARNINGS

Depending on the prevailing Volcano Alert level and the scientific advice received, where applicable, the Director of Civil Defence Emergency Management or the CEO/GM of a regional council will issue warnings. Warnings will be issued in accordance with the Civil Defence Warning System (Part 3 of the National Civil Defence Plan). The purpose is to alert the civil defence organisations at local levels and the general public to the possibility of a serious volcanic eruption. Specific preparatory and precautionary activity by regional councils, territorial authorities and other agencies will be undertaken according to their contingency plans.



MCDEM actions all Science Alert Bulletins received via GeoNet by duplicating them to the relevant regional and district civil defence offices to ensure that they are informed of the developments and status change.

RESPONSIBILITIES

The National Contingency Plan for Volcanic Eruption also identifies the responsibilities of the respective stakeholders in managing volcanic risk and emergencies. Responsibilities are defined in three distinct phases: pre-eruption, eruption and post-eruption.

- 'Pre-eruption' should be considered as including reduction and readiness.
- 'eruption' includes response to imminence of an event as well as ongoing activity.
- 'post-eruption' includes recovery and rehabilitation.

The Plan describes the responsibilities of respectively the Institute of Geological and Nuclear Sciences, local authorities, MCDEM, and other Government departments, organizations, state owned enterprises, and utility providers.

CENTRAL GOVERNMENT

It is anticipated that any large-scale rhyolitic event or lesser events impacting onto heavily populated urban areas would require policy direction by central government. MCDEM administers response and recovery issues at the national level, while under these scenarios it is likely that it will also advise the activation of the structures under the central government crisis management arrangements (Domestic and External

Security Coordination-DESC) to monitor whole of government response and provide strategic oversight. Under these scenarios Central Government involvement is expected to span across both response and recovery direction. Central Government involvement in response and recovery is addressed by the National Civil Defence Plan, Parts 1 & 2.

NEW NATIONAL CDEM PLAN

The existing National Civil Defence Plan will be replaced by a new National CDEM Plan by December 2005. The new Plan is currently under development. It is anticipated that the new National CDEM plan will maintain the essence of the National Contingency Plan for Volcanic Eruption. Whereas the existing contents can be regarded as focussing on general contingency guidance, the new Plan will be more functional but contain specific contingency plans.

To view current updates on the development of the new CDEM Plan visit www.civildefence.govt.nz.

NEW ZEALAND VOLCANO ALERT LEVELS

Frequently Active Cone Volcanoes			Reawakening Volcanoes	
White Island, Tongariro-Ngauruhoe, Ruapehu		VOLCANO ALERT LEVEL	Kermadecs, Northland, Auckland, Mayor Island, Rotorua, Okataina, Taupo, Egmont/Taranaki	
Volcano Status	**Indicative Phenomena**		**Indicative Phenomena**	**Volcano Status**
Usual dormant, or quiescent state	Typical background surface activity; seismicity, deformation and heat flow at low levels.	0	Typical background surface activity; deformation, seismicity, and heat flow at low levels.	Usual dormant, or quiescent state.
Signs of volcano unrest	Departure from typical background surface activity.	1	Apparent seismic, geodetic, thermal or other unrest indicators.	Initial signs of possible volcano unrest. No eruption threat.
Minor eruptive activity	Onset of eruptive activity, accompanied by changes to monitored indicators.	2	Increase in number or intensity of unrest indicators (seismicity, deformation, heat flow etc).	Confirmation of volcano unrest. Eruption threat.
Significant local eruption in progress	Increased vigour of ongoing activity and monitored indicators. Significant effects on volcano, possible effects beyond.	3	Minor steam eruptions. High increasing trends of unrest indicators, significant effects on volcano, possible beyond.	Minor eruptions commenced. Real possibility of hazardous eruptions.
Hazardous local eruption in progress	Significant change to ongoing activity and monitoring indicators. Effects beyond volcano.	4	Eruption of new magma. Sustained high levels of unrest indicators, significant effects beyond volcano.	Hazardous local eruption in progress. Large-scale eruption now possible.
Large hazardous eruption in progress	Destruction with major damage beyond volcano. Significant risk over wider areas.	5	Destruction with major damage beyond active volcano. Significant risk over wider areas.	Large hazardous volcanic eruption in progress.

UNDERSTANDING THE Volcanic Risk

Shane Cronin and Vince Neall
Institute of Natural Resources, Massey University

Ruapehu, Egmont/Taranaki and Tongariro are the three largest stratovolcanoes in New Zealand. They form such large mountains since they are built up by stacked layers (=strata) of solid lava and loose breccia. These volcanoes dominate the regions around them, governing the weather, the river and roading patterns, as well as the soils and the land use. When everyone in New Zealand witnessed the eruptions at Ruapehu in 1995 and 1996, it served as a reminder of the potential impacts these volcanoes can have on our 21st-century lifestyle. These impacts range from the need for jet aircraft to avoid clouds of volcanic ash, health effects on animals grazing ash-covered pastures, to uncontrollable and destructive muddy floods (lahars) that rush down surrounding river channels. Whilst it is easy to now appreciate these events at Ruapehu, it is harder to recognise that very similar events have dominated the recent volcanic past at Taranaki/Egmont and Tongariro volcanoes. For example, as recently as 1655 AD., pumice from an eruption at Mt Taranaki not only buried Maori umu (ovens) in Egmont National Park, but also showered pumice across the Stratford District. Accompanying this eruption, hot flows of pumice and rocks descended the northwestern and southwestern slopes of Mt. Taranaki to beyond the National Park boundary. This was not even the latest eruption of the volcano.

Our research at Massey University has been focused on understanding the details of the past volcanic history of these volcanoes. It comes as no surprise that this record of volcanic activity is far more detailed and complex than we ever envisaged when we began. For example, our results show that Taranaki/Egmont volcano has been actively spreading ash across the Taranaki region for over 130,000 years. The important positive spin-off of this activity is of course the premier soils of the region that the dairy industry takes advantage of today. Whilst there is no activity to be seen in the crater today, this does not mean that Mt. Taranaki/Egmont is extinct; it is only a matter of time before it will erupt once more.

Our research has led to information on what might happen in future eruptions from Ruapehu, Taranaki/Egmont and Tongariro volcanoes and how these effects might be mitigated. Some of these results are described in the civil defence information booklets produced by the Ministry of Civil Defence & Emergency Management for community-wide distribution by local authorities. Information from student and staff research supported by the Public Good Science Fund have resulted in a lahar hazards map for Ruapehu (Fig. 1; also available at http://soils/earth.massey.ac.nz), and a volcanic hazards map for Taranaki (Fig. 2). These are based on the mapping and dating of all the historic and prehistoric lahar and other mass-flow deposits at both volcanoes, and determining their frequency for a large number of sites.

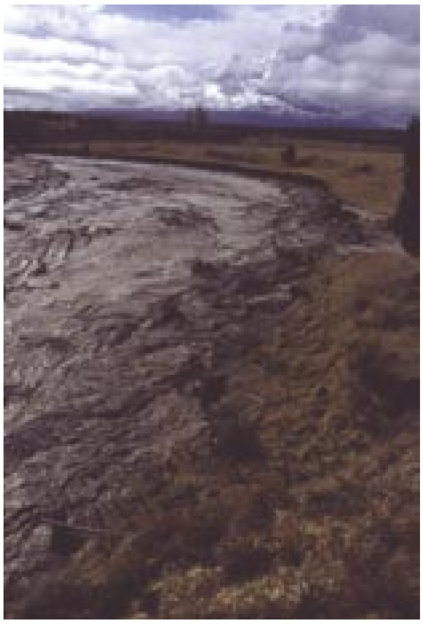
We want to find out why our volcanoes behave in this seemingly irregular fashion. If we can understand these eruption drivers, perhaps we can also develop tests that could be used on ejecta at the beginning of eruptions to give rapid forecasts of what might happen next.

NEW SIX-YEAR RESEARCH PHASE

The Massey-based research team are about to begin a new six-year phase of research into the risks of our mountain volcanoes, funded by the Foundation for Research Science and Technology. This work will involve a number of different ways of improving our understanding of the volcanic risk posed by the main andesitic mountain-building volcanoes.

By looking closely at the record of the last 1000-2000 years of eruptions at Ruapehu, Egmont/Taranaki and Tongariro, we have the best chance to find out the detailed factors controlling the rise and eruption of magmas at andesite volcanoes. Over this geologically brief time-range, a wide range of different events with strong differences in explosivity and hazard potential occurred. We want to find out why our volcanoes behave in this seemingly irregular fashion. The answers will be found by examining the physical and chemical properties of the deposits from these recent eruptions with a range of microscopic and analytical techniques. For this research we will work with research colleagues at the Universities of Auckland and Waikato in New Zealand and the University of Oregon in the United States. If we can understand these eruption drivers, perhaps we can also develop tests that could be used on ejecta at the beginning of eruptions to give rapid forecasts of what might happen next.

Towering over the Grand Chateau on 18 June 1996 is one of the smaller ash plumes produced during the 1995-96 activity of Ruapehu. This eruptive episode, which lasted nearly 18 months spread volcanic ash over much of the central North Island, reaching as far as Auckland at times.



Lahar flowing at Tangiwai on 25 September 1995, during a day of lahars formed by the explosive emptying of water from Ruapehu's Crater Lake. At this time, the lahar contained about 40% by volume sediment!

We know already that the geology of our mountain volcanoes and their surrounds are dominated by the deposits of mass flows, including muddy flood-like "lahars", large landslides of entire mountain flanks in "debris avalanches" and rapidly moving clouds of superheated gas and particles called "pyroclastic flows". All of these flow types have the potential to travel great distances from a volcano within minutes or hours. Their high speeds and intense destructive power make them the most hazardous to life of all volcanic processes. We want to find out how these flows are generated, how far and how fast will they travel if they happened tomorrow and where would they flow? The answers to these questions will be found by collecting new information on the characteristics of past mass-flow deposits and integrating these data into novel methods of numerical (computer-driven) simulations and models. By collaborating with researchers at the University of Buffalo in the United States, we can apply sophisticated computer modelling of different types of flows over so-called "digital elevation models" of the present day terrain. In this way our next generation of hazard maps will have more of a "forecasting" approach. Coupled with the computer modelling, we will also work with colleagues at the University of Kiel (Germany) to use laboratory-scale experiments for understanding more about the physics

The Taranaki region with its rich farmlands and oil fields, including the region's capital of New Plymouth, has a landscape shaped and dominated by the Taranaki Volcanic Succession (in background from right, Kaitake, Pouakai and Taranaki/Egmont).

of hot mass flows at volcanoes. By choosing initially "simple" example events, such as the 1975 eruptions of Ngauruhoe, we can work toward defining the conditions under which hot gaseous "pyroclastic flows" move and how far they can travel before running out of energy.

One of the current issues relating to mass-flow that is currently of great interest to the community, is the possibility of a lahar being created when Ruapehu's refilling Crater Lake first begins to overflow. Our studies have established the history of Crater Lake and the 14 major lahars derived from it in the last 2000 years. In a recently published article in the Natural Hazards journal, we have been able to identify that major spilling of lake waters occurred on seven occasions, and complete breakout of the entire Crater Lake on two or three occasions. In one of these events between 350-600 years ago, the lahar spilled across the Whangaehu fan into the Upper Waikato Stream and thence into the Tongariro River. Two of the events had volumes > 40 million m^3, which is roughly 10 to 20 times larger than the fatal 1953 Tangiwai lahar! Extending from this research, we will examine the issue of sediment-rich lahar formation from Crater Lake floods, and develop new methods of creating 2D simulations of possible scenarios for the estimation of its potential impacts.

PROBABALISTIC MODELS

As well as trying to forecast the physical impacts of a range of eruption scenarios we also need accurate information on how frequently our volcanoes erupt, or more particularly how frequent particular types and magnitudes of eruptions are likely to occur in the future. The key to this will be improving our understanding of the entire geologic record of the past. Studies to

Crater Lake at Ruapehu viewed from its north side in February 2004. The lake is nearing its pre-1995 eruption levels as the 2004 winter begins and in future years will rise even further behind a barrier of loose debris that covers the outlet area. Photo: Tanya O'Neill.

date have focused only on the easily recognisable and datable large-scale events at each volcano. We know that these events represent just the "tip of the iceberg" of volcanic history; the hidden record of minor eruptions is probably the greatest unknown factor in volcanic studies in New Zealand. For instance, the eruption of 1995/96 at Ruapehu caused over $130 million in damage, but was only just a minor "blip" in the geological record and easily overlooked. Filling in the blanks of our geologic records will allow the application of statistical eruption models that have been developed on other volcanoes around the world, such as in Fiji, to derive new probabilistic forecasts of the likelihood of volcanic activity of various types in years to come. These probabilistic models will be developed for each volcano, not only for forecasting the chances of eruption onset over any given time-frame, but also for estimating the chances of any particular area being affected by volcanism in future years.

As well as filling in gaps in our knowledge of recent events at Taranaki/Egmont, Ruapehu and Tongariro volcanoes, we also want to know how these volcanoes began "life" and how they have developed since then. For example the present visible mountain of Taranaki is only around 10,000 years old, although volcanism at this location has been going on for at least 130,000 years. Hence, we know very little about this volcano for up to 90% of its lifetime. At what stage of life is it now, adolescent, mature, or geriatric? These distinctions are more than trivial, we want to know if our volcanoes are in a process of decline, or major growth, or if they go through long-term cycles of both throughout their lifespan. Hence, investigating long-term changes at these volcanoes will help us predict

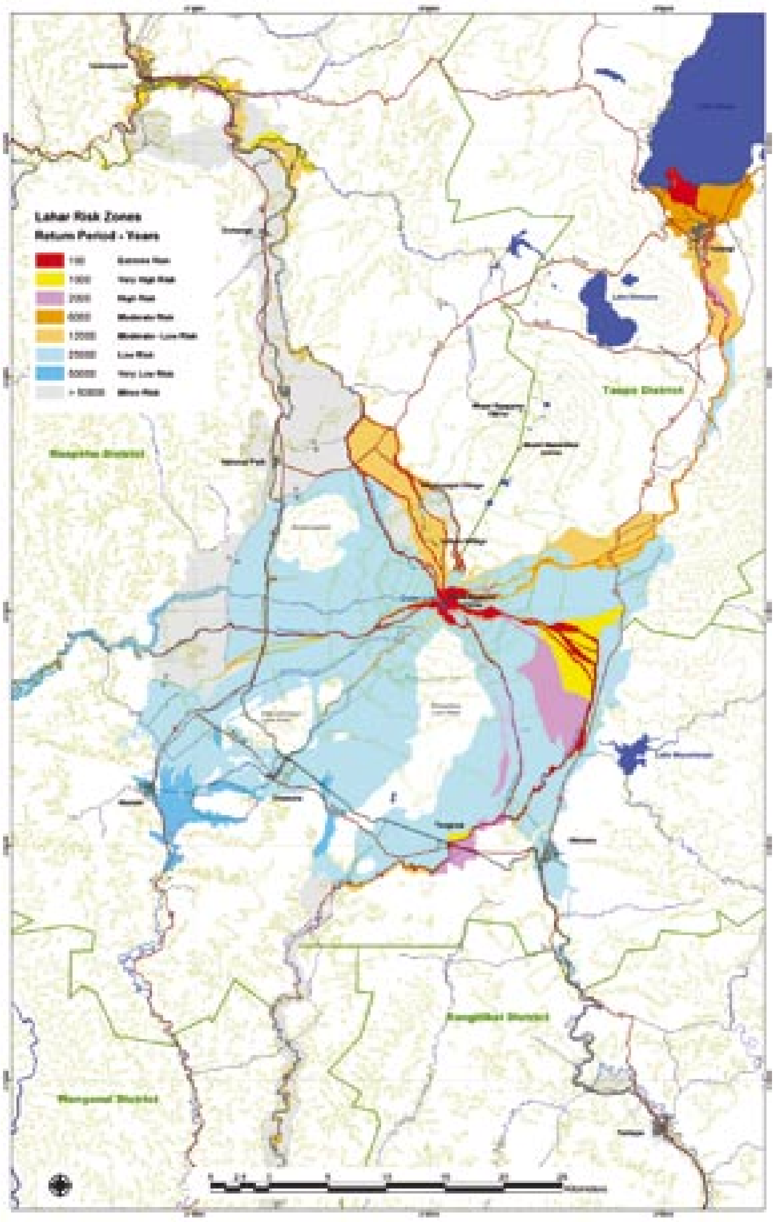


Fig 1: Lahar hazard map for Ruapehu and its surrounds, based on mapping and dating deposits of lahars around the volcano.

what they are capable of. Deposits in coastal exposures in North and South Taranaki and river valleys in the central and southern North Island will hold the keys for us to build an understanding of the long term life-cycles of our mountain volcanoes. Related to this long-term history will be determining the role of climate change in modifying volcanic processes. For example, eruptions on the ice and snow-covered volcanoes during colder "ice-age" times in the geologic past will have led to different types of eruption processes to those of today.

ANALYSING THE RISK

On the other side of the coin – where is this new geological research leading us? How will it help us live and prosper in the shadow of volcanic hazard? The Civil

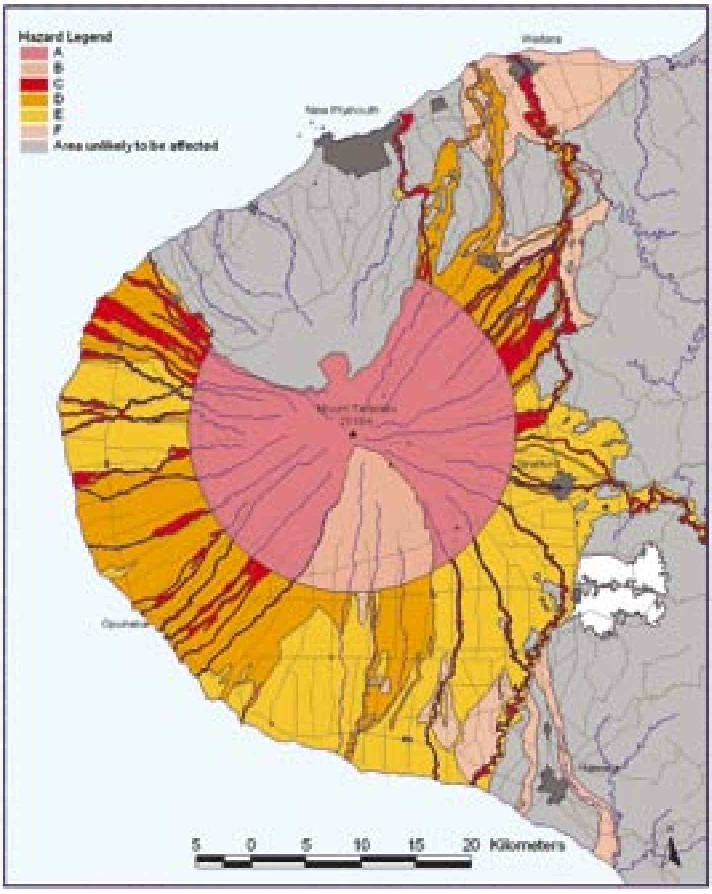


Fig 2: Volcanic hazards map (excluding ashfall) for Taranaki/Egmont and surrounds, based on research into the distribution and age of volcanic deposits on and around the volcano. Zones represent different relative degrees of hazard, with A B and C facing the greatest threat.

Defence Emergency Management Act of 2002 calls for "reducing the risks from hazards through application of risk management". The risk management process begins with an analysis of risk – that is the combination of hazard, vulnerability or susceptibility to it, and the value of what is threatened. Where do we start with this for volcanic hazards? How can we compare such events, which are so rare, unpredictable and unknown with the regular hazards facing our lives such as floods and storms? The planned research at Massey will work toward answering these questions. The geological-based research described above will reduce the unknown factors about the nature of the hazard and its occurrence. By using probabilistic methods, we can reduce volcanic hazards on a temporal or spatial basis to a common numerical denominator similar to that used for floods (think of the 1 in 100 year flood concept). This numerical forecast will be the quantitative basis for carrying out new research into socio-economic vulnerability and potential impacts.

Understanding the socio-economic risks associated with future activity at our mountain volcanoes is more than just investigating direct economic loss/damage scenarios for a range of volcanic events at each volcano, although this will be where we start from. Extending this research will involve us examining the socio-economic impacts of business disruption – which will begin at the first hint of activity in areas such as Taranaki. What are the longer-term impacts likely to be? In some cases, eruptions at our mountain volcanoes may last for years. A good comparison are the eruptions of Unzen in Japan that lasted more than five years and that of Montserrat in the Carribean, which is still going strong since 1995! The style of activity at these two volcanoes is, by the way, identical to what has happened at Taranaki/Egmont on at least six occasions over the last 1000 years. A further aspect of socio-economic risk research will be investigating the extra-regional impact of eruptions at any of our mountain volcanoes. Imagine for instance an eruption beginning at Taranaki/Egmont. National impacts of this could begin with the cut-off of natural gas supply to the nation. The Manawatu floods of February 2004 caused the breakage of a single gas pipeline to the East Coast. This forced the closure of factories in areas completely unaffected by the flood hazard itself. For volcanic activity there are a similar host of potential impacts well outside the region normally considered at risk. This not only applies to the energy, agriculture and tourism industries, but also for the air-transport sector.

Being able to quantify socio-economic risk as a result of our research will increase the capability of industry, local authority, community, iwi and individuals to judge volcanic risk objectively amongst a "portfolio" of risk types faced. This quantification will also allow sensible economic decisions to be made on the appropriate level of investment that should go into preparing for and preventing volcanic hazard impacts to a group, organisation or community. Being able to justify and plan expenditure at a level commensurate with the risk, will help maintain profitability and sustainability of our enterprises and communities.

On another front, new scientific advances will be used to develop accurate and appropriate eruption scenarios and emergency management simulation tools for authorities and communities to use in planning their emergency response and recovery efforts. Geospatial databases and new hazard models will be used in conjunction with Geographic Information Systems (GIS) databases of infrastructure, lifelines, people and resources to develop not only appropriate emergency-management planning and training tools, but potentially also important decision support tools to be used in the readiness, response and recovery phases of actual volcanic emergencies.

It is not enough for industry and local authorities to take responsibility for volcanic risk management;

it is also the responsibility of all communities to build their own capacity for resilience. To do this, large and small communities, as well as iwi groups need to know and fully understand the degree of volcanic risk they face, particularly in relation to other natural or other threats that may exist. Part of the planned Massey research will go into building relationships and rapport with communities and iwi surrounding volcanic areas. These bonds will lead to a basis for choosing appropriate language, strategies, format and delivery style for communicating our scientific results. However, the research will not end there; participatory activities will be used to extend the new understanding of volcanic hazards into methods for evaluating socio-economic risk exposure and designing strategies for implementing appropriate risk management in partnership with communities and iwi.

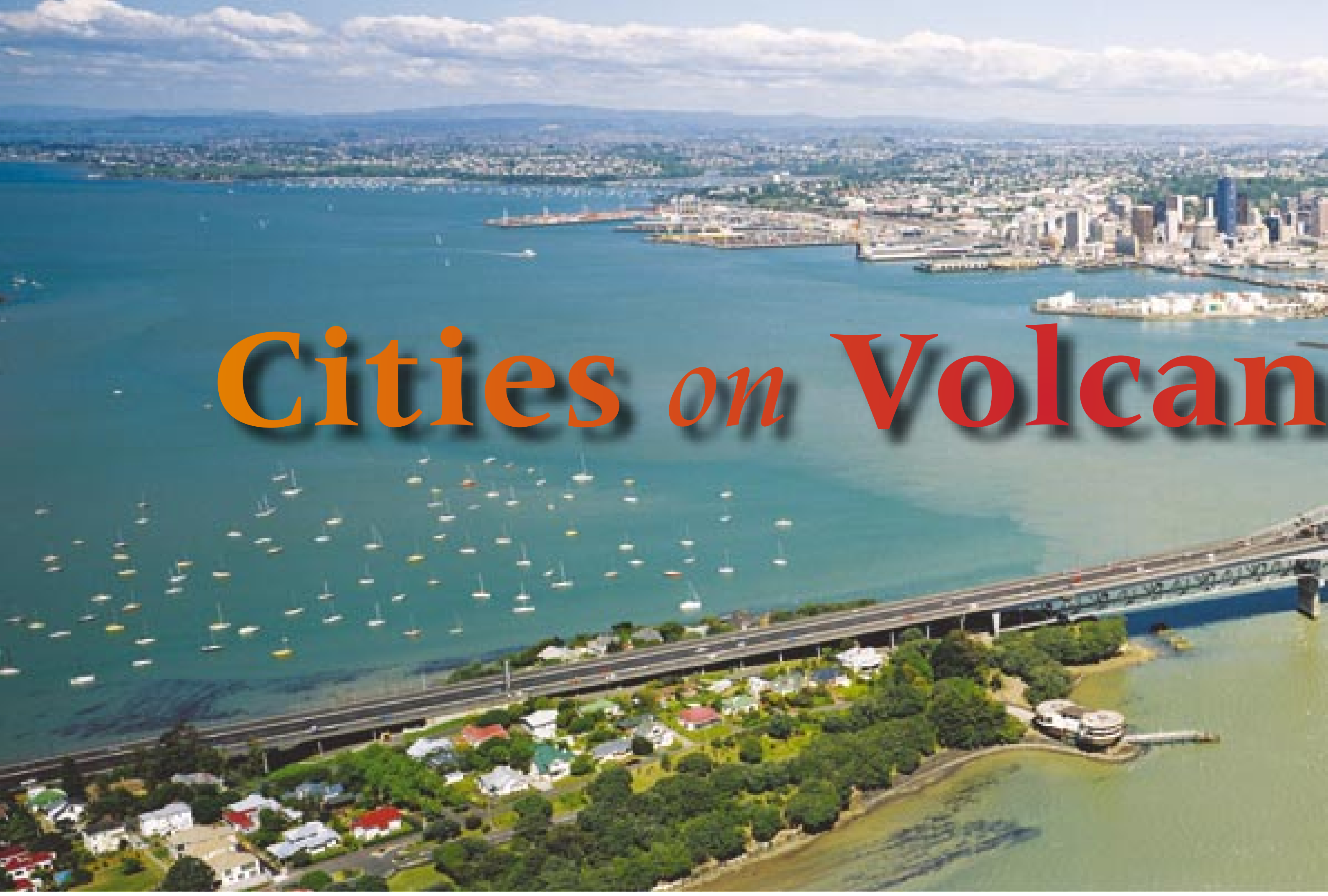
The 1995/96 eruptions of Ruapehu were the last timely reminder of the hazards posed by our mountain volcanoes and focused us on the need for applied volcanological research, that combines new science with socio-economic studies in order to help us build resilient communities in New Zealand.

FURTHER READING

Neall, V.E. 2003. The Volcanic History of Taranaki. Institute of Natural Resources – Massey University, Soil & Earth Sciences Occasional Publication No. 2.

Lecointre, J., Hodgson, K., Neall, V. and Cronin, S. 2004. Lahar-triggering mechanisms and hazard at Ruapehu Volcano, New Zealand. Natural Hazards 31: 85 – 109.

These hills that dominate the western Taranaki landscape represent the deposits of huge landslide-like events called debris avalanches, which occurred when entire sides of the pre-existing Mt. Taranaki collapsed. Each hill or mound can be made up of one or more enormous chunks of mountainside, often with original layering still intact.



Preparing for an eruption from the Auckland Volcanic Field

Louise Chick, formerly Auckland Regional Council; Ann Williams, Amelia Linzey, Kate Williams, Beca Carter Hollings & Ferner Ltd.

Auckland is built on the potentially active Auckland Volcanic Field. Fifty eruptive vents have been identified in this monogenetic field which canvasses an area of 360 square kilometres within which some 530,000 people live. An eruption from this field has the potential to affect the majority of the region's 1.3 million population.

The Auckland Regional Council has developed a contingency plan to provide for coordinated management of response and restoration operations. Although the area of devastation from an Auckland Volcanic Field eruption is expected to be limited to within a 5 km radius of the vent, planning response to such an event is complicated by the following issues:

- the next eruption could occur at any time in the future
- future eruptions will result in the formation of a new volcano or volcanoes at a new location/s
- the warning period is likely to be short (due to low viscosity basaltic magma estimated to rise at speeds of around 5 km/hr)
- the nature of the hazards will depend on the availability of water at the site of eruption (Auckland lies between two coasts)
- potentially widespread disruption of lifeline utilities as a result of ash inundation.

This article outlines how the 'Contingency Plan for the Auckland Volcanic Field' and other preparedness measures provide a framework to manage these unique circumstances, and minimise the risk to Auckland communities.

THE AUCKLAND VOLCANIC FIELD

The earliest eruptions of the monogenetic Auckland Volcanic Field (AVF) are estimated to have occurred 150,000 years ago. Since this time, another 49 basaltic volcanoes have been created. During the last 20,000 years eruptions have been more frequent with events occurring, on average, once every 1000 years. Therefore there is a 5% probability of an eruption from the AVF within the next 50 years. The most recent and largest eruption occurred approximately 750 years ago. It created Rangitoto Island, a volcano that erupted approximately 1/3 of the total magma extruded from the Auckland Volcanic Field.

There are no written or scientific records of an eruption from the Auckland Volcanic Field, and therefore limited knowledge of the length of warning that eruption precursors (eg. volcanic earthquakes) will give. Geological evidence indicates that volcanic activity will give rise to a number of hazards which will have minor to severe impacts both in terms of damage and geographic extent.

VOLCANIC HAZARDS

The areal extent of the AVF Volcanic hazards, described in Table 1, may be greater should there be more than one eruption vent active at a time. Vents in a multi-vent episode are expected to develop within a few kilometres of one another.

The highly developed nature of metropolitan Auckland, and the reliance of its residents on continuance of infrastructural services, makes this city vulnerable to eruptive events.

A number of preparedness measures have been established to reduce the risk to Auckland communities from an Auckland Volcanic Field Eruption.

READINESS MECHANISMS

Preparedness mechanisms established to minimise risk from an AVF eruption include:

- **Seismic Monitoring:** Monitoring of the Auckland Volcanic Field using a network of permanent seismometers.
- **Volcanic Contingency Plan:** Establishes a framework to enable a coordinated civil defence emergency management response and identifies roles, responsibilities and actions for organisations that will contribute to response to, and recovery from, an eruption.

Auckland, with the Auckland Harbour Bridge in the foreground is home to about 1.3 million people. Photo: GNS Lloyd Homer.

- **Lifeline utility preparedness:** Auckland lifeline utility operators are undertaking coordinated volcanic impacts research, and response and recovery planning.

AUCKLAND VOLCANO-SEISMIC MONITORING NETWORK

The Auckland Volcano-Seismic Monitoring Network (AVSN) comprises five sites geographically distributed around the Auckland Volcanic Field (AVF), at which seismic activity is continuously monitored (Fig 1). The data is collected and radioed to a central recording site at the Auckland Regional Council, where it is digitally recorded and then transmitted to the Institute of Geological and Nuclear Sciences at Wairakei and Wellington.

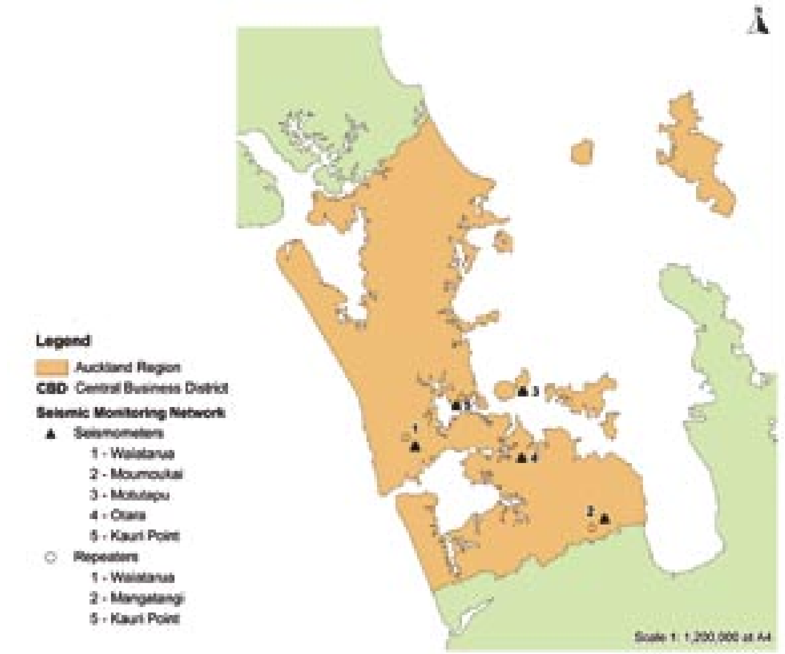


Fig 1: Auckland Volcano-Seismic Monitoring Network.

The incoming data is monitored in near real time 24 hours a day, 7 days a week by specialised computer software. Should any change in the prevailing seismic pattern be detected, a 24 hour duty officer is automatically paged who can provide warning of an impending volcanic eruption within a short time of the initial precursory seismicity (potentially within 1 hour).

Should volcanic activity be detected, additional seismometers would be deployed adjacent to the suspected vent location. To identify locations that have low day to day environmental ground movements that could potentially mask volcanic seismicity, a portable seismometer is annually deployed for a day or two at a variety of sites throughout the AVF.

VOLCANIC CONTINGENCY PLAN

The Contingency Plan for the Auckland Volcanic Field helps to establish coordinated response and restoration operations by:

1. Establishing protocols for the timely and efficient warning of volcanic activity.

Hazard	Areal extent	Anticipated Loss	Recovery period following cessation of activity
Earthquake	Ground shaking, uplift and deformation affect an area of up to 3 to 5km².	Small	Not applicable
Crater, Cone or Ring Formation	Crater of up to 1.5km diameter produced with anticipated maar stretching a 300-500m radius. Formation of steep sided scoria cones of up to 1 km across.	Extreme	Several months to years
Fire Fountaining	Significant effects 200-500m from vent.	Extreme	1 week to several months
Lava	AVF lavas have travelled 0.5-9.5km from vent.	High	Several weeks to several months
Base Surge	Surges flow out to 5km from vent. Near vent deposits likely to be greater than 0.2m thick.	Extreme	1 week to several months
Shock Waves	Affect areas 3-5km from vent.	High	1 week to several months
Lava bombs	Most bombs deposited within 0.4km of vent, but may extend to 1 to 2km.	Moderate	1 week to several months
Airfall Tephra	Ash plume may rise 6-15km resulting in deposition of tephra up to 100km from vent.	Low	1 week to several months
Gas	Asphyxiating gases CO, CO_2, and HF are likely to be localised around vent (up to 3-5km), and concentrated in low-lying areas. Acid rain up to 10km from vent.	Moderate	Not applicable
Lightning	Immediate area of eruption column and plume and up to 10km downwind of the vent.	Low	Up to 1-2 days
Tsunami	Affect low lying coastal areas within 1km of the disturbance.	Low	Up to 1-2 days

Table 1: Anticipated hazards associated with Auckland Volcanic Field eruptions.

2. Allowing for immediate communication and public information activities.
3. Specifying roles and responsibilities of responding organisations.
4. Ensuring that declarations are made as necessary and that the process of declaration is transparent for those involved in civil defence emergency management
5. Providing guidance on appropriate dissemination of information for the management of the civil defence emergency
6. Appropriate prioritisation and allocation of regional resources.

In the Auckland context, managing the provision of warning is made more difficult as the eruption will occur in an as yet new unknown location, and warning periods are likely to be short. Consequently, a unique system to help manage these circumstances has been developed as part of the Contingency Plan for the Auckland Volcanic Field (VCP). This system utilises:

- Scientific Alert Levels (Scott, 2001) defining the status of a reawakening volcano at any time (Table 2)
- Warning Phases (Figure 2)
- Hazard Zone Overlay (Figure 3)

VOLCANIC WARNINGS IN THE AUCKLAND VOLCANIC FIELD

Precursory seismicity will be detected by the Auckland Volcano-Seismic Monitoring Network. As volcanic type activity escalates, Scientific Alert Levels and Warning Phases are issued.

Auckland Volcanic Field - Relative age and volcano distribution.

Scientific Alert Level	Indicative Phenomena	Volcano Status	Warning Phase	*Period
0	Typical background surface activity; deformation, seismicity, and heath flow at low levels.	Usual dormant or quiescent state.	Advisory Phase	Not applicable.
1	Apparent seismic, geodetic, thermal or other unrest indicators.	Initial signs of possible volcano unrest. No eruption threat.	Alert/Warning Phase I or II	A few days and up to a few weeks.
2	Increase in number or intensity of unrest indicators (seismicity, deformation, heat flow etc).	Confirmation of volcano unrest. Eruption threat.	Warning Phase II	Up to 1 to 3 days
3	Minor steam eruptions. High increasing trends of unrest indicators, significant effects on volcano, possible beyond.	Minor eruptions commenced. Real possibility of hazardous eruptions.	Warning Phase III	A few hours to 1 day
4	Eruption of new magma. Sustained high levels of unrest indicators, significant effects beyond volcano.	Hazardous local eruption in progress. Large-scale eruption now possible.	Warning Phase IV	Up to a few hours
5	Destruction with major damage beyond active volcano. Significant risk over wider areas.	Large hazardous volcanic eruption in progress.	Warning Phase IV	Not applicable

*Warning periods assessed for the Auckland Volcanic Field. Periods have been assigned to Scientific Alert Levels (SALs) as a tool for planning purposes only. The SAL may rise to 1 and then return to 0 and is not intended to be a predictive tool.

NOTE: The periods indicated in the table do not reflect either the minimum or maximum duration of each level, but provide an indication of a realistic lower bound time period between warning levels. These periods are an indication of the mobilisation or resourcing time that can be anticipated.

Table 2: Scientific Alert Levels and Warning Phases used for the Contingency Plan for the Auckland Volcanic Field.

WARNING PHASES

Because volcanic activity in the AVF is likely to develop over a relatively short time, 'Warning Phases' have been identified (refer Column 4 of Table 2) and are linked to Scientific Alert Levels. Declaration of each 'Warning Phase' will initiate a series of actions required by responding agencies. These are described in Figure 2.

HAZARD ZONE OVERLAY

The Contingency Plan for the Auckland Volcanic Field contains a transparency (Hazard Zone Overlay) which relates volcanic hazards to distance. This allows an initial hazard assessment to be undertaken for planning purposes once an area of atypical seismicity is identified (Figure 3). The need for an initial hazard assessment tool is created because future sites of volcanic eruption cannot be predicted.

The Hazard Zone Overlay assumes a uniform distribution of hazard zones identified for a scenario eruption (eruptive mass 0.01 km^3 and a column height of 6km), and will be replaced with scientific updates providing more accurate information on the likely impact area, and associated risks, once this information is available.

WHEN SHOULD A STATE OF LOCAL EMERGENCY BE DECLARED?

For the purposes of responding to a local volcanic eruption, it is generally considered that the recommendation to declare a state of local emergency will coincide with Warning Phase II. However, the VCP specifies a number of circumstances that may trigger a declaration:

- Alert Phase notification issued.
- Hazard Zone Overlay (HZO) (or more advanced risk assessment) indicates urban or strategic area may lie within, or be located within 2km of Hazard Zone 1 (ie. within 5 km of the inferred eruption centre)
- Consultation with Scientific Advisory Group and senior staff (including emergency services staff) identifies potential risk to life and functioning and operation of government is significant, and that evacuation is likely to be necessary.

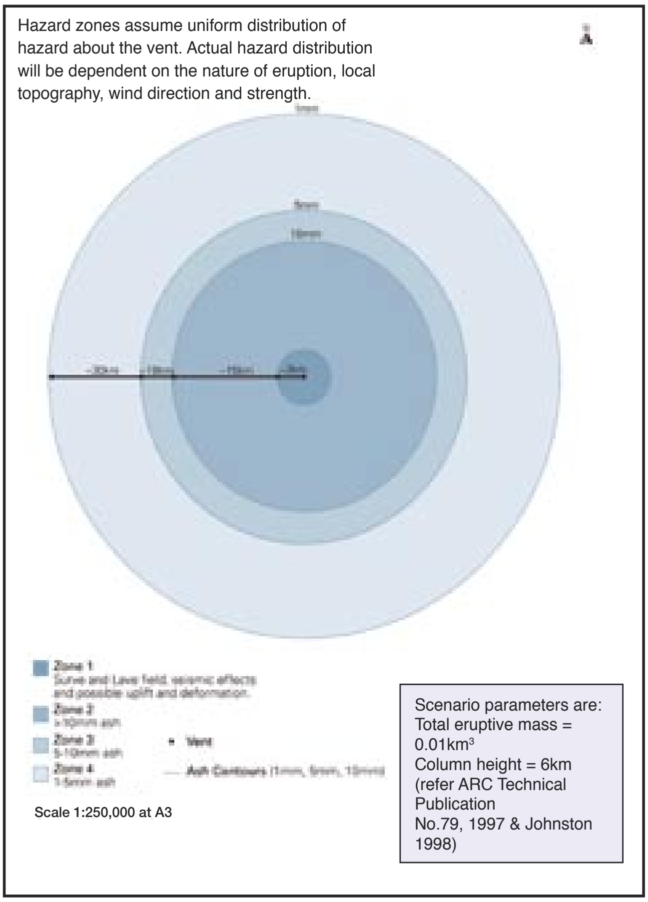


Fig 3: Hazard Zone Overlay (HZO).

Mt. Wellington is the second youngest volcano in the Auckland Volcanic Field, erupting about 9000 years ago. Photo: GNS Lloyd Homer.

AUCKLAND ENGINEERING LIFELINES PREPAREDNESS

A number of lifeline utility operators in Auckland have joined together to form the Auckland Engineering Lifelines Group. The purpose of this group is "to identify measures and coordinate efforts to reduce the vulnerability of Auckland's lifelines to hazard events and to improve service reinstatement after a disaster, so that the community is better able to recover."

This group has undertaken the following:

- **Volcanic hazard assessment:** Identified components of lifeline networks that are vulnerable to volcanic activity, and estimated impacts and likely recovery times (Auckland Regional Council, 1999; Auckland Regional Council, 1997).
- **Volcanic research:** Observed and reported upon the ongoing Sakurajima eruptions with the intent of learning from other lifeline utilities how the impacts of volcanic ash are managed (Durand, 2001); Have commissioned research which specifically investigates the impact of volcanic ash upon lifeline utilities (Auckland Regional Council, 2001b).
- **Coordinated response plans –** "Priority Emergency Routes Project": Undertaken hazard assessment on major roads throughout Auckland metropolitan area and identified roads least susceptible to hazard damage (except where impact area cannot be predicted). Roads of least vulnerability that provide access to critical facilities such as hospitals have been classified as 'priority routes' which will be cleared or rebuilt first. The location of priority routes has been widely disseminated to emergency agencies and utilities in Auckland (Auckland Regional Council, 2001a).

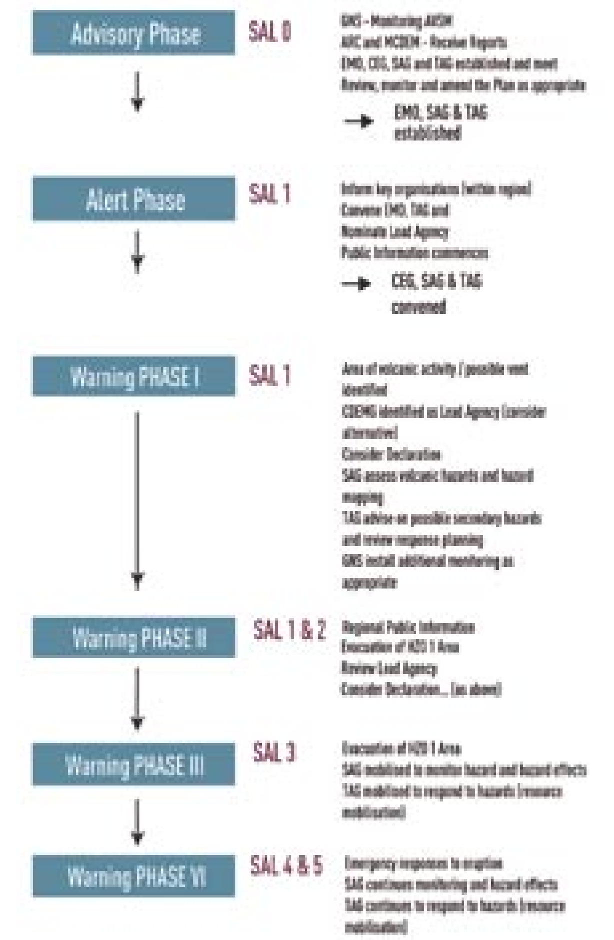


Fig 2: Warning systems for the Auckland Volcanic Field (AVF). AVSN (Auckland Volcano-Seismic Monitoring Network); CDEMG (Civil Defence Emergency Management Group; Coalition of local authority elected representatives); CEG (Coordinating Executive Group; Provides advice to the CDEMG); EMO (Emergency Management Office; Provides administrative support to the CDEMG); GNS (Institute of Geological and Nuclear Sciences; national scientific body responsible for monitoring geological hazards); SAG (Scientific Advisory Group); TAG (Technical Advisory Group).

CONCLUSION

As the location of the next Auckland Volcanic Field eruption is currently unknown, planning for this event poses a unique problem. Auckland local authorities, emergency services, and lifeline utilities have put in place a number of preparedness measures; includng a volcano-seismic monitoring network, a volcanic contingency plan, and a number of research reports and plans that will aid lifeline utility response and recovery.

These preparedness measures are intended to minimise the impact of volcanic hazards on Auckland and its inhabitants, by enhancing response to, and recovery from, an Auckland Volcanic Field eruption.

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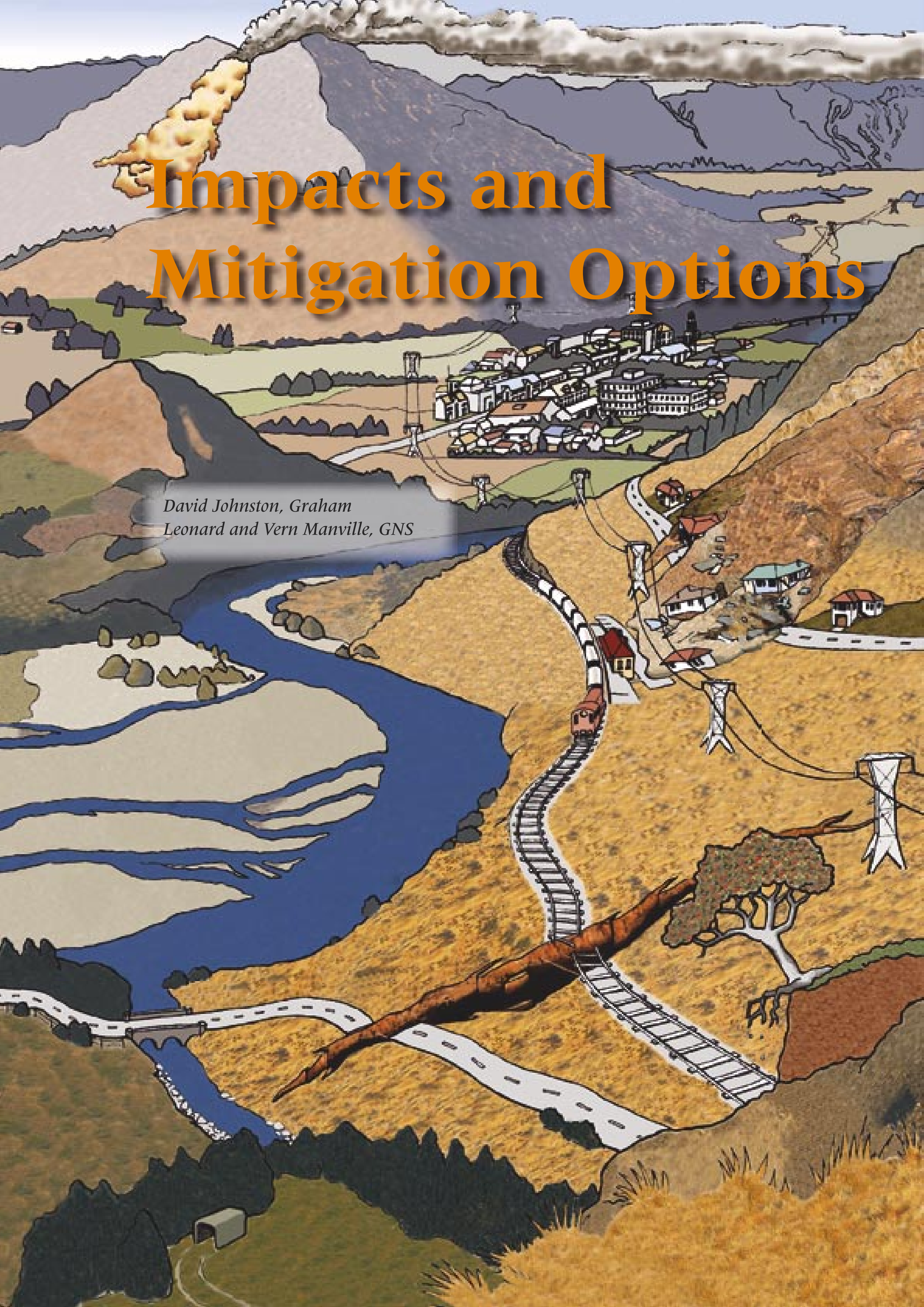
Impacts and Mitigation Options

David Johnston, Graham Leonard and Vern Manville, GNS



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

NEAR-VENT DESTRUCTIVE HAZARDS

ASHFALLS

Large ballistic projectiles rarely land more than 1-2 kilometres from a vent in either a brittle or molten state and are capable of starting fires. The impact of these will cause damage to buildings (including ignition), with the degree of damage dependent on mass, temperature and velocity. Projectiles present a high risk of death or injury to people. In the 1973 eruption of Heimaey (Iceland) incandescent clasts from 0.1 to 2 m in size caused many house fires.

Finer material forms ashfall deposits that, when thick enough, are capable of overloading roof strength causing collapse and possible death or injury to people inside. Since building collapse usually requires ash thicknesses in excess of 100-300 mm, the 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.

A survey of building damage following the 1991 Pinatubo eruption in the Philippines concluded that roofs failed because the ash load was greater than the vertical load-carrying capacity of their supporting structure. Wide-span roofed buildings suffered more damage than short-span domestic scale construction. Pitch angle is also critical to the vulnerability to roof collapse. Ash can obviously slide off steeply pitched roofs. Even moderate pitches can be less susceptible to collapse than flat ones. This has been observed in many instances from ash-affected communities around the world.

PYROCLASTIC DENSITY CURRENTS

Pyroclastic density currents (flows, blasts, and surges) often travel at speeds up to 900 km/h, and cause total destruction in the areas they cover. Flows are more concentrated than blasts and surges and partly follow valleys in the landscape. Pyroclastic density currents are usually very hot (at least several hundred °C) and can start fires. Pyroclastic surges from hydrothermal and phreatomagmatic eruptions are cooler (usually less than 300ºC) because of the interaction with water 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 caught in the direct path of a pyroclastic density current are most unlikely to survive and any survivors will probably receive severe injuries. Buildings offer some protection near the slower-moving edge 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.

LAHARS

People 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, equipment, infrastructure and vegetation caught in their path. Depending on their densities and flow velocities, lahars may either destroy structures, or simply bury them in place. People have survived lahars by climbing onto the roofs of houses which have remained intact despite inundation by the lahar.

LAVA

The distance lava travels depends on the viscosity of the lava, output rates, duration of eruption, volume erupted, steepness of the slope, topography and obstructions in the flow path. Basalt (eg. Auckland) 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 (eg. Ruapehu) are more viscous and rarely travel more than 5 km and may be quite "blocky". Dacite and rhyolite lavas (eg. Taupo) have high viscosity and typically form short, thick flows or domes.

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 cause total destruction of buildings and other infrastructure in their path. Land use possibilities will be significantly altered on a new lava flow.

SECTOR COLLAPSES AND DEBRIS AVALANCHES

Debris avalanches are one of the most hazardous volcanic events. Debris avalanches can travel many kilometres from the summit area. Debris avalanches do 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. They may be triggered by magma bulging the flanks of a cone (eg Mount St Helens, exposing the magma and leading to a blast) or by other causes of slope instability.

VOLCANIC GASES

Emission of gases from volcanoes can be harmful close to a volcano (within about 10 km). Acids, ammonia, and other compounds in volcanic gases can affect human and animal eyes and respiration. The same compounds can cause corrosion of metals and other materials. Heavier-than-air gases such as carbon dioxide can collect in depressions and suffocate people and animals. Concentrations of gases will dilute rapidly away from a volcano and pose little threat to communities more than a few kilometres from the active vent.

DISTANT HAZARDS

ASHFALL 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. These tiny particles commonly have sharp broken edges making volcanic ash a very abrasive material. Freshly fallen ash grains commonly have surface coatings of soluble components (salts) and/or moisture. It is these components that make ash mildly corrosive and potentially conductive. These soluble coatings are derived from the interactions in an eruption column between ash particles and fine mist (aerosols) which may be composed of sulphuric and hydrochloric acid droplets with absorbed salts. This process is most active close to a volcano (ie. within 50 km), although the amount of available aerosols varies greatly, even between eruptions of similar volumes.

IMPACT ON PUBLIC HEALTH

Ashfalls will not initially result in fatalities unless the fall is extremely thick. Falling ash itself is not toxic but will act as an irritant affecting eyes and throats. Respiratory problems result from the inhalation of fine ash and are more acute in patients with existing respiratory disorders. Eye problems include foreign material in eyes, corneal abrasion and conjunctivitis. Minor skin irritations (ash rash) may affect people exposed to ash over a period of time. The possibility of contracting chronic bronchitis (or silicosis from some ash compositions) exists from breathing in an ash-laden atmosphere. Medical literature reports that following initial concern after the Mt St Helens eruption, only those with long exposures to high concentrations of respiratory ash were at any risk from developing chronic medical complaints. Providing and wearing dust masks can heavily reduce a lot of respiratory impacts.

Removing volcanic ash from roofs of buildings at the Whakapapa skifield during the 1996 eruptions.

IMPACT ON BUILDINGS AND BUILDING SERVICES

Light to moderate ashfalls will cause less building damage than falls greater than 100 mm thick. These include soiling interiors, interrupting services (electrical and mechanical) and damage to exterior materials. These effects depend upon the thickness of ash, its mass and chemical reactivity, the building's roof shape, construction and orientation, and the spacing of other buildings nearby.

Damage to exterior materials

The soluble components in volcanic ash can lead to premature ageing and weakening of cladding. The 1995-1996 Ruapehu eruptions deposited a few millimetres of ash on several North Island towns causing minor damage to a small number of roofs. This resulted from a reaction between the ash's acidic coating and galvanised steel and/or paint. Acrylic paint applied within the previous 3-6 months was found to be particularly susceptible to corrosion by this ash.

Soiling interiors

Ash can enter a building by a number of routes ranging from open doors and windows to small gaps between roofing iron or tiles and even gaps around closed doors and windows. Even small amounts of ash entering buildings can take a considerable amount of time to remove. Fine ash easily penetrates carpets and abrades them underfoot.

Damage to services

The highly abrasive and mildly corrosive nature of ash is a threat to mechanical and electrical appliances. Air-conditioning units are vulnerable to ash damage and filter blockage, especially if intakes are horizontal surfaces. However, severe damage is commonly avoided by shutting down systems. Penetration of ash into electrical systems can lead to short-circuiting and fires. Computers and computing systems are also vulnerable to ash damage. In many cases, damage can be avoided by shutdown, sealing or filtration.

IMPACT ON LIFELINES

A community's infrastructure provides the services and linkages which allow society to function. These "lifelines", such as electricity, water, wastewater, fuel, communications and transport are vulnerable to damage from ashfalls.

Electricity

Volcanic ash can cause many different problems for electrical distribution systems. Most commonly these are:

- supply outages resulting from insulator flashover
- controlled outages during ash cleaning
- line breakage.

The factors affecting flashover-potential of insulators are primarily ash conductivity, ash adherence and insulator dimensions. Dry volcanic ash is not conductive enough to cause insulator flashover problems. However, if insulating surfaces are completely coated in ash, the presence of moisture in association with soluble ash coatings can be a critical factor in initiating insulator flashover. Moisture may be derived from the atmosphere in the form of rain (during or after the ashfall), or from the eruption plume itself. With time, rain will dilute the soluble components. Weather conditions at the time of ashfall influence how ash adheres to insulating surfaces. Dry ash generally tends to rest on level or gently sloping surfaces but causes no immediate electrical problems. In contrast wet ash sticks to all exposed surfaces. Since lower voltage insulators are smaller they are more prone to becoming completely covered with ash and water, and therefore are more vulnerable to flashovers than higher voltage insulators. Substation insulators are more susceptible to flashovers than line insulators because of their distinct shape and orientation. Heavy rainfall may eliminate the problem by completely washing away ash deposits.

The consequences of loss of electricity supply are many and widespread, and other public utilities such as water supply pumps, radio and telecommunication facilities may become inoperative during the power loss unless their local backup power supplies (batteries and generators) last the duration.

Cars covered in ash during the 1995 Mt. Ruapehu eruptions. The ashfall affected communities as far away as Te Puke and Auckland, over 250km away.

Water supplies

Contamination of open water supplies is common, even from relatively small ashfalls. Both turbidity and acidity are the most common problems affecting water supplies but will usually return to normal levels within a few hours to days unless ashfalls are prolonged. Hazardous changes in water chemistry are rare. However, leachates from ash can mix with small volumes of water such as roof-fed water tanks, stock water troughs and shallow water bodies and cause chemical contamination to levels above recommended guidelines for drinking water. Other indirect problems can result from increased water demand for clean-up operations by communities affected by ashfall.

Waste

Sewage and stormwater systems are highly vulnerable to damage from volcanic ashfalls, because ash blocks pipes, damages pumps and other machinery and interferes with sewage treatment processes. When ash falls on impervious surfaces, such as roads, roofs and other paved areas, it is easily washed into stormwater systems by rain, or during clean-up operations. It may also enter the sewage system via illegal connections, manholes, sediment trap overload or inter-connections to a stormwater system. Since the grainsize and density of ash particles decreases with distance from an erupting volcano, it is at more distant localities where fine ash enters the system most easily. Very fine ash may remain in suspension and be transported to sewage treatment plants depending on pipe size, fluid pressure and velocity. Where pipes become blocked, local flooding results. Sewage pumps may also be damaged by ash-laden sewage or they may fail if ash impacts on their electricity supply system. This may result in backing up of sewage in urban areas. To remove ash from sewage and stormwater systems is a time-consuming and costly exercise.

Sewage Treatment Plants

Ash-laden sewage may enter a treatment plant overloading solid removal equipment at both the pre-treatment and primary treatment stages. Milliscreens, mechanical grit/sludge removal mechanisms and other equipment may become damaged. Ash falling directly into sedimentation tanks will add to the volume of material which has to be removed. Low density pumice and finer pumice shards may float on the surface of ponds. Ash entering secondary treatment facilities, such as oxidation ponds or biofilters, will tend to reduce or halt the oxidation process until the ash settles out or is removed. Ash may affect the acidity or toxicity level of effluent to such an extent that bacterial growth may be damaged or lost. If there is plant failure and/or deliberate shutdown, untreated sewage may have to be released into waterways. Costs of repair may also be extreme. Shutdown and diversion of raw sewage during and immediately after ashfall may significantly decrease damage and thus diversion duration and also cost in the longer term.

Transportation

Transportation networks (eg. road, rail and air) are extremely vulnerable to volcanic ashfalls, being subject to widespread disruptions and damage. Volcanic ash falling on roads is extremely disruptive to transportation. It reduces visibility on roads and is easily raised in clouds by passing vehicles. This presents an on-going visibility hazard. Wet ash can turn to mud, causing further problems with vehicle traction. Fine ash causes clogging of air filters causing engine failure and radiator blockages resulting in cars overheating. Vehicle brakes are susceptible to damage and it may also enter the engine causing wear on moving parts, reducing vehicle life. To remove ash from roads is a deceptively time-consuming and highly costly exercise.

Rail transportation is less vulnerable to volcanic ash than road, with disruptions mainly caused by poor visibility and breathing problems for train crews. Trains will also stir up fallen ash which can affect residents close to railway tracks. Ash will affect rail engines in a similar fashion to car engines. Light rain on fallen ash may also lead to short-circuiting of signal equipment.

Air transportation is extremely vulnerable to volcanic ash. Severe impacts can result from aircraft-ash encounters, as temperatures reach 3000^{o}C in modern jet engines - enough to melt ash. Over 90 ash encounters have been reported world-wide in the period 1960-1996, with eight aircraft having lost in-flight jet engine power over that period. Luckily, to date, none have crashed as a consequence of such encounters. Drifting volcanic ash can affect large volumes of air-space, commonly resulting in wide aircraft exclusion since ash cannot be detected by aircraft radar. This was the main cause of flight disruptions during the 1995-1996 Ruapehu eruptions. Extensive night shutdown is often required as a precaution in times of possible ash presence. With world-wide air traffic planned to double over the next decade, and with future aircraft being bigger and with fewer engines, the vulnerability will continue to increase. Even minor ashfalls on airports may shut them down, with damage to both aircraft and facilities.

Communications

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

Large quantities of electrically-charged ash can be generated in an eruption column. These cause interference to radio waves. However, there are also numerous examples of radio and telephone communications continuing to function around an erupting volcano and in areas receiving ashfalls (eg. Mount St Helens 1980, Pinatubo 1991 and Ruapehu 1995-1996).

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

IMPACT ON ANIMALS

Ashfall is unlikely to immediately kill animals except when deposition rates are exceptionally high and thickness is great. Ash cover on pastures may result in lack of feed for animals. Following ashfalls 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. Some ashfalls have been poisonous to stock in Iceland, Chile and New Zealand. Fluorine aerosols attached to ash pose the most significant threat to animal well-being. As a result of less than 5 mm of ashfall 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. 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).

IMPACT ON PLANTS

Damage to small vegetation and the soils on which they depend will vary with ash thickness and composition of the ash. Crop damage will result from burial which can kill or damage plants depending on the thickness of the ash and time of year. 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 ashfalls. Ash adhered to healthy crops, especially fruit, may make processing uneconomical due to a need to clean individual pieces.

Degradation of the organic fraction of soils may result from ashfall reducing the productive potential of the area. However, small amounts of ash may improve soils. A positive impact of the 1995 - 1996 Ruapehu ashfalls has been to temporarily reduce the sulphur fertilizer requirement for all sheep, beef and dairy farmers within the ashfall area.

SEDIMENTARY RESPONSE

The impact of ashfall on hydrologic systems depends on a number of factors, including: thickness of the deposits; grain-size distribution; nature of the substrate (ie slope angle); degree of vegetation cover; and climate, in particular the intensity of precipitation. There are two main classes of impact:

- hydrologic effects such as run-off, flash-like stream discharges and higher flood peaks, due to enhanced surface run-off and reduced infiltration rates in catchments.
- erosion and resedimentation processes, which may be partly a function of the hydrologic effects and which act to remobilise and redistribute the ash.

The infilling and blockage of river valleys by pyroclastic flow deposits will trigger a more complex response than described above. Run-off can pond to form small temporary lakes in depressions on the flow deposit's surface or where drainages were blocked by natural barriers of pyroclastic material. Sudden releases of water from these lakes following the collapse of their dams will create floods downstream. Upstream, erosion of pyroclastic valley fills by headward migrating channels may liberate large volumes of pumiceous material which causes downstream sedimentation over large areas for periods of decades. This has been well illustrated following the 1991 Pinatubo eruption. In New Zealand, much of the Heretaunga Plains are covered by 4 - 8 m of pumice sands and gravels underlying Hastings and Havelock North derived from the Taupo eruption 1800 years ago.

Aquatic life is very susceptible to changes in water conditions such as increased acidity, turbidity, temperature and concentrations of soluble elements. Minor fish kills were also reported in ash-affected rivers after the 1995 Mt. Ruapehu eruption but were insignificant in terms of the total population. Minor disturbance to the 1995 trout spawning migration was observed but the Tongariro River fishery has generally remained in good condition. Fresh-water fish are not as capable of recolonising highly perturbed areas as some

Ashfall from the 1995 Mt. Ruapehu eruption had an impact on a number of lifeline utilities, as well as on animals and plants. Photo: GNS Lloyd Homer.

other biota, as evident from the lasting negative effects of eruption of Taupo on the native fish distribution in the North Island in 186 AD (about 1800 years ago).

MITIGATION MEASURES FOR VOLCANIC HAZARDS

Most volcanoes have long intervals between damaging eruptions, ranging from years to many centuries. The management of volcanic hazards can therefore be divided into four distinct time frames. Non-eruptive rest times represent the most common situation and afford the best opportunity to develop mitigation strategies and prepare society for an eruption. The time around an eruption crisis can divided into three periods: pre-eruption, eruption and post-eruption (or recovery).

NON-ERUPTIVE PERIODS

The requirement to mitigate natural hazards in New Zealand is covered by the Resource Management Act (1991) which seeks to provide a structure for natural hazard management that focuses responsibilities and requires effective means of control to be adopted. Implementation of this is carried out by regional and territorial authorities through regional policy statements, regional plans, district plans and resource consents. The Regional Policy Statements and regional/district plans of volcanic areas should recognize explicitly that parts of these regions are susceptible to hazards associated with future volcanic eruptions. Such zones, for example, those close to potential vents and/or on vulnerable flood plains, need to be identified. The new Civil Defence Emergency Management (CDEM) Act 2002 and the associated National CDEM Strategy establishes a vision for a "Resilient New Zealand – strong communities understanding and managing their hazards" and calls for increased community awareness, understanding and participation in CDEM; reduced risk from hazards; and an enhanced national capability to manage emergencies and recover from disasters. For New Zealand to achieve these goals the CDEM sector requires a sound research base that addresses the spectrum from understanding the physical phenomena of natural hazards to an understanding of the impacts of these hazards from a social, economic and cultural perspective.

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

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

Mitigation options should be evaluated in terms of risk reduction and the benefits or opportunities created. In selecting any appropriate option or options the cost of implementation must be balanced against the benefits derived from it. Limitation on the building of permanent structures in high-risk areas is a low-cost mitigation measure.

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

- Conduct a vulnerability analysis of equipment and facilities to determine which would be the most affected and which are adequately protected.
- Identify appropriate methods of protecting vulnerable equipment and facilities.
- Develop a priority list of facilities that must be kept operative versus those that can be shut-down during and after ashfalls.
- Identify effective and efficient ash-removal methods for equipment and facilities.
- Establish plans to implement ash mitigation measures containing procedures for: warning and notifying of potential ashfalls, reducing or shutting down operations, accelerated maintenance and ash-clean-up operations.
- Develop robust and tested connection of response and mitigation plans to early warning systems (GeoNet) in an integrated warning system model.

MITIGATION MEASURES DURING A CRISIS

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

Past eruptions illustrate the vulnerability of urban areas receiving only a few mm or cm of ash, usually distant to the eruption vent. This thickness is still sufficient to cause disruption of transportation, electricity, water, sewage and stormwater systems. However, most systems, if affected only by thin ashfall (<50 mm), can be restored within a few days to weeks after an eruption has ended. Volcanic ash is highly abrasive, mildly corrosive and potentially conductive (especially when wet). Mitigation actions have two basic purposes:

- preventing or limiting ash entering systems or enclosures; and
- effective and efficient removal of ash to prevent or reduce damage. Some more specific mitigation measures have been described above in relation to the relevant hazard and impact type.

The most effective method to prevent ash-induced damage is to shut down, close off and/or seal off equipment until the ash is removed from the immediate environment. In many cases this is not practical or acceptable. Some mitigation procedures can cause additional problems or may be counter-productive. Constant monitoring of ash effects and mitigation procedures is required to achieve the most effective balance between operational requirements and damage limitation.

CONCLUSION

A number of destructive hazards exist close to an erupting volcano and evacuation may be required to protect inhabitants from them. Ashfalls are the most likely hazard to affect communities at a distance from a volcano. In most cases they will be disruptive not destructive, affecting services such as water, sewerage, electricity and transportation. For volcanic hazard management strategies to be effective the hazards posed by the various volcanoes of New Zealand must be well understood. Careful prior scientific analysis will provide the vital information needed for thorough preliminary planning and minimise the unexpected.

EVACUATE!

What an evacuation order given because of a pending volcanic eruption could mean to residents of the Bay of Plenty.

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In about 1315AD Tarawera volcano erupted with enormous force, depositing rhyolitic ash over much of the northern part of the North Island. This was the Kaharoa eruption. Columns of ash may have continued for days or weeks, and these were followed by slow extrusion of lava domes, with intermittent ash eruptions, which may have continued for four years (Nairn et al., 2001). If such an event occurred today it would cause major disruption to the surrounding area, as indicated in Table 1. Evacuation of some areas will be inevitable.

The distribution of ash will largely depend on the wind direction at the time of the eruption, and in an eruption of this magnitude wind direction will change several times. In the 1315 Kaharoa eruption, ash first travelled southeastwards, and then northwestwards, covering an area from Northland to Mahia Peninsula with a layer of ash, with the greatest thickness occurring between Tauranga and Murupara (Fig 1). The dominant high level wind direction is from the west, therefore areas to the east of the volcano are more likely to be covered with ash, even small amounts of which will cause severe disruption to all forms of transportation (Table 2).

EVACUATION ZONES

The next eruption of this type in the Bay of Plenty will most probably be from Tarawera or from Haroharo volcano to the north. When this happens,

Thickness of ash	Effects on roads
0-2mm	Road markings obscured, traction reduced (wet and dry ash), visibility reduced as dry ash is remobilised by traffic and wind. Steep hills difficult for 2WD vehicles to climb.
2-20mm	Moderate hills become difficult for 2WD vehicles to climb, steep hills impossible. Drifts cause larger humps in road. Once dampened and compacted it becomes firmer, easier to drive on.
20-100mm	Slight inclines may be impassable to 2WD vehicles, 4WD vehicles need differential or hub locks to climb moderate hills. Larger drifts (eg 300mm) may hinder or stop 2WD vehicles on flat roads.
100-300mm	Uneven surfaces in the ash stop any 2WD vehicles, compacted damp ash on flat surfaces is still able to be driven on. 4WD utility type vehicles (not cars) may be able to slowly progress on the flat. Drifts may need to be cleared. Moderate inclines difficult, but may be possible for experienced 4WD drivers. Steep inclines generally impassable. Ruts easily formed on hills.
>300mm	Compacted ash may be driven on by 4WD vehicles, softer patches may easily bog vehicles. Gradual inclines possible on compacted ash, but after a few vehicles, ruts in the ash will form, hindering uphill progress for further vehicles.

Table 2. Ashfall effects on road transportation (from Barnard, 2003)

Fig 1. Proximal distribution of Kaharoa ashfall deposits; isopach values in cms (from Johnston et al. 2002)

the highest risk is within a 10km zone around the vent area, and this becomes a Primary Evacuation Zone (Fig 2), including the Rotorua Lakes district (bordering Lakes Rotokakahi, Tikitapu, Okareka, Tarawera and Okataina). Residents of this area would have to be evacuated prior to commencement of the eruption.

Residents on the north shore of Lake Tarawera (along Spencer Road) would be the most vulnerable to any eruption from Tarawera (Fig 3). This area is likely to be completely devastated in a Kaharoa-type eruption from Tarawera or Haroharo, particularly from ballistic ejecta and thick near-vent ashfalls. Therefore, it is imperative that this area evacuates pre-eruption. An added problem is the single evacuation route into and out of the area. Spencer Road ends at the edge of

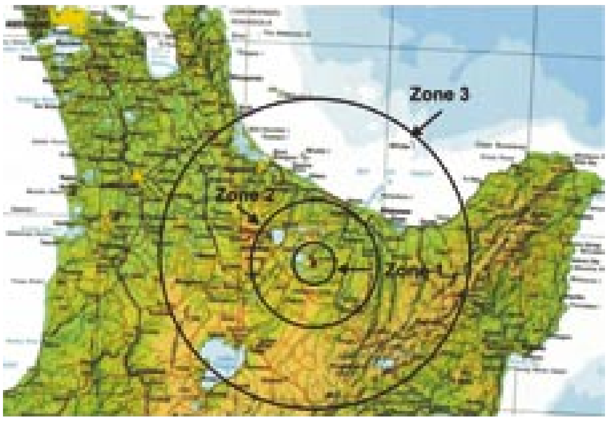

Fig 2. Evacuation Zones: Zone 1 = 10km radius (primary) zone; Zone 2 = 40km radius (secondary) zone; Zone 3 = 100km radius (potentially 'unsafe') zone.

A view looking northeast along the vents of the 1886 AD eruption, from Frying Pan Lake in the foreground to Mt. Tarawera and in the background, the cone of Mt Edgecumbe. Photo: GNS Lloyd Homer.

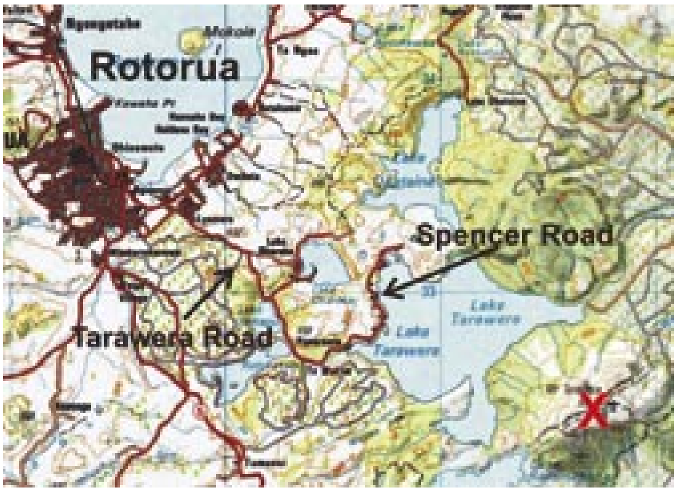

Fig 3. Lake Tarawera area evacuation route. Spencer Road west to Tarawera Road to Rotorua.

Fig 5. Kawerau Evacuation Routes. Two possible evacuation routes: NE via SH30; or south via the main road or the forestry road.

Lake Tarawera and is a long narrow road that extends for ~17 km, from Tarawera Road to Rotorua, making large-scale evacuation on this road hazardous. There is also the likelihood of landslips occurring on the road, associated with pre-eruption seismicity, severing the link to Rotorua. The construction of a loop road extending northwest from Spencer Road to Millar Road, Lake Okareka, should be considered. This would be of benefit to the local residents at any time, but particularly so if an eruption is imminent. The use of a loop road as a mitigation measure was implemented by officials at Mammoth Mountain (Long Valley, California, USA) during an eruption scare (Mader & Blair, 1987).

The next level of risk will be inside a zone of 40 kms radius from the erupting volcano (Fig.2). This is the Secondary Evacuation Zone and would include the urban areas of Rotorua, Kawerau and Murupara. Effects on these towns will depend very much on the wind direction, but such variability puts all in potential danger. The larger population means that any decision to evacuate becomes a major operation and requires careful planning.

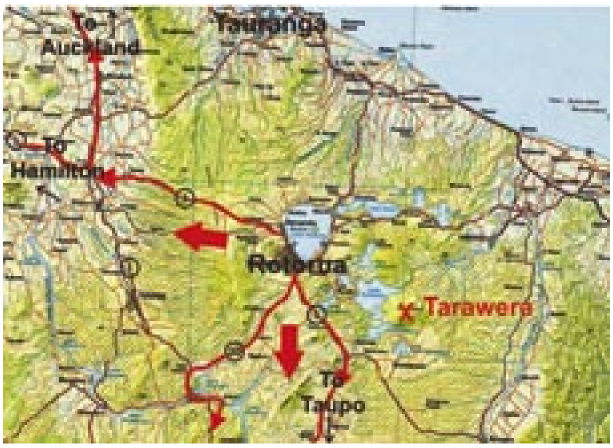

Fig 4. Rotorua Evacuation Routes. Rotorua has two options: south by SH 30 or SH 5 to Taupo; or west by SH 5 to Hamilton.

URBAN AREAS

Rotorua is situated 25 km west-northwest of Tarawera volcano (Fig 4). The population of Rotorua district is 64,473 (Census 2001), and a compulsory evacuation notice may be given if the eruption is large enough or wind direction is from the east. Because of the larger population however, it would be advisable that voluntary evacuation is encouraged earlier, to decrease the number of potential evacuees where the compulsory order is given. The importance of the timing of any evacuation order is critical: too soon, and people will start to return, believing the emergency is over; too late, and many evacuees will try to evacuate at once, causing panic.

Kawerau is situated 20 km northeast of Tarawera volcano (Fig 5), with a population of 6,975 (Census 2001). Kawerau has three main road exits from its township. It must be remembered that Rotorua and Te Teko could also have been ordered to evacuate at this time. This puts pressure on some roads and other evacuation routes.

Population statistics of the potential evacuation areas are presented in Table 3. The percentage of residents who actually evacuate is hard to estimate. A figure of 50-70% of the population, is presented by Auckland Regional Council (1996) as the "anticipated maximum credible [evacuee] number" in the event of an eruption from the Auckland volcanic field. This percentage is supported by Dow and Cutter (2002) who found there was an evacuation rate of 65% during Hurricane Floyd in the USA. Therefore, in Table 3, an estimated 60% of the affected Bay of Plenty region population is taken as a potential figure for numbers of evacuees.

Plans for evacuation movement, ie. major evacuation routes and destinations, must be in place

ASHFALL IMPACT SCENARIO

<10mm (1cm) thickness

- Light dustings of ash. May act as an irritant to lungs and eyes.
- Possible closure of airports.
- Light damage to vehicles, houses, and equipment, caused by fine abrasive ash.
- Possible contamination of water supplies, particularly roof catchment tank and river/stream supplies.

10-100mm (1-10cm) thickness

- Falling ash will act as an irritant to lungs and eyes. Protective masks should be worn in the open.
- Most buildings will support the ash load but weaker roof structures may collapse at 100mm (10cm) ash. thickness, particularly if wet. Minor damage to houses and contents will occur if fine ash enters buildings.
- Electrical supply may be disrupted; shorting occurs at sub-stations if ash is wet and therefore conductive.
- National grid electrical supply may be affected once ash depth reaches 20mm (2cm), particularly if ash is wet.
- Telecommunications may be affaected due to fine ash entering components and overloading of circuits; ash blanketing of air-conditioning systems may cause exchange shut-downs.
- Disruption of radio communications due to electrical interference, and disruption of micro-wave transmissions due to ash particles, particularly if wet; blanketing of solar panels by ash.
- Reception of broadcast radio transmissions will be similarly affected.
- Water supplies may be cut or limited due to failure of electrical supply to pumps and/or treatment facilities.
- Unprotected water pumps may suffer mechanical failure due to ash loadings in water or restriction of combustion engine air intakes.
- Water supply contamination by chemical leachates may occur.
- Stormwater and other drainages may become blocked by ash settlement in pipes. (This problem could be exacerbated by property occupiers hosing ash deposits into the system).
- Sewage systems may be blocked by ash or fail due to loss of electrical supply.
- Road transport will be affected by build-up of ash on roads making sealed surfaces slippery. Poor visibility will result from dust-clouds if ash remains dry. If ashfalls are heavy, near total darkness may result. (Note that headlights are ineffective under heavy ashfall conditions due to lack of penetration, and reflection from airborne particles).
- Internal combustion engines, both diesel and petrol, will be affected by clogging of air filters, rapid wear of bearing surfaces, and infiltration of fine dust into vehicle electrical and lubrication systems. Brake components will wear rapidly.
- Rail transport may be affected by signal failure induced by wet ash short circuits.
- Airports will close due to potential for aircraft damage, and disruption of control facilities. Air carriers will not operate under ashfall conditions.
- Damage to electrical equipment and machinery may occur.

100 – 300mm (10 - 30cm) thickness

All the above effects will be amplified, with additional impacts such as;

- Buildings that are not cleared of ash will run the risk of roof collapse, especially large flat-roofed structures, and more-so if the ash is wetted.
- Loss of electrical reticulation due to falling tree branches and shorting of power lines.

>300mm (30cm) thickness

All of the effects described above, with additional impacts such as:

- Heavy kill of aquatic life in rivers and lakes.
- Major collapse of roofs due to ash loadings.
- Loading and breakage of power and telephone lines.
- Roads unusable until cleared.

Associated Effects

Ashfall has the potential to create additional problems for emergency services and other agencies. Some of these are:

- Heavy demands for public information.
- Difficulty of movement under ashfall conditions.
- Need for protection and 'ash-proofing' of emergency service personnel, vehicles, plant, and communications systems.
- Blanketing of road and street signage, numbers, road markings, hydrants, etc.
- Possible lengthy duration of impacts.
- Physical disposal.
- Unfamiliar operational environment.
- Uncertainty over future course of events.

Table 1. Effects of ashfall (after Tauranga/WBOP District Councils, 2002)

Location	Population	If Only 60% Evacuate
Rotorua District	64,473	~ 39,000
Kawerau District	6,975	~ 4,000
Te Teko	630	~ 400
Te Puke	6,774	~ 4,000
Murupara	1,959	~ 1,200
Whakatane District	32,814	~ 20,000
Tauranga District	90,906	~ 55,000
Total	204,531	~125,000

Table 3. Populations and possible numbers of evacuees in the Bay of Plenty region (Census, 2001)

well before any evacuation is necessary. Plans for hospitals, schools and nursing homes should already have been implemented by each authority, but individual facilities and institutions also need to have an evacuation plan. To achieve this, communication links must be established early in the pre-eruption stage. Locations of evacuation shelters should be confirmed and made accessible and known to agencies and the public. Vehicle protection, ash clearance, bulk ash disposal, contractor resources and arrangements, and availability of fuel are also important. Lists of special equipment and supplies should be compiled, including tow trucks, and taxi/private bus companies. Plans for potential receiving cities need to be updated; the availability of fuel and suitable accommodation will need to be monitored prior to an event.

EVACUATION ROUTE INFORMATION:

The evacuation movement can be either pre-eruption or during-eruption. The primary method of evacuation movement in this area has to be by road, although there is a rail link to Kawerau. Before the eruption, road conditions are unaffected by ash, but apprehension may affect driving skills. Evacuation movement during periods of ashfall, is drastically changed by road conditions, and therefore, the subsequent action taken by drivers. Under this scenario, most recommended and compulsory evacuations take place before any substantial ashfalls in the area.

Viable destinations for evacuees from Rotorua include Hamilton, Auckland and possibly Tauranga and Taupo. However, evacuation to Tauranga and Taupo, or to any other city within the Bay of Plenty region, is better only as an interim measure. These centres could need to be evacuated themselves if the eruption escalated or wind direction changed. If the route to Taupo is taken, the recommendation given to evacuees will be to travel south along SH 30 through to SH 1, as SH 5 passes close to the Primary Evacuation Zone and may be closed prior to the eruption. If the route to Hamilton is taken, the recommendation given to evacuees will be to travel via SH 5 to SH 1 (Fig 4).

Clear advice needs to be given to the public, recommending evacuation routes and destinations (or destinations to avoid), well in advance of an evacuation warning.

If the population leaves Kawerau via Kawerau Road to SH 30, the choice lies in either going to the west or east (along SH 30). The best option is to take SH 30 to the east (Fig 5); they could then travel to Te Teko, turn south and follow the south route and travel on to Taupo via Murupara; or could turn north from Te Teko, or to Matata, on the coast, and then northwest to Tauranga. Following this route would be slow, and would involve travelling in ashfall-prone areas, once the eruption has commenced. Going to the west will compound the problems in the Rotorua area.

A second option is to leave Kawerau by the southern forestry road to Ngamotu Road, although this comes in close proximity to Tarawera volcano, just outside of the Primary risk zone. This option is only possible pre-eruption, and is likely to be closed as soon as the eruption begins. The options from here are east to Pokairoa Road, following it south to Kopuriki Road until Murupara, then turn west earlier to Rainbow Mountain and south to Taupo.

EVACUATION BY ROAD

This is likely to be the most common transportation method used in evacuations for the Rotorua-Kawerau districts. Most people will be advised to evacuate by car, except for a few minority groups who will neither be able to drive, nor be able to travel with friends and family. These include special population groups such as hospital patients, residential

District	Cars	Rental cars	Taxis	Trucks	Buses & coaches	Trailers	Motorcycles	Mopeds	Tractors	Exempt vehicles	Misc.	Total
Auckland	625,590	11,329	3,497	94,595	3,088	71,746	9,187	828	2,530	1,325	3,972	827,687
Hamilton	145,457	481	267	33,112	1,135	38,091	3,200	828	2,486	578	1,190	226,825
Tauranga	92,357	321	129	20,395	506	22,715	2,340	610	1,184	546	1,159	142,262
Rotorua	32,311	69	99	8,147	260	8,284	653	117	459	332	333	51,064

Table 4. Vehicle numbers (registered) in the Bay of Plenty/Waikato/Auckland regions (From Land Transport Safety Authority, 2000)

schools (if there is need for a rapid evacuation), nursing homes and retirement villages. In these cases, it will be recommended that people travel on buses, but each organisation will need to meet their own evacuation procedures.

Rotorua district has 32,311 registered cars in the district (Table 4); 32,479 including rental cars and taxis, together with 260 buses and coaches. Assuming a population of 64,473, the number of cars would appear to be adequate, assuming two people per car. For those without a household car, or without the opportunity to travel with friends or relations, they will need to rely on buses and coaches. Measures must be taken to ensure these are organised in advance, with meeting points and drivers prearranged.

Census 2001 states that 90.9% of households in the Bay of Plenty region have access to a motor vehicle. As there are 86,793 households in the Bay of Plenty, there are therefore 7,899 households without access. With an average household population (Bay of Plenty region) of 2.6 persons, this will result in about 20,535 people in the region without access to a motor vehicle. From these figures it appears that Rotorua has ~6,420 people without access to a motor vehicle, while Kawerau District has ~939 people without access to a motor vehicle. The assumption is made that most of the 7,359 people, from these key areas, will need public transport (Table 5).

Kawerau, with a population of almost 7,000, lies 20km northeast of Tarawera Volcano (out of picture to the right). In the background Lake Pupuwharu and Mt Edgecumbe. Photo: GNS Lloyd Homer.

SECURITY OF EVACUATED AREA

The security of the evacuated area is intimately linked with authority and responsibility. It is extremely important that measures are taken to secure evacuated areas, and that evacuees are aware that this will be done. The security of the evacuated area is also important to continue sustainability of lifelines in the area, to encourage clean-up and return of evacuees after the event. During many past evacuations, (eg. Rabaul 1994) looting and other negative socially destructive actions have occurred, by individuals and groups and this must be avoided at all costs.

RECOVERY

Initial destinations for evacuees are likely to be Auckland, Hamilton, Tauranga, and Taupo. However, many smaller destinations will receive evacuees, with many people wishing to choose their own destination because of relatives or friends. It is also possible that some of the cities (eg. Tauranga and Taupo) could need to be evacuated themselves and are therefore not recommended as ideal final destination points.

Evacuees should be advised to evacuate further than the ~100 km 'unsafe' radius from Tarawera volcano (Fig.2). After initial destinations have been

	Total number of households	Access to a motor vehicle (%)	Average numbers in household	Calculated no. people without motor vehicles	If 60% people evacuate
Rotorua	22,254	89.7	2.8	6,420	3,852
Kawerau	2313	86	2.9	939	563
Total				7,359	

Table 5. Residents without access to a motor vehicle from key centres in the Bay of Plenty region (Census, 2001)

reached, it will be possible to transfer evacuees to other points around the country, and to family and friends outside evacuated zones. This subsequent transfer is recommended to decrease the effect on public resources, and for the preservation of mental health and emotional support, as it is essential to counteract subsequent negative impacts on the evacuees. The National Evacuee Registration system will be required, so that enquiries from friends and relations can be dealt with effectively.

As the largest city in New Zealand, Auckland is expected to have the largest accommodation resource of the cities considered, with numerous hotels, motels, and schools. The short-term accommodation sources are friends and family, motels, camping grounds, and dormitories. Most evacuees are expected and are recommended to travel to these sources once leaving the evacuation shelters. Auckland is also thought to be a good medium and longer-term shelter (and relocation) destination, because of the accommodation resources and potential employment opportunities available.

For short-term shelter purposes, Hamilton can provide up to 900 beds, which would include both motel and marae accommodation. Longer-term shelter resources include various hotels, motels and camping grounds. Hamilton would be a good medium-term sheltering destination, however less so for short-term shelter.

Taupo may be an interim destination, and as such will be able to provide a small amount of support shelter. Taupo and the surrounding district have welfare centres, including the Great Lake Centre and the Events Centre (which can accommodate ~100 each), plus primary schools (22) and motels, which may be available for short-term shelter.

The Tauranga-Western Bay Emergency Management Civil Defence Plan (2002) states that the preferred option for short-term emergency accommodation for smaller numbers of evacuees is the use of the combined district/region's hotels and motels. It states that should large numbers be involved, other facilities will be used. It also states that registers of locations and premises suitable for short-term shelter for evacuees are held by the Emergency Operations Centre. Arrangements for long-term accommodation and/or resettlement of displaced persons are to be addressed by the appropriate Disaster Recovery Manager.

Major shelter facilities (able to provide catering, showers, car-parking, accommodation) include Tauranga Racecourse, Greerton; Papamoa Sports Club, Papamoa; Bay Park Stadium, Te Mauna; QEII Memorial Hall, Tauranga; Blake Park Stadium, Mt Maunganui; and Community Centre, Waihi Beach. Medium-term facilities (greater than 72 hours) include motels, campground cabins, caravan parks and sites, with total capacity estimated to be around 8,000 people. However, as previously noted, Tauranga is not the best medium or long-term sheltering location.

CONCLUSIONS

Local authorities are certainly aware of the possible need for evacuation in the event of an eruption; the National Contingency Plan for Volcanic Eruptions (within the National Civil Defence Plan) highlights the need for awareness of volcanic hazard management and preparedness. However detailed evacuation plans for all areas must be established well before any eruption occurs. Once there are signs of an impending eruption, it is too late to have a well managed, orderly evacuation. How many local people in the potential evacuation areas are aware of the possibility of evacuation is an open question, but one that should be addressed as detailed plans are drawn up.

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The Okataina Threat for the Bay of Plenty

John Thurston, Project Manager, CDEM Group Plan, Bay of Plenty

It is all relative I suppose. Living with the threat of a volcanic eruption. A number of years ago I lived at Scott Base, Antarctica for five months during a Polar Summer with the active Mt.Erebus dominant in the background. Did I really care or did it worry me that it may erupt during my stay on the ice? It becomes hard to rationalise the acceptance of something on your doorstep that could deliver you into all eternity yet not be overly concerned about it. Is this the process going on with those living in the Bay of Plenty? I wish I knew. Does the uncertainty work in favour of blocking out the likelihood of being dealt the "losing marble' of a volcanic eruption. Perhaps we will never know, but we cannot leave it there. We must recognise and be prepared for major problems centred on a volcanic eruption in the Bay of Plenty or the ashfall effects of a distal eruption in far away Taranaki, Auckland or neighbouring Taupo.

There is plenty of evidence around us of past volcanic eruptions here in the Bay of Plenty. You can see the layers of pumice in road cuttings from the 1315 AD Kaharoa Rhyolite Eruption from Mt Tarawera as you drive to Whakatane. Horticulturists use the pumice from Otamarakau in hydroponics growing. We even export it. The enormous reserves of pumice certainly indicate the occurrence of an event of gigantic proportions beyond our wildest comprehension.

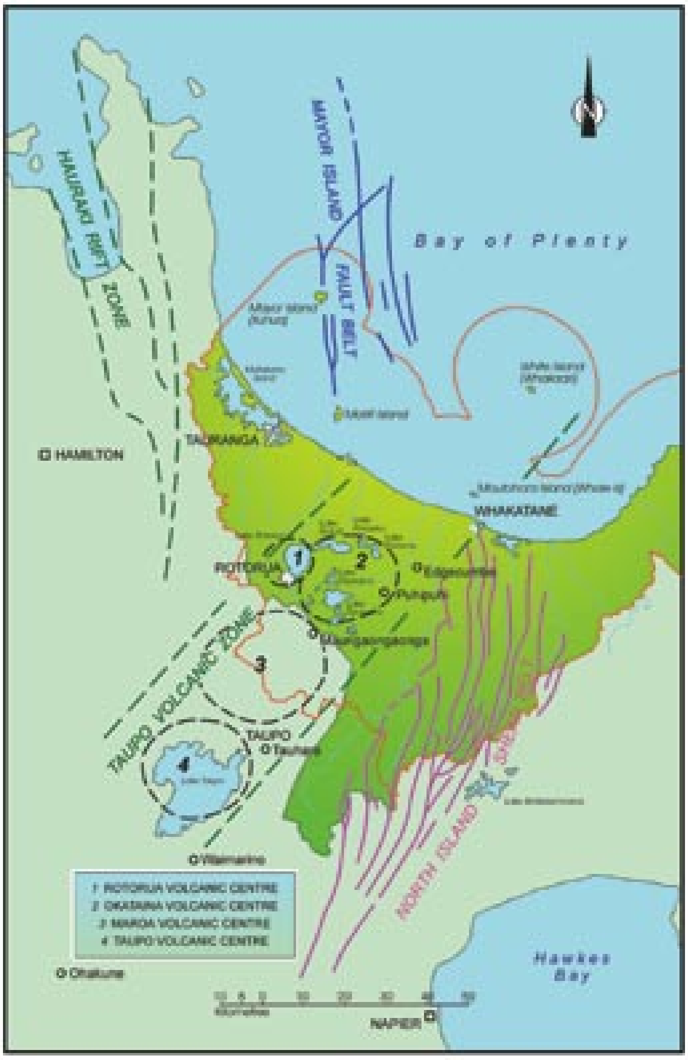
The presence of pending and past volcanic activity further dots our landscape. White Island occasionally plumes away offshore to the northeast. Mayor Island, dormant for many thousands of years, is nearby for those living in the Western Bay. The Okataina Volcanic Centre, with the obvious evidence of the 1886 eruption and the Mt Tarawera fissure or 'rift', overshadows Rotorua and forms part of the Taupo Volcanic Zone. The Okataina Volcanic Centre is recognised as having the most potential volcanic activity in New Zealand.

Would we cope with another Kaharoa eruption and ash layering of our region? Simply we would not if we have not done the planning groundwork.

GROUNDS FOR CONCERN

Does anyone care? Should they be worried? Are we saying to ourselves it won't happen in my lifetime, rather than it won't happen at all. It will happen, but the big question is when? While this is going on someone has to take charge and implement the 4 Rs (Reduction, Readiness, Response and Recovery) should an eruption

Civil defence boundaries of the Bay of Plenty region.



Major earthquake and volcanic features of the Bay of Plenty

occur. How prepared will the community be? How prepared will those vested with the responsibility of Civil Defence Emergency Management be? The problem will not go away. The community must be resilient and accept that there are precautions and measures we all must take.

The effects of a volcanic eruption and the effects of a distal eruption have been well researched over the past few years. Environment Bay of Plenty has commissioned a number of studies with the Institute of Geological and Nuclear Sciences (GNS) and universities. These studies have proved to be invaluable in coming to grips with the magnitude of the problem. A number of graduates have prepared theses for Doctorates and Masters Degrees on various aspects of the effects of the "Big One". This big one being a volcano rather than our other major hazard of earthquakes. The fact that these people are interested in delving into the reasons why, and the possible effects of volcanic activity has certainly been a huge asset for those deciding on an emergency management approach. Having ploughed through the valuable data available and sought the advice of the experts and workshopped through the probabilities, we cannot get away from the fact that we do have a major problem in the hazard field with volcanoes.

Now that the CDEM Act 2002 is a reality, we have formed our Bay of Plenty Civil Defence Emergency Management (CDEM) Group. Along with the support of the Coordinating Executive Group (CEG) our relevant working groups are going through a very robust process of deciding on the hazards affecting the Bay of Plenty Region, with volcanic eruption high on the list.

RESEARCH INDICATORS

The 1315AD eruption from Mt. Tarawera was the largest volcanic episode to have occurred in New Zealand in the last 1000 years. Environment Bay of Plenty held a "Kaharoa Eruption Hazards Workshop" in October 2000 where the event was studied and implications drawn for a present day scenario. The results, as found by Russ Martin and Ian Nairn for "Volcanic Hazard Planning" in summary were:

- The need to manage lengthy pre-eruption phases (1-10 years duration), with the likelihood of false alarms, conflicting scientific views on the likely outcome, sensational media treatment, public anxiety, and possibly severe adverse local economic effects.
- The need to make detailed plans for an impending event of unknown start time, size, duration and (wind-controlled) ashfall scenarios.
- The need to manage a long-duration eruption with multiple large explosive events so that some areas receive repeated ashfalls over several months.
- How to recognise (and guarantee) that the eruption has ended.
- Assessment of the necessity and feasibility of engineering intervention to reduce post-eruption flooding and sedimentation hazards.
- The post-eruption impact on local government in the region and its functions.
- When to start on clean-up operations, how to fund these, and how to select the priority areas.
- How to manage the situation of accommodating and rehabilitating perhaps up to 200,000 evacuees from the region?

We can see from the above that the hazard implications are a grave cause for concern. For a Project Manager such as myself with the task of editing and putting together the Bay of Plenty Civil Defence Emergency Management Group Plan, these studies are invaluable. Our Plan will go a long way to make the critical decision-making easier.

As we read through the implications, the enormity of a volcanic eruption quickly becomes apparent. We are not talking about days, weeks or months but possibly years before anyone is allowed to return. How are we going to cope with the large number of evacuees?

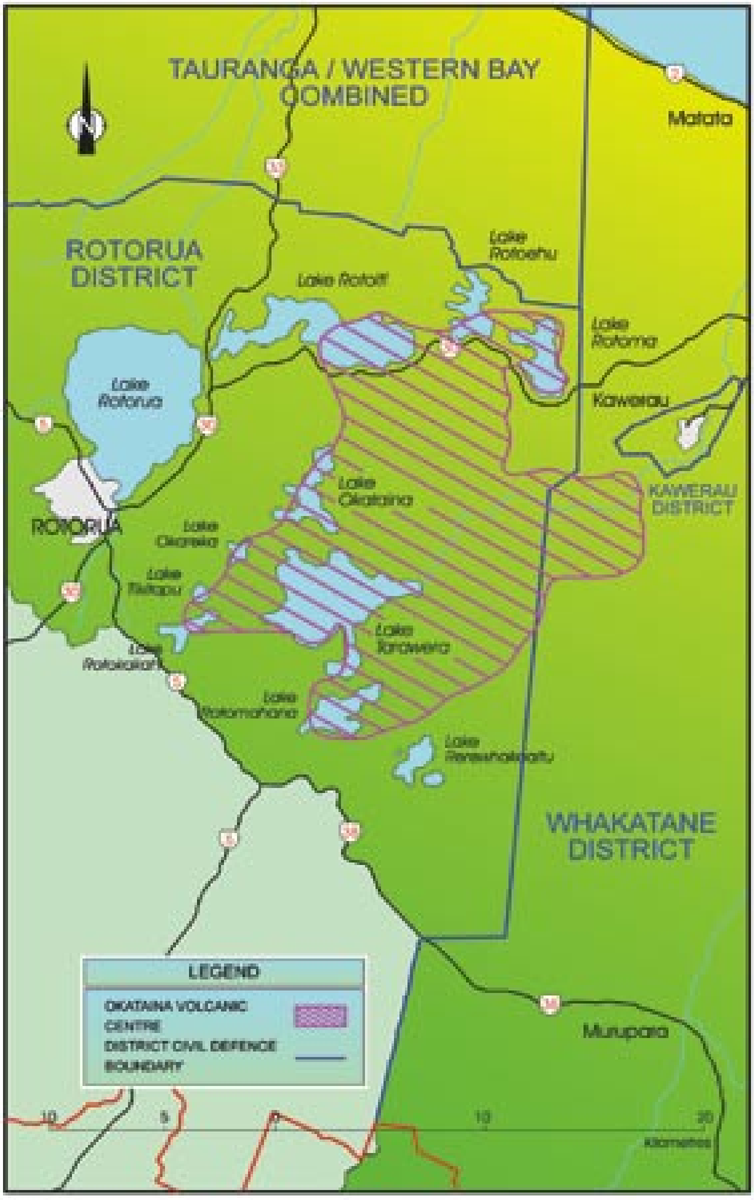
Under the new Group arrangements, the benefits are that we all pool all our resources, share our concerns, investigate the likelihood of certain events or hazards occurring and then plan to fulfil the Reduction, Readiness, Response and Recovery action.

THE EVACUATION PROCESS

Imagine the evacuation process for a moment. Shifting many displaced people from one location to a safer location. How are you going to get there? Are the roads open? Have the rail links been affected? Are there enough rolling stock and other forms of bulk transport available to shift the livestock? What roads are open? How many bridges are still operational? Where are the detours? How prepared are those communities outside the disaster area to take such vast numbers. The sheer logistics of the operation starts to sink in. What lifelines are still functioning? Will road transport be able to function with the presence of large amounts of ash affecting engines, electrics and brakes? Relive the evacuation of Dunkirk. Perhaps evacuation by sea may have to be part of the evacuation plan? We know for sure that our isolation in a far-flung corner of the Pacific means there will be limitations on international help. There certainly will not be convoys of trucks coming across the Tasman as would overland aid in a European disaster.   Will there be enough craft to do this. What part will the weather play. So it goes on.

We are fortunate that in our region there are people who experienced the Rabaul eruption of 1991. Their first hand on the ground experiences have been well documented giving a realistic translation of events and what impacts they would have if such a catastrophic event occurred in our more densely population region.

In 1996, GNS published a Science Report entitled “Guidelines for developing a response to a volcanic crisis in the Bay of Plenty”, co-authored by D M Johnston, B J Scott and B F Houghton. The aim of the report was to identify significant issues that need to be considered in developing a response to a volcanic crisis affecting the Bay of Plenty region. It should be noted that volcanologists as stated in this report refer to a “volcanic crisis” as the whole realm of events concerned with the awakening of a volcano, the building up to an eruption, the eruption and the aftermath as the affected region/area recovers.” This of course covers the steps any plan must have for a comprehensive emergency management approach, part of an ‘all hazards’ strategy, linking mitigation, preparedness, response and recovery. Plans above all must be simple and flexible, focusing on principles rather than details.   An excellent observation made in the report was that ‘the contingency planning



Okataina Volcanic Centre

process is a continuous one (ie. the plan is never complete). The report describes evacuation and evacuation planning as follows:

Evacuations usually involve four types of movement:

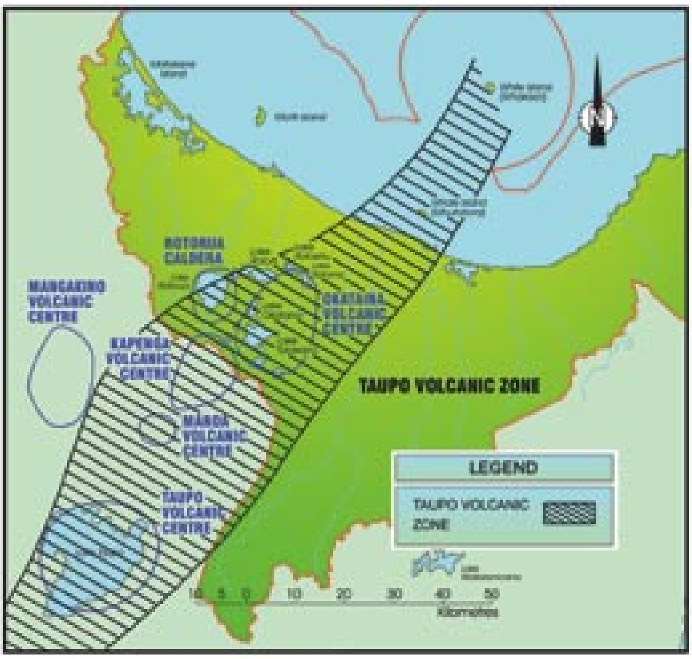
1. Self-evacuation where people move out in their own vehicles or with friends/relatives.
2. Movement of people who do not own or have access to private vehicles.
3. Movement of people from institutions (hospitals, but no prisons in Bay of Plenty).
4. Movement of people with handicaps who require specialized vehicles.

Emergency planning must make provisions for all of these.

THE HIGHLY DISABLED LIVING IN THE COMMUNITY

With regards to the movement of people who have disabilities, the problem was highlighted to us during our public hearing into the development of the Plan. A representation was tabled and discussed to provide for those with high disability who were living at home. A very good submission was put forward to include those in the community who were: totally reliant on others to feed and toilet them; unable to move without assistance; bedridden; and reliant on machines to keep them alive.

The presenters requested that there must be a register set up and maintained, of people living at home with high needs as outlined. Those reliant on life support equipment such as ventilators are at risk when the power is cut. Standby batteries only have a short life (ranging from 6-8-10-12 hours) and contingencies will need to be in place for replacement batteries once the standby batteries have run down. A further example of the plight of those disabled living in the community is that they have the use of touch or voice activation mechanisms to open doors, and activate equipment – again these require electricity and any power cut could have tragic consequences. As we dwell on the logistics of shifting those living in the community with a high level of disability we can see that it is a logistical challenge in itself. It is our task to factor this into any evacuation plan we have. Therefore good liaison with community health service providers and the Accident Compensation Corporation is essential, as well as a regularly updated register. Privacy issues, while respected, would need to have a commonsense approach for the desired end result in an emergency.



Taupo Volcanic Zone

EVACUATION PLANNING

Evacuation Planning must, as highlighted in the 1996 Science Report:

- Designate the lead agency that will issue the evacuation order.
- Designate the agencies that will play supporting and receiving roles.
- Outline the roles and responsibilities of all the agencies involved.
- Identify the potentially dangerous zones to which or through which the population should not be evacuated.
- Identify the preferred evacuation routes and ways to keep them open under eruption conditions.
- Identify assembly points for persons who require transport for evacuation and public information pertaining to these.
- Consider the means of transport, traffic control, assistance and direction.
- Identify potential shelters and accommodation in refuge zones.

We now must make realistic plans which will efficiently and safely convey those from danger to staging points for relocation. There are several strategically located Race Courses within the Bay of Plenty and in neighbouring regions which would serve adequately as short term accommodation and staging points.

Let's explore the implications. The Operations Working Party will be tasked with developing an Evacuation Plan, which will not only cater for volcanic eruptions, but for the other hazards we have within the boundaries of our region. These hazards will include tsunami and earthquakes. Through widely involving our networks and following the founding principles of evacuation we will have a robust evacuation plan, which will be flexible enough to cater for all contingencies and give a foundation to those having to implement it.

While we are discussing the implications of a volcanic eruption we need to discuss the location of EOC's (Emergency Operations Centres). In arriving at this decision we must be mindful of the fact that in our region we can easily be isolated and divided from within through natural and man-made hazards following an eruption. Therefore we must be careful not to put all our eggs in one basket by going for a central EOC catering for all Districts within the Region. Experience and a need for balance suggests that EOC's should be strategically located within a District or shared by neighbouring districts in order for them to be able to function with skilled staff to:

- Collate and disseminate hazard-monitoring data.
- Provide operation support during the emergency.
- Become a base of response and volunteer training in non-emergency times.
- Other activities such as coordination of CDEM exercises.

Lead management centres would also have additional responsibilities such as managing regional warnings, bulletins, resources and monitoring Group Response activity.

There should be a theme of agency cooperation coming through when dealing with CDEM and it is envisaged that all key partners would operate out of the EOC rather than operate remotely from their own Operations Rooms with representation in the EOC. As the CDEM Group Plan becomes a reality, those contributing agencies must contribute to setting up the EOC in a standardised manner, with adequate equipment, databases and subordinate plans to handle any event of a district, regional or national significance. The more the EOC's are used by Emergency Services during significant events, but not within the scope of a local declaration, the more familiar they will be with their equipment and the roles of other agencies. The use of CIMS (Coordinated Incident Management System) will improve, so that when an emergency occurs that leads to a Civil Defence declaration being made, then the roles will already be understood, practised and the end objective more easily arrived at.

PUBLIC AWARENESS

There needs to be a deliberate public awareness programme aimed at preparing the community in areas of high risk on how they can help themselves. Taranaki has prepared a brochure and video setting out what people should be doing to prepare. Exposure at school through inclusion in the education curriculum will ensure awareness for the generations ahead.

RECOVERY

In our planning, we also need to explore the economic impacts of a volcanic eruption. Our pastures, horticulture blocks and tourist attractions would be destroyed. The effects would be greatly felt through the community.

The recovery phase would go on for years. Some very hard decisions would need to be made from the highest level. For instance, when could people return? In how many months or years, or would the landscape be so barren that no great numbers ever return. Frightening isn't it, but all these factors have to be looked into and planned for.

To be better prepared, stronger, and have an enhanced response and recovery capability, we need to work together, involving all members of the community, our stakeholders and allied agencies. The days of working in isolation from one another have now gone.

View of the Rotorua caldera. Situated 25km west-northwest of Mt. Tarawera, Rotorua has a population of over 64,000. Photo: GNS Lloyd Homer.

Research on Volcanoes

A SUMMARY OF WHO'S DOING WHAT IN THE AREA OF VOLCANOLOGICAL RESEARCH AROUND NEW ZEALAND

AT THE INSTITUTE OF GEOLOGICAL AND NUCLEAR SCIENCES

- Dr Colin Wilson (c.wilson@gns.cri.nz) – Physical volcanology. Studies explosive volcanic eruptions.
- Brad Scott (b.scott@gns.cri.nz) – GeoNet, Volcano Surveillance.
- Dr Hugh Bibby (h.bibby@gns.cri.nz) –specialising in electrical techniques for imaging subsurface hydrothermal and magma systems.
- Grant Caldwell (g.caldwell@gns.cri.nz) – specialising in electrical techniques for imaging subsurface hydrothermal and magma systems.
- Dr Bruce Christenson (b.christenson@gns.cri.nz) – gas and water chemistry from active volcanoes.
- Dr Cornell de Ronde (c.deronde@gns.cri.nz) – focus on submarine volcanism.
- Dr Mike Hagerty (m.hagerty@gns.cri.nz) –modelling of seismic waves associated with magma movement.
- Joy Hoverd (j.hoverd@gns.cri.nz) – specialising in volcanic stratigraphy in Auckland.
- Dr Tony Hurst (t.hurst@gns.cri.nz) – focus on Ruapehu and modelling ash distribution.
- Dr David Johnston (d.johnston@gns.cri.nz) – Focus on physical impacts to infrastructure and social impacts of volcanism worldwide.
- Dr Graham Leonard(g.leonard@gns.cri.nz) – volcanic stratigraphy and integrated warning systems.
- Dr Vern Manville(v.manville@gns.cri.nz) – specialsing in lahars and sediment response.
- Steve Sherburn(s.sherburn@gns.cri.nz) – focusing on seismic modelling of Taranaki.
- Dr Nicki Stevens (n.stevens@gns.cri.nz - Specialises in volcano deformation from satellite radar interferometry.
- Dr Cindy Werner (c.werner@gns.cri.nz) – specialising in gas chemistry and monitoring of gas emissions.

AT MASSEY UNIVERSITY

- Prof Vince Neall (v.e.neall@massey.ac.nz) specialises on the hazards at Ruapehu and Taranaki/Egmont volcanoes.
- Dr Shane Cronin (s.j.cronin@massey.ac.nz); focuses on the physical volcanology of, and hazard management for the andesitic volcanoes of New Zealand.
- Dr Jérôme Lecointre (j.a.lecointre) understanding the properties and hazards of mass-flows at stratovolcanoes and current research at the major New Zealand composite volcanoes.
- Dr Bob Stewart (r.b.stewart@massey.ac.nz) volcanic petrology and geochemistry, especially in terms of understanding magma generation and storage processes and the implications of these for eruption dynamics at Ruapehu and Egmont volcanoes.
- Dr Alan Palmer (a.s.palmer@massey.ac.nz) works with other national research agencies on using tephra layers to understand landscape change, fault movement and sedimentary basin development in Gisborne, Hawkes Bay and Wanganui/Rangitikei.
- Dr Cleland Wallace (r.c.wallace@massey.ac.nz) focuses on the geochemical and petrological identification and use of volcanic ashes (tephrochronology) to understand erosion and landscape development processes throughout New Zealand.
- Also within the Massey Group there are currently ten research students working on physical volcanology themes at Egmont/Taranaki, Ngauruhoe, Ruapehu and Vanuatu volcanoes.

AT THE UNIVERSITY OF CANTERBURY

- Professor Jim Cole (jim.cole@canterbury.ac.nz) has an overall interest in the volcanic geology of the Taupo Volcanic Zone (TVZ). His particular interest is in the silicic calderas of central TVZ. He is currently leading a group looking at the effects of ash on urban and rural environments.
- Professor Steve Weaver (steve.weaver@canterbury.ac.nz) is interested in the petrology and geochemistry of volcanic rocks in New Zealand, and the relationship between magma chemistry and tectonics.
- Dr Tim Davies (tim.davies@canterbury.ac.nz) focuses on rock avalanche dynamics, including volcanic avalanches; landslide dam-break aggradation, dynamic rock fragmentation in large-scale geomorphic processes, and natural hazard management.
- Current student research projects include the vulnerability of components of infrastructure to volcanic ash; volcanic risk management and evacuation planning for the Auckland Volcanic Field; and evaluating the potential effects on infrastructure of a larger scale andestitic eruption from the Tongariro volcanoes.

AT THE UNIVERSITY OF OTAGO

- James White (james.white@stonebow.otago.ac.nz) With Vern Manville and Colin Wilson of GNS, he and his students are investigating sedimentary responses to volcanic eruptions, particularly large rhyolitic ones. Related work in New Zealand addresses specific aspects of New Zealand's explosive Rotomahana (Tarawera) eruption in 1886.
- Alan Cooper (alan.cooper@stonebow.otago.ac.nz).He has students working on young volcanic rocks in Antarctica to help assess the development of the Ross Sea Embayment. This is in relation to the ANDRILL programme led by Gary Wilson (gary.wilson@otago.ac.nz) which is designed to use sediment cores from the seafloor around Antarctica to reconstruct timing and intensity of past glaciations and climate changes.

AT THE UNIVERSITY OF WAIKATO

- Prof Richard Price (r.price@waikato.ac.nz): The origins of magmas and nature of the magmatic processes occurring beneath Ruapehu and Taranaki volcanoes and the volcanoes of the Kermadec Islands.
- Assoc. Prof Roger Briggs(r.briggs@waikato.ac.nz): The origins of magmas and the processes occurring within the complex, shallow magma reservoirs of caldera volcanoes in the Coromandel and Taupo volcanic zones.
- Assoc. Prof. David Lowe (d.lowe@waikato.ac.nz): Correlation of tephra units especially cryptic (hidden) tephras to expand dossiers of New Zealand's eruption history, and dating key eruptions to enable past environmental changes in the New Zealand region to be linked and compared with global records.
- Dr Richard Smith (rtsmith@waikato.ac.nz):Research focuses on understanding and modelling the hazard processes and physical impacts of explosive eruptions, in particular from Tongariro cone complex, and the Taupo and Okataina calderas.
- Dr Barbara Hobden (b.hobden@waikato.ac.nz): Establishing the mechanisms and timing of shallow magmatic processes at Ruapehu and Tongariro volcanoes.

AT THE UNIVERSITY OF AUCKLAND

- Associate Professor Ian Smith (ie.smith@auckland.ac.nz) is a specialist in the processes that produce the magmas in volcanic systems. He is actively working on projects dealing with the origin and evolution of volcanic systems at Ruapehu, Taranaki and the Auckland volcanic field and is also involved in volcanic studies in Papua New Guinea and Vanuatu.
- Dr Phil Shane (pa.shane@auckland.ac.nz) is currently working on the eruption history of Okataina volcano. Work also focuses on the history of volcanic ashfall from both local and distal volcanoes in the Auckland region.

On the Web

Some great websites for information on volcanoes and emergency management

National

www.civildefence.govt.nz

Information, tools, and resources to assist with implementing emergency management practices and solutions across New Zealand. Also useful links to local authority websites.

www.geonet.org.nz/

The New Zealand GeoNet Project provides real-time monitoring and data collection for rapid response and research into earthquake, volcano, landslide and tsunami hazards.

www.gns.cri.nz/what/earthact/volcanoes/

The Institute of Geological & Nuclear Sciences website offers a wide range of volcanic hazard services.

www.arc.govt.nz/volcanic/

Auckland Regional Council's website. Site also provides an overview of the volcanoes of Auckland.

International

http://volcanoes.usgs.gov/

The website of the United State Geological Survey, focusing on volcanic hazards. The site provides global updates on volcanic activity, information about risk reduction, and a wide variety of education resources.

www.geology.sdsu.edu/how_volcanoes_work

An educational resource that describes the science behind volcanoes and volcanic processes, sponsored by San Diego State University.

http://volcano.und.nodak.edu/vw.html

Maintained by the University of North Dakota, this website offers information on the most recent volcanic activity across the planet, and provides access to movie clips of eruptions and virtual tours of volcanoes.

www.geo.mtu.edu/volcanoes

This website aims to provide some simple fundamental concepts about volcanic hazards.

You can link to these sites, and more, from the Volcanoes pages at www.civildefence.govt.nz

Volcanic Hazard Risk Perceptions in New Zealand

Kirsten Finnis, University of Otago;
David Johnston and Douglas Paton, GNS

Understanding a community's perceptions of risk is an important part of any decision making process and should be considered an essential component in natural hazard management.

Assessing risk by focusing purely on the physical processes that cause it does not fully accommodate the public's assessment of risk. In the past this has led to problems in communicating hazard information and persuading the public to undertake appropriate mitigation measures. Research has shown that individual and societal perceptions of risk relate to planning behaviour, warning compliance and recovery.

RISK PERCEPTION

We are aware that people's understanding of risk and response to risk are determined not only by available scientific information or direct physical consequences, but also by the interaction of psychological, social, cultural, institutional and political processes. The practice of "unrealistic optimism" and "normalisation bias" also influences beliefs about risk and risk reduction behaviour. Unrealistic optimism describes the situation where risk is amplified by people underestimating the risk to them and overestimating the risk to others. Thus, while people may acknowledge risk in their community, they are more likely to attribute its negative impacts to others rather than themselves.

Normalisation bias results from people extrapolating a minor but rarely occurring hazard experience to a capability to deal with more serious consequences. Both these processes result in people underestimating risk (relative to scientific and planning estimates) and acting in ways that are counterintuitive.

At the opposite end of the spectrum is the phenomena termed 'social amplification of risk'. This problem arises when risk information communicated by sources, such as the media, overemphasises adverse or catastrophic aspects of a problem and fails to provide a balanced view. This was clearly evident during the 1995-1996 Ruapehu eruption. Much of this "social amplification" was fuelled by the media coverage which brought dramatic images of the eruption to people throughout New Zealand and the world. It can also arise in situations where there is a lack of trust in information sources, particularly when these sources dismiss the concerns, needs and interests of the community. Considerable attention, therefore, must be paid to tailoring risk communication messages to each group in the community as well as accommodating hazard source and impact characteristics, perceived personal consequences and effective reactions to the hazard information.

Another issue to consider is that changing risk perceptions alone will not necessarily bring about behaviour change or increased action to address a particular risk issue. Rather, it is a function of a person's thoughts, behaviour and interaction with their environment that governs the relationship between perceived risk and risk reduction actions. People may not be motivated to prepare if they do not perceive or accept their risk status or perceive hazards as more important. Irrespective of the level of risk, action will be constrained if people perceive hazard effects as insurmountable (low outcome expectancy), do not perceive themselves as having the competence to act (low self efficacy), or are not disposed to action (low action coping). Risk perception may not lead to action if people lack resources for implementation (low response efficacy), transfer responsibility for their safety to others (low perceived responsibility), lack trust in information sources, or because of uncertainty regarding the likely timing of hazard occurrence.

A summary of findings from studies investigating risk perceptions of populations proximal to, or potentially impacted by, volcanic hazards from the Auckland Volcanic Field (AVF), Mt. Ruapehu and Mt. Taranaki/Egmont, are presented in this article.

The majority of Auckland's 1.3 million people reside on the potentially active Auckland Volcanic Field (AVF). In a survey of Auckland residents in 2000, while 92% were aware that Auckland is built on a volcanic field, over 67% perceived it as being dormant.

These studies use determinant factors such as hazard awareness, proximity to a volcano, perceived likelihood of future disasters, level of impact and past experiences of disaster impact.

AUCKLAND

The majority of Auckland's 1.3 million people reside on the potentially active Auckland Volcanic Field. This field covers approximately 360km² and extends from Manuwera in the south to Takapuna in the north and contains about 50 volcanoes. While none of the existing volcanoes are expected to erupt again, a new volcano may erupt in this field at any location, at any time. Due to this random nature and the large population, only a relatively small eruption will be enough to cause major problems. Auckland is also capable of being affected by tephra fall from eruptions originating in the Taupo Volcanic Zone (TVZ) and from Mt. Taranaki/Egmont. The 1995/96 Ruapehu eruptions resulted in only ~1mm of ashfall on Auckland, but this was enough to cause disruptions to essential services and transport.

Following a volcanic hazard information campaign (poster distribution) produced by the Auckland Regional Council, GNS and the Earthquake Commission, a study by Ballantyne and others (2000) found that nearly all of the Auckland residents surveyed (92%) were aware that Auckland is built on a volcanic field. However, a majority viewed the AVF as being dormant (67%), rather than potentially active. Just over half (55%) thought that Auckland is prone to volcanic eruptions and less than half (47%) perceived that a volcanic eruption is likely in the next 50 years. Although these results were marginally better than the pre-information campaign results, increased awareness of the volcanic nature of the Auckland region did not translate into increased perceived risk of this hazard.

Two questions in the study further examined risk perceptions through testing recall of information specific to the poster.

Firstly, the poster stated that the largest last eruption in Auckland was the eruption of Rangitoto, about 700 years ago.

Yet only a low percentage (12%) of respondents correctly recalled that the last major eruption in Auckland occurred between 500-700 years ago and over a third (35%) were unsure of the timing.

Secondly, the poster stated that it was unlikely that a future eruption would occur at the site of an existing cone.

Over half the respondents (53%) 'recalled' that the next eruption will occur from an existing cone, with only a third (31%) correctly stating that an eruption will occur in another location.

As understanding of these issues remained relatively poor, so did risk perception. The fact that a majority of the respondents perceive a threat from an existing cone causes problems as those not living close to a cone will perceive little risk. As acknowledged in the report, future information campaigns need to examine better ways of presenting material for more effective uptake of such information.

In a more recent study by Sheehy (2002) residents' perceived risk of tephra fall from a volcano outside the Auckland Region was also found to be poor. When given a series of options for when ash last fell on Auckland (Never, Last 10, 100, 1000, 10,000 years, and don't know) approximately a third (29%) answered correctly (within the last 10 years). Roughly another third (30%) didn't know, and the majority of the remainder responded between the last 100 to 10,000 years. Although the closure of the airport from the 95/96 Mt. Ruapehu eruptions cost the city in excess of $1 million, seven years later this does not seem to have been remembered nor affected respondents' risk perceptions.

MT. TARANAKI/EGMONT

Mt. Taranaki/Egmont's last eruption has been dated to 1755AD and the volcano is considered to be dormant. Moderate to major sized eruptions have been found to occur on average every 330 years. Even though the next eruption may be outside our lifespan, hazards are not only generated by eruptions. Heavy rain can trigger debris avalanches and secondary lahars. The most recent of these occurred in the Oaonui Stream in 1998, which caused damage to Opunake's water supply. In the event of an eruption, pyroclastic flows, debris avalanches, lahars and ashfall are the hazards most likely to affect the surrounding communities. Depending on wind direction, ash may be dispersed as far as Hamilton, Taupo and Palmerston North.

The volcanic hazard risk perceptions of residents in the towns of Stratford, Opunake and Inglewood, and others in more rural areas were investigated in a recent (2002) study (Finnis, in preparation). The survey respondents believed that a volcanic eruption poses a moderate threat to their personal safety, daily life and property. Respondents from rural areas perceived an eruption to have a greater impact on their daily life and property, commenting on a greater concern for their livestock than for their own safety. Less than 15% of respondents had ever experienced an eruption and for most this was simply witnessing the 1995/96 Mt. Ruapehu eruptions.

In relation to the timing of the next eruption of Mt. Taranaki, respondents generally thought that as time passes, the chance of there being an eruption also increases, but not to the extent that an eruption is likely in their lifetime. Respondents did not tend to believe that volcanic eruptions are too destructive to be bothered preparing for, but were not fully convinced that adopting preparedness measures would reduce damage. Less than half (45%) of the respondents had seen the Taranaki Volcanic Hazard Map, less than a third (32%) knew of the Taranaki Volcanic Contingency Plan and less than a quarter (22%) knew which evacuation zone they live in.

As for preparedness, residents felt that their 'local council' is most prepared for a hazard event (although only marginally prepared), followed by 'central government', then 'their own community' and generally they see themselves as unprepared.

These results show that residents who live in communities around the volcano have a low perception of risk of volcanic hazards from Mt. Taranaki/Egmont. Despite extensive education efforts of the Taranaki Regional Council, many do not think that 'the beautiful

The closure of airspace during the 1995/96 Ruapehu eruptions significantly disrupted activities.

mountain in their backyard' will ever erupt again. This denial limits the amount of information residents are willing to take in when presented with it, as they do not acknowledge its necessity.

MT. RUAPEHU

Mt. Ruapehu has been active and generated major hazard events within living memory of most New Zealanders. In 1945, explosive eruptions spread volcanic ash from Wellington to the Bay of Plenty. Eight years later the Crater Lake, which had filled to a level 8m above the pre-1945 level, collapsed, rapidly sending 1,650,000 m^3 of water down the Whangaehu River. Through entraining debris down the river, a substantial lahar was formed. Reaching its peak discharge 42 km downstream at Tangiwai the lahar took out the rail bridge, just before the Wellington-Auckland passenger train crossed it, killing 151 people.

Further hazardous lahars, caused by the displacement of Crater Lake water in 1969, 1971 and 1975, flowed north down the Whakapapa skifield and south down the Whangaehu River, with two of these events causing extensive damage to skifield facilities and to alpine huts. In September 1995, the volcano produced numerous lahars, one of which flowed down the Whakapapa Skifield minutes after closing time. Eruptions in 1995 and 1996 also spread ash from Auckland to Hawke's Bay.

Risk perception and understanding of volcanic hazards was examined by Johnston and others (1999) in two communities (Whakatane and Hastings) both before and after the Mt. Ruapehu eruptions of September-October 1995. While both communities received intense media coverage of the eruption, only Hastings directly experienced the eruption in the form of ashfalls. The change found in risk perceptions between the two communities as a result of the 1995 eruption was interesting.

In Whakatane, prior to the 1995 eruption, volcanic eruptions were thought to have a possible moderate impact on personal safety. Following the eruptions there was little change to this perception. However, Hastings residents who were surveyed thought prior to the 1995 eruption that volcanic eruptions were unlikely to threaten their personal safety and continued to think this, although slightly less so, after being subjected to ashfalls from the eruption. In regard to the perceived ability of volcanic eruptions to disrupt daily life, Whakatane respondents felt disruption was 'likely' both before and after the eruption. Hastings respondents changed their opinion from 'unlikely' before the eruption to close to neutral after the eruption. When asked if the eruption had changed their view of potential volcanic hazards in their region, 45% of Whakatane respondents claimed that the eruption had, compared with 61% of Hastings respondents. The main agents for change in perceptions were social sources, such as newsmedia and authorities (eg. Civil Defence, GNS) for Whakatane respondents and personal experience for Hastings respondents. So, although the direct effect of the 1995 eruption of Mt. Ruapehu did enhance Hastings residents' threat knowledge and risk perception, Whakatane residents still perceived a higher risk from volcanic eruptions.

Perceived level of preparedness was also reported on. Before the eruption, 66% of Whakatane respondents claimed to have undertaken protective measures, this figure remaining unchanged after the eruption. 63% of Hastings respondents claimed to have undertaken protective measures prior to the eruption, dropping to 53% following the eruption, showing that increased risk perception does not necessarily lead to better preparedness.

The perceived change in improved preparedness across central government, local government, the community and individuals was also examined. Whakatane respondents reported a significant perceived improvement in central government preparedness following the eruption, whereas Hastings respondents reported significant improvement in preparedness across all groups. The increased risk perception in Hastings respondents, combined with a reduction in preparedness activities and general increase in perceived preparedness suggests that the relatively benign effect of the eruption led to normalisation bias (where people experience a rare, minor event and extrapolate that they can deal with more serious consequences) in Hastings residents.

More recently, studies by Galley and others (2003) and Leonard and others (2004) have investigated public risk perceptions at Whakapapa ski area in conjunction with testing the effectiveness of the Eruption Detection System (EDS). In both studies, nearly all respondents knew that Mt. Ruapehu is an active volcano (96% in 2000 and 94% in 2003). The correct timing of the next eruption likely to affect the ski area (within the next 10 years) increased significantly from 48% in 2000 to 59% in 2003, possibly due to increased uptake of information presented at the Department of Conservation (DoC) information centre in Whakapapa Village. Although a majority of respondents had a good and increased knowledge that the ski area will be closed in the event of hazards such as lahars, lava flows, volcanic bombs, gas and ash (each over 60% in 2000 and 76% in 2003), the awareness of lahar danger zones on the ski area was relatively low and decreased. In 2000, 21% of respondents knew all the danger zones, 28% knew some, and 52% knew none. In 2003, this dropped to 5% of respondents knowing all the danger

A number of agencies such as GNS, the Earthquake Commission, and the Department of Conservation are working together with civil defence staff on initiatives to raise public understanding of volcanic hazards.

zones, 24% aware of some and 72% not knowing any danger zones. Even though volcanic hazard risk perception and awareness is increasing amongst patrons of the Whakapapa ski area, it once again has not led to 'better prepared skiers' as they are not seeking out where these hazards will occur. In an attempt to solve this problem, Ruapehu Alpine Lifts, DoC, GNS and civil defence have produced posters and fact sheets on volcanic hazards at Whakapapa, which include a large map clearly illustrating where hazards are likely to occur, for distribution during the 2004 ski season.

CONCLUSION

In general, the data to date show that the understanding of the volcanic risk by residents threatened by the effects of volcanic eruptions and associated hazards needs improving. Factors such as threat knowledge, proximity to volcano, perceived likelihood of future disasters, level of impact and past experiences of disaster impact, which are commonly used to determine risk perceptions, do not particularly hold for these populations.

In order to change people's risk perceptions future work should not only concentrate on providing scientific information on the hazards. Nor should it be expected that residents in communities who have been previously impacted by an event or live with the constant or close reminder of volcanic activity automatically have high risk perceptions (leading to the expectation that they will be more ready for an event).

The psychological, social, cultural, institutional and political processes influencing how individuals and communities think about volcanic risk must be understood. Risk perception is important in the preparedness process, as it is needed to initially motivate people into preparing for hazard events, and needs to be adequately raised before people will contemplate making their homes and families safer. It is, therefore, essential that before embarking on new campaigns, means of changing and assessing the public's risk perception be thoroughly explored so they do not revert to old, ineffective ways.

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BE PREPARED

There are seven active volcanic regions in New Zealand. Those living in these regions are at risk from volcanic ash, debris and lava flows. A major eruption can deposit huge quantities of ash across vast areas creating serious problems for both urban and rural communities. We can't prevent disasters. But each one of us can take some simple steps to ensure we will be better prepared to cope when they occur.

Disasters can strike at any time and often without warning. Know what to do before you have to do it.

Before an Eruption Occurs

- Discover whether there are volcanic hazards likely to affect you.
- If you live in an active volcanic zone, assume that you may have to deal with the effects of an eruption.
- If you live in an area that could experience a lava flow during a volcanic eruption, know a quick route to safe ground.

When an Eruption Threatens

- If volcanologists agree that a life-threatening eruption is likely to take place, a civil defence emergency will be declared and the danger area evacuated.
- Listen to your radio for information and follow civil defence advice.

During an Eruption

- Save water in your bath, basin containers or cylinders at an early stage – supplies may become polluted.
- Stay indoors with your pets as much as possible.
- Wear mask and goggles if you go outside, to keep volcanic ash out of your eyes and lungs.
- Keep gutters and roof clear of ash – heavy deposits can collapse the roof.
- Take your outdoor clothing off before entering a building – volcanic ash is difficult to get rid of.
- Take your Getaway Kit with you if you have to leave. Turn electricity and gas off at the mains.

AT HOME

Develop a household emergency plan which includes:

- Who is responsible for checking essential items in your Emergency Survival Kit
- How to turn off gas, water and electricity at the mains
- How to maintain contact with each other during an emergency
- How to contact your local civil defence organisation for assistance during an emergency

Know the local Civil Defence warning system. If possible, know the location of your nearest Civil Defence or Community Emergency Centre. It is also useful to learn First Aid and how to control small fires, and escape from a fire.

IN YOUR STREET

Join or form a neighbourhood support group. You and your neighbours will have skills and resources that can be vital in an emergency. Start discussing today what you can do to assist each other. Contact the Police for advice.

Become a civil defence volunteer. Ask your local civil defence organisation how you can help.

EMERGENCY SURVIVAL KIT

If you prefer to keep your Emergency Survival Kit items in the house for everyday use, make sure you know where to find them when an emergency occurs.

FOOD AND WATER – ENOUGH FOR 3 DAYS

- Canned or dried food
- A can opener
- A primus or BBQ to cook on
- Bottled water (at least 3 litres per person per day)

Check and renew the food and water every 12 months.

EMERGENCY ITEMS

- First Aid Kit and essential medicines
- Spare toilet paper/plastic rubbish bags for emergency toilet
- Pet supplies
- Waterproof torches and spare batteries
- Radio and spare batteries

Check the batteries every three months.

SUPPLIES FOR BABIES AND SMALL CHILDREN

- Food and drink/clothing/favourite toy

SPECIAL SUPPLIES FOR THOSE WITH DISABILITIES

- Hearing aids/Mobility aids/Glasses

EMERGENCY CLOTHING

- Windproof and rainproof
- Sun hats
- Blankets or sleeping bags
- Strong shoes for outdoors

Put all items, especially blankets and clothing, into leak proof plastic bags.

Download your household emergency checklist from: www.civildefence.govt.nz

YOUR GETAWAY KIT

Everyone should have a small bag for a Getaway Kit, ready for evacuation. Most of the items are part of your Emergency Survival Kit. Other items include:

Family Documents

- Birth/marriage certificates
- Family photos
- Drivers licences/passports
- Insurance policies

Personal Hygiene Items

- Towels/soaps & toothbrushes
- A change of clothes

PEOPLE WITH DISABILITIES/SPECIAL NEEDS

If you have a disability, make arrangements with a family member, friend, or neighbour to help you in an emergency.

People with hearing impairment may not be well served by radio. Make arrangements to be sure you are informed by somebody.

People with sight impairment may have difficulties if their home is disrupted and may have extra difficulties in an unfamiliar Civil Defence Centre. You should arrange some form of "buddy" system.

People with asthma and other respiratory disorders may be especially affected by stress, dust or volcanic ash. Have plenty of medicines and face masks in your Emergency Survival Kit.

If you have special food needs, be sure to include as much as you can in your Emergency Survival Kit.

CIVIL DEFENCE

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