



TEPHRA

KIA TAKATU TAHI TATOU

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EARTH MOVEMENTS



Te Rākau
Whakamarumaru

Ministry of Civil Defence
& Emergency Management

From the Editor

EARTH MOVEMENTS



Aotearoa, the land of the long white cloud. A land which many of us think of as our little piece of paradise. It is also, however, a land where Earth does unleash her fury. And when she does, the effects can be both phenomenal and devastating. From floods and storms, to earthquakes and volcanoes, hazards are very much a fact of life in New Zealand.

New Zealanders may feel about 200 earthquakes a year, and thousands of smaller ones are recorded as well. The experts tell us with unnerving conviction that we can expect a major earthquake in the next 20-40 years on the Alpine Fault, which runs up the spine of the South Island. A rupture of the Alpine Fault would produce one of the biggest earthquakes since European settlement of New Zealand, and have a major impact on adjacent communities.

As a country on the Pacific Ring of Fire, New Zealand is also at risk of devastating volcanic eruptions. Auckland, our largest city, is built on a volcanic field. And in 1995 and 1996, the Mt Ruapehu eruptions were only gentle reminders of the impact that volcanoes can have on our communities. Scientists expect the Crater Lake to overflow sometime between late 2002 and 2006, with the threat of a lahar flow potentially 90% larger than the Tangiwai disaster of 1953, when 151 New Zealanders lost their lives.

We have also had a surprisingly large number of landslide disasters – the 1983 Abbotsford Landslide, the spectacular 1991 Aoraki/Mount Cook rock avalanche, and the landslides triggered around Gisborne during Cyclone Bola in 1988, and the 1976 floods in Wellington.

Over the last few years, Tephra has sought to provide a scientific and educational platform for helping New Zealanders understand better the hazards that we face. The journal aims to bring together relevant information on the leading edge work that is being done by scientists and researchers in New Zealand, and illustrate how that knowledge is applied around the country. The case studies from councils on how they have dealt with, or are preparing to deal with particular hazards, are aimed at providing practical information for all those involved in the civil defence emergency management sector.

This issue looks at Earth Movements in New Zealand – landslides, subsidence, lahars and volcanic eruptions, and of course, earthquakes. The articles

seek to help us to understand better what causes the hazards and what they can do to us. And more importantly, what we can do to reduce the impact of these hazards on our communities when they do occur, and how we can be better prepared to respond and recover from them.

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Cover illustration: An artist's impression of earth movements by Gary Gibson

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An **EARTH MOVING EXPERIENCE** in New Zealand



*by Dick Beetham, John Beavan
and Nicki Stevens, GNS*

After torrential rain in 1979, seven landslides occurred from cliffs at Omokoroa overlooking Tauranga Harbour. The landslides created waves a metre high in the harbour. (Photo: Lloyd Homer, GNS)

Not only are we being transported at amazing speeds as our planet Earth circles around the Sun as part of the solar system, and our solar system hurtles through space as part of our galaxy, but the very ground we live on and regard as stable is also moving. These ground movements take a variety of forms and rates, from subtle, imperceptible movements of the huge tectonic plates that cover the globe, to extremely rapid landslides.

The Earth's crust is made up of tectonic plates that are moving relative to one another. Although some plates move at rates of up to 100 millimetres per year, in New Zealand our tectonic plates shift about 40 to 50 millimetres per year. New Zealand straddles two major plates. Much of the New Zealand land mass— the North Island, northwest Nelson and the West Coast— is on the Australian Plate, while the remainder of the South Island— Marlborough, Canterbury, Otago and Southland— is on the Pacific Plate. The Alpine Fault, along the western foot of the Southern Alps, is the

boundary between the two plates in the central South Island. For the North Island the plate boundary is the subduction zone, a region off the eastern coast where the Australian Plate is overriding the Pacific Plate. Here the Pacific Plate is sinking down into the Earth's interior. Most of the earth movements we experience in New Zealand can be related back to these plate movements.

Many of the natural hazards we face in New Zealand— earthquakes, volcanoes and landslides— result from earth movements generally related to plate tectonics.

EARTHQUAKES

The movement of tectonic plates— where the plates push against and override each other— can cause stresses to build up in the rocks of the Earth's crust. Eventually the rocks rupture, causing an earthquake. Where the rupture breaks the surface, we see fault lines, such as the Alpine Fault and Wellington Fault. Many earthquakes are tiny, occurring when only a few metres of a fault break during an event, while some are huge. In the 1855 earthquake in the Wairarapa, the countryside ruptured over a length of 150 kilometres, with the two sides of the fault moving past each other by up to 12 metres.

LANDSLIDES

The tectonic movements and earthquakes also cause uplift and the formation of mountain ranges, such as the Southern Alps and the North Island ranges. Once the hills, ranges and mountains are uplifted, landslides and other erosion processes shape them into the spectacular landforms we admire. New Zealand has many fine examples of a variety of different types of landslides.

VOLCANOES

Volcanoes typically form on the overriding plate along subduction zones. Wet sediments and rocks dragged deep into the crust along a subduction zone are heated as they descend, eventually melting and rising to the surface as magma (molten rock), and forming volcanoes. In New Zealand, the Taupo Volcanic Zone of the central North Island has many spectacular examples of awesome prehistoric volcanic eruptions and their products, as well as recently active volcanoes such as Ruapehu.

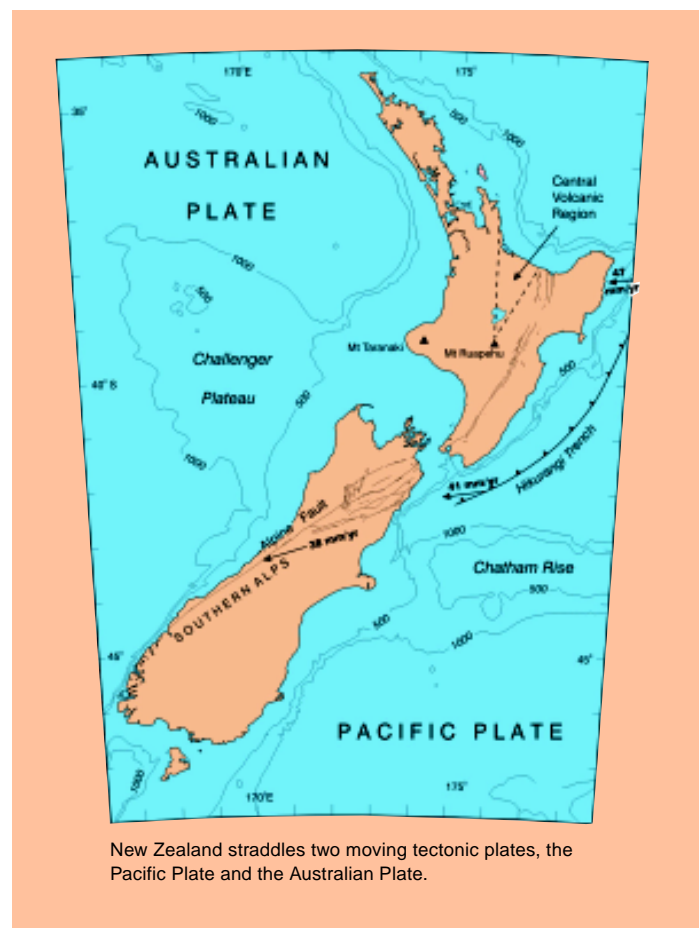
MEASURING EARTH MOVEMENTS IN NEW ZEALAND

Very small plate tectonic and other movements can now be measured directly using satellites and sophisticated electronics that were originally developed by the US to aid in military navigation and positioning. In New Zealand, Dr John Beavan of GNS has been a leader in the development and use of Global

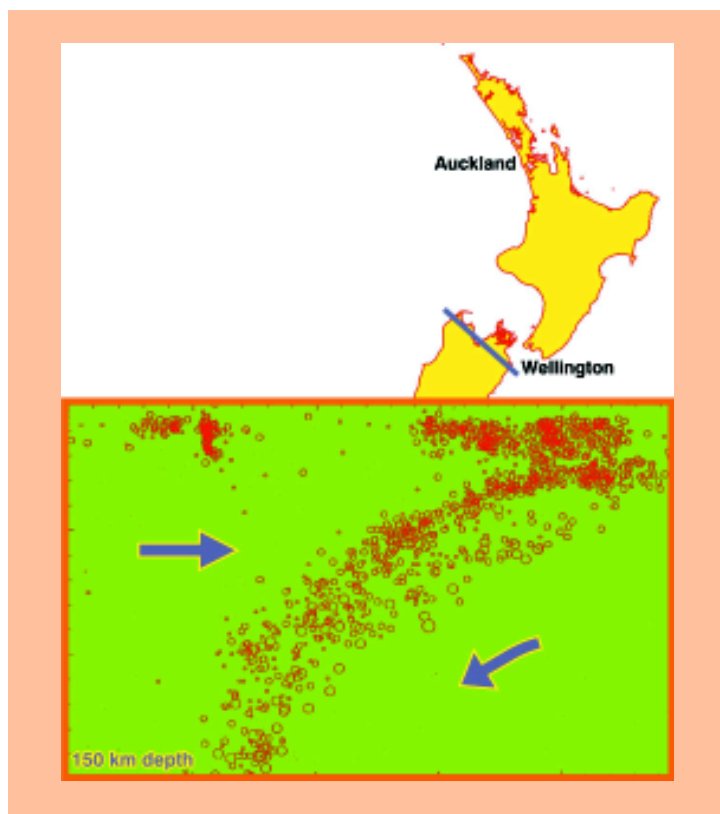
Positioning System (GPS) surveying for the direct measurement of earth movements. Further new technology developments in satellite- and aircraft-carried side-band radar are allowing the detection and measurement of small earth movements over large

In an average person's lifetime, Christchurch will move four metres closer to Australia, while Auckland will not move at all relative to Australia.

areas with unprecedented accuracy. Dr Nicki Stevens, also of GNS, is using her expertise to study the use and applications of these Synthetic Aperture Radar (SAR) methods in New Zealand.



The earth movements most familiar to us are the sudden and sometimes catastrophic motions due to earthquakes, volcanoes and landslides. But New Zealand is in fact being continuously deformed in response to the motion of two of Earth's great tectonic plates, the Australian and the Pacific. Indeed, it is the steady build-up of these slow and continuous motions that is directly or indirectly responsible for our occasional earthquakes, landslides and volcanic eruptions.



In this cross section across the northern South Island, earthquakes (red circles) reveal the presence of the Pacific Plate as it descends beneath the Australian Plate.

In an average person's lifetime, Christchurch will move four metres closer to Australia, while Auckland will not move at all relative to Australia.

As the two plates collide and move past each other at rates of up to five metres per hundred years, the region in between the plates is squashed, sheared, twisted and pulled apart. The eastern and southern North Island and Marlborough were originally part of the Australian Plate but they now lie in this "plate boundary deformation zone" between the two plates. Similarly, the Southern Alps are made up of Pacific Plate rocks which now lie in the deforming zone.

Different types of motion occur in different parts of the plate boundary deformation zone. In the central South Island the collision of the two plates has caused the uplift of the Southern Alps over the past five or six million years. In the North Island, the Pacific plate is descending (or subducting) beneath the east coast and causing a variety of deformation on the ground above. In the Wellington region, the island is being compressed— the east coast is presently moving towards the west coast at more than one metre per hundred years, so that the island is getting narrower. (This is what is happening at present, but next time we get a big subduction zone earthquake the island will widen again by several metres.) In the Taupo Volcanic

The east coast of the North Island is actually being pulled away from the Waikato so that Gisborne is moving away from Hamilton at more than one metre per hundred years.

Zone, by contrast, the east coast of the North Island is actually being pulled away from the Waikato in response to forces associated with the subduction, so that Gisborne is moving away from Hamilton at more than one metre per hundred years.

It is almost as if the east coast of the North Island— at least the part north of Hawke's Bay— is behaving as a small tectonic plate of its own, separate from either the Pacific or Australian plates.

Some of this information has been known for many years, based on geological and surveying work in New Zealand, and on global studies of plate tectonics. But in the last ten years the use of high-precision GPS surveying has allowed us to "see" the continuous deformation of New Zealand with unprecedented accuracy.

THE GLOBAL POSITIONING SYSTEM (GPS)

The GPS system consists of 24 satellites orbiting the Earth in 12-hour orbits and arranged in such a way that at least four, and often as many as nine or ten, satellites are in view at any one time from any position on Earth. Each satellite transmits a coded radio signal that can be picked up by a GPS receiver on the ground. If the GPS receiver can get a "fix" on four or more satellites, then the receiver can calculate its position. The receiver is rather like a surveyor, who can fix his or her position on the ground by taking sightings on two or more trig stations whose positions are known. The standard GPS receivers that are familiar to many yachtsmen and trampers are able to fix positions to an accuracy of roughly five metres. By using more sophisticated GPS receivers, and by using them in differential mode ie, measuring the differences between two or more receivers, we are able to measure distances between stations with an accuracy of a few millimetres, even for receivers separated by tens or hundreds of kilometres.

GPS CAMPAIGNS

Most of the high-precision GPS measurements made in New Zealand over the past 12 years have been made during GPS campaigns. A particular region of the country is targeted for a 1-3 week period, and measurements are made using up to 20 GPS receivers at a number of survey markers (such as benchmark or trig stations) throughout the region. To obtain the highest accuracy, measurements are usually made at

each survey mark for a period of about two days. Because of the millimetre-level accuracy obtainable with high-precision differential GPS, it is very important that the GPS antenna is positioned precisely above the ground survey mark, and that the survey mark has a firm and stable attachment to the ground.

GROUND MOTION FROM REPEATED GPS CAMPAIGNS

Using the data collected during a GPS campaign, the relative positions of all the survey marks occupied during the campaign can be determined to within a few millimetres. When the campaign is repeated, generally two to three years later, these positions will have changed slightly in response to plate tectonic motions and plate boundary deformation. Since the accuracy of each survey is a few millimetres, and the size of the plate tectonic motions in New Zealand can be anything up to 50 millimetres per year, it is possible to measure the

motion of each survey station quite accurately after only a few years. We usually show the motions of the survey stations in terms of their horizontal velocity, as on the map below.

The arrows on the map represent the amount and direction of motion at each point during any one year, relative to the Australian Plate. The arrows are very small in Auckland and Northland, as these areas are part of the Australian Plate. By contrast, the arrows are very large on the east coast of the South Island, as this area is on the Pacific Plate and is moving relative to Australia at about 40 millimetres per year (or 4 metres per century).

THE DEFORMATION MAP

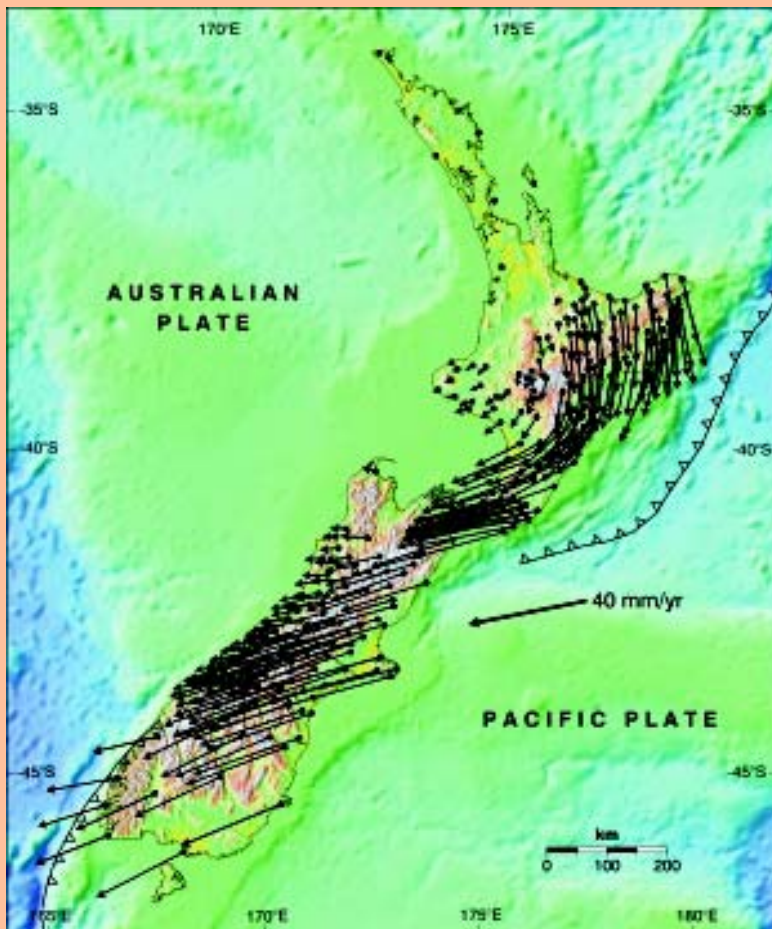
On the velocity map, if all the arrows are large but in approximately the same direction (as, for example, in Canterbury) it means that the motion of this area is quite large relative to Australia. However, because all the points are moving with about the same

velocity there is not much *deformation* happening. The highest rates of deformation normally occur where the velocities are changing most rapidly from point to point, ie, where nearby points are moving at different rates. We can plot this in several ways as a deformation map, which highlights the places where the velocities are changing most rapidly.

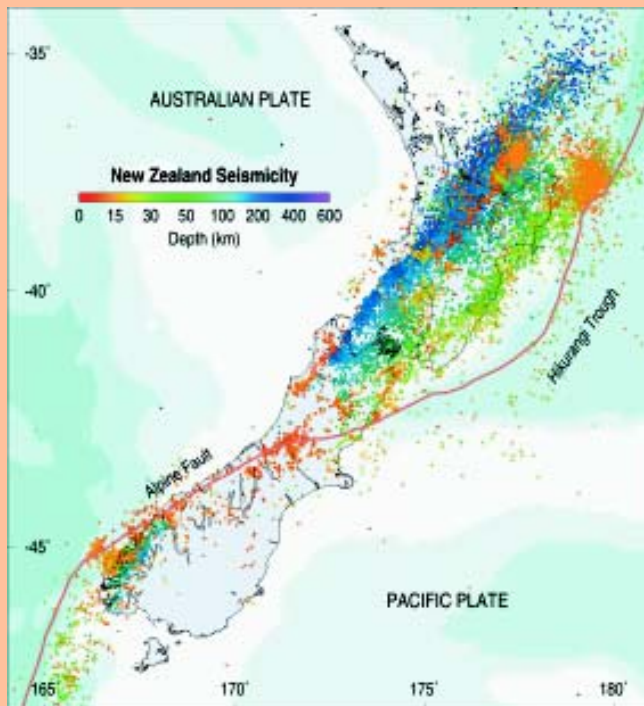
The deformation map highlights regions of shearing (or sideways sliding), with the most rapidly deforming regions shown in red. It can be seen that the highest rates of deformation are in the areas we previously described as being within the plate boundary deformation zone. Since the regions that are deforming most rapidly may well be those that experience the highest frequencies of earthquakes, this type of map is likely to be useful in improving regional estimates of earthquake hazard.

NEW ZEALAND'S SURVEY SYSTEM

Since it is now routinely possible to do GPS surveying with an accuracy better than the annual rates of plate tectonic motion, it has become vital for plate tectonic deformation to be allowed for within



This map shows the surface velocities, relative to the Australian Plate, of a number of geodetic sites in New Zealand. The velocities have been measured by combining repeated GPS observations made over the past 10 years. The arrow offshore of the east coast shows the magnitude and direction the Pacific plate is moving relative to Australia.



Numerous earthquakes shake the New Zealand region. This map shows the earthquakes that have occurred at varying depths in just five years.

New Zealand's land survey system. Land Information New Zealand (LINZ) recognised this a decade ago and since 2000 have instituted a new survey datum (NZGD2000) that accounts for ground deformation. The GNS velocity map is now used by LINZ to transform survey data collected at varying times to the way that data would have appeared if it had been collected on 1 January 2000. This enables all New Zealand survey data to be combined in a consistent manner.

CONTINUOUS GPS

The velocity map has been derived from GPS campaigns, with measurements taken every few years in many parts (though not yet all) of New Zealand. As time goes on, however, more and more *continuous* GPS stations are being installed in New Zealand. These are GPS receivers with antennas that are mounted on permanent ground marks such as specially-constructed reinforced concrete pillars. These receivers allow ground motions to be tracked continuously. Continuous monitoring is particularly important in

areas where we expect changes in motion to occur. It is known that changes in velocity occur following large earthquakes, due to the effect of the earthquake on the flow of hot rock in the lower crust and upper mantle. But it is also possible that ground deformation may occur in advance of some earthquakes, and such motions certainly occur prior to many volcanic eruptions, so that continuous GPS measurements may assist with forecasting such events.

CONTINUOUS GPS (CGPS) NETWORKS IN NEW ZEALAND

There are four high-accuracy continuous GPS networks currently operating or under construction in New Zealand.

Otago University and GNS operate four CGPS stations at the Auckland, Wellington, Lyttelton and Dunedin tide gauges. These are designed to measure the vertical ground deformation at these sites, so that the tide gauge records may be corrected for ground motion. This will enable the data from the tide gauges to be used to reliably estimate any sea level rise that may be occurring as a result of global warming.

The Massachusetts Institute of Technology, along with GNS and Otago University, are operating five CGPS stations across the Southern Alps south of Mt Cook in order to measure the rate and distribution of uplift of the mountains, and to use this information to understand more about mountain building processes.

LINZ is funding GNS to install a national network of continuous GPS, initially 15 stations in the



Surveyors Ashley MacFarlane and Kim Saunderson measure the height of the GPS antenna above a survey mark, at the start of GPS measurements in Fiordland.

North Island, that are designed to help maintain the national survey network and to support accurate surveying throughout the country. The North Island network will be fully operational by mid-2003.

Finally, as part of the Earthquake Commission-funded GeoNet network, GNS will be installing CGPS stations in regions where the risk of earthquakes and volcanic eruptions is particularly high, and where it is expected that time-varying deformation is likely to be important. The first two areas targeted under GeoNet will be the southern North Island and the Taupo Volcanic Zone.

RADAR INTERFEROMETRY

As well as GPS surveying, scientists at GNS also measure surface deformation via radar interferometry. This is a technique that uses pairs of radar images from satellites orbiting at an altitude of several hundred kilometres above the Earth. Radar images are obtained by broadcasting a pulse of electromagnetic radar energy towards the Earth, and by measuring what returns to the satellite.

In radar interferometry, the satellite images are acquired at different times, and any deformation occurring between the times they are acquired can be measured to centimetre accuracy. The technique is also



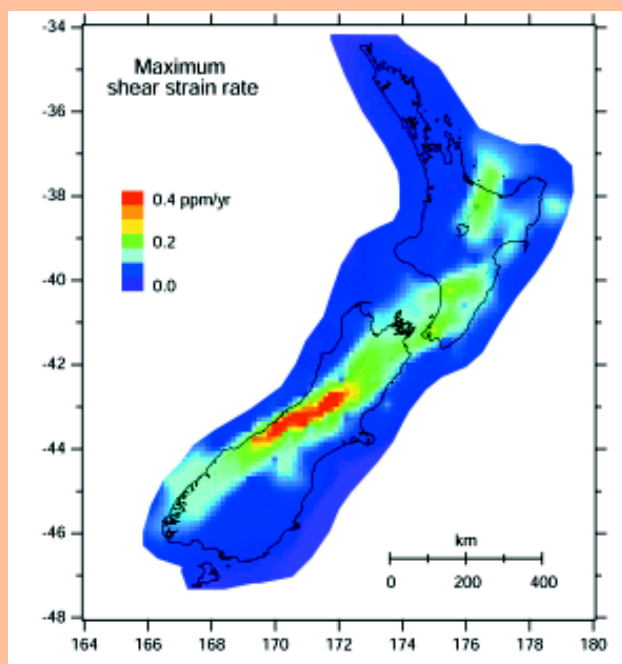
This continuous GPS site in the Southern Alps network is on Annette Plateau above the Tasman Valley, near Mt Sefton and Mt Cook. Measurements at this site are helping us to understand the growth of the mountains.

advantageous because, in ideal conditions, a measurement of deformation is obtained at 30 metre intervals across large areas. Radar has an added benefit— cloud cover does not affect measurements, a particularly important consideration in New Zealand, “land of the long white cloud.”

At first glance it seems impossible to be able to measure centimetre-scale surface movements from, in the case of the ERS-2, a satellite orbiting about 800



During the 1987 Edgecumbe earthquake, movement along the Edgecumbe fault opened up a rift across the countryside.



This map shows the amount of deformation by shear, or sideways sliding. It is highest under the Southern Alps, but belts of high shear deformation extend throughout both islands. Regions of high shear deformation are likely to be the sites of future earthquakes.

kilometres above the Earth. However, the technique is relatively straightforward. The two radar images are aligned exactly, so that each pixel in each image corresponds to the same point on the Earth's surface. The ERS-2 radar data then contains two components—the amplitude, which is a measure of the strength of the returning signal, and the phase, which is a measure of the sinusoidal nature of the radar electromagnetic wave, and at what point it reflected back from the surface to the satellite. It is the phase that is used for measuring the surface deformation. The wavelength of radar energy emitted from the ERS-2 satellite is 56 millimetres. If the phase of the signal shifts between images, this can be due to a number of things, including topography, atmospheric noise, and surface deformation. Radar interferometry is the art of measuring the phase shifts, and removing the effect of topography and atmospheric noise, thus leaving us with measurements of surface deformation.

At GNS a number of projects involve radar interferometry at various sites within New Zealand. Funded by the Foundation for Research, Science and Technology, we are applying the technique to plate tectonic motion in the Taupo Volcanic Zone and the Southern Alps. Under the Earthquake Commission's GeoNet funding, we are using the technique to monitor deformation of New Zealand's volcanoes (including the Auckland volcanic field). In addition, funded by the Earthquake Commission, we are measuring the

movement due to landslides in Dunedin.

One of the challenges we face is that the technique is adversely affected by moisture changes and by vegetation growth during the time between the acquisitions of radar images. However, the technique shows promise, especially in urban areas and sparsely vegetated areas such as the Desert Road near Ruapehu. Now that the European Space Agency has successfully launched the next radar-carrying satellite, ENVISAT, we will continue to use this technique to measure and explore surface deformation in New Zealand for many years to come.

THE FUTURE

By combining earth movement measurements from GPS, SAR and other sources with data obtained from records of seismic waves by seismographs, scientists in the future may be able to better forecast when and where volcanic eruptions, earthquakes and perhaps landslides are most likely to occur. This is certainly the expectation of the Earthquake Commission, who over the next ten years are helping to fund the renewal of seismic and GPS monitoring networks in New Zealand through a project called GeoNet (see the GeoNet article on page 49).

With a new and denser network of modern seismographs installed, all earthquakes occurring in the New Zealand region, including the small earthquakes that cause no damage and may not even be felt, can be accurately located in the Earth's crust. This will greatly improve our picture of where earthquakes are occurring and the stresses causing them. These stresses may be causing small movements on the surface that can be measured with GPS and radar interferometry, so that scientists can assemble a picture of the stresses and strains (movements) that are occurring in the crust before and after earthquakes.

Scientists know that there is commonly a period of unrest before a volcanic eruption occurs. Beneath a volcano in the magma chamber, a zone of molten rock deep in the crust, pressure will start to build up and the magma may move towards the surface prior to an eruption. The pressure build-up may cause the volcano to swell, with detectable bulging movements of the surface, and trigger small earthquakes as the crustal rocks deform. In addition, the upward movement of magma causes a distinctive type of small earthquake with a recognisable tremor. The length of unrest before an eruption may vary from days to years, but hopefully it will be long enough to allow threatened areas to be evacuated and emergency preparations to be made.

The Abbotsford Landslide



- its nature and causes

Above: A close view of some of the damaged houses that toppled into the graben. (Photo: Don Bird, EQC)

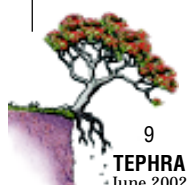
by Graham Hancox, GNS

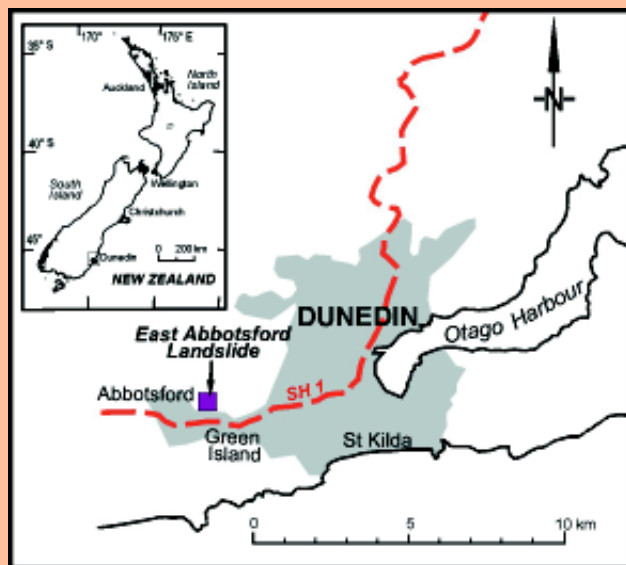
The East Abbotsford Landslide occurred on the night of 8 Aug 1979 in Abbotsford, a suburb of Green Island borough in southwest Dunedin. Because this landslide occurred in an urban area and caused unprecedented damage to dozens of houses, it is possibly New Zealand's most famous landslide in the last 50 years. It was later the subject of a Government Commission of Inquiry, whose primary tasks were to determine the cause of the disaster, whether actions by man contributed to its cause, and the adequacy of measures taken before, during and after the event (Commission of Inquiry, 1980). This brief summary describes the main features of the Abbotsford Landslide, and discusses some possible causes.

Today, almost 23 years after the dust has settled, the Abbotsford Landslide still offers valuable lessons about the causes of slope movements, both natural and man-made, and possible measures to avoid such disasters.

WHAT HAPPENED

The Abbotsford Landslide did not occur without warning. In June 1979 large cracks opened up through the suburb of Abbotsford, and over a period of more than two months a section of the suburb began to slowly creep downhill. The movements increased to a rate of about 100 to 150 millimetres per day in the week prior to the main landslide. The final rapid failure started at about 9pm on 8 Aug 1979 and lasted about 15 minutes. A large block of land, containing a number of houses and seventeen men, women and children, slid southwest towards Miller Creek. The block left behind it an arcuate trench (graben) up to 16 metres deep and 150 metres wide at the head. Because the movement of the landslide was slow and much of the





Map showing the location of the Abbotsford Landslide

block remained intact, no lives were lost and no one was injured. The stranded people were rescued within a few hours. The landslide resulted in the loss of 69 houses, which were either destroyed or rendered inaccessible by the graben. Surprisingly, many of the houses on the sliding block survived the landslide, and these were later transported to new sites away from the area.

The overall cost of the landslide disaster has been estimated to be about 10 to 13 million dollars.

A state of civil defence emergency had been declared and the area largely evacuated two days prior to the landslide, following intensive investigations, including drilling holes and monitoring cracks. These measures had correctly identified the imminent likelihood of slope failure, although not its precise timing. During the civil defence emergency, which lasted until 18 Aug, 450 residents left their homes and were not allowed to return until geotechnical experts were satisfied that it was safe.

THE NATURE AND GEOLOGY OF THE LANDSLIDE

The Abbotsford Landslide occurred on the end of a broad, gently sloping spur on the western side of Miller Creek, a small tributary of Kaikorai Stream. The block that slid covered about 18 hectares, and the landslide involved about 5 million cubic metres of material, largely sand and overlying colluvium up to 40 metres thick. The block slid about 50 metres, down layers within the underlying sediment sloping at about 8°. Although not particularly large by world standards, the landslide's urban setting and the spectacular damage made it headline news.

The landslide area is underlain by surface layers

of clayey loess (3-4 metres) and bouldery colluvium (5-10 metres) overlying Tertiary sediments (see the cross section on page 12). The Tertiary sediments include the uncemented Green Island Sand and the underlying Abbotsford Formation – a thick sequence of silty sand with clay layers and mudstone. The strata dip 6-8° southeast towards Miller Creek, which borders the landslide on its eastern side. Abbotsford was not the first landslide to occur in the area. Past instability of this slope is indicated by the presence of a prehistoric landslide, the Sun Club Slide, which occurred more than 10,000 years ago. The older landslide was incorporated in the northern block of the Abbotsford Landslide. The old slide was displaced downwards and southeast by about 39 metres – it remained essentially intact but it was wrinkled up, forming compression ridges in the toe area, as did the main slide block to the south.

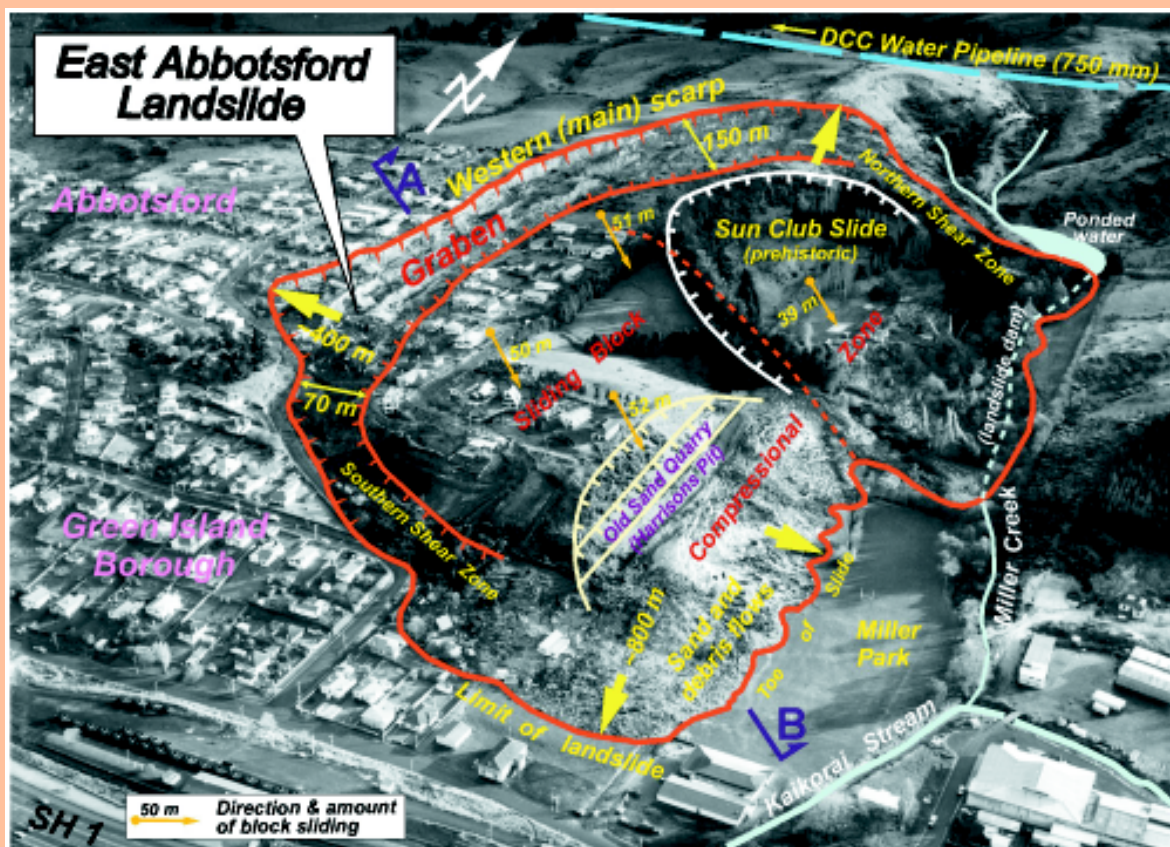
THE CAUSE OF THE LANDSLIDE

In order to determine both the future long-term stability of the landslide and its cause, intensive geotechnical work was carried out, including some 27 drill holes, shafts and test pits. The slide surface was located – it was about 10 metres below the ground surface, within thin clay layers in the top metre of the Abbotsford Formation. These clay layers showed well developed slickensides, and had very low residual shear strength. In the presence of significant (but not abnormally high) groundwater pressures, the strength of the clay was low enough to bring about failure.

A number of possible natural and man-induced causes were explored by several investigation teams, which shared all the basic information gathered before and after the landslide, and the information was presented in 89 submissions and supported by sworn evidence to the Commission of Inquiry. Many of the submissions related to the primary issues – namely the cause of the Abbotsford Landslide, and whether modifications to the land made by man had contributed to the disaster. The Commission sat for 58 days and produced their report in November 1980.

The Commission concluded that geological structure was the basic precondition for the failure. Foremost in this were the potentially unstable, thin, very weak clay layers, rich in a clay called montmorillonite, within the 6-10° dip slope. Contrary to the Commission's view, although very weak bedding plane clay layers are relatively rare, they are not unique in New Zealand. Landslides in Tertiary sediments in eastern and northern Otago, the central North Island and Wairarapa are often attributed to the presence of such layers.

Clearly, in the case of the Abbotsford Landslide,



Annotated aerial photo of the East Abbotsford Landslide looking northwest on 9 Aug 1979, the day after failure. A number of the houses on the sliding block survived the landslide and were later moved to other sites, but those that toppled into the graben were destroyed. Green Island Railway Station is in the left foreground. (Photo: Aeropix, Dunedin)

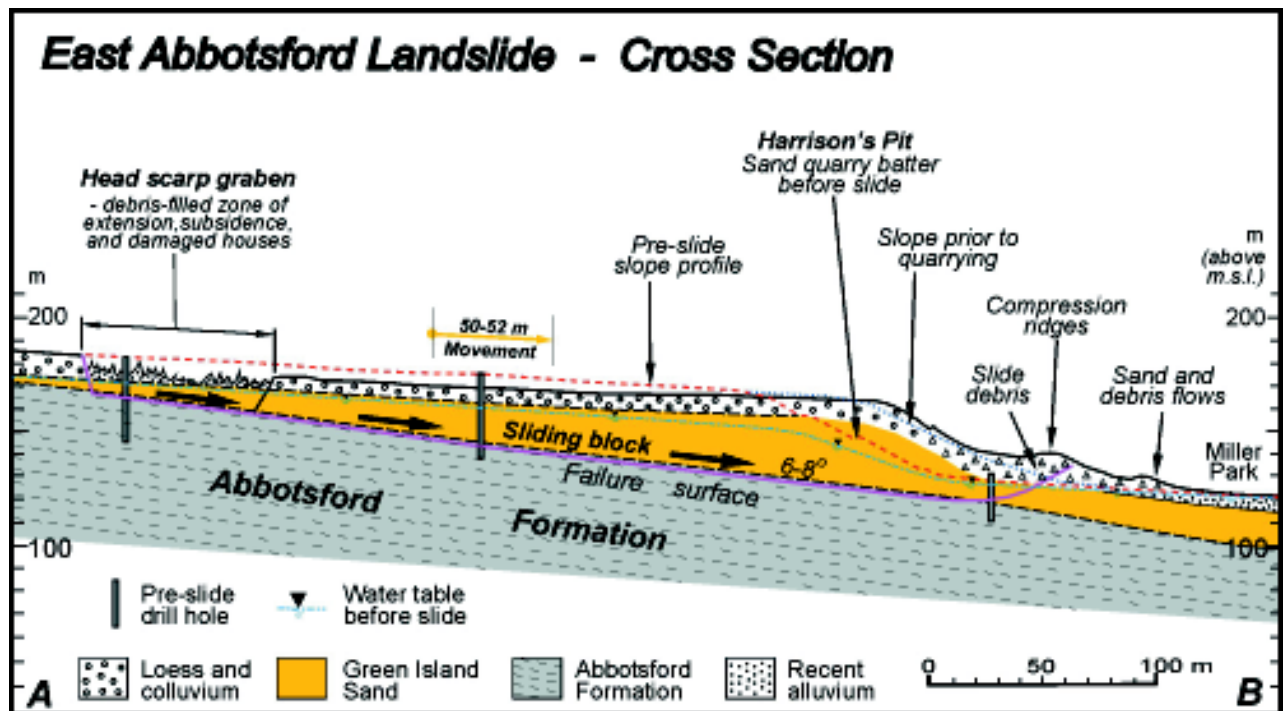
unfavourable geology and topography – the sediment layers dipping down slope and the thin clay layers – were the basic preconditions for the landslide. However, several other factors, notably a sand quarry at the toe of the slope, and high groundwater levels from greater than normal rainfall and a leaking water main above the slide area, also contributed to the failure.

Between 1964 and 1969, about 300,000 cubic metres of sand had been removed from Harrison's Pit, a sand quarry at the foot of the slope. An analysis showed that this reduced the stability of the overall slope by about 1%. A house about 80 metres south of the pit developed cracks in 1968 – this may have been caused by initial slope movements. Evidence of the movement that led to the Abbotsford Landslide first became apparent in November 1978, when water mains ruptured in Christie Street, about 250 metres upslope from the pit. Although sand excavation at the toe of the slope did not cause it to fail immediately, it clearly reduced the stability of the slope and, in combination with other factors, may have advanced the onset and timing of the failure. Therefore, from the evidence presented, the Commission found that the

excavation of Harrison's Pit was a causative factor in the landslide.

Because there was very little information about the slide area before it failed, in particular any accurate history of groundwater levels, the Commission considered it would never be possible to determine the proportionate effect of the pit excavation. For example, a similar 1% reduction in stability would have resulted from a uniform 0.3 metre rise in groundwater levels over the slide area. A rise in the long-term groundwater levels is thought probable, due to increased long-term rainfall and a leaking water main (a segmented concrete pipe with rubber ring joints) at the top of the slope above the slide area.

The volume of water that leaked from the water main is unknown, but the Dunedin City Council (DCC) estimated it was about 5 million litres per year since 1976. This represents an average leakage rate of 6-9 litres per minute, with 4-5 litres per minute likely to infiltrate the ground. The annual infiltration rate of rainfall into the slide is estimated to be about 12-13 litres per minute. The water leaking from the main since 1976 is thus equivalent to a 30-40% increase in rainfall over that period. It is likely, therefore, that the



Cross section through the Abbotsford Landslide showing its geology, the topography before and after the landslide, and other significant features (section location shown in aerial photograph).

combined effects of greater than average rainfall over the past decade and water from the leaking water main raised groundwater levels in the landslide area and advanced the onset of slope failure.

There isn't enough data on groundwater levels before the slide to precisely determine the effects of water leakage on the slide area. However, drilling records, together with extensive sand flows at the toe of the slide, suggest that groundwater levels in the landslide area at the time it failed were abnormally high. The Commission therefore decided that, although the exact amount of water from the leaking water main reaching the slide area was not known, it was probably sufficient for its effect on the slide mass to be significant.

DISCUSSION — LESSONS LEARNT

The main lessons to be learned from the Abbotsford Landslide are the inherent dangers of certain types of strata underlying urban areas, even areas with relatively gentle topography. This geological structure, together with unfavourable slope orientation, unwise positioning of a sand quarry, greater than normal rainfall, and a leaking water main at the top of the slope, all combined to cause the failure. The landslide occurred in an area with a history of slope instability. Today that would call for greater vigilance in allowing development, in particular in developing a quarry at the foot of a slope, especially adjacent to a landslide such as the prehistoric Sun Club Slide. This landslide had been known since Professor

Benson reported on the DCC pipeline route in 1945, and it was later noted in a site evaluation for motorway construction in 1960. Its full significance and implications for instability of the adjacent slopes did not become apparent until after the Abbotsford Landslide had occurred. Looking back, it is perhaps somewhat ironic that most of the sand excavated from Harrison's Pit between 1966-68 was used to stabilise a nearby landslide reactivated by motorway construction.

The Abbotsford disaster also draws attention to the potential dangers of leakage from water mains, especially on slopes in unstable ground. The DCC water main had been leaking since 1976 but had not been repaired. The amount of water leaking at the time of the slide could not be established because the pipeline had been emptied in an effort to repair the leaks, and in so doing some of the rubber joints were sucked into the pipe. Likewise, the effects of the leakage in the landslide area before failure were not known because of a lack of drilling records and groundwater data. Whatever these effects on the water table were, however, because of the earlier excavation of sand from the toe of the slope, the water table in the slide area had to rise about 0.3 metres less in order to reach the critical stability in the slope at the time it failed. So in this sense leakage from the water main, together with an inferred long-term rise in groundwater levels due to increased rainfall, was probably responsible for the timing of the Abbotsford Landslide.

The Commission of Inquiry identified unstable geology as "the basic pre-condition (cause) for the



Aerial view, looking south, of the Abbotsford Landslide on 12 Aug 1979. In the foreground sharp ridges and deep cracks up to 15m deep can be seen within the extensive head scarp graben. In the distance earth moving equipment have smoothed off the head scarp and partly infilled the graben to stabilise the area. (Photo: Graham Hancox, GNS)

failure”, and identified increased rainfall and two human actions – the sand quarry and the leaking DCC water main – as the main contributing factors. Sand excavation clearly destabilised the area directly above Harrison’s Pit, but the slope remained essentially stable for ten years after the excavation. This suggests that this action was not the immediate cause of the failure. On the other hand, elevated groundwater levels in the area (due to both increased rainfall and water leakage) could affect the slope. In the longer term the slope would probably have failed eventually because of unfavourable geology and the sand quarry. However, in the author’s view, elevated groundwater levels hastened the failure, and to this extent can be considered to have triggered the Abbotsford Landslide. Because it was not possible to determine precise

groundwater levels prior to the landslide, this conclusion is speculative, but it is consistent with the available data.

Leakage from a segmented water main laid in unstable ground was recently recognised as a prime cause of the 1997 Thredbo Landslide disaster in Australia. Both the Abbotsford and Thredbo landslides are graphic reminders of the potential role of water in slope failures. Through increased awareness of the effects and dangers illustrated by these disasters it is hoped that they may serve some useful purpose in preventing similar events in the future.

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Commission of Inquiry (1980), *Report of the Commission of Inquiry into the Abbotsford Landslip Disaster*. NZ. Government Printer, Wellington, 196 pp.



Compression ridges formed at the toe of the Sun Club Slide area. This deformation destroyed the swimming pool and tennis court (left), and also the badminton court (right). (Photos: Graham Hancox, GNS)

The Crater Lake issue -



Mt Ruapehu from the east showing path of lahar and sites of ERLAWS sensors and bund. (Photo: Dave Wakelin, DoC)

a management dilemma

by Harry Keys and Paul Green

Department of Conservation

Tongariro is New Zealand's oldest national park, and the fourth oldest park in the world. It was established in 1887 when Horonuku Te Heuheu Tukino, the paramount chief of Ngati Tuwharetoa, gifted the central portion of the park to the nation. The outstanding natural values of Tongariro were officially recognised in 1990 when it was awarded World Heritage status. The area's important Maori cultural associations were also accorded the same status in 1993. The Park is currently managed by the Department of Conservation.

Situated within Tongariro National Park, the volcanoes of Ruapehu, Tongariro and Ngauruhoe and their surrounding lahar ring plains comprise major landscape features in the central North Island. The Whangaehu Valley is the major lahar (volcanic mud flow) path from the volcanoes and is possibly the most

active lahar path in the world. The Whangaehu outwash fan and lahar deposits further downstream preserve records of previous lahar activity over thousands of years. This is the most dynamic natural landscape in New Zealand.

Mt Ruapehu and Crater Lake represent one of the world's most active and distinctive examples of volcanism. Ruapehu is one of the most frequently active composite volcanoes in the world erupting every 1-3 years on average. Volcanic processes can be seen in action and studied as a 'natural laboratory'. Crater Lake is one of two crater lakes (together with Kelut in Java) regarded as classic case studies of interaction between magmatic fluids and lake water which often produce lahars. The Crater Lake, located over the actual vent of the volcano, is especially important. The lake is partly surrounded by permanent snow and ice and is the most accessible of only two or three such active crater lakes on Earth.

Twice last century Crater Lake was completely emptied during eruptive episodes. On both occasions, 1945 and 1995, bridges were destroyed and damaged.

When the lake partially emptied on 24 Dec 1953, the lahar washed away a rail bridge at Tangiwai, killing 151 of the 285 passengers and crew aboard an express train.

THE PRESENT SITUATION

The national park/world heritage status, dynamic volcanic nature and destructive potential all help focus a great deal of public media and political attention on the issue we have today. Tongariro is currently facing its most testing management dilemma in its 115-year history.

The eruptions of 1995 and 1996 built up a deposit about 7 metres thick of tephra (ash, scoria and rocks) on the crater rim at the former lake outlet. (The deposits were over 15 metres thick near Pyramid Peak but there pose only a minor and less direct hazard due to potential slumping). Therefore on refilling, the lake will encounter a barrier, or dam of tephra, and rise above the normal overflow level (2530 metres). Sudden collapse of the tephra dam is highly likely given the permeable and weak nature of the material but it cannot be predicted at what lake level the dam will collapse. The impounded water could burst out in a way similar to the 1953 event producing a lahar with a peak discharge at Tangiwai, possibly as much as 90% larger (the "worst-case event") than the 1953 event. Whatever volume is released, the majority of the lahar will travel down the normal Whangaehu lahar path, but the worst case event would be large enough to spill over into the Waikato Stream and enter the Tongariro catchment and Lake Taupo.

Close monitoring and extrapolation indicate Crater Lake will become full probably sometime between the summers of 2002/2003 and 2003/2004. The lake is currently about 67% full after almost six years of refilling, whereas six years after the 1945 eruption, the lake was over 100% full. The difference is due to the crater being larger now than post-1945, fewer and possibly smaller meltwater streams flowing into it now due to glacial recession, and probably other factors affecting input and output of water, including volcanic activity. Scientific literature suggests the volcano was more active after the 1945 eruption than it was after 1996 but there have been several cycles of heating and eruptive activity since 1996 (most recently in Feb 2002). The temperature of the lake water five years after each eruption was similar (21°C).

Infrastructure at risk from the potential dam-break is mainly down the Whangaehu Valley. The main assets are transmission pylons of the national grid near the aqueduct site and bridges of the main trunk railway and State Highway 49 at Tangiwai. Also at Tangiwai are some power poles and fibre optic cables across the bridges, the Tangiwai memorial and toilets.

Downstream, one small farm-bridge (Strachan's) and a small rural bridge (near Tirorangi marae) are at risk, plus some sections of the Whangaehu Valley Road. Some distance below the marae, the lahar will become similar in size to normal rain floods. Other assets at risk include DoC's Whangaehu footbridge. Most of these structures and other assets have been built in the knowledge that the Whangaehu is a major lahar path. State Highway 1 is at risk from potential spillover and Rangipo power station might need to cease production until spillover lahar sediment is cleared. There is no housing at risk.

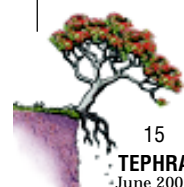
ASSESSMENT AND MITIGATION

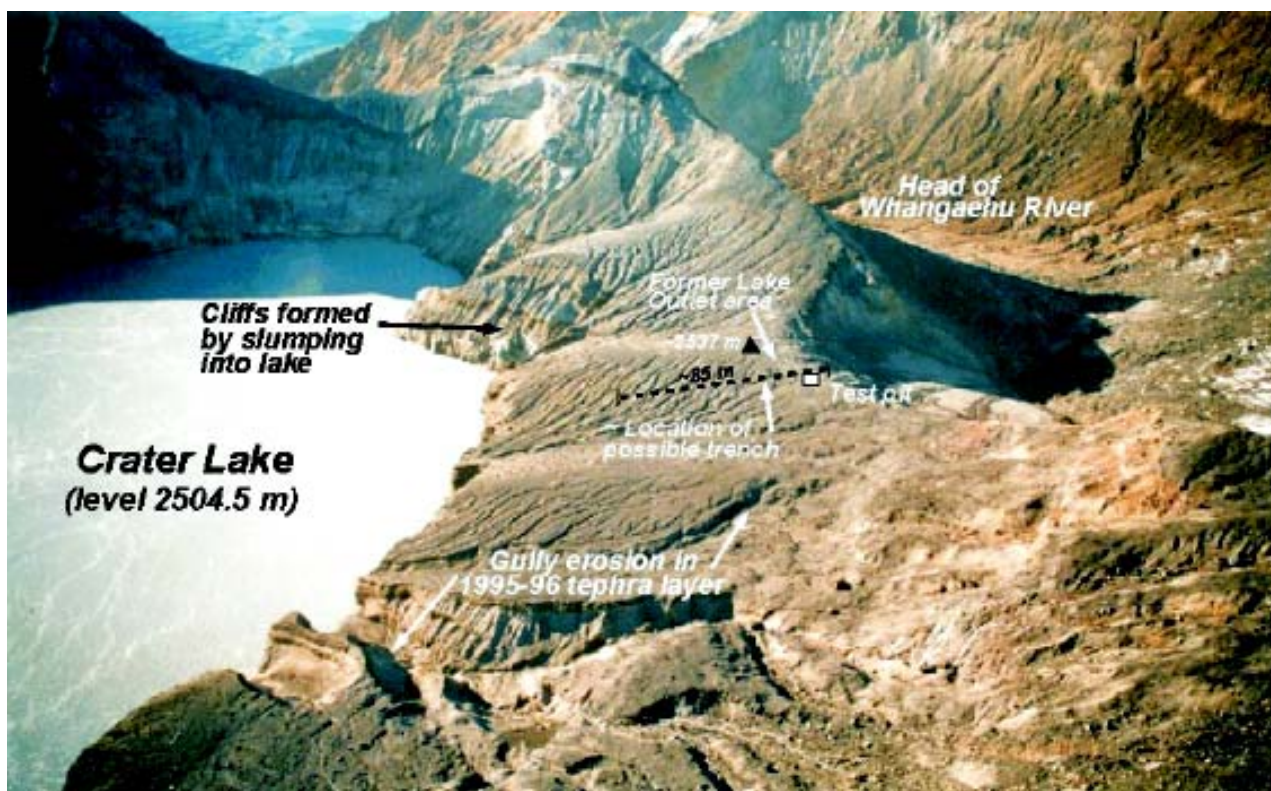
The Minister of Conservation is responsible for the management of national parks in New Zealand. Clause 4(1) of the National Park Act 1980 states "shall have effect for the purpose of preserving in perpetuity as National Parks, for their intrinsic worth and for the benefit use and enjoyment of the public, areas of New Zealand that contain scenery of such distinctive quality, ecological systems or natural features so beautiful, unique or scientifically important that their preservation is in the national interest."

The Department of Conservation produced an 'Environmental and Risk Assessment for mitigation of the hazard from Ruapehu Crater Lake' in April 1999. This followed a draft Assessment of Environmental Effects (AEE) in October 1998 based on scientific information and consultation. Forty-six submissions from local government agencies, state-owned enterprises, environmental and recreation groups, iwi, private citizens, as well as unsolicited letters and other input were all taken into account. The Minister requested that the Department's final AEE be scientifically peer reviewed in addition to the public review.

The AEE presented 24 options in six categories that included:

- allow lahar to occur: develop alarm and response system, improve land use planning but no engineering intervention at crater or in lahar flood zones
- allow lahar to occur but intervene in lahar flood zones to reduce its size and/or confine it
- prevent or reduce lahar by hardening or perforating tephra barrier at the crater
- prevent or reduce lahar by excavating a trench through the 1995-1996 tephra barrier at the crater
- prevent lahar and reduce lake volume by excavating trench into underlying lava at outlet.
- prevent or reduce lahar by other options eg, siphoning, barrier truss





View of the Crater Lake area in April 2001 showing mantle of 1995/96 tephra deposit. (Photo: Graham Hancox, GNS)

ERLAWS AND PLANNED RESPONSES

In May 2000, the Minister of Conservation decided to action the installation of an alarm warning system and formalisation of emergency management response and contingency plans. Following discussions with scientists, technicians, computer specialists and Genesis Power Ltd, and a technical design review, the Eastern Ruapehu Lahar Alarm and Warning System (ERLAWS) was installed during the 2001/2002 spring and summer, along with radio repeaters at Dome Shelter, Taiping and Tukino Road.

The ERLAWS design consists of three types of sensors at three sites down the upper Whangaehu Valley:

- Site 1 (Crater Lake outlet) – water level sensors to detect a sudden drop in Lake level, a buried tripwire to detect collapse of the dam and three geophones to detect the vibration of the collapse and from lahars.
- Site 2 (NZ Alpine Club hut) – two geophones to detect the vibration from passing lahars
- Site 3 (near Tukino skifield) – two geophones to detect the vibration from passing lahars.

Data from these sensors is telemetered through dual pathways to the Genesis control room at Tokaanu power station. There the data is monitored on an independent computer (and backup), mirrored on the Genesis SCADA system, sent to a DoC server in Wellington, and displayed on a special ERLAWS

website. When incoming data exceeds pre-set thresholds, an alarm will automatically be sent via pagers to police, district council staff, Transit and duty scientists who will then respond in accordance with predetermined plans. There will be up to two hours before the lahar reaches Tangiwai.

ERLAWS will also trigger systems to be installed by Transit to warn road users. These will include automatic barrier arms at the State Highway 49 bridge, plus flashing lights and/or signs there and on State Highway 1.

District councils and the police are developing the primary response plans. Ruapehu District Council (RDC) is responsible for the southern plan centred on Tangiwai and the upper Whangaehu Valley, while Taupo District Council is responsible for Tongariro River planning. The plans will be integrated with each other, and with individual agency plans, including those of Genesis, TransRail (who have their own alarm system for stopping trains), Transit New Zealand, Transpower, the Army, Police, Winstones Pulp International, and DoC. Exercises and training will be held so that plans are ready before the end of 2002, although RDC and the Ohakune police already have a basic plan in place. The Ministry of Civil Defence & Emergency Management is facilitating and overseeing these activities.

EMBANKMENT—'BUND'

In December 2000, the Minister of Conservation requested that the Tongariro National Park Management Plan be amended to permit the construction of a 'bund' or embankment to prevent overflow from the Whangaehu River into the Tongariro catchment. This embankment is located just inside the National Park boundary near the head of the Whangaehu outwash fan. This site is not as sensitive as that at the Crater Lake itself.

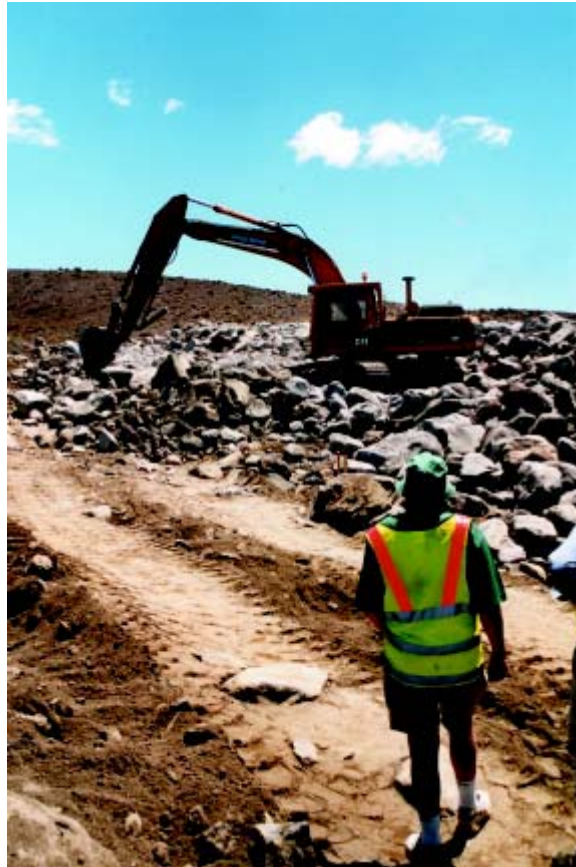
The structure was completed in February 2002. It is almost 300 metres long, up to 4.6 metres high and about 20 metres wide, composed of gravel, ash and boulders bulldozed from the lahar flood plain. The core material was compacted, then armoured in front and on top with a layer up to 2 metres thick of well-graded boulders up to 1.5 metres in diameter. The bund was designed to withstand, and have 1.6 metres of freeboard above the worst case lahar possible from a sudden collapse of the tephra dam.

The primary aim of the bund is to increase public safety. It will greatly reduce risks to people crossing the Waikato Stream bridge and culvert section of State Highway 1, as well as protect public safety in the Tongariro River. Its secondary purpose is to protect the aquatic environment of the Tongariro River and Lake Taupo. It will have a negligible effect on the main part of the lahar down the Whangaehu River. According to lahar hydrological modelling, the maximum spillover prevented by the bund is only about 7%, which is very small compared to the non-spilling portion, and much smaller than uncertainties in calculated lahar parameters. For example, it would increase the depth of the worst-case lahar at Tangiwai by about three centimetres, which is much less than the expected heights of waves on the lahar surface.

FURTHER ACTION AND DECISIONS

The Minister ruled out intervention at Crater Lake in December 2001. DoC, at the Minister's request, has convened a scientific advisory panel of geologists (including lahar specialists) and civil engineers to provide independent advice, including an oversight role of ongoing work monitoring the refilling of Crater Lake. More information will also be made available to the public as the lake becomes full, including warnings at vulnerable places.

A fundamental question the Minister had to address was whether interference with natural, cultural and scientific values of a World Heritage site should proceed simply because there are 'residual' risks. The risk to life is low because of the warning and response system, including those of Transit and TranzRail, plus the construction of a bund, but cannot



Construction of the bund which was completed in February 02 with Conservator Paul Green looking on. (Photo: Herwi Scheltus, DoC)

be absolutely mitigated. Carrying out engineering work at Crater Lake would not be without risk, either due to the high altitude alpine volcanic nature of the site as was underscored by reported small eruptions in February 02. Such work would also create precedents for further direct interference with other volcanic risks in the National Park as well as more common natural hazards elsewhere.

Would it not be a more appropriate management action to use the knowledge of lahars to place infrastructure such as roads, rail and power lines at sites less likely to be at risk or to design them in ways to make them safe? This is what Ruapehu Alpine Lifts have done at Whakapapa Skifield, and what TranzRail believe has been done with their rail bridge at Tangiwai. This is a more sustainable course of action. Assuming successful operation of the alarm and warning systems, and good progress on response planning, such other mitigation actions would reduce risks to a low level, even for larger lahar hazards that the recent geological record tells us will no doubt occur sometime in the future.

Planning for a Lahar Event



by Barbara Dempsey

Ruapehu District Council

Mt Ruapehu Eruption — September 1995. The crater lake with Mt Ngauruhoe is in the background. (Photo: Lloyd Homer, GNS)

On 18 Dec 2001, the Minister of Conservation released the decision on the intervention at the crater rim. The Minister concluded that the measures put in place to address the threat of lahars from the Mount Ruapehu Crater Lake adequately address concerns to human safety and infrastructure risks. The Minister therefore did not support any engineering intervention at the crater rim.

Section 39 of the Civil Defence Act 1983 sets out the obligations of territorial authorities (councils) as follows:

“Except where a regional council or united council has agreed under section 31 of this Act to undertake civil defence on behalf of a territorial authority, every territorial authority or group of uniting territorial authorities shall maintain a civil defence organisation for the district or combined

districts together with such units and services as are considered necessary or desirable to enable civil defence measures to be carried out during a state of national emergency or civil defence emergency”

Section 2 of the Civil Defence Act 1983 defines a civil defence emergency as:

“Civil Defence Emergency” means a situation (not attributable to an attack by an enemy or to any warlike act) that causes or may cause loss of life or injury or distress or in any way endangers or may endanger the safety of the public and cannot be dealt with by the Police, the New Zealand Fire Service, or otherwise without adoption of civil defence measures.”

If the tephra dam at the crater rim collapsed at an early point, and it was considered that the police and local emergency services could cope without any extra powers, there would be no need to declare a civil defence emergency. However, if the dam collapsed

when the lake was at a level where it was considered appropriate to declare a civil defence emergency, the Ruapehu District Council (RDC) would be the lead authority, with the legal obligation to ensure the safety of the community.

While the Civil Defence Act is currently the legislation that governs the actions in an emergency, the Ruapehu District Council, along with horizons.mw (the regional council) and the other councils within the regional boundaries have been working for some time in readiness for the Civil Defence Emergency Management (CDEM) Bill to be enacted.

The Civil Defence Emergency Management Group (CDEMG) has formed and has embraced the concepts of the Bill. Planning has been based on the "4 Rs" of Reduction, Readiness, Response, and Recovery.

REDUCTION

The district and regional councils, supported by other stakeholders, have actively canvassed the Minister of Conservation in an attempt to promote intervention at the crater rim to illuminate the risk of build-up and collapse of the crater dam, and so stop a lahar of this type.

Intervention at the crater rim would take away the tephra build-up that was deposited following the 1994/1995 eruptions. It would not resolve volcanic-type lahar events that occur regularly but only produce small-scale lahars that pose little threat to people or assets in the Whangaehu valley.

READINESS

Following the Minister's decision, a group of representatives from Ruapehu District Council, the regional council, New Zealand Police, and the Ministry of Civil Defence & Emergency Management, formed a group with the objective of formulating a Response plan to enhance the local level planning, and integrate the responses of emergency services and asset owners. An invitation has also been extended to the Department of Conservation (DoC) to appoint a member to this group in an advisory role.

The local Southern Ruapehu Emergency Management Committee have prepared emergency procedures for lahar events, and while it is

acknowledged that this planning provides a good base contingency plan, the plans need to take into account the national and international implications of this event.

Ruapehu District Council has recently appointed a Project Manager, who will work with the appropriate agencies to coordinate the excellent contingency planning that has been undertaken by individual organisations into one integrated plan for the district. The primary objective of the planning will be the safety and wellbeing of people.

The planning will be in two parts, firstly an operational component and secondly, the communication component.

RESPONSE

A very real concern for districts like Ruapehu is the level of resources available to react to an emergency of the potential scale of this event. The readiness planning will identify the areas where the district requires assistance, and judging by the commitment and support shown to date, the Ruapehu District Council is confident that assistance will be given where necessary.

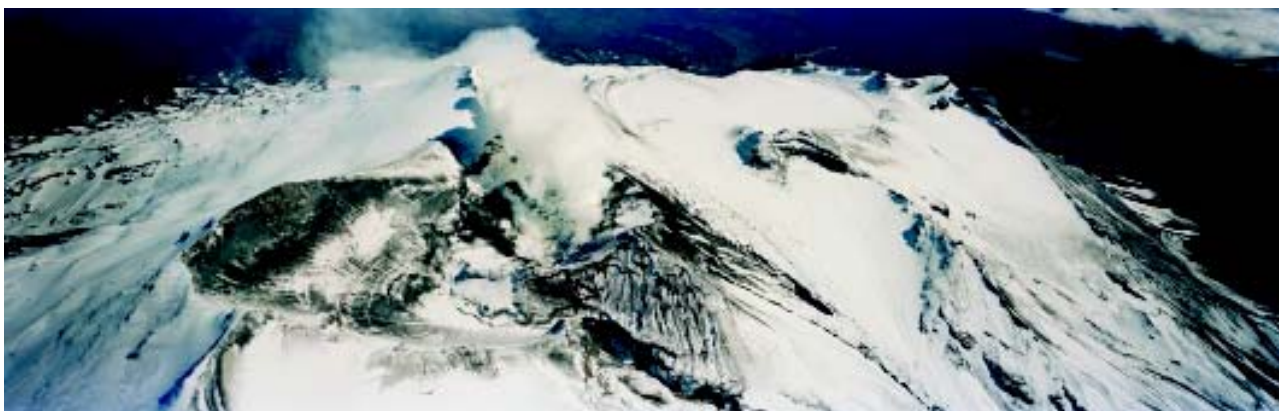
RECOVERY

Very little has been done, to date, on the recovery plan. By working with the other agencies involved, the group will have a better understanding of the risks to business continuity, and the measures that need to be put in place to minimise the risk and to recover a level of service as soon as possible.

While the Minister of Conservation has stated that in an event of a maximum, or near maximum level, Cabinet will favourably consider an application for recovery assistance from the Ruapehu District Council, the reality is that the majority of the cost of damage will be met by the owners of the infrastructure - companies like Transit New Zealand, Transpower, councils, Winstone Pulp International and the private land owners in the lahar path.

The economic effect on the communities around the mountain and the wider North Island tourist trade is unknown at this stage.

Evaluating the Risks and Coordinating Planning



Mt Ruapehu eruption — November 1995 (Photo: Lloyd Homer, GNS)

by John Norton, Director

Ministry of Civil Defence & Emergency Management

The Ministry of Civil Defence & Emergency Management supports the existing approach to the management of the Ruapehu lahar threat. A lot of good scientific work has been done through the Department of Conservation (DoC) to understand the threat and evaluate the alternatives.

Specifically, DoC has been monitoring the development of a large potential lahar from the crater lake of Mount Ruapehu for a number of years. In 1999, DoC completed a landmark *'Environmental and risk*

We believe that the lahar must be allowed to come down the mountain, and in the process remove the loose tephra material. If this material is allowed to remain, then the scale of the problem in the future will only get bigger.

assessment for mitigation of the hazard from Ruapehu Crater Lake'. That work assessed the scale and likelihood of various lahar scenarios arising, discussed the possible outcomes and also assessed a range of mitigation options. This provided enabling information for other organisations, in particular, utilities such as Transit, TranzRail and Transpower, to assess, for example, the

likelihood that specific utility assets would be damaged, and if so, what scale of harm might arise and with what probability. All of the key local and central government agencies and utility companies also share a very large body of scientific knowledge about the state of the Crater Lake and the crater rim.

The Minister of Conservation's subsequent decisions, including the installation of an alarm system (ERLAWS), monitoring the refilling of the lake, and the construction of the bund, have been informed by this evaluation. Independent advice from a specially convened scientific advisory panel of geologists (including lahar specialists) and civil engineers has also been vital.

The Ministry of Civil Defence & Emergency Management supports this position, subject to an evaluation and ongoing monitoring of the levels of risk. The combination of an early-warning monitoring of crater lake levels, a state-of-the art electronic warning system, emergency response plans, and construction of a bund to prevent overflow into the Tongariro River should provide a good mix of measures to ensure that, in the event of a maximum, or near maximum level lahar, safety to life is maintained.

We believe that the lahar must be allowed to come down the mountain, and in the process remove the loose tephra material. If this material is allowed to remain, then the scale of the problem in the future will only get bigger. Our focus now is to evaluate and monitor the ongoing risk, and to ensure that the systems in place, and the response plans being



Mt Ruapehu eruption — June 1996 (Photo: Lloyd Homer, GNS)

prepared, are able to provide appropriate levels of safety.

RISK ASSESSMENT PROJECT

In fulfilling this task, and to facilitate and coordinate response and infrastructure planning, the Ministry of Civil Defence & Emergency Management is now undertaking an assessment of the residual risks of adverse outcomes of the impending lahar. This will incorporate an assessment of the efficacy and reliability of the asset protection, and of the warning and response measures currently in place or planned. The aims of the assessment project are to:

- provide an overview of the residual risks and outcomes associated with the lahar, and inform any discussion as to whether further measures might be appropriate

- assist utilities, local authorities and emergency services in preparation of their emergency response plans
- provide all parties with a quantitative framework and performance benchmarks for the ongoing risk monitoring and decision-making regarding asset protection, warning and response systems.

When complete, the project will provide a full, high-level overview of the potential adverse outcomes from the impending lahar, the efficacy and reliability of the measures in place to protect against those outcomes, and the tolerability of the residual risk with the proposed arrangements in place.

This level of quantitative risk assessment is a first for the Ministry. The technical framework is being provided by Dr Tony Taig, an eminent UK expert in risk management, currently resident in New Zealand, who has been engaged to lead and manage the project.

The outcome from this assessment is providing the basis for the Ministry to coordinate and help a number of organisations develop their own asset protection, lahar warning and emergency response plans to ensure an

integrated level of security. There is a very high degree of cooperation between these groups and a strong commitment to managing the risks associated with the lahar.

The Ruapehu District Council has the lead in developing a Combined Response Plan for south of Ruapehu, and Taupo District Council for one north of the mountain.

The groups actively working together on the emergency response planning are the Ruapehu District Council, Taupo District Council, horizons.mw, Environment Waikato, Ministry of Civil Defence & Emergency Management, Department of Conservation, Police, TranzRail, Transit New Zealand, Transpower, and Genesis Power.

Towards a Resilient New Zealand

by Hans Brounts

Emergency Management Planner, Ministry of Civil Defence & Emergency Management

THE BACKGROUND

New Zealand is considered to be a great place to live - clean, green and secure. Our enviable reputation rests on assumptions such as continued protection of the environment and maintenance of levels of personal safety. We share an expectation that our security is assured - that government, the emergency services and lifeline utilities are working together to minimise the impacts of disasters.

When emergencies such as floods, earthquakes, wildfires or terrorist attacks unfold in the media, our natural tendency is to breathe a sigh of relief that we have not been directly affected. Usually we fail to heed the warning these events provide, by asking:

“Am I confident that my family, my business or organisation could survive a major disaster?”

In New Zealand we must all cope with the challenges posed by a broad range of natural and technological hazards. Flooding has been New Zealand's most costly natural hazard, causing NZ\$125¹ million damage per year. Potentially the most dangerous natural hazard is earthquake, especially for large urban centres such as Wellington and Christchurch. The most underrated natural threat for northern regions comes from volcanic eruption. It is not widely recognised that the level of volcanic risk to Auckland is similar to the earthquake risk to Wellington. In addition, exposure to technological and other man-made hazards - such as the 1998 Auckland power crisis - is increasing as growing urban populations put pressure on stretched infrastructure and levels of technology become ever more complex.

Added to this equation, threats from terrorism, economic, agricultural, biological, and other types of hazard also demand our attention. The reality is that disasters, such as the loss of 12,000 people in 1918 to the influenza pandemic, may occur at any time.

The recasting and, in some cases, the weakening of the nation's civil defence emergency management (CDEM) capability over the past two decades has to be seen in the context of this volatile mix of hazards. Changes in social and economic direction since the mid-1980's have seen Government's role and resources

diminished through restructuring and deregulation. Communities are now expected to take ownership of, and play a larger role in, managing their own civil defence and emergency management. Deregulation across many sectors such as telecommunications, transport and energy has resulted in dispersion of lifelines into individual components that may not function in a coordinated, cross-sector manner.

The result of these changes is that New Zealand needs to rebuild a robust national CDEM capability. Whilst many agencies or authorities individually plan for emergencies, this capability is often not integrated across sectors – or the nation. New Zealand is not well prepared for emergencies other than small, localised events.

WHAT CAN WE DO?

A series of reviews over the past 12 years have all concluded our nation's arrangements for managing disasters are inadequate. To deal with this, all sectors of the nation must own the problem, and only by working cooperatively together can we improve the nation's resilience.

As a nation, New Zealand has determined to improve its resilience to emergencies by introducing major changes to the way in which every sector of society approaches CDEM. Improving our ability to adapt to changing circumstances and to better coordinate limited resources, requires in part:

- strengthened relationships between sectors and agencies involved in CDEM activity
- encouraging behaviour that promotes cooperative planning for continuity of operation
- seeking individual action to deliver more effective risk management
- raising awareness of compliance with legislation and consistency with national planning.

Practising risk management, cooperative planning and carrying out CDEM activity together are all possible under the existing Civil Defence Act 1983. However, the CDEM Bill 2000 currently before Parliament places a stronger emphasis upon taking a risk management based approach to the sustainable management of hazards – natural and man-made. This risk management process is applied across the '4Rs' of risk reduction, readiness, response, and recovery, and improves integration through involvement of all sectors within the wider CDEM community.

The Bill's stated purposes include:

- improving and promoting sustainable hazard management to improve safety of the public and property
- encouraging communities to achieve acceptable levels of risk
- requiring local authorities to coordinate CDEM planning and activity
- ensuring integration of national and local CDEM planning
- encouraging CDEM coordination across a wide range of agencies that prevent or manage emergencies.

WHO WILL DO WHAT?

CENTRAL GOVERNMENT AGENCIES

Government and its agencies provide support and guidance, promote community values and create action through leading by example. The government departments with responsibilities under the CDEM Bill are those listed in Schedule 1 of the State Sector Act 1988. Central government departments will be required to:

- ensure the department is able to function to the fullest possible extent, even though this may be at a reduced level, during and after an emergency
- perform any functions required under any CDEM Plan.

In addition, there is an expectation that departments will participate in the development of a National CDEM Strategy and National CDEM Plan, as well as provide technical advice on CDEM issues.

LOCAL AUTHORITIES

The duties of a local authority apply to all councils named in the First Schedule of the Local Government Act 1974.

Local authorities will be required to:

- ensure they are able to function to the fullest possible extent, even though this may be at a reduced level, during and after an emergency
- plan and provide for civil defence emergency management within their districts.

These duties are in addition to the requirement to be part of, and carry out the functions and obligations of, a member of a CDEM Group. To encourage regional coordination and cooperation, every regional council will be required, within six months of enactment, to unite with the territorial authorities within its region to establish a CDEM Group.

Within two years of establishment, CDEM groups will produce a CDEM Group Plan. Public

consultation is required throughout this process to ensure hazards and risks are dealt with to a level the community accepts. CDEM Group functions include:

- hazard management
- providing resources
- providing for emergency response and recovery.

EMERGENCY SERVICES

Emergency Services are defined in the CDEM Bill as the New Zealand Police, the New Zealand Fire Service, the National Rural Fire Authority, rural fire authorities and hospital and health services. Emergency services will be required to:

- participate in the development of the National Strategy and CDEM Plans
- have a representative at the Coordinating Executive Group level within each CDEM Group.

VOLUNTEERS, INDIVIDUALS AND BUSINESSES

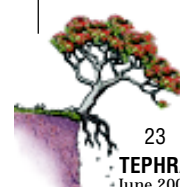
Individuals and businesses must take all necessary steps to comply with any function or duty set out by the CDEM Bill when enacted, or any CDEM Regulation or CDEM Plan made under the enacted Bill. They make, and contribute to the making of choices about managing hazards and risks within their communities.

LIFELINE UTILITIES

Fortunately, many New Zealand utilities practice sound risk, asset and emergency management and cooperate through arrangements such as Lifelines Groups. However, there are valid concerns that such continuity planning is often focused on internal corporate risk to the detriment of continuity of service. Gains in business efficiency may be at the expense of cooperation and coordination between utilities that is so essential during times of emergency.

Lifeline utilities are expected to play a significant role in improving the nation's resilience by strengthening relationships within and across sectors, and by individually committing to actions that ensure continuity of operation. Such improvements clearly serve to protect marketplaces and strengthen each utility's prospects of surviving a major emergency. An underlying obligation to shareholders and customers to plan for and ensure continuity is reinforced by a clear message we all must share - **it is not an option to be unprepared.**

This message does not impose new business requirements or alter existing responsibility for risk, asset and emergency management. The emphasis is simply upon ensuring utilities provide continuity of operation, particularly where this may support essential CDEM activity such as rescue operations, emergency service headquarters or hospital response. Sound



relationships need to be established through the planning process.

Lifeline utilities may also be asked to contribute towards developing a National CDEM Strategy and Plan. The effectiveness of this cooperative planning will be monitored at both regional and national levels.

These processes help forge relationships that strengthen our communities' resilience towards disasters whilst at the same time supporting the continuity of businesses.

THE MINISTRY'S ROLE IN ACHIEVING A 'RESILIENT NEW ZEALAND'

The Ministry has developed a broad work programme to engage with all CDEM stakeholders – from the public, through government departments, local government, to lifeline utilities. This programme includes working individually and collectively with sectors to develop and put into effect:

- the CDEM Bill 2000
- a new National CDEM Strategy and National Plan
- guidelines – on CDEM Group Formation, Planning, Lifeline Utilities, Recovery Planning, Departmental CDEM Planning, Health and Welfare sector CDEM Planning
- improved National Readiness & National Crisis Management Centre arrangements, promoting a 'whole of government' approach to CDEM
- response initiatives of high importance such as improving the nation's Urban Search and Rescue capability
- professional development initiatives through MCDEM courses, University courses and support for local training
- improved international linkages through programmes such as the International Search and Rescue Group (INSARAG) and United Nations Disaster Assessment and Coordination programme (UNDAC), and with agencies such as Emergency Management Australia
- a national exercise programme, and assistance with regional scale exercises such as Exercise Phoenix III
- planning workshops for specific sectors, regions/ CDEM Groups as requested
- support by field liaison staff to assist individual and collective CDEM planning and activity.

Over the next three years the Ministry aims to improve the nation's ability to manage an event of national significance. This includes assisting government departments, local government, lifeline utilities and other sectors to improve their individual business continuity capability, their ability to

coordinate together, and their effective linkages at the national level.

Key to this process is an 'overarching' National Capability project, assessing the nation's CDEM capability by using a risk management framework adapted from the New Zealand standard AS/NZS 4360:1999. The aim is to identify where the nation's CDEM weaknesses lie, prioritise them and agree on plans of action to address them with the relevant stakeholders. The review process will include a series of focused stakeholder workshops and comprise a balance of both setting objective criteria and subjective assessment.

The Ministry will provide leadership and direction where required. But it is up to each of us, individually and collectively to own the process of making our nation resilient to disasters.

For more information and detail, refer to the discussion documents, guidelines and other information available on the Ministry's website at www.civildefence.govt.nz

¹ Ministry for the Environment: 'The State of New Zealand's Environment' 1997 (Ch7.16) - Govt Press NZ

Protecting the National Grid



Haywards Power Station

by Geoff Wishart

Consultant writer, Transpower New Zealand Ltd

Risk management has always formed a part in the design and build of electricity networks. But at Transpower, traditional specifications setting equipment strength to resist earthquakes are giving way to more holistic approaches that focus on achieving acceptable service performance and restoration times.

Transpower owns and operates New Zealand's power system often referred to as the National Grid. Conceptually, this is the network right from but excluding the generator, right to but excluding the local transmission (or distribution) networks. It includes substations, transmission towers, and transmission lines.

Much of the power system was constructed in the 50's and 60's. Consequently, towers and substations, in particular, were constructed to a variety of design thresholds that have generally increased over time in response to failures. For example, earthquake

design levels were originally set at 0.2 g¹, but were changed to 0.25 g after the Napier earthquake. Similarly, wind loading for transmission towers has changed several times since the 50's in response to failures in Canterbury and then Wellington during the 1968 Wahine storm.

Design levels are set so that the probability of them being exceeded is acceptable to the public in terms of life, safety and disruption.

Ground shaking levels for design at a specific location are specified by a Response Spectrum that summarises how the shaking will affect structures with different natural frequencies and levels of damping. The size and shape of the spectra for a particular location depend on the local soil characteristics and the distance to likely sources of earthquakes. For more recently developed spectra, their size relates directly to the probability of that level of shaking being experienced at the location.

In the late 60s, New Zealand led the world in specifying a seismic response spectrum when purchasing electrical equipment. This was thought at the time to represent shaking that would occur on average once every 100 years. In the last decade,

Transpower added to its design specification another larger spectrum, which better represents the shaking close to faults.

Whatever the design load for individual components, there is an earthquake for which things will fail, no matter how well it is constructed. As an example, observations of the 1994 Northridge earthquake in California demonstrated that system failure occurred despite considerable time and cost having been applied to strengthening equipment at High Voltage Direct Current (HVDC) stations near Northridge.

REASSESSING SEISMIC DESIGN LEVELS

The much better understanding of the occurrence of earthquakes like Northridge in the last few decades has enabled historic seismic design levels to be reassessed in risk terms.

For earthquakes larger than the maximum designed for, it is inevitable that damage and loss of service may occur. Good design should limit the time needed for repair and restoration of service after a large earthquake while minimising the possibility of outage during smaller but more frequent shakes.

Dr Richard Sharpe, earthquake engineer with Beca Carter Hollings & Ferner Ltd explains:

“Traditional structural design of the 50’s and 60s used the ‘working stress’ method. It sized and sometimes tested the components of a system or network to ensure that the design load could be met with a margin of safety against failure. Working stress was not concerned with levels of failure - just that failure didn’t occur.”

“However, for the last 30 years, structural engineers have more often used a ‘Limit State design’ approach, which matches higher design loads with the failure level. For rare, large loads, this approach effectively accepts a zero factor of safety against collapse. It is a more practical approach.”

The Limit State design approach better recognises the inherent resilience (eg, ductility) of different materials. Specifically, some ductile materials

and structures do not fail catastrophically when their limit state is reached. For example, mild steel and copper are very resilient to repeated cycles of permanent deflections. In fact, mild steel has the capacity to deflect up to six times further than its yield deflection before it fractures. This post-yield deflection absorbs energy and limits the loadings induced by an earthquake.

While much of Transpower’s network is constructed using steel (as in transmission towers), earthquakes pose particular problems for some equipment, particularly in substations, through the extensive use of porcelain insulators. Porcelain is brittle and breaks suddenly the first time its capacity is exceeded – in other words it is not very ductile.

Not all items of substation equipment are as brittle as porcelain, nor as essential for the continued supply of electricity under emergency situations. Unfortunately, in actual earthquakes overseas, the collapse of a relatively unimportant piece of equipment has either pulled over a critical piece of equipment like a porcelain insulator or, in a number of cases, destroyed the spares.

Put simply the preferred approach is to view the electricity system as a whole, or holistically, in order that acceptable performance in a wide range of possible earthquakes can be achieved.

Continual strengthening of individual components is fine in theory. In practice, failure of the weakest link will still disrupt the power supply. Indeed, inappropriate strengthening may actually weaken rather than strengthen components. Transpower’s predecessors discovered this in the 70’s when they followed a policy of adding extra bracing to transmission towers. Later studies showed that the degree of inaccuracy in drilling the holes for the bracing was, in fact, weakening the overall strength of the towers.

Therefore, the smart money is not on attempting to prevent failure at all, but on understanding how failure can be used in risk management to the advantage of the power system.

SACRIFICIAL COLLAPSE

Transpower since the 80’s has followed the concept of “sacrificial collapse” - allowing and planning for the failure of non-critical elements of the power



system to avoid collapse of critical components.

This was tested during the 1987 Edgecumbe earthquake. Some equipment in the area had been installed on concrete posts that were designed to fail in a ductile manner that protected the equipment. It worked. The concrete underwent massive spalling and localised reinforcing failure, but this easily-repaired damage ultimately prevented breakage of the brittle porcelain insulators mounted on them.

A larger project involving performance criteria rather than the specification of strength was the extension of the Haywards substation in the Hutt Valley in the late 80's. Because of its proximity to the Wellington Fault², an increased seismic design level was required. The specification was worded in a way that allowed for failure to occur, thus:

"... (the station is required) to be undamaged and functional with retention of full safety factors after an Operating Basis Earthquake (OBE), and undamaged with marginal safety factors and able to be simply repaired or quickly replaced locally after a Maximum Design Earthquake (MDE)."

Emphasis for this specification was placed on the qualification of the system as a whole and not on the piecewise qualification of individual items of equipment. It was driven by a real concern that if only the level of shaking at which there was to be no damage was specified, the extent of damage at higher levels of shaking would not be controlled. In other words, without the qualification in the specification, an earthquake could occur that breached the equipment threshold and cause complex damage in a way that puts the station offline for weeks.

In the case of the HVDC station at Haywards, the strengthening involved setting out a failure hierarchy of equipment such that non-critical elements could collapse in a manner that protected critical equipment while enabling the quick restoration of supply.



Single circuit poles carrying two single 110 kV circuits. While Transpower has over 17,000 such pole structures in service, the number is gradually declining as multiple single circuit transmission lines such as these are replaced with newer double circuit lines.

Additionally, during the HVDC station upgrade, more thought went into the critical interdependency of services offered by others. For example, fire fighting water supplies could not be relied on, so sufficient on-site capacity is maintained to ensure primary equipment fires can be extinguished or, at worst, isolated.

Transpower has since employed extensively ductile structures, along with base isolation (placing equipment and structures on flexible bearings so they are not excited by earthquakes), in all new and existing installations.

Transpower's Network Support group has now also begun a rationalisation of its seismic standards with the assistance of Dr Sharpe. Its current standards are largely prescriptive, orientated towards the design of equipment, and generally expressed in Working Stress design terms.

Furthermore, successive revisions of the New Zealand Loadings Code (NZS 4203) and its underlying seismic hazard model of New Zealand have begun to overtake the basis of the Transpower seismic response spectra. Finally, the impending new Civil Defence Emergency Management legislation requires utilities to be more transparent with their plans for recovery from natural disaster.

Against this background, Transpower's seismic



standards rationalisation has begun with a new seismic policy (setting out Transpower's intent with respect to seismic performance and expected recovery times), and a new seismic design standard to apply to all Transpower's assets (both buildings and equipment).

It is also proposed to replace the current Transpower spectra with those from the draft revision of the joint Australia/New Zealand Loadings Code. This revision, which is expected to become a New Zealand Standard at the end of 2002, defines clearly those faults considered active, and specifies how installations close to them should take their proximity into account. For example, the seismic zoning map reflects the latest knowledge on the hazard posed by the Alpine Fault in the South Island - a feature that runs parallel to Transpower's HVDC transmission line.

Transpower is currently finalising its performance requirements for the Design level shaking (average return period of 1000 years), and its choice of Serviceability level - below which supply should continue uninterrupted.

Equipment, which is often moved from one region to another in its lifetime, will still be designed for the most seismic region in New Zealand. Equipment-specific requirements preserving the experience of many years will be appended to the seismic design standard in such a way that they can be incorporated in procurement documents directly.

As Beca's Richard Sharpe notes "This updated seismic policy and design standard will clarify some of the issues that have crept in over recent years as new knowledge has brought changes to best seismic design practices. I am sure they would be endorsed by the seismic design pioneers in Transpower's predecessors -

such as the late Harry Hitchcock who made such an impact in the 70s."

In a wider context, the move to the more holistic limit state design approach mirrors advances in risk management thinking overall. Prevention measures of the 50's and 60s have given way to an acceptance that certain emergency events will occur. The question is not how to stop components from failing, but how best to respond and recover if they do.

Indeed, while working stress design can be seen in the light of the first R of emergency preparedness - that of reducing risk, the limit state design approach goes some way to at least addressing the other three - Readiness, Response and Recovery.

Instead of relying solely on an approach that assumes damage can be prevented, the limit state design approach accepts that damage can occur and instead, plans for a quick response and recovery.

For further information on Transpower's seismic philosophy and design standards, contact Bob Wildash, Senior Network Support Engineer, Transpower New Zealand Ltd - bob.wildash@transpower.co.nz

¹ 0.2g represents a seismic loading of one fifth of the equipment weight applied horizontally.

² The Wellington fault exhibits a pattern of movement with an average return period of about 700 years and a time to last rupture of about 350 years.

This article has been prepared with valuable technical comment and review from Bob Wildash, Senior Network Support Engineer, Transpower New Zealand Ltd, and Dr. Richard Sharpe, Earthquake Engineer, Beca Carter, Hollings & Ferner Ltd

Single circuit steel towers forming part of the core HVAC 220 kV transmission network which make their way through the country. Transpower has nearly 3000 towers of this type.



Sinkhole at Waihi



Aerial view of the Barry Road sinkhole

by *David Dennison*

Opus International Consultants

At 12:15 am on 13 Dec 2001, a sinkhole about 40 metres in diameter developed on the southwestern margin of Barry Road, midway between Seddon Street and Kenny Street. The sinkhole developed suddenly and engulfed a residential section and house, parts of the adjacent sections and the road.

Fortunately the five people in the house were rescued unharmed and the adjacent properties were safely evacuated. Surface cracks around the sinkhole indicate the immediate affected area was approximately 100 metres in diameter. The 13 Dec 2001 event follows similar sinkhole events in 1961 and 1999.

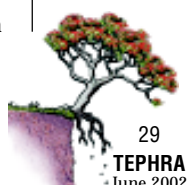
MINING PRACTICES

All three of the sinkholes are located over the old workings of the Royal Lode in the Martha Mine. The original Martha Mine operated for about 70 years

until it closed in 1952. The underground workings extended to a depth of 600 metres. Part of the mine was backfilled with waste rock after the ore was removed, but much of the mine was apparently left open.

The mining method employed in much of this area is known as shrinkage stoping. The mining technique involved driving tunnels or levels into the ore from the various shafts at intervals of 25 to 45 metres vertically. The excavation between the levels was referred to as a 'stope'. Timber sets were used to support the levels. Short chutes were installed in every other set to allow all the ore in the stope to be lowered evenly as it was worked.

The roof of the stope was drilled and blasted to a depth of about 1.5 metres at a time. The succession of horizontal slices was continued, while just enough broken ore (about 40%) was drawn off through the chutes in the level below to keep the level of the ore in



the stope at a convenient distance from the roof for drilling. When the stope was complete, the remaining broken ore was drawn off through the chutes and sent up the shafts for processing. The shrinkage stoping process is illustrated below.

Mining records for the year 1922 note that shrinkage stoping was completed in the area directly under the Barry Road Sinkhole, and that the hanging wall (roof) broke in two places and ran up in slidy (sic) ground. Records show that the stopes under the sinkhole form a slot about 250 metres vertically by 2 to 10 metres wide.

Underground mining operations ended in 1952, when the original mine was closed. The existing open pit Martha Mine commenced operations in 1988. It is operated by the Waihi Gold Mining Company, which has no connection with the earlier underground mining operation.

COLLAPSE MECHANISM

Features that are common to the 1961, 1999 and 2001 collapses include:

- their shape, size and position in relation to the Royal workings
- probable presence of unfilled Royal workings at depth beneath the three events
- loss of a large volume of solid rock (approximately 20,000 cubic metres).

Sinkholes occur when the soils over the workings collapse into the void. This type of sinkhole

can only occur above the voids left by old mine activities. The cover soils and rocks above the mine workings are approximately 150 metres thick at the Barry Road sinkhole.

The most likely mechanisms for the sinkhole formation are described below.

- **Sudden Roof Collapse** – possibly associated with pre-existing defects within the rock that intersect to form a failure wedge extending to surface.
- **Chimney Failure** - under this scenario, relatively small blocks of rock fall from the roof into the lower part of the mine. Over time, the void migrates towards the surface as pieces of the roof progressively fall into the mine. Eventually, the bridge of soil and rock over the opening is too thin to support its weight and the remaining roof material collapses suddenly into the void.
- **Soil Erosion** - it is possible that the void forms at higher levels within the profile as soil is washed down into the mine by groundwater. A sudden collapse occurs when the void becomes too large for the overlying soils to bridge over. Tomos (cavities in the ground) observed in the area suggest that this type of internal or piping erosion is possible.

It is possible that some combination of these mechanisms contributed to the formation of the sinkholes. Because the mechanism is uncertain, the length of time a sinkhole takes to develop is not known.

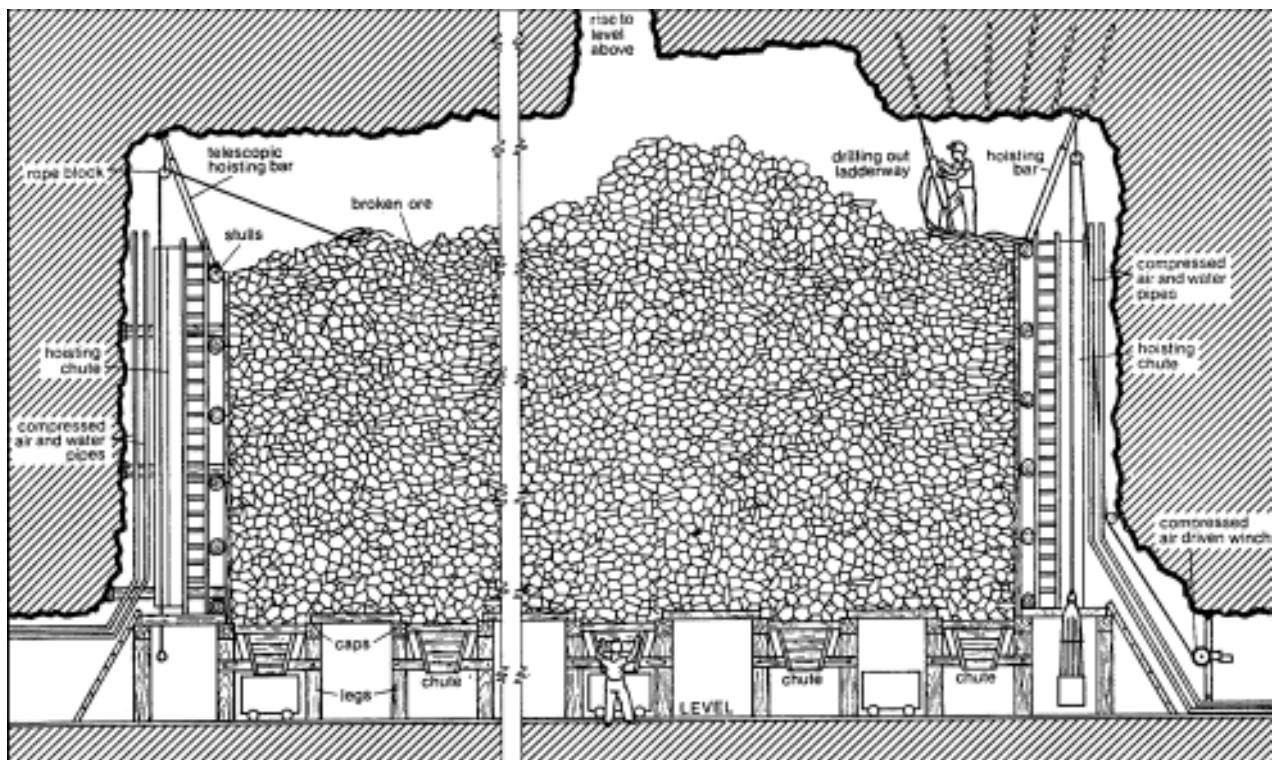


Illustration of the shrinkage stoping mining method

The influence of the present mining activities, especially blast vibrations and dewatering, on the formation of sinkholes is uncertain. It cannot be a direct cause of the sinkholes as one out of the three events occurred in the interval between the closure of the original underground mine and the start of the current mine.

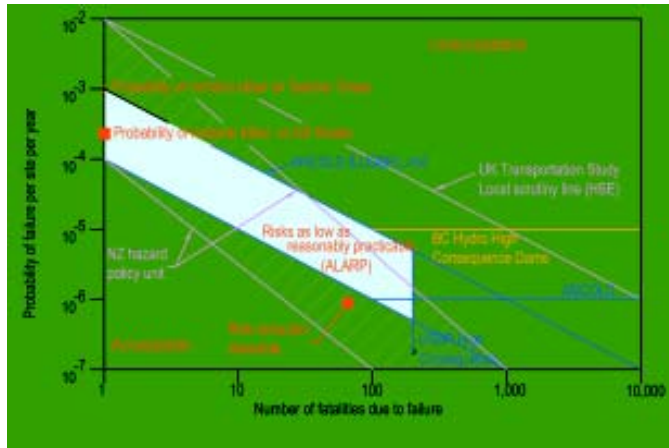
PREVIOUS SINKHOLES

The first of the three sinkholes occurred in February 1961 in a disused area that is now within the open pit mine.

On 4 Feb 1999, a large 40 metre diameter sinkhole occurred in Waihi between Seddon Street and Waihi Gold Mine's Martha open pit. This sinkhole occurred in public parkland during the early hours of the morning. Following this event, cracks appeared in Seddon Street and Hauraki District Council (HDC) staff became concerned that these cracks may be the first signs of another sinkhole. The road was immediately closed and the investigations began.

Opus International Consultants undertook an analysis of the risk to people, property or the environment from future sinkholes in the vicinity of the 1961 and 1999 events. The assessment was primarily of the risks to motorists on Seddon Street. It considered the spatial risk of an event in the high hazard area, and in the worst case, if a vehicle fell into a sinkhole one person would be killed. There were some 3500 vehicles/day using Seddon Street, which is a 50km/hr speed zone. The risk analysis is summarised below.

- P(D) The probability of Death of a vehicle occupant caused by a sinkhole - as determined below
- P(EVENT) The probability of an Event (sinkhole) occurring anywhere in the hazard zone. The similarity in location, shape and size of the two sinkholes were key issues in the assessment. The first one occurred 1961 and the second, 37 years later (1999), annual probability of an event was taken as 1 in 25, (0.04).
- P(VEHICLE/EVENT) The probability of a Vehicle being at the same location as an Event (sinkhole) in any 24 hour period. This analysis assumes that the length at risk is 40m (sinkhole diameter) plus a 50m safe stopping distance on approach, total 90m (0.09km) = $0.09/50 \times 3500/24$
- P(DEATH/VEHICLE) The probability of Death of a single occupancy vehicle = 1 (certain)
- P(AREA/EVENT) The probability of the Event occurring in an Area which would affect vehicles = 0.1
- P(D) = P(Event) x [P(Vehicle| Event)] x P(Death| Vehicle)] x P(Area| Event) = $0.04 \times [0.090/50 \times 3500 / 24] \times 1.0 \times 0.1 = 10^{-3}$ (0.1%)



Societal Risk Criteria

This probability, 0.1%, was then evaluated in terms of its acceptability to society (societal risk) by contrasting it with other known classified risk profiles developed by ANCOLD (Australian National Committee on Large Dams) and USBR (United States Bureau of Reclamation). The graph above also shows the limits adopted by the New Zealand Hazard Policy Unit, (NZHPU), 1987. The risk level falls within the ANCOLD/USBR 'unacceptable' zone and in the 'risk reduction desirable zone' adopted by NZHPU. The probability of a motorist being killed on New Zealand roads is shown for comparison and falls into the ALARP zone, 'as low as reasonably practicable'.

Measures were considered which would reduce the probability of being killed on Seddon Street to at least the ALARP zone but preferably to the acceptable zone. The measures included closing the road (or restricting traffic), bridging the area, backfilling the empty stopes and installing an early warning system. For each option the cost versus effectiveness was evaluated and presented to HDC for use in their risk based decision making.

HDC decided to close the section of Seddon Street that passes through the hazard area, restrict public access and relocate some nearby residential flats. These measures, which could be reliably quantified, reduced the societal risk in the hazard area to an acceptable level. The effectiveness of other mitigation measures (eg, a reinforced concrete pavement) was considered much more uncertain. Also their relative costs exceeded that of road closure (including relocation costs).

At the time, it was recognised that the hazard could extend beyond the study area around the 1999 sinkhole. A working group of affected parties was formed to assess the risks in the greater Waihi area. Unfortunately, the Barry Road sinkhole occurred before the working group could complete its work.

RESPONSE TO BARRY ROAD SINKHOLE

Immediately after the sinkhole at Barry Road occurred an evacuation zone was created to secure the safety of the nearby residents. In addition, the state highway (Kenny Road) was closed and traffic diverted away from the sinkhole area. Fences were constructed to restrict access to the hazard zone.

Kenny Road was reopened after several hours had elapsed with no further ground movement near the road. After reviewing the available plans of the underground mine workings in the days following the collapse, the initial hazard zone was expanded to include part of the rugby grounds.

The hazard zone included all of the area outside the existing mine boundaries that are underlain by the Royal Lode mine workings. In addition, a buffer zone of about 30 metres was included on the footwall (south east) side of the mine workings.

One of the crucial activities in the aftermath of the sinkhole was providing information to local residents and the public at large. A newsletter was published within two days of the event describing the facts of the situation, the extent of the hazard and actions that had been undertaken. In addition, a public meeting was held to provide additional information and to answer questions from the public. An aerial plan was presented that showed most of the underground workings are within the area of the

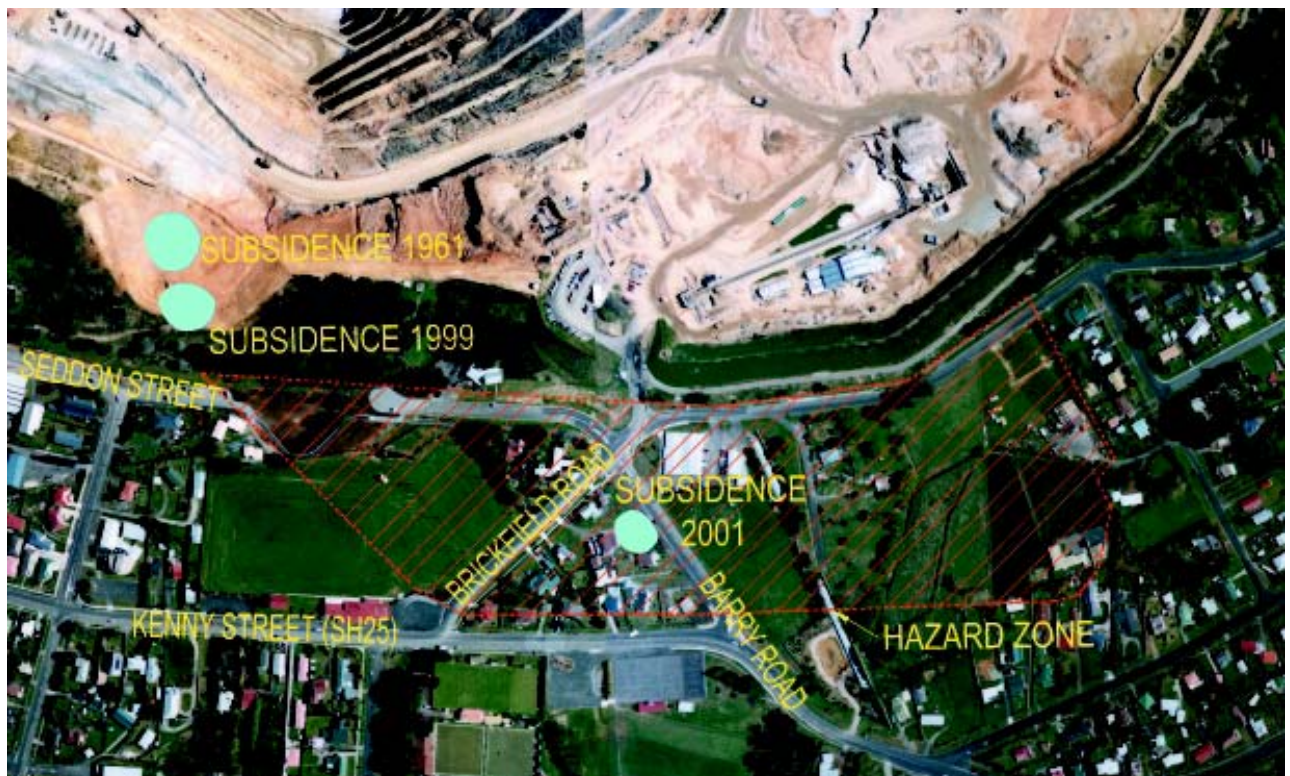
existing mine and that most of the town is not underlain by mine workings at all. This information helped allay the concerns of many local residents who must have wondered if their homes were at risk.

A survey and inspection programme was set up to monitor any further ground movements around the area. In the hours following the initial ground collapse, there was some additional cracking and minor subsidence around the sinkhole, but no further large scale movements. The small movements may have been caused by additional drawdown at the base of the sinkhole, or by slumping or relaxing of the over-steepened sides of the hole.

Eventually an inner hazard zone was created and maintained around the immediate area of the sinkhole. Limited access, controlled by the Council and the mining company, was allowed in the outer hazard zone for monitoring activities, salvage of property, and maintenance of the site.

RECOVERY PLAN

Opus International Consultants was engaged by Hauraki District Council to prepare a recovery plan for the area around the incident. The purpose of the report was to identify the necessary actions to provide a similar level of service to the affected parties and to provide a rough order estimate of costs associated with the recovery plan. For the purposes of the recovery plan, we assumed that all of the assets in the area

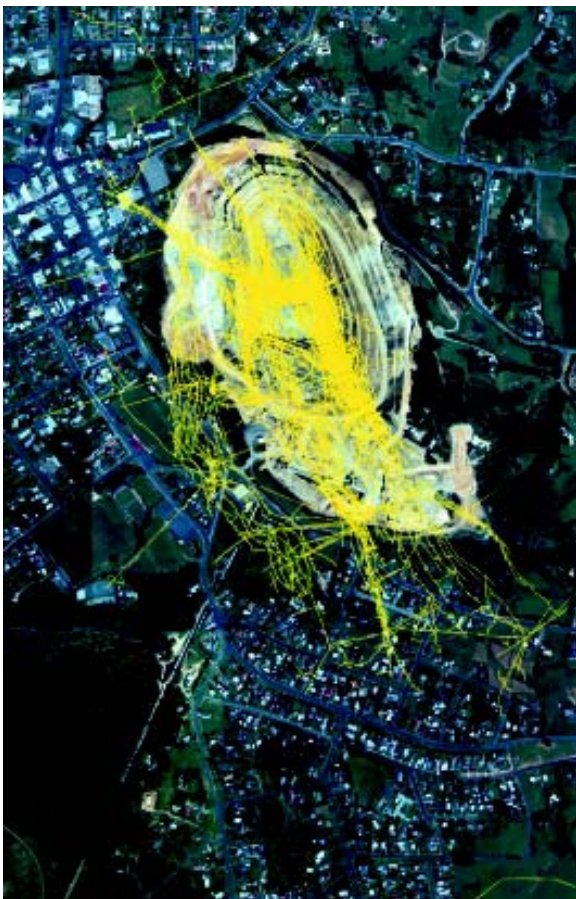


Map showing the extent of the hazard zone that was fenced off.

underlain by the Royal Lode mine workings would be abandoned or decommissioned.

Actions identified in the report included:

- the impact on the existing roading network will require improvements at two existing intersections and the widening of existing carriageways to accommodate the additional traffic volumes
- existing utility services, stormwater, sanitary, sewer, water, power and phone within the hazard zone have to be abandoned. Service connections to the existing houses have to be disconnected and removed
- the closure of Brickfield Road, Barry Road and Pipe Lane will make the existing road and footpath network within the hazard zone redundant and as such the area will be landscaped. In addition, it is likely that the Barry Road sinkhole will be filled
- a section of the existing Waihi Rugby/Football pitch was severed by the erection of the hazard zone safety fence. The recovery plan included provision to relocate the club facilities
- there are 16 houses within the affected area. Four houses are likely to be too badly damaged or in too poor condition to be relocated. Waihi Gold Mining Company owns three of the houses within the hazard zone.



Approximate extent of underground mine workings in Waihi.

A quantitative risk assessment, similar to the one undertaken after the 1999 sinkhole, was not carried out after the Barry Road sinkhole as the current hazard zone now includes most of the area underlain by the Royal Lode workings. Certainly, we would have to increase our estimate of the frequency of sinkhole events. The final scope of the recovery plan depends on the extent of the hazard zone and the ultimate land use within the area.

Several issues relating to the long-term management of the sinkhole hazard remain to be addressed, including the following:

- confirmation of the extent of the hazard zone over the Royal Lode mine workings.
- what limitations or restrictions will be placed on land use within parts of the hazard zone - particularly after closure of the existing mine?
- assessing the risk of ground subsidence in areas underlain by other mine workings or shafts in the Waihi area.
- evaluating remedial measures to reduce the risk of further sinkholes or provide advanced warning of future events.

CONCLUSION

We are grateful that the residents of Barry Road escaped the sinkhole event without serious injury or worse. However, the sinkhole hazard in Waihi has had serious effects on the town, including displacement of residents who lost their homes, disruption to infrastructure, economic loss to residents and businesses and loss of confidence in the town. The challenge now is to manage the aftermath of the previous events, as well as the risk of future events, to minimise these effects.

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Speedy Response to Waihi Subsidence

by Mike O'Leary

Manager Readiness, Ministry of Civil Defence & Emergency Management

The Waihi subsidence event that occurred in Waihi on 13 Dec 2001 completely consumed one house, vehicles and outlying sheds and necessitated the urgent rescue of three young children.

It also put at immediate risk another 14 homes. An urgent evacuation was completed of these homes and the area cordoned off. The evacuation was completed by a combined group comprising the Waihi Fire Brigade, Waihi Mining Rescue Team, and the police.

The subsidence occurred in the Hauraki District, which is part of the Thames Valley Combined Civil Defence District. The incident was managed by a Emergency Management Committee chaired and led by Police Inspector Alan Shearer - District Manager for the Police Area. No civil defence declaration was required though the local civil defence organisation was represented on the Emergency Management Committee.

Hauraki District Council (HDC) reacted immediately with Mayor Basil Morrison (who is also the Combined District Controller), General Manager Langley Cavers, and their staff providing an extremely able service to the people affected. HDC ensured that all affected persons were relocated into appropriate housing, were fully briefed and had adequate welfare services. They also oversaw the protection of the affected homes, removal of personal effects where possible, and the security of other at-risk areas.

Because it was so close to Christmas, HDC saw the issues of welfare as even more critical than usual. They saw that Christmas, which is a time traditionally associated with families and relaxation, could place added strains on people if they were not in adequate accommodation. A mayoral relief fund was established to assist with the welfare needs of the evacuees and generous local donations ensured the children affected weren't short of presents.

The immediate response of HDC and their very strong community focus were noted by central government and played a significant part in the timely

response to the emergency. The Government was able to quickly appraise the situation and contribute \$10,000 to the Mayoral Relief Fund.

The Waihi Gold Mining Company also contributed significant resources to the initial management of the subsidence. Besides the use of the Mine Rescue Team they assisted with the ongoing security at the site.

The Ministry of Civil Defence & Emergency Management (MCDEM) was asked to facilitate the implementation of a solution to the Waihi problem, with particular emphasis on addressing the rehousing issues. This included an assessment of the situation, and an analysis of what needed to be done, and who should pay for it.

The Government took the position that it would assist but only with a joint community-based solution. Though MCDEM was asked to facilitate a solution, it was always clear that the solution would be 'owned' and implemented by HDC.

To coordinate Government's response to the event, MCDEM established an informal officials group, which met regularly. Other involved departments included the Department of Prime Minister and Cabinet (DPMC), the Treasury, the Ministry for Economic Development (MED), and EQC.

In addition, officials from MED, EQC and MCDEM visited Waihi and worked with HDC and the Waihi Gold Mining Company Ltd to facilitate a joint solution to the rehousing issues.

In order to ensure a workable solution to the problem Cabinet decided to appropriate money for ex-gratia payments for rehousing on the basis that property ownership ultimately transferred to a third party. Although the event was outside the scope of EQC, their processes were used and the ex-gratia payments were to be equal to those the residents would have received from the Earthquake Commission (EQC) if the subsidence was an event covered under the Earthquake Commission Act 1993.

With this assistance HDC were able to broker a deal between themselves, EQC and the Waihi Gold Mining Company. This deal ensured that residents could either have their homes moved to a new location, rebuilt if destroyed or be paid out the rateable value of their home. All residents have now taken advantage of one of these options.

On the Web

Some great websites for information on earth movements and emergency management

National

[www.civildefence.govt.nz/The Emergency Sector](http://www.civildefence.govt.nz/The_Emergency_Sector)

Information, tools and resources to assist the emergency sector in implementing emergency management practices and solutions across New Zealand. Includes useful links to related agencies

www.doc.govt.nz/Regional-Info/007-Tongariro-Taupo

Analysis and recommendations on environment/risk assessment for future lahar emissions from the Ruapehu crater

www.niwa.co.nz/pubs/wa/09-1/avalanche

Looks at the effect of avalanches on different parts of New Zealand

www.gns.cri.nz/earthact

Gives details of plate motion and deformation, volcanoes, earthquakes, New Zealand geology and land stability

www.ew.govt.nz/ourenvironment

Land and soil – cultivation, erosion, excessive drainage, pugging and compaction

www.wrc.govt.nz/em/hazard

Wellington Regional Council's site on environmental management with earthquake hazard maps etc

www.ecan.govt.nz/Civil-Defence

Environment Canterbury's civil defence section, including the results of an investigation into the vulnerability of the infrastructure serving metropolitan Christchurch

www.branz.co.nz

Looks at earthquake resistant design of buildings

International

www.ngdc.noaa.gov/seg/hazard/resource/geohaz/ldslhaz.html

A very interesting American site including volcanoes and floods, has virtual tour of a landslide

www.ngdc.noaa.gov/seg/hazard/resource/geohaz/

Index page of above site with links to avalanches, earthquakes and volcanoes

www.pdc.org

Excellent website looking at earthquakes, volcanoes, hurricanes and wildfires. Try the earthquake simulation feature!

http://directory.google.com/Top/Science/Earth_Sciences/Natural_Disasters_and_Hazards

Links to a large number of sites on avalanches, earthquakes, landslides, volcanoes, weather, asteroids, preparedness, education and research

www.reliefweb.int/w/rwb.nsf

Archived information, from 1981 to the present, about major natural disasters, focusing on international humanitarian relief efforts. From the UN Office for the Coordination of Humanitarian Affairs (OCHA)

www.usgs.gov

US Geological Survey website

www.geophys.washington.edu/SEIS/PNSN/

Pacific Northwest earthquake information from the Pacific Northwest Seismograph Network

Planning/ Business Continuity Planning

[www.civildefence.govt.nz/All-New-Zealanders/Information for Businesses](http://www.civildefence.govt.nz/All-New-Zealanders/Information_for_Businesses)

If you own a business, then your business needs to be prepared for an emergency. This includes identifying and managing any hazards within your business as well as planning how your business will work through or after an emergency. Links to other relevant sites

See also

www.aucklandcity.govt.nz/council/emergency_management/civil_defence/at_work

www.wemo.wcc.govt.nz/bus1

www.qualityplanning.org.nz

Promotes and provides guidance on best practice in the development of regional and district plans under New Zealand's Resource Management Act (RMA). It is also a database of RMA publications and articles, and provides discussion forums and contact details for councils

www.thebci.org

Information and resources for both the business continuity novice and expert as well as allowing members the opportunity to communicate and network with each other

Emergency Management

www.risksociety.org.nz

The NZ Society for Risk Management was established in 2000 to improve the knowledge and practice of risk management in New Zealand

www.fema.gov/library/bizindex

A step-by-step approach to emergency planning, response and recovery

www.redcross.org/services/disaster/beprepared

Offers a step-by-step approach to emergency planning, response and recovery

www.disasters.org

Disaster preparedness and emergency response reference material, job opportunities, and related information

emc.ornl.gov/emc

Conducts a wide range of research related to disasters such as evacuation, public response, emergency planning, and post-disaster audits

You can link to the above sites from the Ministry's website at www.civildefence.govt.nz

The next Great West Coast Earthquake

by Mauri McSaveney, GNS

A great earthquake is one whose magnitude is 8.0 or greater. New Zealand's last great earthquake was the great Wairarapa earthquake of 1855, which had an estimated magnitude of 8.2. Few New Zealand faults are capable of releasing the energy required for such a large magnitude event. Obviously, the North Island Wairarapa fault was one of them, but we do not expect it to give a repeat performance in the current millennium. Another strong candidate for generating earthquakes greater than magnitude 8 in the North Island is a much less obvious fault, one that has no surface expression on land. This is the fault marking the boundary between the Australian plate and the downgoing Pacific plate as it slides under the east coast of the North Island. Scientists are attempting to decipher a record of the timing of its earthquake activity, but that story is as yet too incomplete to be told. Recent research on the South Island's Alpine fault has shown that it too is capable of generating great earthquakes because sometimes it slips more than 8 metres along its full length of 450 kilometres.

Great earthquakes are of interest because of the huge areas affected by severe ground shaking. Even though these earthquakes may occur in regions distant from major population centres, their effects are likely to be felt nationally as well as regionally. One morning, somewhere on the planet, people are going to awake to



Plate tectonic setting of New Zealand, and location of the Alpine fault and the Whataroa catchment in the South Island. During earthquakes extensive landslides may occur in the c. 50 kilometre wide zone (shown in red) centred on the Alpine fault.

the news that there has been a devastating great earthquake in New Zealand. As likely as not, this great earthquake will be on the Alpine fault. The earthquake will have its greatest effects on the west coast of the South Island, and in the Southern Alps, but these will not be the only areas affected.

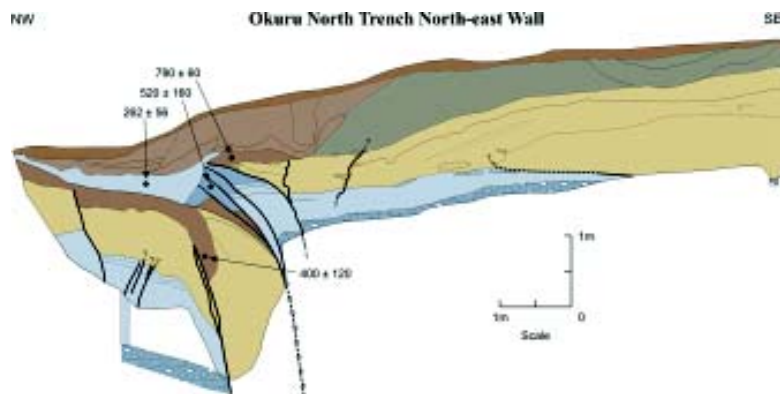
Some recent research suggests that the great West Coast earthquake may not be as imminent as we thought a few years ago. Other research results indicate that many of the effects of this earthquake are not going to appear in the minutes of violent ground shaking. For some communities, serious problems are going to develop over months and may persist for decades, as rivers erode the deposits of many earthquake-triggered landslides and spread the massive quantities of gravel and silt over the coastal lowland farm communities downstream.

WHEN? – THE BIG QUESTION

Murphy's Law would have the next great West Coast earthquake on a dark and stormy night, and given the Coast's notorious rainy climate, there is a 50% chance that Murphy will be at least half right. But earthquakes show no preference for time of day,

weather or season. A most informative piece of new research on the Alpine fault by Russ Van Dissen and David Rhoades of the Institute of Geological & Nuclear Sciences adds no new data, but changes how we interpret what data we have, and any new data added in the future.

The Alpine fault has been generating earthquakes for more than a million years in its role as the boundary between the Pacific and Australian tectonic plates through the South Island. These plates are inexorably moving relative to each other at some 36 millimetres a year, but their boundary at the fault is somehow locked, preventing slip. The strain is being stored elastically, much as in winding a spring, until the next rupture, when the accumulated elastic strain energy will be released in a ground-shattering earthquake. The last rupture, over a length of about 450 kilometres, had about 8 metres of lateral and 3 metres of vertical displacement, and occurred in about 1717 AD. The big question now is how well “wound” is the Alpine fault “spring” for the next rupture. Direct measurement of the relative plate motions over the past few years suggest that the “spring” currently is wound for a displacement of about 7.7 metres, and the expected displacement is increasing by about 27 millimetres each year. Just how much more elastic strain energy has to accumulate before the fault can be expected to rupture is *The Big Question*. We can only attempt to answer it in terms of probability—such as what has been the most frequently occurring



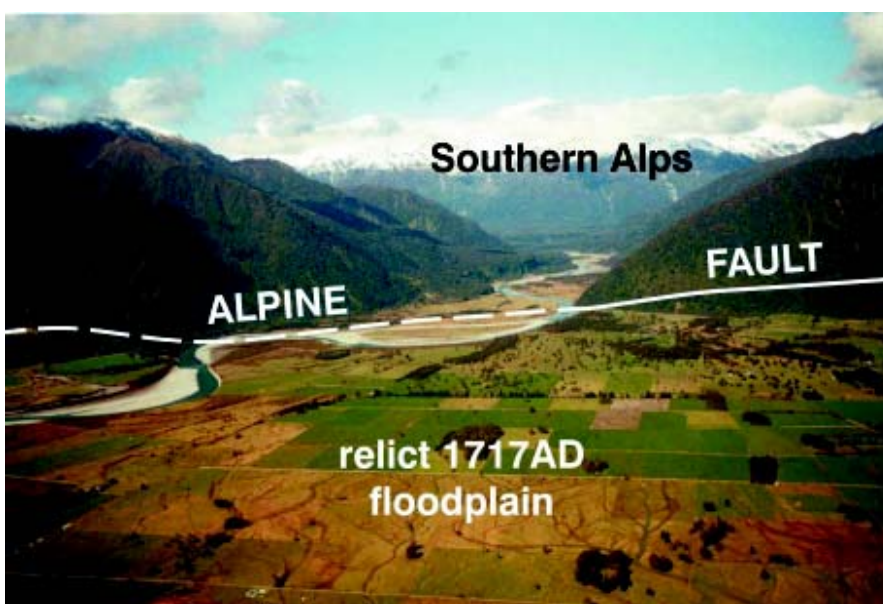
This diagram shows the layers offset by faulting in the wall of a trench dug across the Alpine fault at Okuru, south of Haast.

interval between past ruptures, or what has been the average time between ruptures. From either of these we can subtract the 285 years or so since the last rupture. It turns out that these give very different answers for an estimate of the time of the next great earthquake, and so we have to be very careful about how we interpret the answer.

The cumulative effect of the repeated fault movements is plain to see, but determining the frequency and magnitude of individual earthquakes is more difficult and evidence is not easily found in the rainforests of Westland. One technique for determining the history of faulting is to dig trenches across the fault. Scientists examine the way in which various layers of sediment have been offset by faulting, and obtain radiocarbon dates of organic material in the layers to

tell when the offsets occurred. Evidence for the time of occurrence and displacement of the last four ruptures has been found for the northeastern end of the fault, and for the last three, at the southwestern end. These most recent ruptures, however, are but a very small sample of the thousands of ruptures that have occurred along the fault, so we must be cautious in interpreting information about the entire population of earthquakes from these most recent ruptures.

Studies of ruptures of plate boundary faults elsewhere in the world show that, for a given fault, the amounts of fault slip during earthquakes and the intervals between



The Whataroa River flows across the Alpine fault at the front of the Southern Alps. The rocks closest to the front of the range are soft, highly deformed schist. The coastal plain consists of deposits laid down by late Pleistocene glaciers and by more recent rivers. (Photo: Graham Hancox, GNS)



By coring trees and counting their rings, researchers can determine the age of trees in South Westland.

earthquakes are closely related, but they are often very variable. It takes time for plate-tectonic motion to accumulate enough strain energy to cause a fault to rupture, but many factors determine just how much strain energy must build up. A series of ruptures along a given fault may have different amounts of slip and different intervals between them. Relatively short intervals (and small slips) are relatively rare; longer intervals and slips occur more frequently, but very long intervals and slips are also rare. Some of these intervals can be very long indeed, and when the fault gives way, huge amounts of slip, and a correspondingly massive earthquake, may occur.

I can illustrate the effect using three dated ruptures of the southwestern portion of the Alpine fault in 1717, 1450 ± 100 , and 1150 ± 50 AD, which constitute a very small sample of the thousands of Alpine fault ruptures in the last few million years. The total slip at Haast from these three events is 25 metres, and so we can infer how long the plate-tectonic crustal "spring" had been "winding up" before the event of c.1150 AD. From these data, we can calculate that the fault last ruptured 285 years ago, that the previous rupture was about 267 years before that, and another about 300 years earlier. The average slip in the three ruptures was 8.33 metres, and so at 27 millimetres per year, the average interval between the last four ruptures has been about 309 years.

At face value, the most probable time to the next rupture would thus appear to be a very short 24 years (allowing for uncertainties, Russ van Dissen and David Rhoades extended this to about 35 years). They also determined the likelihood of a rupture in the southwest in the next 20 years to be about 12%, and for the northeast where rupture appears to be more frequent, about 15%.

Scientists are also interested in the longer-term average time to rupture and the average amount of slip. Studies of faults such as the North Anatolian fault in Turkey, which has a very long historical record of earthquakes, suggest that the interval between quakes can vary considerably. While 309 years and 8.33 metres are the modal rupture interval and slip for the recent movements along the Alpine fault at Haast, the average interval for all possible earthquakes along the Alpine fault could be as much as 430 years, with a slip of 11.5 metres. So, ignoring uncertainties, after 285 years, we still may be well over 100 years short of the average interval between ruptures.

These new views of past Alpine fault earthquakes do not alter when the next Alpine fault earthquake will occur, but they do alter our expectation of how long we might have to wait, and what it is that we might be waiting for.

WHAT ARE WE WAITING FOR?

The next great West Coast earthquake will probably produce at least a minute or so of violent destructive shaking within tens of kilometres of the rupture, and potentially damaging amplification of long-period rolling motion in susceptible ground and tall buildings for a hundred or more kilometres. These, however, are just the immediate effects. An interdisciplinary team of researchers from the Institute of Geological & Nuclear Sciences and Lincoln University is looking at how landscape evolution in South Westland has been affected by past Alpine fault earthquakes. Because the effects of more recent earthquakes tend to obliterate evidence of earlier ones, the story is limited to the last few events. We now know that these earthquakes reflect the recent pattern of more frequent earthquakes, and were thus probably less severe than the average.

The study has concentrated on the behaviour of the Whataroa River drainage basin. The most recent rupture of the Alpine Fault to affect the Whataroa area involved a roughly 400km-long segment rupturing in 1717 AD, with prior earthquakes in about 1620 AD, and 1460 AD. The magnitude of these earthquakes would have ranged from 7.3 to 8.3, and the Southern Alps east of the fault would have experienced ground accelerations greater than 0.4 g, ie the mountains would have been tossed upward at four-tenths the acceleration due to gravity. Such motion would have triggered numerous landslides for up to 50 kilometres from the fault. Fed by annual rainfalls in the mountains of more than ten metres, rivers draining the western Southern Alps would have swept the large volumes of sediment brought down in these large earthquakes down to the West Coast lowlands.

The study at Whataroa tests the idea that recent changes in the landscape have been dominated by the effects of Alpine fault rupture. By combining geomorphic mapping, stratigraphy, and dating of soils, terraces and fans with information on the age of areas of forest obtained by tree-ring counting, the study team has evaluated the nature and timing of recent periods of build-up of alluvium on the Whataroa lowland plain.

HOW OLD IS THAT TREE?

Much of the forest within the Southern Alps and to the west of the Alpine fault is dominated by long-lived trees (commonly living more than 700 years) that tend not to tolerate shade well. These trees become established on land surfaces disturbed by landslides or floods, or in areas where the major forest canopy has collapsed. Forested areas that have been affected by major disturbance typically contain an approximately even-aged stand of trees (a cohort) because they all became established at about the same time in disturbed openings. By determining the age of the oldest trees in a cohort, by coring and counting of growth rings, the date of the disturbance that formed the opening can be estimated.

Tree ages on the Whataroa lowland alluvial-fan surfaces were collected from 14 stands of trees. In all 267 trees on the fan were cored.

The upper reaches of the Whataroa alluvial fan near the mountain front are largely covered by relatively young trees, most of which became established after the Alpine fault earthquake of 1717 AD. In contrast, the lower reaches of the fan closer to the coast are dominated by older trees that were established before 1717 AD and the reach also includes a group established around 1625 AD.

The earthquakes of 1717 and c.1620 AD appear

to differ in their local impact. On the Whataroa and nearby Ohinemaka alluvial fans, the earthquake of c.1620 AD appears to have caused a massive aggradation of river sediment, creating new surfaces for trees to colonise over much of the existing fan surface. This aggradation also appears to have had a major impact on the lower reaches of the Wanganui floodplain. In contrast, the aggradation following the 1717 AD earthquake was less extensive on the Whataroa lowland, where it was mostly confined to the upper reaches of the fan.

HOW OLD IS THAT GRAVEL?

Erosion of the banks of the Whataroa River has exposed layers illustrating some of the earlier history of gravel deposition in the valley. Downstream of the Alpine fault, which cuts across the catchment at the steep front of the range, the present-day river bed is incised 5 to 10 metres into an older Whataroa fan surface. The river is also actively cutting into the toes of other alluvial fans from small range-front valleys. The various fan deposits and their relationships to one another have been mapped, together with the present and buried soils of the various former river levels. The ages of the former surfaces have been determined from radiocarbon ages of material incorporated into the fan deposits or from remnants of former forests overwhelmed by fan or terrace aggradation, and from the ages of trees on various terrace levels.

The work shows a succession of rapid accumulations of coarse-to-fine angular schist gravels, separated by young, but recognizable soil horizons. Within the soil horizons are rooted stumps of trees killed by the rapid influx of gravel. The information is interpreted to represent infrequent pulses of river

aggradation, with intervening periods of relative stability and river downcutting. Successive aggradation episodes, dated from the many buried forest remnants and wood, indicate a limited fan-building episode around 1717 AD, a more extensive episode after 1620 AD, and perhaps an episode around 1400 AD.

WHAT HAVE WE LEARNED?

The data from the Whataroa River valley suggests that the 1717 AD rupture of the Alpine fault was followed by a period in which the river



This view upstream on the Whataroa River from near the Alpine Fault shows, in the distance, a high terrace remnant of gravels deposited about 10,000 years ago. They lie about 100 metres above river level and were raised mostly by movement along the fault. In the left foreground are gravel terraces related to aggradation of the valley bottom following Alpine-fault earthquakes in C.1620 and 1717 AD. The river has cut down about 5 metres since the gravels were deposited.

(Photo: Lloyd Homer, GNS)



Exposed in the banks of the river are successive layers of river gravels, separated by a buried soil, detrital wood and an *in situ* tree stump. The organic material has been radiocarbon dated to determine the ages of the layers.

aggraded from 5 to 8 metres in the main valley. Sediment from this aggradation crossed the line of the Alpine fault, obliterating all trace of the fault across the valley floor. The aggrading gravels spread out and thinned across the upper part of the Whataroa alluvial fan, where most of the Whataroa farming community is now sited. In most of the smaller valleys along the range front, however, a major episode of aggradation does not seem to have followed 1717 AD, except in a few local drainages.

The event around 1620 AD by comparison caused much more extensive changes, with major fan building from the range front and in the Whataroa plain. New forests sprang up in the lower coastal reaches, implying extensive aggradation in the upper reaches as well. A prior event around 1400-1460 AD is also identified from the ages of trees and, more tentatively, in the dating of trees buried in the range front fan deposits.

This difference in local impact of aggradation episodes triggered by the Alpine fault rupture could reflect differences in magnitude of the earthquakes. A smaller earthquake could cause fewer and smaller landslides in upland catchments and consequently less aggradation, and thus less new forest growth. However,

the amount of aggradation could also be determined by the amount of loose material available in upland catchments. This could depend on the time since the last major episode of earthquake-triggered erosion. Given the roughly 100 year interval between the c.1620 AD and 1717 AD earthquakes, and the c.160 years between the c.1460 and c.1620 AD events, more sediment may have been available at the time of the c.1620 AD earthquake, leading to a more extensive aggradation across the floodplains.

The researchers infer that Alpine fault earthquakes have played a major role in landscape evolution in the Whataroa River catchment (and perhaps more generally in most of the Westland valleys), but only because rainfall has always been sufficient to transport the loose debris out of the mountains onto the lowland alluvial plains. Prior large aggradation episodes have had intervals between events of 100 to 160 years, but the elapsed time since the last event is 285 years. More material may potentially be still sitting in the headwaters of streams in the Southern Alps at present than before the two most recent aggradation episodes. A future aggradation episode might therefore be larger than the last two episodes.

To complicate the issue, the Fox River fan, south of Whataroa at Fox Glacier, has had *no* major fan aggrading episodes through the last three ruptures of the Alpine fault!

WHERE NEXT?

Researchers plan to refine the ages of forests destroyed by aggradation through radiocarbon dating of *in situ* tree stumps at Whataroa. Episodes of aggradation and erosion of the range-front fans will also be looked at more closely, to see whether the 1717 AD event did cause more aggradation at other locations. Older deposits and buried soils indicate a potential to date other fan-building episodes going back at least a thousand years.

In upstream parts of the catchment the researchers will try to determine the volume of material available for release in the next large earthquake, as well as identifying how much erosion

occurs between earthquakes. The occurrence of the nearby Mt. Adam rock avalanche in October 1999 indicates that some slopes in the alpine valleys along the mountain front are close to failure.

ACKNOWLEDGEMENTS

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Mt Adams rock avalanche—a foretaste of the future

The Mt. Adams rock avalanche of 6 October 1999 had a volume of 10-15 million cubic metres. It was formed by a collapse of part of the Mt Adams massif and involved both loose slope debris and fractured schist bedrock. Average slopes in the head-scarp area are 45° to 60°. The avalanche fell almost 1800 metres into the Poerua Valley, damming the Poerua River. The trigger for the landslide is unknown— there was no recorded seismic activity at the time of the fall and it wasn't raining. Nevertheless, this event represents the type of landsliding expected to occur widely through the Southern Alps during future great earthquakes on the Alpine fault.



The Mt Adams rock avalanche dammed the Poerua River, creating a temporary lake. The dam failed during the first heavy rainstorm, sending a flood of water and debris down the river. Over a number of months the river spread debris out onto the farmland at the foot of the mountains.

(Photos: by Graham Hancox, GNS)



The 1999 Mt Adams rock avalanche fell from the crest of the ridge. The total flow path flow is about 3 kilometres long with a vertical fall of 1790 metres.

Hipaua Steaming Cliffs and Little Waihi Landslide

by Lamorna Cooper

Hazards Analyst, Environment Waikato

The Hipaua Steaming Cliffs have been the source of several devastating debris flows in the last 160 years, which resulted in the deaths of more than 60 people and the destruction of a village. Environment Waikato and the Taupo District Council are working together to minimise the risk and safeguard the community.

In 1846, and again in 1910, the eastern edge of the hamlet of Little Waihi was devastated by landslide debris flows. These landslides originated from a geothermal area known as the Hipaua Steaming Cliffs and flowed down the Waimatai Stream, killing 65 people. With the recent pressure of population growth and the extension of subdivisions into areas previously regarded as marginal, it is appropriate that local authorities work at reducing the risk to the public in the event of future slope failures.

To deal with issues of this magnitude, Environment Waikato and the Taupo District Council use the Resource Management Act 1991, the Civil Defence Act 1983 and the Building Act 1991. All three are fundamental in providing guidance for hazard analysis and risk reduction, and form a framework for community-based contingency planning.

With the Civil Defence Emergency Management (CDEM) Bill undergoing scrutiny during its second reading in Parliament it is important to note that once it is adopted, the focus on reduction via hazard identification, land use planning and proactive mitigation will be highlighted more extensively than in the preceding legislation.

SETTING THE SCENE

Hipaua Steaming Cliffs overlook the south-western tip of Lake Taupo from the lower slopes of the Kakaramea volcano. The cliff-face can be seen from

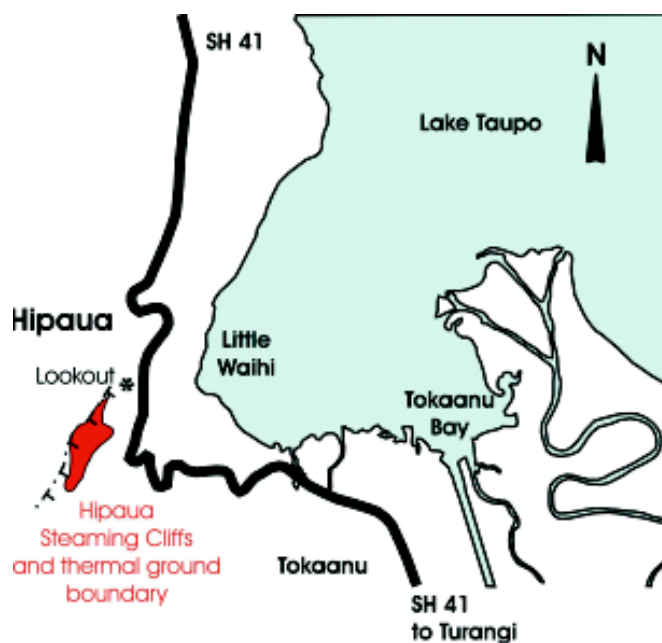


Fig 1: Map showing the position of the Hipaua Steaming Cliffs and thermal area in relation to Little Waihi, Lake Taupo and the southern end of SH41 to Turangi.

State Highway 41 (SH41) to the northwest of Tokaanu and is part of the Tokaanu-Waihi-Hipaua thermal area. This thermal area forms part of the Tongariro Volcanic Centre and is located along the western edge of the Taupo Volcanic Zone (TVZ).

The Hipaua cliff-face has developed along the eroded southeastern edge of the Waihi Fault scarp and sits above a steeply incised valley. This valley is thickly vegetated with manuka, kanuka, fern and mixed native scrub. The valley catchment is drained by the Waimatai Stream, which flows under SH41 through a culvert. To the east of the Waimatai Valley is the Omoho Stream, which also travels under SH41 via a culvert. Both of these streams converge downslope of SH41 and become Slip Stream, which feeds into Lake Taupo.

Hillslope soils are sourced from highly altered Kakaramea Andesite, laharic deposits from the Kakaramea massif and volcanic ash, lapilli and blocks that make up the Oruanui Sand and hill soils formation. The thickness of the soils in this area is estimated to vary from approximately 10m thick towards the peak of Mt. Kakaramea, at 1300m, down

to 4m thick as the soils near the valley floor. Rainfall averages (1941-1970) are estimated at 1400-2200mm/year, which encourages native vegetation growth and contributes to the breakdown of volcanic material.

The flat land that extends towards the lake at the base of the Waimatai Valley has been created by stream drainage, as a prograding delta. At the base of the Waimatai Valley is the frontal lobe of the 1910 debris flow, which extends partially into the lake and is situated slightly north of the current stream mouth.

The combination of steep slope faces of the Waimatai Valley, highly altered and weak volcanic clays/soils, and the remains of previous debris flows greatly increase the risk to the existing Hipaua/Little Waihi community. Any future development along the lakeshore in the vicinity of this valley is at risk, as is SH41, power transmission lines, communications networks, water and sewerage supplies.

Safeguarding this community is a priority for Environment Waikato (EW) and the Taupo District Council (TDC). Over the past 12 years EW and TDC have:

- commissioned consultants reports to outline the hazards
- undertaken ongoing monitoring and analysis of results
- determined a site-specific contingency plan and provided community education on the site risks and agency responsibilities.

THE THREAT

There are three main threats to the lake edge community at the base of the Waimatai Valley and Hipaua Cliffs. These are:

- failure of the cliff-face and debris slope
- failure of the valley drainage system and (possibly) SH41,
- failure of the debris slope overlooking Little Waihi Village.

CLIFF, TALUS AND SLOPE FACE FAILURES

The slope instability witnessed along the Hipaua Cliffs and road-cut sections adjacent to SH41 are related to a number of contributing factors.

The Hipaua cliff-face is an eroded surface feature of the Waihi Fault and as such contains a high proportion of fractured fault zone material, which is inherently weak.

Thermal activity throughout this zone has



Fig 2: Main slip site (December 2001) following the removal of approx 2000m³ of debris. Note that the remaining vegetation is well established and well rooted, but fails to provide adequate support for this highly altered volcanic 'glue' of surface and subsurface material in heavy rain events.

altered the original andesitic rock, resulting in predominantly kaolinite clay. This clay has a high plasticity index, retaining minimal cohesion and flows easily when saturated (see Fig 2). Overlying Oruanui soils are sourced primarily from Kaharoa and Taupo ash and contain some lapilli and blocks. The result is a highly erosive surface and subsurface.

Slope angles down the Waimatai Valley vary upwards of 22° and are generally >35° along the Waihi Fault scarp, Hipaua cliff-face and talus slopes. The maximum angle at which a slope is stable is dependent on the slope geometry (discontinuities, bedding etc), the soil properties and the pore pressure distribution. The road cut angle at this site often exceeds 20° and there would have been a high pore pressure during the December 2001 failure due to a high level of ground saturation. Combine these factors with the nature of the geothermally altered surface and subsurface material within these slopes (altered volcanic clay

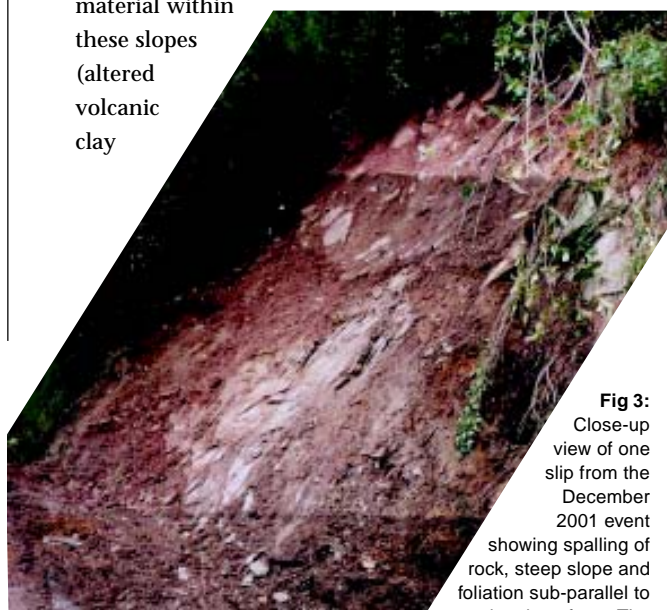


Fig 3: Close-up view of one slip from the December 2001 event showing spalling of rock, steep slope and foliation sub-parallel to the slope face. The slope material consists of andesite blocks, highly weathered and geothermally altered lahar debris (primarily kaolinite) and Oruanui soils.

retains no engineering strength or cohesion), and recurrent road-cut slope failures will occur. The factor of safety for these slopes is likely to be extremely low ($F < 0.8$).

Flow banding seen in andesite lava flows and bands of autobrecciated lava within the Waihi Fault zone dip at a shallow angle to the east and down towards SH41 in the section uphill of the Waimatai Stream culvert. This creates preferential failure surfaces resulting in slope failures like those seen in Fig 3.

Fractured and unconsolidated debris material from the 1846 and 1910 flows is present in the slopes directly beside SH41 and along the base of the Hipaua cliff-face. This material is inherently unstable and contains large (+4 tonne) blocks of unaltered andesite. Failure presents a risk to travellers using SH41, as well as a risk of cliff-face failure as toe material is systematically removed by storm event erosion and subsequent road clearing. There would be little or no warning of slope failure along these slopes and the speed of run-out, indicated by the failure in December 2001, would be extremely rapid (Velocity Class 6 or 7).

The thermal field identified at Hipaua is migrating along the Waihi fault towards Waihi Village and SH41. This migration leaves geothermally altered

and weakened rock in its wake.

The overall size of the Hipaua geothermal field has increased from approximately 3000m² in 1941 to approximately 10,000m² in 1999. Indications are that the activity from the Hipaua field is unlikely to reduce.

Changes to the groundwater level and flownet characteristics are likely to occur as a result of the migration of this field as well as changes during/after severe rainstorm events (as seen 7-9 Dec 2001). This could trigger slope failure in the surface and subsurface soils.

WAIMATAI VALLEY DRAINAGE SYSTEM AND SH 41 FAILURE

The section of SH41 that runs through the Tokaanu-Waihi-Hipaua thermal field forms part of the main 'alternate' route around Lake Taupo. It continues southwest to Taumarunui or connects up with State Highway 32 heading north to Tokoroa. The average annual daily traffic numbers recorded by Transit NZ for 2001 show traffic volumes at the Waihi Stream Bridge to be 1730. This indicates that there could be a significant risk to motorists if there was a slope or road failure from the Hipaua site.

Upstream of the SH41 culverts, the Waimatai Stream and the Omoho Stream each drain through a narrow gut lined with large boulders. After storm

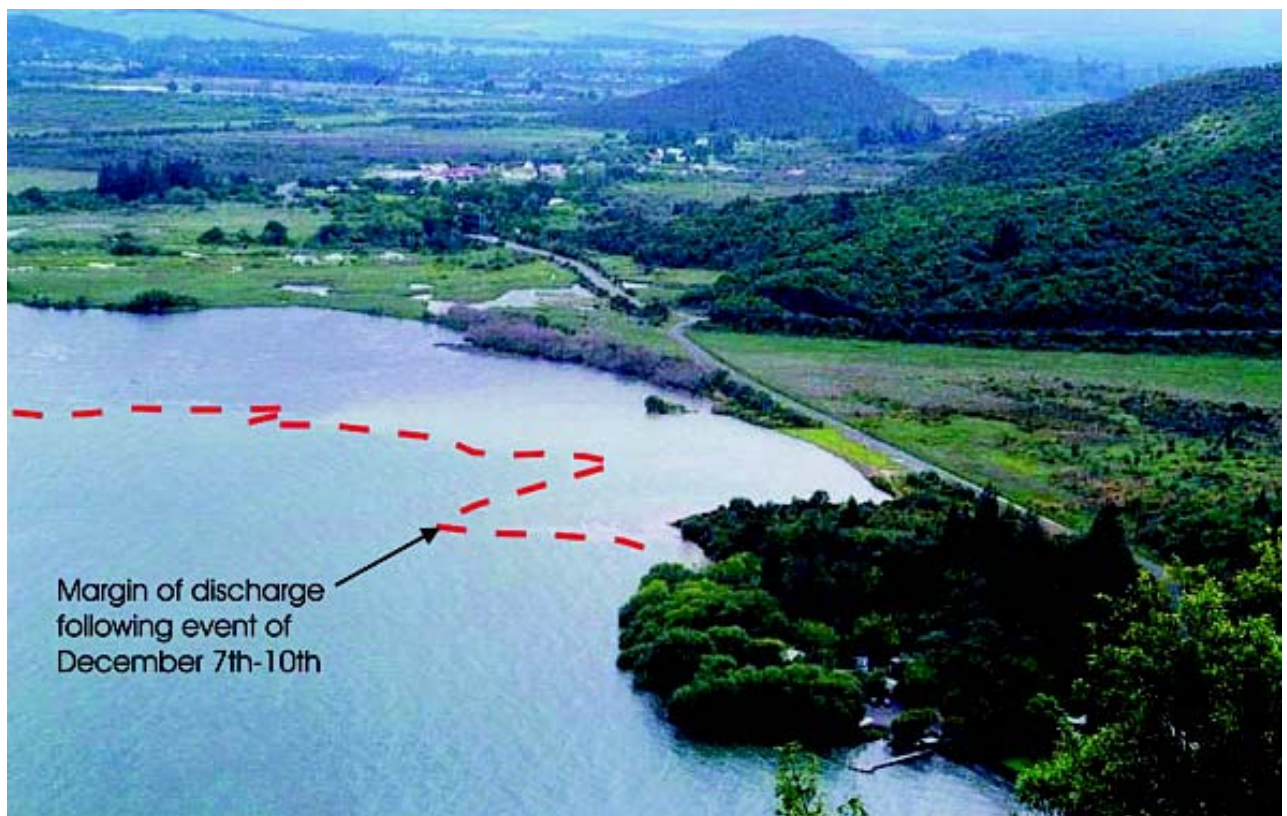


Fig 4: Discharge of sediment and debris from the Waimatai and Omoho Streams flowed into Lake Taupo following the storm event of 7-9 Dec 2001. Braxmere Lodge at bottom right is built on the lobe of the 1910 Hipaua debris flow. SH 41 to Turangi can be seen in the centre right of the image.

events the runoff from these streams can be seen entering Lake Taupo with a heavy sediment load (see Fig 4). Because of the lush vegetation that is loosely anchored in the volcanic clays of the Waimatai and Omoho Valleys, these storm flows can carry heavy vegetation loads.

In extreme storm events, the steep drainage gut of the Waimatai and Omoho Streams becomes choked with trees, shrubby vegetation and debris scoured from the catchment slopes. This blockage acts as a dam, impounding the water and debris upstream of SH41 (see Fig 5). As the water level rises, so will the pressure exerted on the road and culverts, causing them to breach. Once this occurs the accumulated water and debris will cascade down the slope into Lake Taupo. This form of failure has occurred in the past ten years, with the road being partially washed out and material entering the lake from Slip Creek.

While the risk of road failure has been recognised, it is important that road users are safeguarded by having in place a contingency plan developed by the local community agencies and Transit NZ.

As the water level backs up due to culvert blockage, there is likely to be a rise in the groundwater level in the surrounding hill slopes. This may lead to an increased risk of failure to already saturated talus, debris slope and cliff-face.

DEBRIS SLOPE FAILURE ABOVE LITTLE WAIHI VILLAGE

Slope failures have also been identified above Little Waihi Village. Isolated blocks of rock can be seen within the steep slope above the village in the vicinity of the waterfall. Rock fall from this slope poses a threat to the houses at the northern end of the village, as well as to the village water supply.

A walkover of the slope by Taupo civil defence and emergency personnel indicated that the high number of these rock fall sources was far too extensive to be dealt with easily or economically. Some clearance work was undertaken on material that was easiest to access.

TRIGGERING MECHANISMS

The main triggering mechanisms have been identified as:

- continued geothermal alteration of slope materials and northwards migration of the Hipaua thermal field
- high-intensity rain event over several days, with already-saturated ground
- damming of the Waimatai and Omoho culverts, with failure of the road and flushing of slope talus and slope debris
- an earthquake of magnitude M6.3 on the Waihi Fault.



Fig 5: View looking up the Waimatai Valley with the Waimatai Stream entering a culvert under SH41 to the bottom left of the view.

EXISTING LEGISLATIVE REQUIREMENTS

Under the Civil Defence Act 1983 (CD Act), Environment Waikato is directed to produce a Regional Civil Defence Plan. This sets out specific direction on the procedures and actions that will be followed by Environment Waikato staff and other organisations if and when a civil defence emergency occurs. When considering the '4Rs' of Reduction, Readiness, Response and Recovery, much of the planning, training and publicity to come from this plan is geared towards readiness, response and recovery. Reduction is largely overlooked by the existing CD Act, but generally picked up in the new Civil Defence Emergency Management Bill, and various sections of the Resource Management Act (RMA) 1991, by regional and territorial authorities.

Direct reduction occurs under s30 of the RMA, where regional authorities are obliged to use policies and objectives to avoid, remedy or mitigate natural hazards. Among the hazards identified are erosion, falling debris, subsidence, slippage or inundation. To assist by providing information on natural hazards, s35 directs local authorities (regional and territorial) to keep appropriate natural hazards information and records, while s92 can require those parties seeking a resource consent to provide even further information. The scale and technical depth of this information is entirely arbitrary and in some cases is coloured by other legislation.

One example is the requirement under the Building Act 1991 for territorial authorities to provide the 50-year design flood level for building purposes, while regional authorities (usually) provide the 100 year design flood levels. This difference in scale also applies to individual hazard assessment, where a regional council may map their hazards at a scale of 1:50 000, while the territorial authority can look at a specific title (via a Land Information Memorandum), a proposed subdivision (via a Project Information Memorandum), or community (via the District Plan).

A geotechnical assessment can be requested as part of a subdivision resource consent process if it is felt there is a risk to the public from a particular natural hazard. This may occur whether the resource consent is likely to go notified or non-notified.

Even without a consent process, if a hazard is identified as capable of providing a high level of risk to the public, then research is often undertaken at the expense of local authorities. This is not an immediate process and requires community consultation, council buy-in and the usual projected financial budgeting. Unless an extreme risk is identified, the process of planned mitigation can take several years.

Under s31, territorial authorities are directed to

control effects (actual or potential) resulting from land development (or land protection) to avoid or mitigate natural hazards. This means that any real 'development' control is outside the immediate jurisdiction of regional councils. In extreme cases some consent authorities may not grant a subdivision consent if they feel that there is a risk of natural hazard occurrence under s106.

With the CDEM Bill, more emphasis is placed on hazard reduction. This should lead to an increase in the level and volume of natural hazards that are identified as part of the legislative process of regional authorities. From that process will come increased recognition of natural hazards, identifying the increased risk of those hazards if subdivision development occurs, and an assessment of the sociological and economic effect to the local community.

CURRENT HIPAUA MITIGATION

Dealing with the issue of hazard management for Hipaua has been undertaken by combining Taupo District Council and Environment Waikato funding for thermal imaging, and civil defence emergency management logistical support. The existence of slope instability at Hipaua was officially highlighted in a Barrett-Fuller consulting report undertaken for Environment Waikato in 1993. The Institute of Geological and Nuclear Sciences also undertook work for the Taupo District Council in 1996, as part of a district-wide hazard identification project.

Environment Waikato and Taupo District Council have since commissioned reports from Tonkin & Taylor and IGNS. These include a risk assessment which quantified previous failures, reviewed earthquake, rainfall and hydrothermal risk data, as well as thermal imaging over a 10-year period with analysis of results.

When considering contingency planning, Little Waihi Village has an estimated population of 70, at risk by rock fall and wave effects from debris flow. The area across the 1910 failure debris flow is identified in the TDC District Plan and means that the guests at Braxmere Lodge will need to be taken into account when evacuating. Community-based contingency planning has been undertaken as directed by the TDC and their Emergency Management Officer and has included:

- practice evacuation exercises from the shore utilising the Lake Taupo rescue boat
- alternative jetboat transportation (based in Taupo)
- discussions with landowners regarding emergency alternative transport routes (in the event of a blockage to SH41) utilising forestry roads from

Kuratau Junction to Lake Otamangakau

- discussions on the installation of an evacuation siren and
- assistance with evacuation instructions for Braxmere Lodge.

RECOMMENDED MITIGATION

Following an assessment of past and current monitoring and investigation for the Hipaua site, the following recommendations were put before the Taupo District Council on 11 Feb 2002 by Environment Waikato's natural hazards and emergency management programme.

- Recognise that an extreme rain event will trigger slips along this section of SH41. Encourage Taupo District Council to use this 'recognition' tool to monitor the road and advise the appropriate authorities of possible risks to motorists ie, proceed with extreme caution versus blocking the road, remembering that boulders in excess of 2 tonne are identified in the road cuts.
- Insert monitoring points for the two culverts that lead into Slip Stream, in an attempt to reduce the risk of road failure and landslide initiation due to culvert blockage and associated groundwater perching.
- Continue to run infra-red surveys of the main Hipaua slip, monitor movement and provide information to the down-slope community on the risks associated with road-cut and/or Hipaua Cliffs and slope failure.

There are two trains of thought on movement of the Hipaua thermal area. Infra-red surveys undertaken in 1991 and 2001 show no apparent movement during that period. On the other hand, on-site monitoring undertaken from 1993 to 1995 indicates that the field is migrating towards the Waihi Village and that it is (historically) increasing in size. These variants in results support a requirement for further monitoring of slope movement, although detailing costs and equipment requirements has yet to be undertaken.

Two items that need to be addressed in the short

term are the further definition of the community contingency plan and a request for Transit NZ to assess their own contingency plan in terms of road closure and remediation. Further community liaison is likely to occur through the community board members and local iwi representatives.

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SHAKIN' THE HOUSE DOWN

There'll be earthquakes in Canterbury this year and for earthquake enthusiast and engineering graduate, Jeff Matthews, the bigger the shake the better.

The quakes will be no natural occurrence. Jeff and his University of Canterbury Department of Civil Engineering team will be simulating, then testing and measuring man-made earthquakes on a slice of a building representing a lower floor in a multi-storey pre-cast concrete building.

The aim is to find out just how much load and stress parts of a building, and in particular the pre-cast concrete structures will handle in the event of an earthquake.

Jeff Matthews' PhD research is funded through the Foundation for Research, Science and Technology's Technology for Industry Fellowships (TIF) scheme. This has enabled him to work alongside businesses such as Firth Industries and Stresscrete, who are very interested in the performance of concrete in construction. Jeff is carrying out the research using the University's equipment and expanding his own background in earthquake engineering.

Recent events have highlighted the performance of buildings under stress, and the research builds on New Zealand's internationally regarded expertise in earthquake engineering.

"We've used the same construction methods over the past 20 years in New Zealand and this is a unique opportunity to really test the entire structure and see how the building performs with pre-cast floor slabs. We'll be using hydraulic rams to simulate the forces of a real earthquake and computer-tracking the action of the components in slow motion. What we want to find out is how much pre-cast concrete can take and still remain standing," says Jeff.

Len McSaveney, formerly of Stresscrete, one of the partner companies in the research project, says this research is significant as it is the first time an entire building structure has been tested in this way. Early results from the research were presented to a conference in Rotorua recently and earthquake-prone countries are following progress closely.

Email: civl295@it.canterbury.ac.nz for more information.



Jeff Matthews at the University of Canterbury's Department of Civil Engineering

GeoNet: **MONITORING HAZARDS IN A NEW CENTURY**



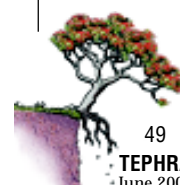
Ash from the 1995 and 1996 eruptions of Mount Ruapehu spread for hundreds of kilometres downwind. (Photo: Lloyd Homer)

by Hugh Cowan, GNS

On 28 Feb 2001, the greater Seattle area in the United States of America was shaken by a magnitude 6.8 earthquake. Centred at a depth of approximately 50 kilometres, the earthquake occurred in the Juan de Fuca plate, which plunges beneath the North American continent. Even before the shaking had subsided, high-fidelity records of the ground motions had been relayed to computers of the Pacific Northwest Seismic Network, where key data on the earthquake was automatically processed. Within minutes, agencies throughout the region had received alert information via pagers and the Seismic Network's web pages (www.geophys.washington.edu/SEIS/PNSN/) and an organised response by emergency services was underway.

In the same region, some 18 months earlier, a transient change had been detected in the relative positions of a number of continuous GPS (Global Positioning System) stations, although no earthquakes had been recorded at that time. The GPS instruments, part of the Pacific Northwest Geodetic Array, could measure changes with millimetre precision. From the data they recorded, scientists were able to determine that some slip had occurred along the face of the subducting Juan de Fuca plate¹. Whether or not this slip is related to the later earthquake remains to be seen. But the Seattle experience illustrates scientists' growing capability to monitor earth processes continuously and cost-effectively over large areas, and the use of technology to help community services to respond swiftly when disaster strikes.

With the advent of digital recording, high-speed computers and data storage, man's technological ability to continuously monitor geological hazards has grown rapidly. This new technology has been applied initially in earthquake-prone regions such as Japan and



California, and is now used in countries as diverse as Taiwan, Iceland and Slovenia.

New Zealand citizens live in a high-risk country. We are exposed to a wide range of geological hazards—earthquakes, volcanoes, tsunamis, landslides and geothermal activity— that can cause extensive damage and have devastating social and economic consequences. Until recently, however, scientists here monitored these hazards using a fragmented network of aging instruments. New Zealand scientists, engineers and emergency managers, and international scientists asked to review New Zealand's monitoring systems, were long aware that New Zealand's existing hazard monitoring networks were inadequate and in need of upgrading.

Five years of equipment trials and consultation have now led to a plan for a new network. It will provide real-time monitoring of hazards and high-quality information for emergency response, as well as providing data for research on earthquakes, volcanic eruptions, landslides, geothermal activity, and tsunamis. In a collaborative project sponsored by the Earthquake Commission (EQC), the Foundation for Research Science and Technology (FRST) and the Institute of Geological and Nuclear Sciences (GNS), scientists will design and build the New Zealand *GeoNet*.

GeoNet is the name given to a new modern national network of instruments designed to monitor earthquakes, volcanic unrest, land deformation, land stability, geothermal activity, and tsunamis. The network will be phased in gradually over the next decade, and will be designed, installed and operated by GNS.

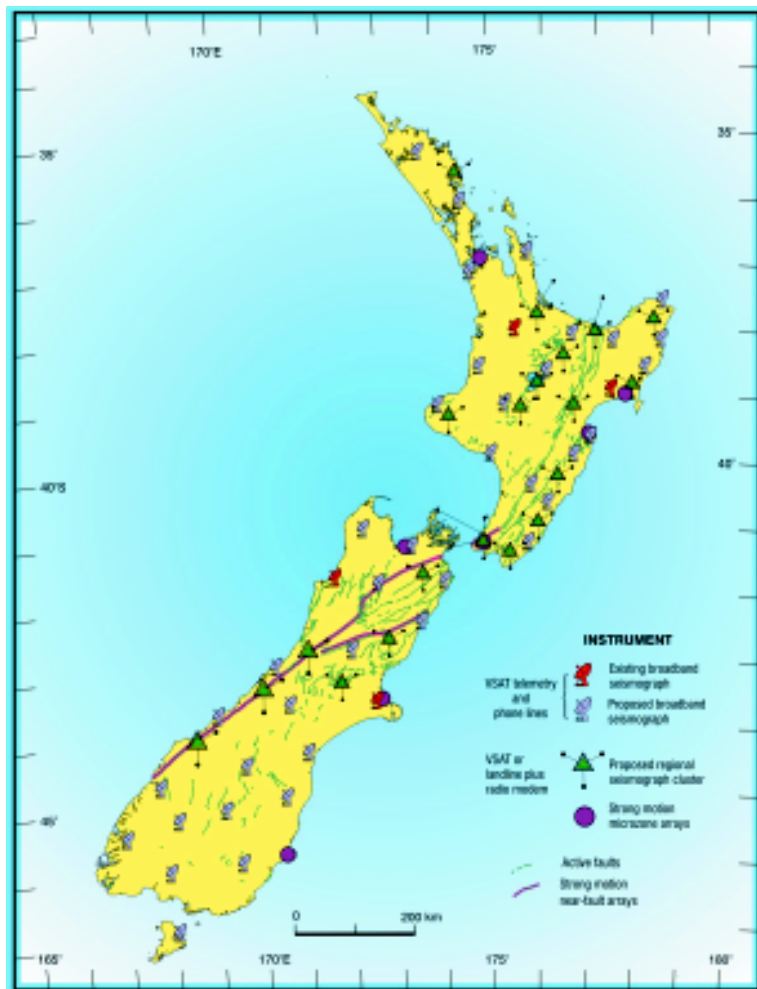
Following consultation with government, it was decided in February 2001 that EQC would provide 60 percent of the long-term funding needed to get the project underway. This equates to NZ\$5 million a year for the next 10 years. This substantial contribution will be used to modernise the equipment in the national network in the first few years and to fund the operation of the system thereafter.

GNS and EQC will invite other national and regional organisations to contribute according to their level of need for hazard information. After the first few years, *GeoNet* should be approaching target levels of approximately \$35 million capital and about \$5 million a year operational funding for the improved monitoring system.

GEONET: UPGRADING THE NETWORK

EQC funding will provide the instruments forming the heart of the new network:

- an array of new seismographs will be installed, positioned to cover all parts of the country. These instruments will measure accurately the magnitude and location of earthquakes
- GPS equipment in dense arrays will be used to pinpoint areas of the country where strain is building up. The information will be used to identify regions where that strain could be released in the form of damaging earthquakes
- seismic recorders for buildings, bridges, dams and other structures will give engineers information on how these structures stand up to the stresses caused by earthquakes
- seismic, chemical, and GPS equipment will be set up to detect and monitor early signs of renewed activity at New Zealand's volcanoes
- survey equipment will be provided for teams to measure and monitor landslides.



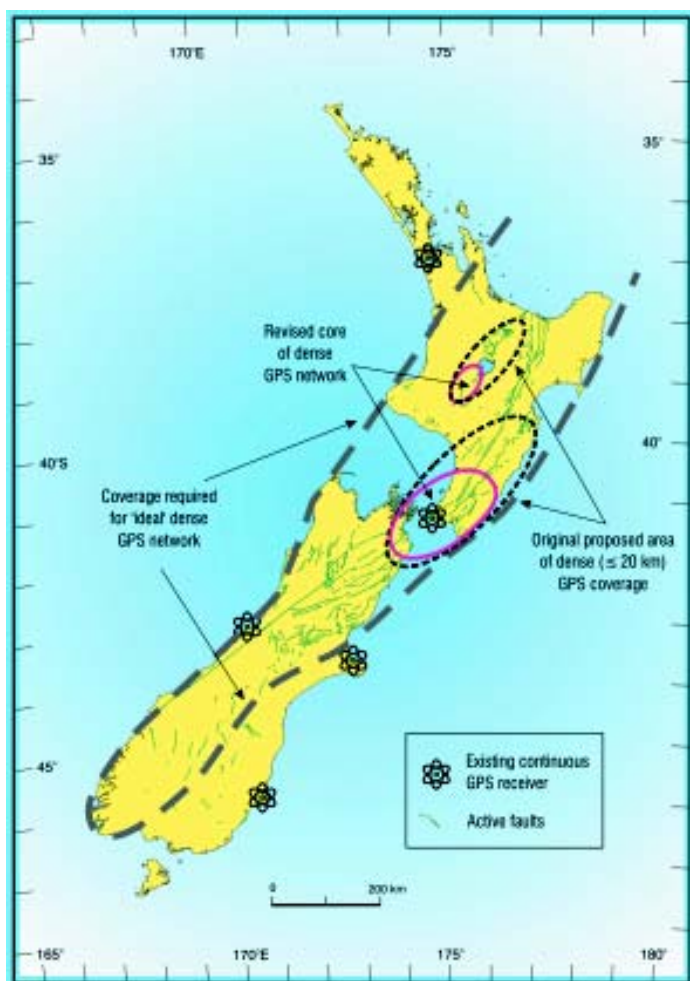
The new *GeoNet* seismic monitoring network will provide a more even distribution of seismic instruments around the country to detect earthquakes. The instruments will be developed and installed during the next three years.

The GeoNet programme will allow around-the-clock operation of the monitoring system, cover expenses for mobilising teams of scientists, and fund a modern data management centre. Much of the centre's information will be available in near real-time, as the equipment will be linked by satellite and radio to data centres in Wairakei and Wellington.

GEONET: MONITORING THE DANGER

The GeoNet monitoring system is a non-profit "public good" initiative. Data collected from GeoNet will thus be "free-to-air" – in other words, there will be no charge for the basic information to New Zealanders and the worldwide research community. Any organisation, however, may use the basic data to provide customised information on a commercial basis.

GeoNet will contribute to the development of safer communities. Accurate and timely data about geological hazards is vital to help us manage the response to any disaster, and reduce the vulnerability of our communities through better planning and mitigation measures.



GeoNet will use arrays of GPS equipment for monitoring earth movements. The proposed long-term coverage by the GPS networks is indicated by the black (dashed) ellipses. The red ellipses indicate the potential coverage after 10 years, with available funding.

EARTHQUAKES: EMERGENCY RESPONSE AND RECOVERY

The new seismic monitoring network can quickly provide information on the location, size and nature of an earthquake. Acquiring accurate information within minutes is critical to organising the response of emergency services. Many agencies in New Zealand have limited resources, so the ability to quickly determine the areas likely to be in greatest need is extremely important.

The question of the best policies for reconstruction arises almost as soon as the ground stops shaking. GeoNet can quickly provide a full range of seismological information, allowing officials to rapidly evaluate damage to structures and their performance during the earthquake. This analysis is needed to ensure that damaged buildings are not unnecessarily demolished, and to help determine if design standards need to be changed for repair and reconstruction.

WARNING OF VOLCANIC ERUPTIONS

While major earthquakes often strike without warning, volcanic eruptions are often preceded by deformation or swelling of the earth's surface, by earthquake activity, and by the release of gases from vents in the ground. Monitoring of these events provides early warning of an impending eruption, which in turn provides valuable time to organise emergency measures. Once an eruption is underway, monitoring provides vital information on local dangers and on the regional effects of the eruption. For example, the network can be used to track the dispersal of plumes of volcanic ash which pose severe dangers to aircraft. Ash can play havoc with communities– collapsing roofs, damaging machinery and vehicles, and causing breathing difficulties and eye irritation. In rural areas, ash may contaminate feed used by livestock.

WARNING OF TSUNAMIS

In March 1947, the North Island coast between Mahia Peninsula and Tolaga Bay was swamped by tsunami waves that were in places up to 10 metres high. The tsunami washed away two houses and a bridge, and engulfed a number of people, who luckily survived. This tsunami, and another in the same year on 17 May, followed offshore earthquakes that were only mildly felt along the nearby coast. GeoNet instruments may provide the first warning that an offshore earthquake capable of generating a tsunami has occurred.



Many new seismograph stations will be linked to the monitoring centre via satellite.

INSURANCE AND OTHER MITIGATION MEASURES

Scientific assessment of data from the monitoring network contributes information about major geological risks in various regions. This knowledge can be used by insurers to assess potential losses from future hazard events and to adjust the risk fairly.

GeoNet will directly benefit the community. In particular, GeoNet will contribute to improved planning at the community level before an event and to community preparedness and response during and after an event, all of which lie at the heart of reforms in the way we currently manage emergencies.

REFERENCE

¹ Dragert et al. (2001) *Proceedings of the American Geophysical Union*, Fall meeting, San Francisco.

SEISMIC HAZARD ASSESSMENT

To determine the likely severity of ground shaking in any given area during future earthquakes, data is needed from seismic monitoring, from geological studies and from the dating of prehistoric earthquakes. This information is vital if communities are to make well-informed decisions on building construction and on where to site community lifelines such as roads, bridges, and water and gas pipes.

EARTHQUAKE ENGINEERING

Recordings of strong ground motion, from instruments both in structures and on the ground near the source of large earthquakes, are essential if engineers are to design safe, cost-effective structures, such as buildings, bridges and storage tanks, that can withstand earthquakes.



Scientists regularly analyse gases from volcanic vents, as changes in the amount of gases such as sulphur dioxide may indicate an impending eruption.

BE PREPARED

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.

At home:

Develop a household emergency plan which includes:

- Where to shelter in an earthquake, flood or storm
- 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 (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 and plastic rubbish bags for your 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

SPECIAL SUPPLIES FOR THOSE WITH DISABILITIES

- Hearing/mobility aids/glasses

EMERGENCY CLOTHING

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

Put all items, especially blankets and clothing into leakproof 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/soap & toothbrushes
- A change of clothes

PEOPLE WITH DISABILITIES

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 — perhaps in an earthquake — 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.

EARTHQUAKES

BEFORE AN EARTHQUAKE OCCURS

- Secure heavy furniture to the wall or floor
- Place heavy items near the floor
- Put strong catches on cupboards
- Check that your chimney is secure
- Secure your hot water cylinder
- Check your household insurance
- Don't put chemical cleaner in the toilet cistern. This will poison a potential source of drinking water

DURING AN EARTHQUAKE INSIDE

- Take cover under a table or brace yourself in a doorway
- Do not attempt to run outside
- If in a lift, stop it at the nearest floor and get out
- Do not look for your pets until shaking ceases

DURING AN EARTHQUAKE — OUTSIDE

In a high rise area

- Take cover in a doorway
- Do not run into the street

If you are driving

- Slow down, pull over to the side of the road and stop
- Stay in the vehicle. It will provide some cover

AFTER AN EARTHQUAKE

- Check those around you and help them if necessary
- Make sure that someone reports the damage in your area to the nearest Civil Defence Centre
- Put out small fires. Evacuate the building if the fires cannot be controlled
- Listen to the radio for advice and information
- If your property is damaged, try to take notes of damage for the loss adjuster
- Do not go sightseeing

VOLCANOES

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.

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 a 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.
- Keep below ridge lines in hilly terrain — the hill will offer some protection from flying volcanic debris
- Don't go sightseeing
- Don't leave home unless advised to by Civil Defence

For further information on what you should do to prepare for an emergency, contact your local council or visit www.civildefence.govt.nz. Find out what you need to do BEFORE you need to do it.



www.civildefence.govt.nz



www.civildefence.govt.nz