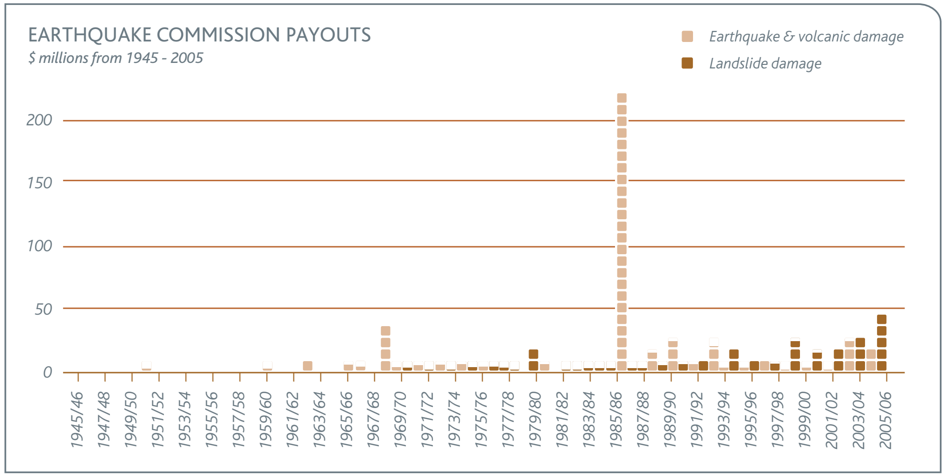
HAZARD EVENTS IN NEW ZEALAND

New Zealanders have been, and continue to be, at risk from a broad range of hazards. However, the types of emergencies that have occurred in New Zealand have changed over time. In the 1800s and early 1900s many people died in shipping accidents, fires and epidemics – the 1854 measles epidemic and 1918 influenza epidemic collectively accounted for more than 12 600 deaths. The Mt Tarawera eruption in 1886 and Hawke's Bay earthquake in 1931 were the most significant natural events of this period, with 153 and 256 deaths respectively.

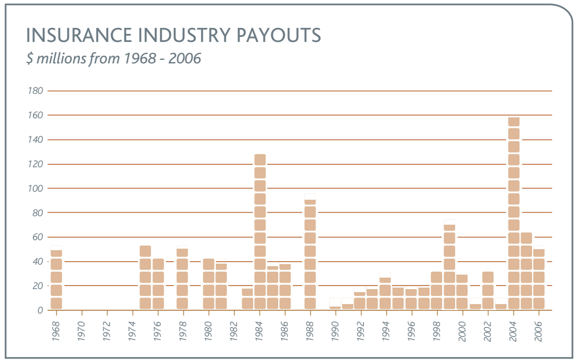
Since the mid-1900s relatively few people have died from natural hazards, with most hazard deaths attributed to transport accidents. The three main transport accidents were the Tangiwai train derailment in 1953, the sinking of the *Wahine* in 1968, and the Air New Zealand flight TE901 Mt Erebus crash in Antarctica in 1979. The crash of flight TE901 remains New Zealand's deadliest disaster with 257 deaths.

The scene of the 1953 Tangiwai train derailment. The Wellington to Auckland express train plunged into the Whangaehu River on Christmas Eve, killing 151 people, after a lahar from Mt Ruapehu washed away part of the rail bridge. *Alexander Turnbull Library.*

Since 1970 there have been many floods causing significant evacuations of people and damage to property, but few deaths. The most notable natural hazard event in the last 20 years was the 1987 Edgecumbe earthquake.



Earthquake Commission payouts for earthquake and volcanic damage (light brown) and landslide damage (dark brown) 1945/46-2004/05 in 2006 dollars. The 1987 Edgecumbe earthquake was by far the most expensive event during this period, resulting in $209 million in Earthquake Commission payouts, followed by the 1968 Inangahua earthquake, and landslide events during 2005. *Earthquake Commission.*



Insurance industry payouts for weather-related events 1968-2006 in 2006 dollars. The 1984 Southland flood, Cyclone Bola in 1988, and the February 2004 storm have been New Zealand's most expensive weather-related events during this period. *Insurance Council of New Zealand.*

Some significant New Zealand hazard events (1846 to 2007)

Some significant New Zealand hazard events are listed in the following table. Many of the geological and meteorological events, and in particular earthquakes, floods and snowstorms, have had significant economic impacts.

Date	Event
May 1846	Landslide at Te Rapa, Lake Taupo – at least 60 dead
October 1848	Marlborough earthquake – 3 dead
1854	Measles epidemic – 4000 dead
January 1855	Wairarapa earthquake – 7 dead
January 1858	Flooding in the Hutt Valley – 9 dead
February 1863	HMS Orpheus wrecked on the Manukau Bar – 185 dead
July 1863	Snowstorm and floods in Otago – about 100 dead
April 1865	The ship Fiery Star burned near the Chatham Islands – 78 dead
September 1878	Severe floods in the Clutha Valley with widespread damage
February 1879	Kaitangata mine explosion – 34 dead
April 1881	The steamer Tararua wrecked at Waipapa Point – 131 dead
June 1886	Eruption of Mt Tarawera – 153 dead
February 1909	The steamer Penguin wrecked in Cook Strait – 75 dead
September 1914	Explosion and fire at Ralph's mine, Huntly – 43 dead
1918	Influenza epidemic – 8600 dead
July 1923	Train crash at Ongarue – 17 dead
June 1929	Murchison earthquake – 17 dead
February 1931	Hawke's Bay earthquake – 256 dead
February 1938	Flash flood at Kopuawhara – 21 dead
June 1943	Express train derailed at Hyde, Otago – 21 dead
November 1947	Ballantyne's department store fire, Christchurch – 41 dead
October 1948	National Airways Electra crash on Mt Ruapehu – 13 dead
March 1949	National Airways Lodestar crash in the Tararua foothills – 15 dead
December 1953	Express train derailed at Tangiwai – 151 dead
July 1963	National Airways Dakota crash in the Kaimai Range – 23 dead
January 1967	Explosion at the Strongman mine, Greymouth – 19 dead
April 1968	TEV Wahine wrecked in Wellington Harbour – 51 dead
May 1968	Inangahua earthquake – 3 dead, 300 evacuated
February 1973	Parnell chemical leak – 4000 families evacuated
October 1978	Otago and Southland floods – about 3000 evacuated
August 1979	Abbotsford landslide – 69 houses destroyed or badly damaged
November 1979	Air New Zealand DC10 crash at Mt Erebus – 257 dead
June 1980	Taieri flood – 1400 evacuated
September 1980	Marton LPG leak – 1500 evacuated
April 1981	Thames Valley flood – 2250 evacuated
July 1983	Golden Bay and Marlborough flood – 200 evacuated
January 1984	Southland floods – damage to more than 1200 homes
February 1985	Thames Valley flood – 4 dead, 170 evacuated
July 1985	Poverty Bay flood – about 100 evacuated
January 1986	Nelson Bays flood – 150 evacuated
March 1986	Aorangi flood – 1 death, 1360 evacuated
March 1987	Edgecumbe earthquake – 5000 evacuated
March 1987	Southland flood – 700 evacuated
March 1987	Thames scrub fire – 130 evacuated
March 1987-88	Canterbury drought
March 1988	Cyclone Bola – 5 dead, 5000 evacuated
May 1988	Greymouth flood – 402 evacuated
July 1988	Palmerston North flood – 1200 evacuated
September 1988	Greymouth flood – 1 death, 356 evacuated
January 1989	Great Barrier Island flood – 154 evacuated
March 1990	Cyclone Hilda (Taranaki and Wanganui) – 147 homes evacuated
February 1991	Catlins flood – 128 evacuated
August 1992	Canterbury snowstorm
January 1994	Southland and Otago floods – more than 3000 tourists displaced
March 1994	South Canterbury flood – 240 evacuated
August 1994	Timaru grain store bulge – 300 evacuated
November 1994	Wanganui flood – 157 evacuated
April 1995	Cave Creek viewing platform collapse – 14 dead
1995	Mt Ruapehu eruption
July 1995	Thames Valley flood – 30 evacuated
December 1995	Waitaki and Waimate flood – 100 evacuated
1996	Mt Ruapehu eruption
December 1996	Thames-Coromandel storm – 1 dead, 2000 evacuated
January 1997	Thames-Coromandel storm – 3 dead, 140 evacuated
February 1997	Opuha dam failure, Timaru district – 200 evacuated
June 1997	Wairoa flood – 166 evacuated
October 1998	Buller flood – 66 evacuated
October 1998	Buller flood – 220 evacuated
October 1998	Kapiti Coast and Wanganui flood – 1 death
January 1999	Far North flood – 270 evacuated
February 1999	Central Otago rural fire – 1 dead, more than 200 evacuated
November 1999	Otago floods – 140 evacuated
June 2002	Thames and South Waikato flood – 1 dead, 500 evacuated
October 2003	Kapiti Coast flood and landslides – 5 evacuated
February 2004	Manawatu-Wanganui, Taranaki, Hawkes Bay, Waikato, Wellington and Marlborough floods – more than 1800 evacuated
July 2004	Opotiki and Whakatane flood and landslides – 1 dead, more than 1300 evacuated
May 2005	Bay of Plenty flood and landslides – more than 410 evacuated
April 2006	Dunedin flood – about 120 evacuations
June 2006	Canterbury snowstorm – widespread power and telecommunication outages, and many roads closed
March 2007	Mt Ruapehu lahar
March 2007	Far North flood – evacuations and damage to roading and other infrastructure
July 2007	Taranaki tornadoes – 73 properties damaged
July 2007	Upper North Island flood and severe wind – settlements isolated, roads closed, power and telecommunication outages
July 2007	Hawke's Bay flood – 1 evacuated
July 2007	South Otago flood – 40 evacuated

Hill country erosion after Cyclone Bola in 1988. Up to 750 mm of rain fell over an area from Hawke's Bay to East Cape in four days. *GNS Science*.

Milk silos at the Edgecumbe dairy factory after the 1987 Edgecumbe earthquake. This earthquake remains New Zealand's costliest to date. *Whakatane Beacon*.

Prestonville industrial area and part of suburban Waikiwi, Invercargill, January 1984. *Otago Daily Times*.

Waimakariri River flood, 1868. Flooding near the Canterbury Provincial Council Buildings in Christchurch. The Waimakariri River overflowed near Halkett and entered old channels flowing through Avonhead and Fendalton to the Avon River. *D. L. Mundy, Canterbury Museum collection.*

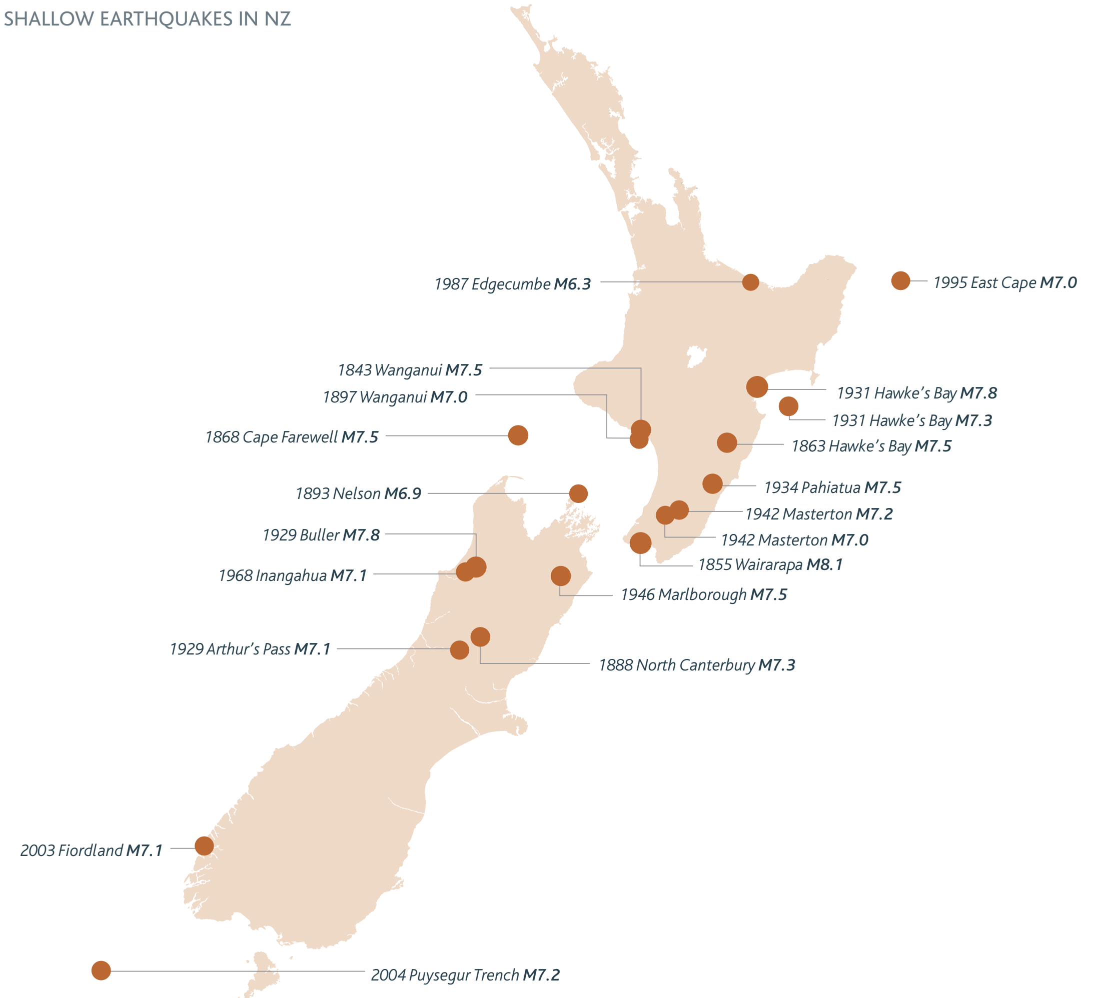
NEW ZEALAND HAZARDSCAPE

EARTHQUAKES

New Zealand experiences many earthquakes because it is located across the boundary of two tectonic plates. Ten to fifteen thousand earthquakes are recorded each year in and around New Zealand, but only about 150 of these are felt.

Based on its seismic history, New Zealand should experience 10 to 20 magnitude 5 earthquakes and one magnitude 6 earthquake each year, and a magnitude 7 earthquake each decade. However, earthquakes are not evenly spread over time and they often occur in clusters. The last 60 years have been relatively quiet with only two onshore earthquakes greater than magnitude 7. But a damaging earthquake could happen at any time. At least a million New Zealanders (around 25 per cent of the population) are expected to experience shaking great enough to damage household contents and buildings in the next 50 years.

NOTABLE SHALLOW EARTHQUAKES IN NZ
1840–2005



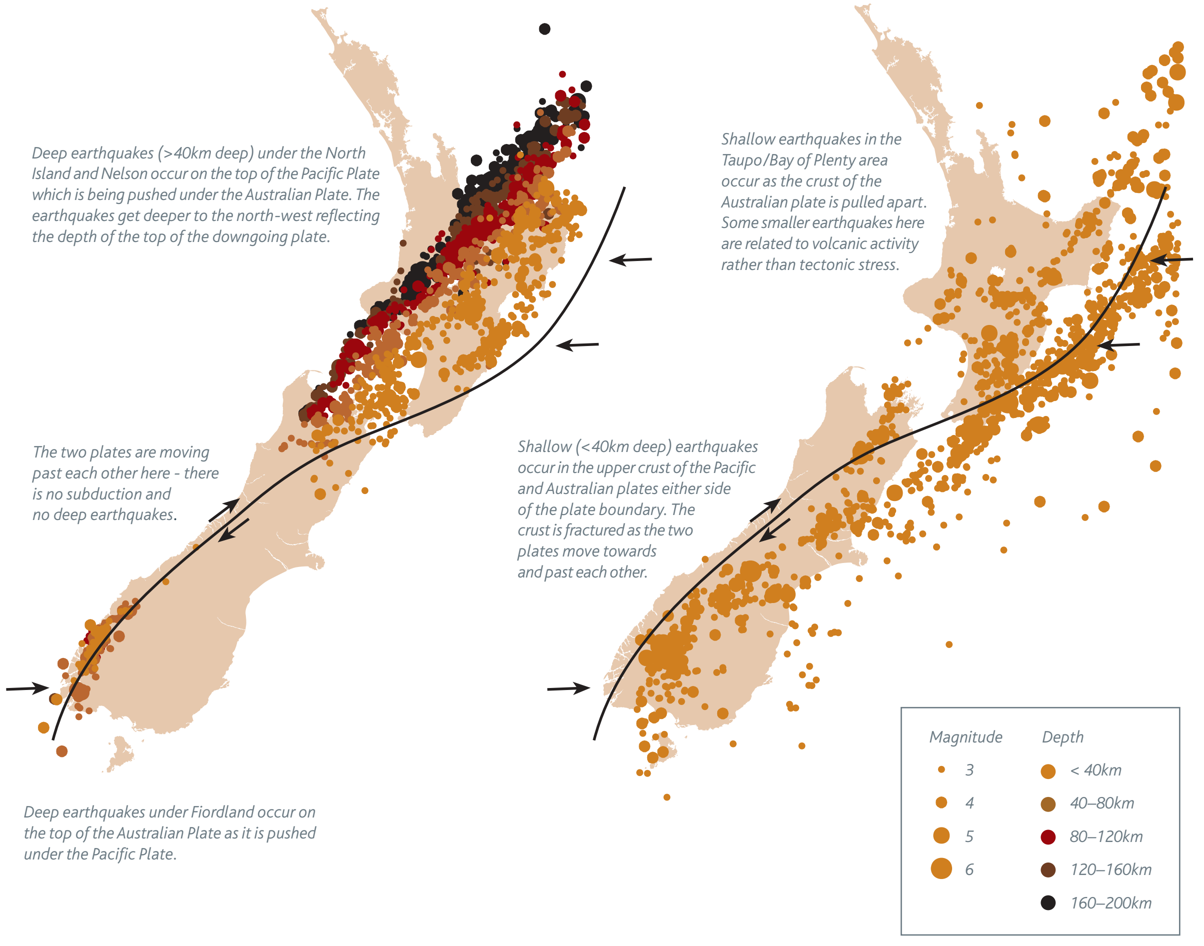
Major historic earthquakes in New Zealand since 1840. Many damaging earthquakes occurred in the early years of European settlement but there have been few over the last 60 years. *GNS Science.*

New Zealand's earthquakes

An earthquake is the sudden release of slowly built-up strain along a fault (fracture) in the earth's crust. In New Zealand that strain accumulates as the Pacific and Australian tectonic plates move past each other. Most of New Zealand's seismic activity, including its major historic earthquakes, occur within a broad zone of deformation about 100km wide that runs along the plate boundary from offshore East Cape to Fiordland.

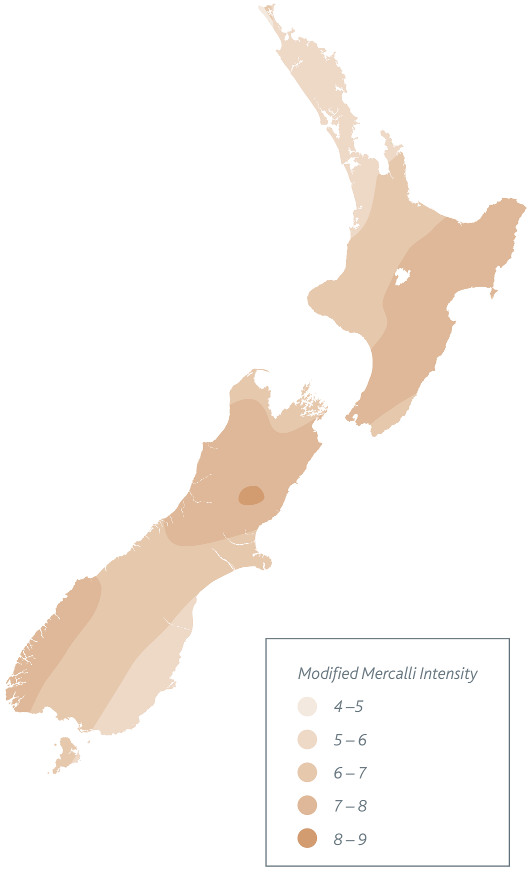
High-hazard areas along this zone include Gisborne, Hawke's Bay, Wairarapa, Wellington, Marlborough, North Canterbury, Buller, the Southern Alps, and Fiordland. The earthquake hazard in these areas is comparable to that in California. Northland and southeastern Otago, farthest from the plate boundary, have the lowest earthquake hazard. Moderate but damaging earthquakes have however occurred in both these locations.

SHALLOW AND DEEP EARTHQUAKES



Earthquakes of magnitude 2 or greater recorded in New Zealand in 2005. The distribution and depth of earthquakes is related to the behaviour of the two tectonic plates. *GNS Science.*

INTENSITY OF GROUND SHAKING



The earthquake hazard in New Zealand represented as the intensity of ground-shaking expected in a 50-year period, based on historical seismicity and the location of active faults in New Zealand and how frequently they move. *GNS Science*.

EARTHQUAKE MAGNITUDE AND INTENSITY

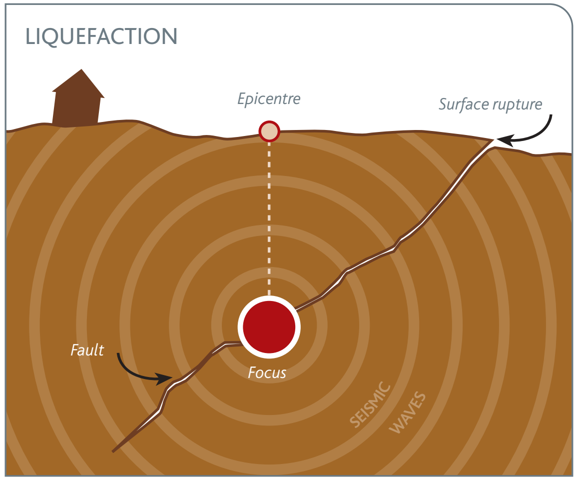
Earthquakes are described by both their magnitude and their intensity. Earthquake magnitude is a measure of the energy released during an earthquake, or its 'size'. Charles Richter first devised a magnitude scale in 1935 using data recorded on seismographs.

Earthquake intensity describes how much ground shaking occurred, or how 'strong' the earthquake was, at a particular location. Earthquake intensity depends not only on the magnitude of the earthquake but also on how far away it was, how deep it was, and the local geology, for example whether the ground is sand or rock. An earthquake generally feels less intense further away from the epicentre. In New Zealand intensity is measured using the Modified Mercalli (MM) intensity scale which is a descriptive scale from 1 to 12 based on how people feel an earthquake, and the damage to contents and buildings.

Shaking below MM intensity 4 is generally not felt or only felt inside. With MM intensity 7 shaking, it is difficult to stand, furniture breaks and loose bricks and tiles fall. Intensity 8 shaking damages ordinary masonry and topples chimneys and towers. Intensity 9 shaking causes panic and damages or destroys masonry and foundations. Damage is almost total with shaking at MM intensity 12.

Earthquake hazards

The energy released in an earthquake, and the permanent ground deformation produced, creates earthquake hazards with a range of both local and widespread impacts.



Earthquakes generated on faults in the earth's crust can cause fault rupture, ground shaking and liquefaction at the ground surface.

Ground-shaking

The energy released during an earthquake radiates away from the earthquake source as a variety of wave types. The intensity of ground-shaking at a particular point depends not only on the magnitude of the earthquake but also on the distance from the earthquake and the local geology. Soft ground, such as sandy or silty sediments, tends to amplify ground-shaking. Aftershocks will also occur after a large earthquake as the land adjusts to the displacement that has occurred.

1931 HAWKE'S BAY EARTHQUAKE

New Zealand's most destructive earthquake happened on the morning of 3 February 1931. A magnitude 7.8 earthquake centred 25km northeast of Napier was felt from Auckland to Canterbury.

Many of Napier's and Hastings' masonry buildings collapsed, including the new nurses' home, killing staff and sleeping nurses. The technical college also collapsed but, as it was morning tea time, most students were outside. In total 256 people died in Napier, Hastings, and Wairoa, and thousands were injured. About 3500 hectares of land, formerly the Ahuriri Lagoon north of Napier, was uplifted almost 2m. A lack of water and sewerage hampered recovery, as did aftershocks including a magnitude 7.3 earthquake 10 days after the main shock. The earthquake highlighted the need for stronger buildings and prompted the development of New Zealand's building standards.

Much of Napier's central business district was destroyed in the 1931 earthquake - many buildings collapsed and were subsequently gutted by the fire that burnt for two days. *Hawke's Bay Museum and Art Gallery.*

These smaller earthquakes can continue for weeks, months, or even years after a large earthquake.

Ground-shaking during an earthquake is inevitable and can be regionally extensive, but buildings and other structures can be sited and constructed in ways that reduce the likelihood of damage and injury.

Fault rupture

If an earthquake is large and shallow (generally greater than magnitude 6.5 and less than 40km deep) the displacement on the fault may reach the ground surface, offsetting the ground both horizontally and vertically. New Zealand has many active faults within the plate boundary deformation zone that have ruptured the ground surface in this way. The largest historic fault displacement was recorded on the Wairarapa Fault, which moved 18m horizontally in the 1855 Wairarapa earthquake. Some faults move more often than others – there are more than 50 faults in New Zealand that, on average, move every 2000 years or less. The most active faults, the Alpine Fault and the Hope Fault in the South Island, move on average every few hundred years, creating large earthquakes and metres of permanent displacement along the fault.

Fault rupture will sever underground services, such as water pipes, that cross the fault, and can damage or destroy structures built on the fault. Fault-rupture hazard is confined to a relatively narrow corridor along the fault, and because fault rupture tends to generally occur repeatedly in the same place, the location of future ground rupture can be predicted with some degree of confidence.

Surface rupture of the Edgecumbe Fault in the 1987 Edgecumbe earthquake, New Zealand's most damaging earthquake in the last 35 years. The ground surface was vertically displaced across several fault strands by a total of 2.5 metres. *GNS Science.*

Liquefaction

Liquefaction occurs when saturated fine-grained sediments, such as sand and silt, behave more like a liquid than a solid during an earthquake. During intense ground shaking (greater than MM intensity 7) these sediments can lose their strength, and buildings may sink or tilt. Buried services such as pipes can become buoyant and rise to the surface, and unsupported or poorly-supported land such as riverbanks and wharves can spread sideways.

A road after the 1931 Hawke's Bay earthquake. Liquefaction of soil under the road caused it to subside. *Hawke's Bay Museum and Art Gallery.*

Areas that may be susceptible to liquefaction can often be identified by their geology. Important facilities can be sited away from these areas, or the soil can be treated by compaction or other engineering techniques to reduce the potential for liquefaction.

Landslides and tsunamis

Landslides are second only to building collapses as causes of death in New Zealand earthquakes, claiming 16 lives in the 1929 Murchison earthquake and three in the 1968 Inangahua earthquake. Large earthquakes can cause widespread landsliding, particularly in the steep and fractured Southern Alps.

Tsunamis can be generated when earthquakes occur off the New Zealand coast, either by rupture of the sea floor or through underwater landslides. Tsunamis triggered by local earthquakes may reach the shore within minutes.

Coastal areas may be inundated due to uplift or subsidence of land during an earthquake. For example, parts of Lambton Quay in Wellington were temporarily flooded immediately after the 1855 Wairarapa earthquake. This was because land west of the Wairarapa Fault was raised, causing water to 'slosh' back and forth across the harbour.

Landslides and tsunamis are also caused by other mechanisms. The consequences of landslides and tsunamis, whatever the cause, can be catastrophic and they are discussed in further sections of this report.

Managing earthquake hazards

Earthquakes happen with little or no warning. Hazard and emergency management for earthquakes relies on risk reduction and planning for response and recovery at an individual and organisational level.

Research by the Institute of Geological and Nuclear Sciences (GNS Science), National Institute of Water and Atmospheric Research (NIWA), universities, and many private consultancies contribute to earthquake hazard management in New Zealand. Research ranges from paleoseismology – determining when prehistoric earthquakes have happened – through to geodesy – measuring how much New Zealand is being deformed on either side of the plate boundary.

Risk reduction

BUILDING DESIGN AND CONSTRUCTION

Building collapses account for the majority of earthquake deaths worldwide. New Zealand, however, is a world leader in earthquake engineering and has a resilient housing stock and high building standards. Most residential buildings in New Zealand are one- or two-storey houses with light timber frames and timber cladding. European settlers realised after the 1848 Marlborough and 1855 Wairarapa earthquakes that wooden buildings withstood earthquake shaking much better than unreinforced brick or stone buildings.

The first earthquake loading standard for buildings, intended to improve lateral strength, was introduced in 1935 in response to damage from the 1931 Hawke's Bay earthquake. The standard was updated in 1965, 1976, 1984, 1992, and 2004. Today's building code aims to avoid structural damage in a moderate earthquake, and to prevent collapse and protect life in a major earthquake. Previous building codes only applied to new buildings but recent changes in the Building Act 2004 apply standards retrospectively to older buildings, which must now be strengthened.

A significant number of vulnerable early concrete and steel buildings, and unreinforced masonry buildings, still exist. Many road and rail bridges were also constructed before modern earthquake codes, and with limited hydrological information.

Lead rubber bearings (base isolators), invented in New Zealand, have been fitted in many buildings both in New Zealand and overseas. These steel-covered blocks of rubber with a lead core isolate the building from its foundations and absorb earthquake energy, helping to protect the building and its contents from ground-shaking damage.

LAND-USE PLANNING

While widespread ground-shaking during a large earthquake is inevitable, some earthquake hazards can be avoided. However, land use planning has, until recently, placed little or no emphasis on earthquake hazards with regard to either the location or the intensity of development.

Areas of soft sediments, which may amplify ground shaking or liquefy in an earthquake and zones where fault rupture may occur are being mapped. This information is used to inform land-use planning at local and regional level. Land-use planning policies are generally not designed to prohibit development in identified high earthquake-hazard areas, but rather to control the type of development. For example, some district plans restrict or place conditions on developing high-rise or important community buildings, such as hospitals, in areas of liquefaction potential, while still allowing lower-risk residential housing.

This approach is advocated in Ministry for the Environment guidelines produced in 2004 for development on or close to active faults, which have been adopted by several territorial authorities in New Zealand. These guidelines promote a risk-based approach to controlling development on or near active faults, based on the fault's activity and complexity and the type of building proposed.

Fault-avoidance zones delineated around the active Ohariu Fault in Kapiti Coast District. The width of the zones depend on how well the location of the fault can be determined. Fault-avoidance zones have been incorporated into several district plans around New Zealand so that development on or near active faults can be managed. *Greater Wellington Regional Council*.

The South Island looking north along the Alpine Fault, one of the most significant onshore faults on earth. The fault has displaced rocks in Nelson and Fiordland that were once adjacent by 480km and has created the Southern Alps. *Image Science and Analysis Laboratory, NASA Johnson Space Center, image ISS006-E-39504.*

THE NEXT ALPINE FAULT EARTHQUAKE

The South Island's Alpine Fault marks the boundary between the Australian and Pacific tectonic plates through the South Island and forms the western margin of the Southern Alps. The Alpine Fault has not moved since European settlement of New Zealand, but geologists believe it is capable of producing magnitude 8 earthquakes involving many metres of fault movement at the ground surface. Evidence suggests that the last earthquake on the fault, involving surface rupture along almost 400km of the fault, occurred in 1717 AD. Previous earthquakes have been dated at approximately 1630, 1460 and 1220 AD.

Probability estimates for the next Alpine Fault earthquake vary, but are as high as or higher than for any other fault in New Zealand. Most scientists agree that given the current rate of stress accumulating along the Alpine Fault, a large earthquake is very likely within the next 100 years.

The next Alpine Fault earthquake will cause major damage across the South Island. Transport routes will be impassable with bridges damaged and landslides blocking roads and railway lines. Electricity supply will be disrupted in large parts of the South Island. If the earthquake occurs in summer, many tourists will be isolated on the West Coast. International assistance is likely to be required and many aftershocks will affect response and recovery.

Earthquake-induced landslides in the Southern Alps will also feed large amounts of sediment into rivers, which will slowly work its way down valleys and onto the coastal plains. This is likely to produce erratic river behaviour including major changes of course and flooding, particularly on the West Coast lowlands, for years after the earthquake.

WELLINGTON EARTHQUAKES

The Wellington region was the scene of New Zealand's largest historic earthquake – the magnitude 8+ 1855 Wairarapa earthquake. Occurring on the evening of 23 January, the earthquake was accompanied by surface rupture along 140km of the Wairarapa Fault on the eastern margin of the Tararua Range. The earthquake also caused up to 6m of uplift to the west of the Wairarapa Fault, triggered landslides across 20 000km^2 of land, and generated a tsunami that measured 9m in Palliser Bay and 2–3m in Wellington Harbour.

The population of Wellington at the time was only around 6000, and the mostly timber framed buildings sustained little damage. It had become apparent after the 1848 Marlborough earthquake seven years earlier that timber buildings were the best construction for earthquake resistance. However, almost all the chimneys in Wellington fell down – one killing a hotelier – and there was severe damage to brick buildings. Up to six more people were killed in the Wairarapa when a whare collapsed.

The Wairarapa Fault is one of several active faults under the Wellington region. The residents of Wellington in 1855, who had recently moved there from the flood-prone Hutt Valley, didn't realise that they had settled over the active Wellington Fault. One hundred and fifty years later, Wellington is the nation's capital and the Wellington metropolitan area is home to 375 000 people. An earthquake on this fault today would cause around 3000–4000 casualties, including between 200 and 600 deaths (depending on the time of day), and cause more than $10 billion worth of direct damage. The Wellington Fault is thought to rupture, producing a major earthquake, every 500–800 years; it last ruptured about 400 years ago.

The active Wellington Fault, capable of generating a magnitude 7.6 earthquake, runs from the Wellington south coast, through Karori Reservoir and Thorndon and north along the western side of Wellington Harbour and the Hutt Valley. *GNS Science.*

Readiness

The ability to monitor earthquake location and size is improving but scientists still cannot predict when and where a damaging earthquake will occur. Some major earthquakes, such as the 1929 Murchison, 1888 North Canterbury and 1987 Edgecumbe earthquakes, were preceded by many small tremors, but most of New Zealand's damaging earthquakes have occurred with no warning. However, high quality, near real-time earthquake information, provided by the EQC funded national geological hazard monitoring system 'GeoNet', enables emergency management organisations to quickly establish the location and size of a major earthquake and the appropriate response.

New Zealanders will need to be self-reliant for days, if not weeks, after a large earthquake because infrastructure may be damaged over a wide area, with lengthy repair times. The lack of recent damaging earthquakes may have created some complacency, and some people may not be adequately prepared.

Response and recovery

Pre-event recovery planning – identifying in advance the land-use planning decisions that will need to be made during the recovery phase of a large hazard event – is particularly important for earthquakes but has received little attention in the past. One of the challenges in this is weighing the need for communities to regain daily functioning versus the opportunity for more considered planning resulting in increased long-term resilience. This issue warrants more discussion, particularly at territorial authority level in high earthquake-hazard regions.

The Earthquake Commission provides insurance against earthquake damage, up to a certain limit, for residential buildings and contents that are covered for fire damage.

Emergency services and local authorities will be involved in responses to damaging earthquakes. CDEM response to damaging earthquakes follows generic response and recovery procedures set out in CDEM Group plans, the National CDEM Plan and the Guide to the National CDEM Plan.

THE EARTHQUAKE COMMISSION

New Zealand is unique in having the Earthquake Commission (EQC), a government-owned organisation that insures the holders of residential fire insurance against natural hazard damage.

Originally established in 1945 to protect against earthquake and war damage, it now covers earthquake, landslide, volcanic eruption, hydrothermal activity, tsunami, storm/flood (land only), and fire caused by any of these events (war damage was removed in 1994). Residential houses are insured for up to $100,000 worth of damage, and contents for $20,000. EQC's Natural Disaster Fund currently totals $5.4 billion which is reinsured offshore and also backed by a Government Guarantee.

As well as providing insurance, EQC also encourages preparedness through public education, funds natural hazard research and research capabilities including university teaching, engineering standards development, and the national geological hazard monitoring system 'GeoNet'.

FURTHER INFORMATION

GENERAL EARTHQUAKE INFORMATION

GNS SCIENCE
www.gns.cri.nz/what/earthact/earthquakes/index.html
TE ARA ENCYCLOPAEDIA OF NEW ZEALAND
www.teara.govt.nz/EarthSeaAndSky/NaturalHazardsAndDisasters/en

GEONET

GEONET
www.geonet.org.nz

EARTHQUAKE COMMISSION

EARTHQUAKE COMMISSION
www.eqc.govt.nz

EARTHQUAKE ENGINEERING

CANTERBURY UNIVERSITY
www.civil.canterbury.ac.nz/research/research.shtml

BUILDING CODE

DEPARTMENT OF BUILDING AND HOUSING
www.dbh.govt.nz/blc-building-code-and-review

LEAD RUBBER BEARINGS

ROBINSON SEISMIC
www.robinsonseismic.com/products/lrb.html

ACTIVE FAULT GUIDELINES

MINISTRY FOR THE ENVIRONMENT
www.mfe.govt.nz/publications/rma/planning-development
-active-faults-dec04/index.html

Bay of Plenty earthquake 1987. Damage to rail infrastructure.
David Plews, Whakatane.

VOLCANOES

Volcanic activity occurs when magma (hot molten rock) rises to the surface from deep within the earth. Most of New Zealand's volcanic activity is associated with its location on a plate boundary and the subduction of the Pacific Plate under the Australian Plate.

Volcanic eruptions since human settlement have been uncommon and most have been relatively small. Even so, these eruptions have had significant impacts: volcanic activity has caused at least 338 deaths over the last 150 years, more than any other natural hazard in New Zealand, and infrastructure, agriculture, and tourism have all been affected. Any level of eruption can have potentially catastrophic impacts on the primary sector.

On a geological time scale, however, New Zealand's volcanoes have erupted very frequently over the last several hundred thousand years, and have erupted large quantities of magma, compared to other volcanic regions in the world. Eruptions have ranged from small, localised eruptions of ash and lava to catastrophic landscape-altering events.

A large volcanic eruption in New Zealand, while very unlikely in any given year, will certainly occur again in the future. Volcanic activity has been called New Zealand's most underrated hazard.

Volcanic hazards

Volcanoes create a range of hazards varying greatly in geographic extent and potential impact.

Ash fall

Ash can be carried and deposited over an area up to hundreds or even thousands of kilometres, making it the most likely volcanic hazard to affect the most people. In large concentrations ash can even influence climate. Ash fall is dictated by wind strength and direction. Westerly winds prevail in New Zealand, but any part of the North Island and possibly parts of the northern South Island could be affected by ash fall during an eruption.

Even a small amount of ash – as little as a few millimetres – can have significant effects such as:

- skin, eye and throat irritation
- damage to electrical and electronic systems
- interference with radio communications
- damage to machinery and engines, particularly aircraft engines with consequent disruption to air travel
- contamination of waterways and open water supplies
- blockage of stormwater and sewerage pipes and damage to pumping systems
- crop and stock losses, through fluorine poisoning or lack of feed (although soils generally benefit from a small amount of ash).

Heavier deposits (more than 50mm thick) can damage buildings, close road and rail links, disrupt electricity supplies, bury crops, damage trees, kill or distress stock, and poison aquatic life in streams and lakes.

Lava flows

Lava flows in New Zealand are usually confined within a 10km radius of the volcano vent. The distance they travel depends on the lava's viscosity, the volume and rate of lava erupted, and local topography. Lava flows rarely threaten life because they move so slowly, but they will destroy any built infrastructure in their path.

Pyroclastic flows

Pyroclastic flows are rapid, ground-hugging surges of gases, ash and rock. At temperatures of up to several hundred degrees Celsius, and travelling at several hundred kilometres an hour, they are the most destructive volcanic hazard. Pyroclastic flows obliterate everything in their path and have shaped large areas of New Zealand's landscape. They are extremely rare.

Lahars

Lahars are fast-flowing, slurry-like mixtures of water, ash, and rock. Lahars can occur during volcanic eruptions, especially if the eruption has melted a lot of snow, or they can occur months or years after an eruption, when ash and debris are mobilised during heavy rain or a crater lake overflow. Lahars are generally confined to existing drainage channels but can be highly destructive.

A lahar in the Whangaehu River during the 1995/96 Ruapehu eruptions. Lahars have the consistency of wet concrete and are highly erosive. *Vince Neall.*

Sector collapses and debris avalanches

Volcanic cones are often steep-sided and can be unstable. Occasionally the side, also called a sector, of a cone volcano collapses catastrophically, creating a debris avalanche that can travel many kilometres. These collapses can be triggered by rising magma bulging the flanks of a cone, by earthquakes, or by heavy rainfall. Debris flows travel extremely fast and will destroy everything in their path. There is evidence that New Zealand's cone volcanoes have had sector collapses but, like pyroclastic flows, they are rare.

Tsunamis

Offshore volcanic activity can cause tsunamis that could reach New Zealand's coastline, particularly in the northeast. It is unlikely, however, that such tsunamis would be large enough to cause significant damage. Tsunamis can be triggered by submarine eruptions or by landslides or debris avalanches flowing into the sea from an island volcano. Volcanic material entering a lake can cause seiching ('sloshing'), causing the lake water to inundate adjacent low-lying areas.

New Zealand's volcanoes

Volcanic fields

Volcanic fields produce many small volcanoes (0.1–1.0km^3), which each erupt only once, at intervals of hundreds to thousands of years. It is difficult to determine where the next eruption is likely to occur in a volcanic field until it is imminent.

Eruptions within New Zealand's volcanic fields generally involve lava flows and lava fountains forming small scoria cones. Explosions of rock and steam are also likely where hot magma meets cold groundwater or seawater, creating craters in the ground.

Mt Eden and Auckland city. One of 50 volcanoes in the Auckland Volcanic Field, Mt Eden was created 20 000–30 000 years ago. *GNS Science.*

AUCKLAND VOLCANIC FIELD

The Auckland Volcanic Field contains 50 known volcanic vents within a 360km^2 area. The field is fed by a 'hot spot' about 100km below the earth's surface, from which 'bubbles' of magma occasionally rise to create a new vent. Eruptions in this field have generally been of two types. The first type is when magma meets cold groundwater or seawater, causing short explosive eruptions which blast out steam, gas, and rock fragments. These eruptions create circular craters up to 1km across, such as Orakei and Panmure basins. The second type is when lava fountaining over a longer period of time produces small scoria cones like One Tree Hill.

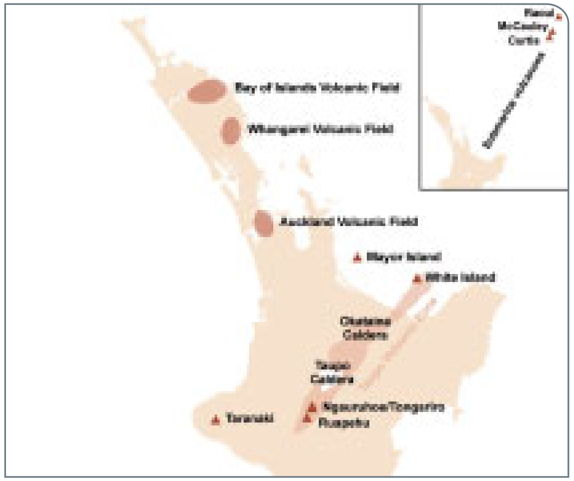
Eruptions started in the Auckland area around 140 000 years ago and the last 20 eruptions have occurred in the past 20 000 years. Eighteen of these occurred between 10 000 and 20 000 years ago. The largest and most recent eruption was Rangitoto, in Waitemata Harbour, 600–700 years ago. None of Auckland's existing volcanoes is likely to erupt again, but the Auckland Volcanic Field is still geologically young and potentially active.

THE NEXT AUCKLAND VOLCANO

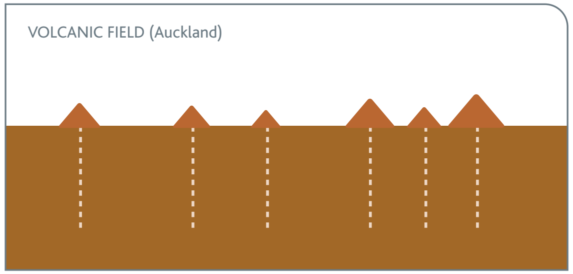
There are 530 000 people living on the Auckland Volcanic Field and a further 750 000 live in the wider Auckland region. Even a small, localised eruption would cause major damage near the vent and widespread disruption.

Planning for an Auckland Volcanic Field eruption assumes that buildings and infrastructure within 3km of the new vent would be destroyed by an initial surge of hot gas, steam and rocks. Ash would fall over most of the greater Auckland area, up to 10cm thick near the vent. Ash and acid rain would pollute water supplies and most likely damage stormwater and sewerage infrastructure. Auckland International Airport would be closed for weeks. Insured losses could be in the order of $1–2 billion, and indirect costs could be much more.

Managing an Auckland Volcanic Field eruption presents significant challenges. Mass evacuation, for an unknown length of time, would be essential. Even though the field is monitored to detect magma movement within the earth's crust, the location of the next vent, and hence the area to be evacuated, may not be known until eruption is imminent.



New Zealand's volcanic areas. Most of New Zealand's volcanoes are located in the Taupo Volcanic Zone, New Zealand's most active volcanic area, which extends from Ruapehu to White Island. *GNS Science.*



Volcanic fields produce many small volcanoes.

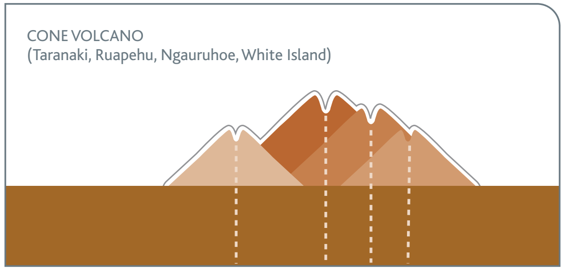
BAY OF ISLANDS AND WHANGAREI VOLCANIC FIELDS

The Bay of Islands Volcanic Field contains 30 vents, mostly comprising scoria cones and lava flows and domes. Little is known about the field or its activity but it is likely to have erupted 10 times in the last 20 000 years. The last eruptions, which produced explosions and small lava flows, occurred 1300–1800 years ago. The area is not heavily populated but the Bay of Islands is a popular tourist destination.

The smaller Whangarei Volcanic Field last erupted around 250 000 years ago with small eruptions of ash, scoria, and lava.

Cone volcanoes

Cone volcanoes are the product of many eruptions at approximately the same location, which build up layers of lava and ash to form a cone. Lahars and sector collapses can originate from cone volcanoes. New Zealand has three onshore cone volcanoes – Taranaki, Ruapehu and Tongariro/Ngauruhoe – and many offshore cone volcanoes.



Cone volcanoes form through many eruptions from one volcanic vent.

TARANAKI

The Taranaki volcano has been erupting for the last 1.7 million years forming a series of cones, including the now eroded Pouakai and Kaitake ranges to the north of the current vent of Mt Taranaki. The volcano has been erupting at its current site for around the last 130 000 years, but most of the cone that can be seen today is less than 10 000 years old because the mountain has gone through successive phases of cone formation and collapse.

Taranaki has produced mostly lava domes and flows, which make up most of the cone itself, as well as small amounts of pumice, scoria and ash. Sector collapses occurred before human settlement, spreading debris up to 80km from the volcano. Taranaki has erupted at least nine times in the last 1000 years – the last eruption was around 1755.

More than 85 000 people live within 30km of Mt Taranaki. Of these, 40 000 live in high-priority evacuation areas, if an eruption occurs. Lahars are likely to travel down many of the watercourses draining the mountain. Pyroclastic flows and sector collapses could affect areas up to 15–20km from the vent. Ash fall is almost certain, but the area affected will depend on the amount erupted and the wind at the time. Lava flows are likely to be confined within Egmont National Park which comprises the area within a 10km radius of the vent.

The Taranaki region has a large dairy industry, partly due to its fertile volcanic soils, which would be significantly affected by an eruption. It is also the source of all New Zealand's natural gas, and an eruption would disrupt petrochemical industries within the region as well as reticulated supply throughout the North Island.

Mt Taranaki dominates the region's landscape. Prehistoric collapses of the cone have spread debris across the Taranaki lowlands creating the hummocky landscape between Opunake and New Plymouth. *GNS Science.*

RUAPEHU

Ruapehu is New Zealand's largest cone volcano and is unusual in that it has a crater lake which modifies eruptions and creates a high lahar hazard. Ruapehu has probably been erupting for at least 800 000 years, but the oldest known lava is only around 230 000 years old because the volcano has gone through several cycles of building and destruction.

Ruapehu has produced mostly lava and ash in its frequent eruptions. Eighteen eruptions have been recorded since 1861, the most recent and smallest of these in 1995/96. Lahars have also occurred, the most destructive on Christmas Eve 1953. The main trunk railway line was washed away at Tangiwai causing a passenger train to derail into the Whangaehu River, killing 151 people.

The area around Ruapehu is sparsely populated but the region is heavily dependent on tourism, particularly skiing. The effects of an eruption on these industries is significant. Ash from Ruapehu eruptions can spread over large areas, especially towards the east from the prevailing westerly winds.

Ruapehu erupting in 1996. Ash covered the upper slopes of Mt Ruapehu and fell up to 250km away during the 1995/96 eruptions. *GNS Science.*

RUAPEHU 1995/96

The 1995/96 Ruapehu eruptions were the largest volcanic events in New Zealand for 50 years. The first eruption began in September 1995 and eruptions continued episodically until August 1996. Ash was deposited up to 250km from the volcano, affecting Hawke's Bay, Gisborne, and the Bay of Plenty. A wide flight-exclusion zone disrupted air travel, and central North Island airports were closed and flights were cancelled. State Highway 1 was closed three times. Many lahars were triggered both during and after the eruptions, which mainly affected the Whangaehu and Tongariro rivers.

The eruptions were a similar size to the previous 1945 eruption but they had a much greater effect due mainly to the increase in population and development, and expansion of the tourism and aviation industries between the two eruptions. There were no deaths, but total economic losses were calculated at around $130 million.

Two ski seasons were shortened which was the main contributor to the estimated $100 million loss to the tourism industry. Electricity generation losses were estimated at $22 million. About half of that was the cost of repairing the Rangipo power station damaged by ash-laden water moving through its turbines.

Cancelled flights accounted for at least $2.4 million. Agriculture sustained relatively light losses of around $400,000 – 2000 sheep were poisoned when they ate ash-covered grass, and ash destroyed Gisborne's cauliflower crop.

TONGARIRO/NGAURUHOE

At 2500 years old, Ngauruhoe is the youngest cone in the large Tongariro complex. It has been built up and partially destroyed (mostly by glacial erosion) over the last 340 000 years. Ngauruhoe's last eruption was in 1975, producing lava flows and ash. It is currently experiencing the longest period of inactivity in its recorded history.

WHITE ISLAND

Uninhabited White Island lies 55km off the Bay of Plenty coast and is the visible tip of a mostly submerged volcano 750m high and 17km wide. It is currently New Zealand's most active volcano, with three eruptive cycles recorded since 1976. White Island produces lava flows and minor ash falls, and its crater has collapsed several times in the past. One collapse in 1914 killed 11 sulphur miners living on the island. There is no evidence of material erupted from White Island reaching the mainland, but geological research suggests that the volcano is capable of producing large eruptions.

White Island with its characteristic steam plume. The privately owned island was mined for sulphur intermittently between the 1880s and 1930s. *GNS Science*.

SUBMARINE VOLCANOES AND THE KERMADEC ISLANDS

A string of large, mostly submarine volcanoes extends from White Island northeast to Tonga. The largest of these – Raoul, Macauley, and Curtis – form the Kermadec Islands, 1000km to the northeast of New Zealand. They are all similar in size to Ruapehu. Little is known about the eruptive history of these volcanoes, especially those that are wholly submarine, but their range of eruption sizes is larger than would normally be expected for cone volcanoes.

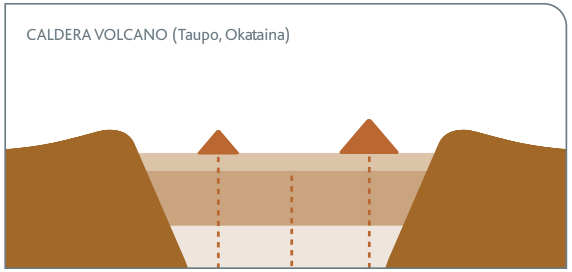
Raoul Island has experienced many historic eruptions. The most recent, in March 2006, killed a Department of Conservation worker who was taking crater lake samples at the time. This was New Zealand's first volcanic casualty in more than 50 years. Other volcanoes in the Kermadecs emit steam and gases, indicating magma is present at shallow depths.

Caldera volcanoes

A caldera is a large depression created by the collapse of a volcano after the rapid eruption of magma from a vent. A caldera may contain several different vents and eruptions can vary greatly in size and frequency. Caldera eruptions in New Zealand are often highly explosive, characterised by pyroclastic flows, lava flows, and ash fall.

Caldera volcanoes frequently exhibit periods of unrest marked by earthquake activity, ground deformation, and changes in gas and steam discharge. These signs of unrest are not necessarily indicative of an impending eruption, but can be hazards in themselves.

There are three caldera volcanoes in New Zealand – Taupo, Okataina, and Mayor Island.



Caldera volcanoes collapse in on themselves creating large craters, often containing smaller lava domes.

TAUPO

Taupo has not erupted since human settlement of New Zealand, but it has been one of the most active caldera volcanoes on earth over the last 300 000 years. Lake Taupo partially fills depressions left by the explosive eruptions and subsequent collapses of the Taupo volcano during that time. The largest known eruption, 26 500 years ago, expelled more than 500km^3 of lava, ash, rocks and gas. Taupo is thought to have erupted at least 28 times since then – the last major eruption, around 180 AD, was the most violent eruption in the world in the last 5000 years. The effects of the ash from this eruption are recorded in Chinese writings of the time.

The size and the time between past eruptions has varied greatly. Taupo has been intensively studied but scientists do not know when or how big the next eruption will be. The impact of a relatively small eruption from Taupo could be devastating for the central North Island, and the effects would be felt across the entire country. Apart from direct damage, the tourism, agriculture, forestry and North Island hydroelectric generation industries would suffer severe losses.

OKATAINA

Okataina is the second most productive caldera volcano in the world after Taupo, and has a similar history of eruptions. The last major collapse of the volcano was 64 000 years ago and since then smaller eruptions have largely filled in the collapsed area with lava domes like Mt Haroharo and Mt Tarawera.

Okataina's last activity was the eruption of Mt Tarawera on 10 June 1886. The eruption occurred with almost no warning, burying nearby buildings in ash and hot mud, killing at least 153 people, and destroying the world-famous Pink and White Terraces. It was the largest and most destructive volcanic eruption in New Zealand's written history, but one of the smallest in the Okataina caldera over the last 21 000 years.

MAYOR ISLAND

Mayor Island is the summit of a volcano 15km wide and 750m high, rising from the sea floor 25km off the Bay of Plenty coast.

The volcano has erupted at least every 3000 years for the last 130 000 years, including at least three caldera collapses. Most eruptions have been relatively small and have not greatly affected the mainland, but the most recent and largest eruption, involving a caldera collapse, produced a pyroclastic flow into the sea and deposited ash on parts of the North Island.

Only renewed activity equivalent to the largest known prehistoric eruption on the uninhabited island would pose a direct threat to people on the mainland. However, ash could fall over parts of the Bay of Plenty, Coromandel, the Waikato, and South Auckland from even a small eruption. Mayor Island magma is rich in toxic chlorine and fluorine which would poison stock and pollute water, even with small amounts of ash.

McRae's Hotel in Te Wairoa after the 1886 eruption of Mt Tarawera. Many people were sheltering in the hotel when it collapsed under the weight of ash and mud. The eruption is the largest volcanic event to have occurred in New Zealand over the last 1000 years. *Charles Spencer/Museum of New Zealand Te Papa Tongarewa*.

GEOTHERMAL HAZARDS

There are extensive geothermal areas in the Taupo Volcanic Zone, where geysers, mud pools, and hot springs exist. Minor hydrothermal eruptions are common in these areas as steam expands under the ground. Occasionally these areas experience large violent hydrothermal eruptions that can throw steam, mud, and rocks tens of metres into the air and scatter debris over a wide area. Volcanic activity or earthquakes may trigger these eruptions.

Smaller hydrothermal eruptions have affected residential areas around Rotorua in the past, and houses have had to be moved away from new steaming vents and mud pools. Other buildings have been declared uninhabitable because of toxic levels of hydrogen sulphide gas seeping up from the ground. Eleven deaths have been attributed to hydrogen sulphide poisoning in Rotorua in the last 50 years.

Managing volcanic hazards

The focus of managing volcanic hazards is on readiness, particularly monitoring, and response and recovery once an event has happened, rather than on risk reduction. There are two reasons for this. Some volcanic hazards can cover a large area and the exact size of that area can be difficult to predict in advance. Also, there is often some warning period before a volcanic eruption during which precautions such as evacuations and covering water tanks can be taken.

Research into the nature of New Zealand's volcanoes and associated hazards is undertaken at GNS Science and the universities of Canterbury, Otago, Waikato, Auckland, and Massey University.

Risk reduction

Volcanic hazards, except ash fall, have been mapped for all New Zealand's most active volcanoes. The main purpose of these maps is to aid evacuation planning before an eruption.

Land-use planning is only viable for volcanic hazards where the area of potential impact is relatively localised and can be defined reasonably accurately, such as lahars. There are currently no land-use planning provisions in New Zealand specific to volcanic hazard. However, National Parks surrounding two of the most active volcanic areas (Taranaki and Ruapehu/Ngauruhoe/Tongariro) can be considered de facto land-use planning tools where restrictions on development exist.

Volcanic hazards are not addressed in the New Zealand Building Code. However, the Department of Building and Housing has identified volcanic eruption impact threats, such as ash loading and corrosion, as a concern that needs addressing in the current Building Code review.

Readiness

GeoNet continually monitors New Zealand's active volcanoes, particularly the most active ones – White Island, Ruapehu and Ngauruhoe. Monitoring techniques include visual observations through field visits and remote photography, and seismic monitoring to detect volcanic tremors indicating movement of gas and magma within the earth's crust. GeoNet also analyses gas, hot-spring, and crater-lake chemistry, and monitors deformation of the land surface. Seismic monitoring of Mt Taranaki and the Auckland Volcanic Field is undertaken in partnership with Taranaki and Auckland regional councils.

The Department of Conservation also operates an eruption detection system (EDS) on Mt Ruapehu to warn of a possible eruption and lahar from the crater lake through Whakapapa ski field. If activity is detected the chairlifts are stopped and skiers and boarders must move from valleys to higher ground

GNS Science has developed scientific alert levels, based on observed activity, ranging from 0 (dormant or quiescent state) to 5 (large hazardous volcanic eruption in progress). Scientific alert bulletins are issued to emergency management agencies and the news media when there is a significant change in volcanic activity, whether the scientific alert level changes or not.

GeoNet's volcano-seismic network monitors volcanic earthquakes that indicate magma movement within the earth's crust. Volcanic earthquakes are distinguished from normal tectonic earthquakes by their slower vibration frequency. *GNS Science.*

GEONET

The GeoNet project monitors earthquake, volcanic, landslide, and tsunami activity within and around New Zealand. It provides real-time data collection and dissemination to enable rapid response to geological events. GeoNet includes strong and weak earthquake motion recording, volcanic surveillance, landslide response, and earth deformation monitoring, supported by data communication and management systems.

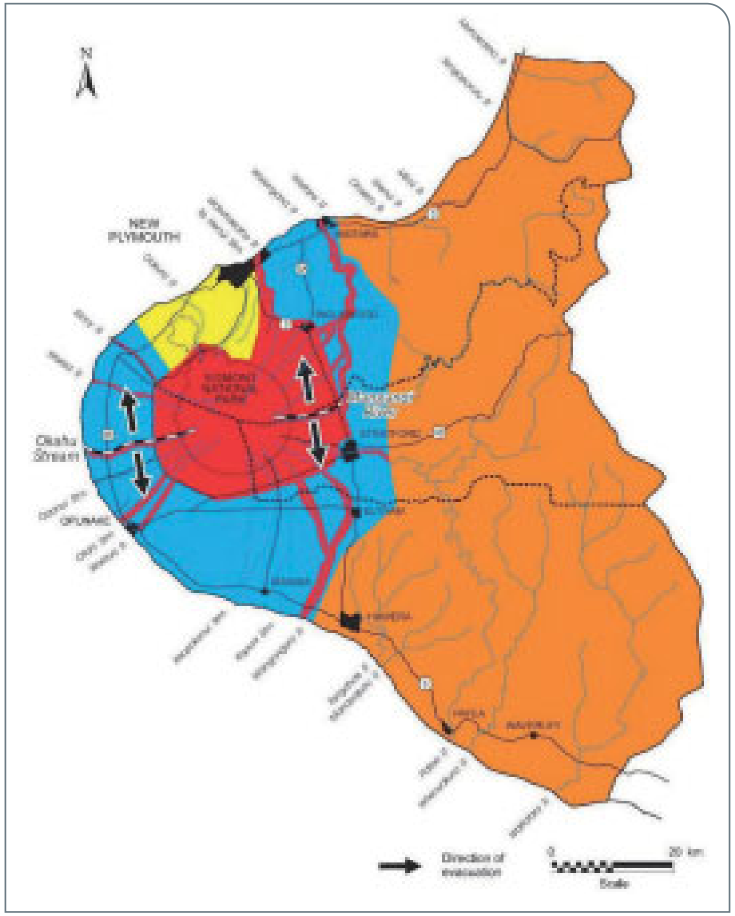
GeoNet has been operating since 2001 and is funded by the Earthquake Commission and the Foundation for Research, Science and Technology. GNS Science manages the project and the collected information is freely available to researchers and the public.

Response and recovery

While volcanic eruptions can often be predicted, the precise timing of the eruption and how long it will last are generally unknown. Ash fall alone, unless very heavy, is unlikely to warrant evacuations and people can stay in their homes as long as precautions, such as protecting water supplies, are taken.

Eruptions involving lava flows, pyroclastic flows, or lahars could significantly change the landscape, and evacuations for an unknown amount of time may be necessary. This creates challenges for managing response and recovery efforts for volcanic emergencies.

Caldera unrest is one of the most difficult volcanic hazards to manage because the unrest may or may not indicate impending volcanic activity. There is potential for adverse social and economic effects to escalate unnecessarily through media speculation and unwarranted emergency management action.



The Taranaki CDEM Group Volcanic Strategy includes procedures for evacuating people from pre-mapped hazard zones around Mt Taranaki. The red and blue zones will be priority areas for evacuation. *Taranaki CDEM Group.*

During an eruption the MetService works with GNS Science to issue volcanic-ash advisories to the aviation industry outlining the areas and heights where ash could be a hazard. GNS Science also models ash fall based on wind data supplied by the MetService, and information on the volume of ash erupted, and the ash column height.

The Earthquake Commission provides insurance, up to a certain limit, for residential buildings and contents that are covered for fire damage if they are affected by volcanic and hydrothermal eruptions.

The National CDEM Plan has superseded the former National Contingency Plan for Volcanic Eruption. The provisions within the National CDEM Plan are intended to be generic and to enable a coordinated response and recovery to all hazards, including volcanic eruption.

The Auckland, Bay of Plenty, and Taranaki CDEM Groups have volcanic strategies or contingency plans in place. These plans outline the coordinated CDEM response to a volcanic eruption and set out roles, responsibilities, and actions for organisations involved. Emergency management actions are related to scientific alert levels.

FURTHER INFORMATION

GENERAL VOLCANO INFORMATION

GNS SCIENCE
www.gns.cri.nz
TE ARA ENCYCLOPAEDIA OF NEW ZEALAND
www.teara.govt.nz/EarthSeaAndSky/en
GEONET
www.geonet.org.nz
MINISTRY OF CIVIL DEFENCE & EMERGENCY MANAGEMENT
www.civildefence.govt.nz/memwebsite.nsf/wpg_URL/For-the-CDEM-Sector-Publications-Tephra-2004-Index?OpenDocument

RUAPEHU CRATER LAKE AND THE ERLAWS ALARM SYSTEM

DEPARTMENT OF CONSERVATION
www.doc.govt.nz/Regional-Info/007~Tongariro-Taupo/004~Conservation/Crater-Lake/index.asp

TARANAKI CDEM GROUP VOLCANIC STRATEGY

TARANAKI CDEM GROUP
www.trc.govt.nz/PDFS/EM/volcanic_strategy.pdf

AUCKLAND VOLCANIC PLAN AND AUCKLAND VOLCANIC FIELD

AUCKLAND REGIONAL COUNCIL
www.arc.govt.nz/arc/environment/hazards/volcanoes-of auckland/volcanoes-of-auckland_home.cfm
www.arc.govt.nz/arc/environment/hazards/vcp.cfm

VOLCANIC ASH ADVISORY CENTRE (FOR AVIATION)

METSERVICE
vaac.metservice.com

BUILDING CODE REVIEW

DEPARTMENT OF BUILDING AND HOUSING
www.dbh.govt.nz/blc-building-code-and-review

AGRICULTURAL IMPACTS

MINISTRY OF AGRICULTURE AND FORESTRY
www.maf.govt.nz/mafnet/rural-nz/emergency-management/volcano-eruption-impact/httoc.htm

LANDSLIDES

Landslides are frequent in New Zealand, because of the country's steep slopes, active tectonics, and high rainfall in some areas. But while New Zealand has a relatively high landslide hazard compared to other countries, there are relatively few landslide deaths because of the country's low population density, especially in steep mountainous areas. Landslides most commonly affect New Zealand's property and infrastructure – they are the natural hazard most frequently responsible for road closures.

Most landslides in New Zealand are triggered by earthquakes or intense or prolonged rainfall, although there may be other contributing factors. Some landslides, like the 1991 Mt Cook rock avalanche, have no apparent trigger. New Zealand has had some massive prehistoric landslides. The 12 000–13 000-year-old Green Lakes landslide in Fiordland is one of the world's largest landslides, involving the collapse of a 27km^3 portion of mountainside covering a 45km^2 area in debris.

Landscape modification has significantly increased the incidence of landslides in New Zealand. Vegetation clearance, excavations for buildings and roads, altered natural drainage, and poorly-controlled stormwater have all increased the frequency of landslides in urban and rural areas, particularly those triggered by rainfall.

The 1979 Abbotsford landslide. Undercutting of the landslide toe and a leaking water pipe contributed to the movement along the boundary of two different rock types. This landslide prompted changes to legislation enabling territorial authorities to refuse building permits on hazard-prone land. *Otago Daily Times*.

Landslide types

A landslide is the downward movement of rock, soil, or vegetation, but the type of movement, the amount of material moved, and the speeds at which they move vary. A landslide may be a few falling rocks or it may be the rapid failure of many cubic kilometres of debris.

Slides, slumps, flows, and falls

Landslides are classified by the material and the movement mechanism involved.

Shallow soil slides, sometimes referred to as regolith slides, involve the movement of the upper soil layer including vegetation or rock debris. These regularly occur over large areas of grass-covered slopes of the North Island hill country during intense rain, but can also happen on steep, bush-clad slopes in the Southern Alps during heavy snowfalls or earthquakes.

Larger, deep-seated slides involve translational sliding or rotational slumping within weak rock and soil and can happen slowly or accelerate into a fast-moving landslide. Deep-seated slides can also form along the boundary of two different rock types. One of New Zealand's most damaging landslides happened in this way, destroying 69 houses at Abbotsford in Dunedin. The landslide had moved very slowly for almost 10 years before sliding 50m in 15 minutes in August 1979.

Deep-seated creeping earthflows occasionally happen in saturated clay-rich sediments, particularly in the North Island hill country. Earthflows can happen even on very shallow slopes and are generally slow moving, travelling a few metres each year.

On very steep slopes, such as cliffs or terraces, rock and soil may simply fall and accumulate at the bottom of the slope as debris. Rock falls often comprise large boulders and can be particularly damaging.

Debris flow

A debris flow is a mixture of water, sediment, rock, and vegetation. Debris flows are typically generated in small, steep and easily erodible catchments during intense rainfall, and deposit material onto steep debris fans downstream, which can be identified by their uneven surface.

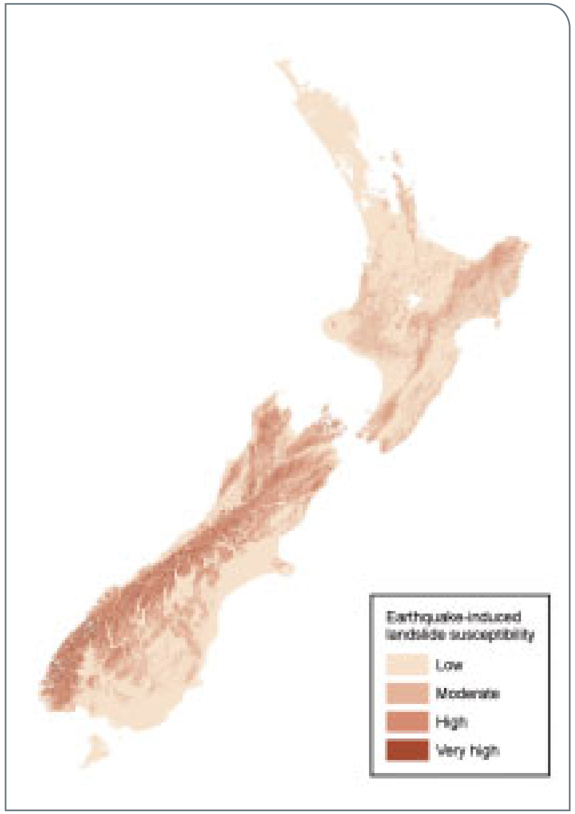
Debris flows have the consistency of wet concrete and are more dangerous than floods because they generally travel faster and can carry large boulders and other material such as tree trunks. They present considerable risk to life, property, and infrastructure but it is often difficult to predict their size and occurrence. Recent debris flows at Paekakariki in 2003 and Matata in 2005 have highlighted the damage that these flows can cause.

2005 MATATA DEBRIS FLOWS

Two debris flows engulfed parts of the small community of Matata in the eastern Bay of Plenty on the night of 18 May 2005. The debris flows were caused by a band of very intense rain – as much as 95mm fell in one hour in the small steep catchments behind Matata. This initiated many small landslides in the already-saturated catchments. These small slides, mixed with water, boulders, and vegetation, created two debris flows, the larger of which is estimated at 100 000m^3. The debris flows destroyed 36 houses and damaged another 25. The most surprising aspect of the Matata debris flows is that no lives were lost.

The rainfall that triggered the 2005 debris flows was estimated to have a 200 to 500-year return period. The land on which Matata is built shows evidence of debris flows over the last 7000 years that were as large or much larger than the 2005 flow, and there have been smaller debris flows over the last 150 years. Debris detention dams and building exclusion zones have been recommended to reduce the risk from future debris flows at Matata.

Matata debris flow. The catastrophic flow from Awatarariki Stream on 18 May 2005 destroyed 36 houses in the eastern Bay of Plenty village. *Whakatane Beacon*.



Probability of earthquake-induced landslide in New Zealand over a 475-year time frame, and the main areas affected by landslides during large earthquakes during the last 150 years. The areas of highest hazard are the steep slopes of the Southern Alps along the plate boundary. *GNS Science.*

Earthquake-induced landslides

Earthquake-induced landslides are the second-largest cause of death in New Zealand earthquakes (after building collapses) and they have caused significant damage to roads and other infrastructure.

Earthquake-induced landslides in New Zealand are strongly controlled by the amount of ground shaking and the angle of the slope. Landslides occur on susceptible slopes with ground shaking of MM intensity 7 and become progressively more widespread and damaging at MM intensity 8 and 9. Ground shaking of MM intensity 7 or higher can be expected near the epicentre of even a moderate magnitude 6 shallow earthquake.

The largest earthquake-induced landslides in New Zealand (those greater than one million m^3) have been rock avalanches and rock slides or falls from slopes steeper than 30°. Most earthquake-induced landslides, however, are smaller (less than 10 000 m^3) rock and debris falls and slides on gravel banks, terrace edges, road cuts and natural slopes steeper than 50°.

ROCK AND DEBRIS AVALANCHES

Rock and debris avalanches are extremely large (greater than one million m^3), turbulent, fast-moving landslides of fractured rock. They have very long run-out zones that can extend several kilometres. Rock avalanches generally only occur in the highly fractured rocks of sparsely populated mountainous areas in New Zealand and are rare – estimated at one a century for every 10 000km^2 in the Southern Alps. However, they can affect a large area, and will obliterate anything in their path, and so present a serious risk to alpine communities and infrastructure.

Rock avalanches can be triggered by earthquakes, such as the Falling Mountain rock avalanche generated by the 1929 Arthur's Pass earthquake, or they can occur without any obvious trigger, like the 1991 Mt Cook rock avalanche that narrowly missed a group of climbers in an alpine hut. Debris avalanches include those generated from very rare collapses of sections of volcanic cones. These have occurred prehistorically at Taranaki, Ruapehu, Ngauruhoe, and Tongariro. Some have travelled up to up to 80km from their source and devastated the landscape.

The Falling Mountain rock avalanche in the Southern Alps, triggered by the 1929 magnitude 7.1 Arthur's Pass earthquake. Fifty-five million m^3 of rock fell and flowed 4km down the Otehake River. This avalanche occurred in a remote area and did not directly affect people or property. *GNS Science.*

1929 MURCHISON EARTHQUAKE

The magnitude 7.8 Murchison earthquake in June 1929 caused widespread landsliding over approximately 7000km^2 of Buller and northwest Nelson. Sixteen of the 17 deaths caused by the earthquake were from landslides. The earthquake caused more than 50 landslides of more than one million m^3, including two giant slides of 120 and 210 million m^3 on the northwest Nelson coast 40km from the earthquake epicentre.

Many landslides dammed rivers. Landslide dams in larger valleys lasted only a few days but many in small, narrow valleys remain today. Landslide damage to roads was widespread and parts of the earthquake–affected area were isolated for weeks.

The Matakitaki landslide near Murchison, triggered by the 1929 Murchison earthquake. Debris from this very large (18 million m^3) rock slide travelled one kilometre across the valley floor, killing four people in two houses in its path. The inset shows the top story of one house rafted on the slide debris. The landslide dammed the Matakitaki River, forming a lake extending 5km upstream. The dam breached 10 years later but caused little damage downstream. *GNS Science.*

LANDSLIDE DAMS

Landslides, particularly in steep valleys, can form dams which block rivers and create lakes. These dams are dangerous because they can breach suddenly, releasing a flood of water down the river.

Most landslide dams fail within a few days, usually during a 'fresh' or flood in the river, but some dams remain for years before overtopping and breaching.

Landslide dams blocked the Matakitaki River after the 1929 Murchison earthquake and the Buller River after the 1968 Inangahua earthquake. Residents downstream of the Buller landslide dam were evacuated before it breached the next day.

A rock avalanche from Mt Adams with no apparent trigger blocked the Poerua River in South Westland in 1999. The dam breached after six days sending a torrent of water down the river, flooding farmland.

The danger of a landslide dam breach in the Callery River near Franz Josef was recently recognised and a camping ground was moved as a result. Motel units in the area are also considered at risk from flooding, but these continue to operate, and warning signs have been erected. Engineering works, such as stopbanks, were considered but not adopted because of the high cost and questionable effectiveness.

Areas affected by significant rainfall-induced landslide episodes since 1970. Most large rainfall-induced landslide events have been in the North Island, the most extensive being caused by Cyclone Bola in 1988, and the February 2004 storm. *GNS Science*.

Rainfall-induced landslides

Rainfall-induced landslides, like earthquake-induced landslides, are dependent on the slope angle but are also strongly influenced by other factors such as vegetation cover, soil depth, drainage patterns, and the frequency of intense rainstorms (more than 100mm of rain in 24 hours).

Some slopes that typically fail under strong earthquake-shaking, like narrow ridges, very steep rock slopes, cliffs, and escarpments, are generally less affected by heavy rainfall.

Most rainfall-induced landslides are small (less than 1000m^3) shallow soil slides and flows on moderate to steep (more than 20^o) grass-covered hill slopes. Few are large or deep-seated bedrock landslides. Individually these small landslides do little damage and rarely threaten life but cumulatively, over a widespread area, they can cause a large amount of damage to road, rail and farm infrastructure, and are the most common form of hill country soil erosion.

Significant rainfall-induced landslide events occur more frequently in New Zealand than earthquake-induced events. There have been at least 15 rainstorms in the last 35 years that have caused extensive landsliding over large areas, especially in areas of erodible mudstone hill country in the North Island from Manawatu–Wanganui to Gisborne. The effects of these events are far-reaching. Pasture loss decreases productivity, and silt washed into streams and rivers degrades water quality and increases flood risk. The annual cost of soil erosion is estimated at $100–150 million.

Very few rainfall-induced landslides occur in areas covered in native bush, scrub, or exotic forest. The forest canopy intercepts rainfall, reducing the rate of run-off on the ground, and tree roots help to bind the soil. Deforestation is estimated to have increased landsliding in the North Island hill country by around seven times its natural rate.

Rainfall-induced landslides also damage buildings and infrastructure on steep urban slopes, particularly those modified by cutting into the slope to create building platforms, roads, and sports grounds. All but two of the 1149 landslides identified in Wellington in 1974 occurred on cut slopes, as did 70 per cent of the landslides in the December 1976 Wellington storm.

Climate change is likely to increase the frequency and intensity of rainstorms in some areas of New Zealand, which may mean an increase in rainfall-induced landslides.

FEBRUARY 2004 STORM

Shallow soil slides and deep-seated landslides in the Mangawhero Valley after the February 2004 storm. The storm caused widespread landsliding in the lower North Island hill country. The Whangaehu, Turakina and Pohangina valleys were also severely affected. *Graham Hancox*.

The heavy and prolonged rainfall of the February 2004 storm caused widespread landsliding over approximately 16 000km^2 of the southern North Island. Many thousands of small to medium (less than 1000m^3), shallow (1–2m deep) soil and debris slides and flows occurred, along with some larger (1000–200 000m^3), deep-seated landslides. Landslide damage during this storm was more extensive than in Cyclone Bola in 1988, and affected a more diverse area.

Damage to farmland was extensive across the region, and many roads were severely damaged and closed by landslides. State Highway 3 through the Manawatu Gorge was closed for three months. Landslides came close to houses and other buildings but few were significantly affected – only one house, at Karaka Bay in Wellington, was destroyed. Another large landslide (200 000–300 000m^3) dammed the Hutt River near Upper Hutt and diverted the river through the golf course, causing extensive erosion.

Most landslides occurred on steep (20–35^o) grass-covered hill slopes and gullies. Debris from landslides in gullies and riverbanks put considerable sediment and vegetation into flooded rivers, contributing to bridge failures and covering downstream farmland with silt and debris.

Land use and vegetation clearly influenced landslide distribution. Hill slopes covered with native bush or exotic forest were much less affected by landslides than grass slopes.

Managing landslides

Risk reduction is central to managing landslides. There is greater opportunity for human intervention in landslide processes compared to other geological hazards. Readiness, response, and recovery from landslides are generally small scale, or part of a larger response to an earthquake or rainfall event.

Risk reduction

LANDSLIDE HAZARD MAPPING

Landslides tend to occur at or near the sites of previous landslides, and are more likely to occur on steeper slopes or areas of weak or fractured rock. Landslide hazard zones can be defined using aerial photo interpretation and GIS mapping.

Landslide-hazard zones include not only the area of the landslide itself but the area at the bottom of the slope where material is deposited (the run-out zone). This is particularly important for debris flows which have large run-out zones. Landslide-hazard zone information can be used for land-use and infrastructure planning.

LAND-USE PLANNING

Avoidance is the best landslide-risk reduction option, especially for rapid landslides such as debris avalanches and debris flows, where engineering solutions are often ineffective or uneconomic. It is generally unrealistic, however, to completely avoid development on slopes or debris fans, and a risk-based approach should be adopted using site-specific information.

Few district plans outline specific landslide-hazard zones for which a resource consent is required before development. Most planners rely on provisions in the RMA and Building Act 2004 to make decisions on land-use planning with respect to landslide hazards. However, district plans generally do contain rules to control the scale of excavations and vegetation removal on erosion-prone land.

GNS Science has completed a landslide hazard guideline for local government planners. The guideline allows planners to evaluate the effectiveness of their current plans and better assess consent applications based on risk evaluation. The public-good funded guideline was developed with input from MCDEM, the Ministry for the Environment, the Earthquake Commission, the New Zealand Geotechnical Society and local government planners.

ENGINEERING SOLUTIONS

The likelihood of a landslide occurring can be reduced by removing or strengthening susceptible material, or by modifying the slope. Engineering works are often expensive, and the decision to undertake this work depends on the value of the assets to be protected and environmental considerations.

An example of major landslide stabilisation work that was justified on the basis of asset value and the reduction of risk to local communities is the Lake Dunstan landslide stabilisation programme. More than $900 million (2006 value) was spent stabilising 16 landslides along the lake above the Clyde Dam, to prevent a sudden slide into the lake and consequent overtopping of the dam. Some of the slopes have required recontouring and buttressing.

Rapidly-moving landslides – debris flows and rock avalanches – are more difficult to prevent or modify. Debris-flow barriers can be constructed but they are very expensive to build and maintain. This is a cost that communities cannot usually afford. They are usually only economic where high value assets that cannot be relocated are at risk. As with flood stopbanks, the owner and consenting authority must also consider and accept the consequences of events that

WAIHI LANDSLIDES

Several large landslides, which have formed very large debris flows, have occurred at the Hipaua Steaming Cliffs on the Waihi Fault scarp at the southern end of Lake Taupo over the last 230 years.

The first of these landslides is thought to have occurred around 1780, burying a nearby pa and killing around 150 people. A better-documented event occurred at night in May 1846, killing at least 60 people in Te Rapa (Little Waihi) village. The most recent landslide happened on 20 March 1910 but people were alerted to the debris torrent and all but one person escaped. The village of Te Rapa was subsequently abandoned.

The landslides appear to be related to ongoing geothermal activity in the area, and future landslides could be triggered by geothermal eruptions, earthquakes, or prolonged heavy rainfall. The probability of another debris flow at Waihi in the next 50 years is estimated at 65 per cent. Such a debris flow has the potential to damage State Highway 41, as well as a fishing lodge and houses in Waihi village.

The 1910 landslide at Waihi on the southern shores of Lake Taupo and the same area in 2002. The landslide debris covered an area 800m wide and extended two kilometres from its source to the lake shore, with an estimated volume of 3 million m^3. *GNS Science*.

exceed the design capacity of the structure.

Developers of residential subdivisions on hill slopes are now tending to move away from cut-and-fill engineering to create building platforms, towards extensive recontouring of the land, removing ridges and partially filling gullies. This often removes the shallow landslide hazard.

PUBLIC AWARENESS AND LAND OWNER ACTION

Land owners can take measures to reduce the risk of landslides on their own and neighbouring properties. Poorly-maintained retaining walls, inadequate stormwater drainage, vegetation removal, and excavation can all contribute to landslides. Some territorial authorities, such as Hutt City Council, have produced guidelines for land owners outlining these issues and how landslide risk can be reduced.

CATCHMENT MANAGEMENT

Sustainable land management in the headwaters of river catchments is an integral part of shallow landslide and soil erosion control. This requires long-term, multi-faceted approaches to encourage sensible land use, including education, advice, farm planning, possible land purchase by local and central government, regulations, monitoring, and financial assistance to help farmers with the capital cost of changing land use. Regional councils play a significant role in soil and catchment management along with LandCare Research in raising public awareness.

Readiness

Many landslides occur rapidly with little or no warning, giving little opportunity for people or assets to move or be moved. Signs that often indicate the onset of landsliding are cracks in the ground or buildings, subsidence or bulging of the land, and tilting trees or seepage.

Some currently slow-moving landslides in New Zealand are monitored by asset owners and councils where there is potential for movement to accelerate and affect assets. Monitoring may range from yearly measurements of a few survey points across a landslide to complex networks, such as that along Lake Dunstan, which involves 3500 monitoring instruments and measuring points.

Response and recovery

Emergency services, local authorities and asset owners will be involved in responses to small damaging landslides. Any CDEM response to major damaging landslides follows generic response and recovery procedures set out in CDEM Group plans, the National CDEM Plan and the Guide to the National CDEM Plan. Because widespread landsliding is almost always triggered by heavy or intense rainfall or earthquake shaking, the response is usually part of a wider response to a flood or an earthquake.

The Earthquake Commission (EQC) insures residential buildings and contents against landslide damage for those home owners who hold fire insurance.

Landslides onto roads, particularly during an earthquake, create a large amount of debris which must be removed to reopen roads. MfE and MCDEM have recently developed a guide for the use of the emergency works provisions of the RMA for use in such situations.

GeoNet maintains a rapid-response capability for large or significant landslides. The primary aims of these responses are to provide advice for managing public safety and to collect information that will contribute to a better understanding of the causes and mechanisms of landslides.

FURTHER INFORMATION

GENERAL LANDSLIDE INFORMATION

GEONET
www.geonet.org.nz
TE ARA ENCYCLOPAEDIA OF NEW ZEALAND
www.teara.govt.nz/EarthSeaAndSky/NaturalHazardsAndDisasters/Landslides/en
MINISTRY OF CIVIL DEFENCE & EMERGENCY MANAGEMENT
www.civildefence.govt.nz/memwebsite.nsf/wpg_URL/For-the-CDEM-Sector-Publications-Tephra-2002-Index?OpenDocument

LANDSLIDE HAZARD PLANNING GUIDELINE

GNS SCIENCE MISCELLANEOUS SERIES 7
www.qualityplanning.org.nz/pubs/Draft-Landslide-Guideline-Feb-2007.pdf