

TSUNAMIS

Tsunamis are waves generated by a rapid displacement of a large volume of water. Tsunamis are most commonly produced by large, offshore earthquakes that cause uplift or subsidence of the sea floor, but they can also be caused by coastal or submarine landslides, volcanic eruptions, and meteor impacts.

Tsunami waves differ from normal sea waves because they move through the entire column of water from the surface of the sea to the seabed and therefore have significant momentum. They travel extremely quickly, up to 900km/h in the open ocean where their wave heights are generally less than a metre. As water becomes shallower near the shore, the tsunami's wave speed reduces and the wave height increases. The time between successive tsunami waves can vary between several minutes and a few hours, and the first wave may not be the largest. A tsunami may approach the land as a large breaking wave, or like an extremely high tide moving rapidly onto the shore.

New Zealand's tsunami risk is comparable to or larger than its earthquake risk. Large tsunamis have occurred in New Zealand within written history, but have resulted in few deaths and only modest damage. However, Maori tradition records several large tsunamis killing many people within the last 1000 years. Archaeological evidence indicates that several coastal settlements around New Zealand were abandoned for higher ground in the mid-1400s. There is also geological evidence of tsunamis with up to 60m run-ups affecting the New Zealand coast within the last 6000 years.

With intensification of coastal development over the last few decades, a large tsunami today is likely to be highly damaging.

TSUNAMI HEIGHT AND RUN-UP

Tsunamis are described by both their wave height and their run-up. Tsunami height is a measure of the vertical trough-to-crest height of a tsunami wave. Tsunami height is not constant – height increases substantially as the waves approach shore and depends on the near shore bathymetry.

Tsunami run-up is the maximum vertical height that the tsunami reaches on land above normal sea level at the time. Run-up is dependent on the type and size of the tsunami as well as coastal topography and land use. Tsunami run-up is a more useful measure than tsunami height as it relates more closely to the onshore effects of a tsunami.

Tsunami sources

Distant sources

Distant-source tsunamis are those that are generated more than three hours' travel time from New Zealand. Distant-source tsunamis that are large enough to cause damage in New Zealand originate from subduction zones around the rim of the Pacific Ocean, particularly those along the coast of South America.

The subduction zone at the boundary of the Pacific and South American tectonic plates off the South American coast produces very large earthquakes and is one of the most frequent sources of tsunamis in the Pacific Ocean. Tsunamis generated along this coast can be directed towards New Zealand both by the orientation of the plate boundary and the shape of the sea floor between South America and New Zealand. The three largest distant-source tsunamis to hit

New Zealand within written history – in 1868, 1877 and 1960 – have all originated from this area. Tsunami-generating earthquakes of magnitude 8.5 or greater off the South American coast have an average return period of 50 years.

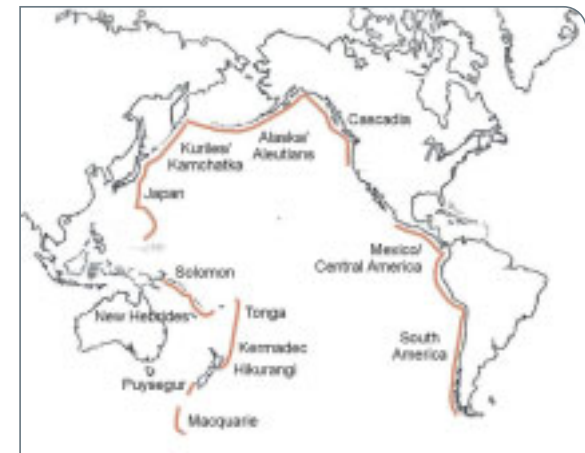


Plate boundary areas around the margins of the Pacific Ocean. The most likely distant tsunami source for New Zealand is the South American coast, particularly adjacent to Peru, followed by Alaska/Aleutian Islands and Cascadia. *GNS Science.*

The 1868 tsunami was generated by a magnitude 9.1 earthquake off the Peru/Chile coast, an area oriented in a manner which directs tsunami waves toward New Zealand. The tsunami destroyed a village and killed one person in the Chatham Islands, and caused damage in Lyttelton Harbour and other bays around Banks Peninsula.

1960 TSUNAMI

The most recent damaging distant-source tsunami to affect New Zealand was generated by a magnitude 9.5 earthquake off the coast of Chile in 1960. The tsunami arrived in New Zealand 14 hours later during the night of 24 May. It caused fluctuations of up to 4.5m above normal sea level along the New Zealand coast, damaging many boats and harbour facilities.

There were no deaths in New Zealand, but the tsunami washed people from their tents and damaged cabins at Te Awanga, north of Hastings. It damaged boats and electrical equipment at the port in Lyttelton, and further inside the harbour it inundated a hotel and several houses, and drowned 200 sheep.



The 1960 tsunami arriving in Lyttelton harbour and flooding the dry dock. There were no deaths in New Zealand but the tsunami killed several thousand people in Chile, 61 in Hawaii and 199 in Japan. *Christchurch Star*.

Tsunamis generated by large earthquakes near Alaska and the Aleutian Islands have historically only caused wave run-ups of up to 2m in northern and eastern New Zealand, although they have been devastating in parts of the northern Pacific. It is possible that future earthquakes in this region, and along the Cascadia margin between California and Vancouver Island, may produce damaging tsunamis in New Zealand, but the earthquake sources are not well oriented for directing tsunamis towards the southwest Pacific.

Other areas around the margin of the Pacific Ocean, such as Mexico and Central America, Japan the Solomon Islands and Papua New Guinea, are unlikely to produce tsunamis with damaging impacts in New Zealand, either because they do not produce very large earthquakes, or because their orientation does not direct tsunamis towards New Zealand.

Distant landslides and volcanic cone collapses or eruptions are unlikely to cause damaging tsunamis in New Zealand. The possibility of a tsunami generated by an asteroid impact does exist, but the probability is very low.

Regional sources

Regional-source tsunamis are those that are generated one to three hours' travel time from New Zealand. The most significant regional tsunami sources for New Zealand are earthquakes in tectonically active areas to the north of New Zealand. Regional-source tsunamis from the south, east, or west are unlikely.

The southern Kermadec trench is the most significant regional tsunami source with wave run-ups of up to 13m possible along parts of the Auckland coast. Modelling of a large (magnitude 8.6) earthquake along the southern New Hebrides subduction zone indicates the possibility of a tsunami in northern New Zealand, but

run-up heights are unlikely to exceed 2m.

Other regional earthquake sources, mainly Tonga and the northern Kermadec trench to the north and the Macquarie Ridge to the south, are not thought to produce earthquakes over magnitude 8.5, and their orientation makes them an unlikely tsunami source.

Volcanic activity between White Island and the Kermadec Islands, northeast of New Zealand, is not a likely source of damaging tsunamis for New Zealand, and any regional landslide sources are unknown.

Local sources

Local-source tsunamis are those generated less than one hour's travel time from the nearest New Zealand coast.

Around one third of New Zealand's earthquakes occur on offshore faults. Large offshore earthquakes are capable of producing large (7–10m or greater) tsunamis along tens to hundreds of kilometres of coastline. Thirteen local-source tsunamis have been recorded since 1840 in New Zealand, all generated by earthquakes and some accompanied by coastal landslides. The 1855 Wairarapa earthquake produced a tsunami measuring 9m in Palliser Bay, 4–5m along parts of Wellington's south coast, 2–5m in the inner harbour, over 4m in Marlborough, and 2–3m along the Kapiti coast. Two local tsunamis, one up to 10m high, occurred along the coast north of Gisborne in 1947. Geological research indicates that even larger local-source tsunamis have occurred before human settlement of New Zealand.

The most significant potential local tsunami source from earthquakes is the Hikurangi subduction zone along the east coast of the North Island. This subduction zone has not ruptured historically, but it is capable of producing a magnitude 7.5–8.5 earthquake, large enough to generate a tsunami which would affect many kilometres of coastline

along the east coast of the North Island and upper South Island, and the Chatham Islands. There are also many faults along the continental shelf off New Zealand's east coast which are capable of generating tsunamis.

There are many other offshore faults around New Zealand that could be capable of generating localised damaging tsunamis along tens of kilometres of coast, particularly off the eastern North Island, Manawatu, Fiordland, and Kaikoura coasts, and in Cook Strait.

Submarine and coastal landslides are possible local tsunami sources. Many large submarine landslides have been identified off the New Zealand coast with volumes ranging from 0.25km³ to 3000km³ from the 170 000-year-old Ruatoria debris avalanche. The tsunami generated by the Ruatoria debris avalanche is estimated to have been 125–700m high but such a tsunami is extremely rare. Smaller but still significant landslides in the Kaikoura Canyon or along the northern Hikurangi margin and the Kermadec Trench are more likely. Tsunami waves generated by landslides tend to rapidly reduce in height away from the source because the source is a point rather than a line, which is more typical of fault rupture-generated tsunamis. They can also be highly directional, sending a concentrated 'beam' of waves in the direction of the landslide movement. So while the waves generated can be large, their impact is often very localised.

Coastal earthquake-triggered landslides have caused localised tsunamis in the past at Westport during the 1929 Murchison earthquake, north of Napier in the 1931 Hawke's Bay earthquake and in Charles Sound in the 2003 Fiordland earthquake.

Mayor and White Islands are the only near-shore active volcanoes in New Zealand. Neither volcano is expected to experience large enough eruptions or sector collapses to generate damaging tsunamis along the Bay of Plenty or Coromandel coasts.

1947 GISBORNE TSUNAMI

On 26 March 1947 a tsunami up to 10m high struck the Gisborne coast between Mahia Peninsula and Waipiro Bay, half an hour after an apparently small earthquake. It inundated the Tatapouri Hotel, just north of Gisborne, up to its windowsills and swept nearby small outbuildings out to sea. It almost entirely demolished a cottage at Turihaua, leaving only the kitchen, with three people inside. The tsunami swept the Pouawa River bridge 800m inland and shifted a house off its foundations at Te Mahanga Beach. There were no deaths, but there could have been many casualties had the tsunami struck during the busy summer holidays.

Less than two months later another tsunami up to 6m high, also generated by an offshore earthquake of magnitude 7.1, hit the coast between Gisborne and Tolaga Bay.



All that remained of a four-bedroom cottage at Turihaua after the 1947 Gisborne tsunami. Seaweed was left hanging off the power lines behind the cottage. *Tairāwhiti Museum.*

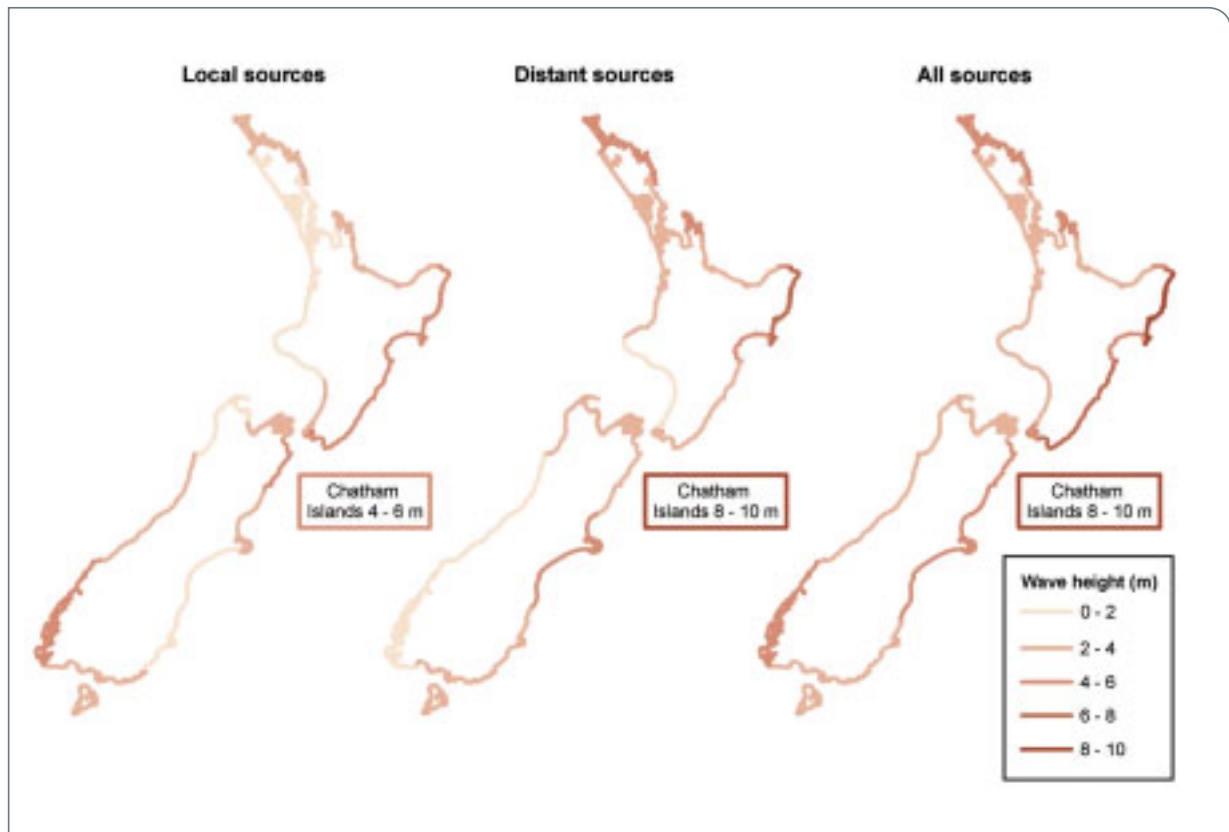
New Zealand's tsunami hazard

While no part of the New Zealand coastline is completely free from tsunami hazard, there is a large variation in the tsunami hazard around New Zealand from local, regional, and distant sources.

The tsunami hazard from local sources is greatest along the east and south coasts of the North Island, and the Marlborough and Fiordland coasts in the South Island. The tsunami hazard from distant sources is greatest along the Northland, Bay of Plenty, Coromandel, Gisborne, Hawke's Bay, and Canterbury coasts. The Chatham Rise, in particular, tends to enhance distant-source tsunami wave heights around Banks Peninsula.

The area of greatest hazard from any tsunami source, combining local and distant-source hazard information, is the east coast of the North Island. The tsunami hazard in the Chatham Islands is most likely even greater.

The largest contributors to New Zealand's tsunami hazard are earthquakes off the South American coast or along the southern Kermadec and Hikurangi subduction zones to the east of the country. Other offshore local faults also contribute but to a lesser degree.



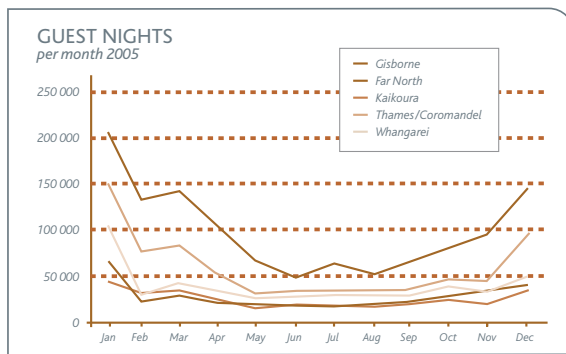
A tsunami hazard and risk study undertaken by GNS Science for MCDEM in 2005 estimates damages of \$12–21 billion nationally from a 500-year return period tsunami. Deaths and injuries are highly dependent on the time of year and time of day, and on whether a warning can be issued before the tsunami reaches the coast. All major distant tsunami sources are more than 10 hours' travel time from New Zealand giving, in theory, adequate time for warning and evacuations, although wave heights may be difficult to predict.

Regional and local tsunami sources, however, may be only minutes to a few hours travel time from the nearest New Zealand coast. This creates serious challenges for emergency management and there may not be enough time to confirm a tsunami and issue a warning before it reaches New Zealand.

The impacts of a tsunami depend on tsunami height and run-up. Several factors contribute to tsunami damage and casualties. Fast-flowing water hits structures, vessels and people, and can erode coastal land. The 'outrush' of water when a tsunami wave recedes is often the main cause of drowning as people are swept out to sea. A large amount of debris is picked up in tsunami waves, which damages structures and injures people on both the incoming and outgoing waves. Fire and contamination are often caused by tsunamis when fuel installations are damaged and hazardous substances and sewage are released into the water. Ponding of saltwater over large areas causes damage to buildings, electronics, and fittings, and destroys pasture and crops.



Generalised tsunami hazard in New Zealand expressed as the 500-year return period wave height above sea level. Significantly higher or lower water levels may occur at a particular location depending on local bathymetry and coastal topography. *GNS Science.*



Guest nights per month for selected territorial authorities with coastal resort towns. Coastal populations show significant seasonal variation peaking between December and March. A tsunami occurring during these months would have a much larger impact than one occurring during winter. Guest nights make up only around a third of the total population increase over the summer months, the remainder staying in private accommodation. *Ministry of Tourism.*

Managing tsunamis

Risk reduction

The emphasis for managing tsunami hazards is on readiness and response. However, there is growing recognition of the potential effectiveness of risk reduction, particularly land-use planning and urban design. There has been little progress in implementing such measures in New Zealand because of the infrequency of damaging tsunamis in the recent past in New Zealand and the low population density. Few territorial and regional authorities in New Zealand have plan provisions that specifically address tsunami hazards, but many have provisions to reduce the risk from coastal erosion and other coastal hazards which help reduce the risk from tsunamis.

In some locations the tsunami risk could be considered high enough to warrant restrictions on the location and type of coastal development, particularly where the risk is from local source tsunamis.

Non-regulatory mitigation methods could be considered in planning and development proposals, many of which can be incorporated into new developments with minimal or no extra cost. Methods include dune restoration (dunes act as a buffer to some of the tsunami impact and are also useful in protecting against coastal erosion), increasing surface roughness by planting vegetation behind dune systems, locating reserves between the coast and development, and meandering or angled beach access ways.

Other methods, including locating key infrastructure and community facilities away from the coast, designing roading patterns that increase access perpendicular to the coast, and designing higher or stronger buildings, could also be considered.

Structural protection works that are used in other countries such as Japan to protect against tsunami waves are unlikely to be economically viable or environmentally acceptable in New Zealand.

Readiness

The Pacific Tsunami Warning Center (PTWC), based in Hawaii, monitors the Pacific Ocean for large earthquakes and tsunamis. MCDEM (as well as the MetService and Airways Corporation) receives warnings for distant and some regional-source tsunamis from the PTWC and passes them on to CDEM Groups. CDEM Groups then coordinate evacuations in their regions if necessary, following procedures set out in their CDEM Group plan.

PTWC warnings do not contain forecasted wave heights. It is the responsibility of each nation's response system to evaluate likely

TSUNAMI RISK AND READINESS IN NEW ZEALAND

The disastrous consequences of the 26 December 2004 Indian Ocean tsunami prompted the Government to review New Zealand's risk from tsunamis and its preparedness for them. GNS Science was commissioned by MCDEM to prepare a science report assessing New Zealand's tsunami hazard and risk, and a preparedness report reviewing the adequacy of current tsunami warnings in New Zealand. The reports incorporated work by many New Zealand tsunami researchers and were completed in September and December 2005 respectively.

The tsunami preparedness report gave several recommendations for improving national and regional management of tsunami risk. Recommendations centred around improving GeoNet's capability for generating alerts and predicting effects, developing national level resources and guidelines, investment at a national level in tsunami research, and CDEM Group level improvements in risk reduction and readiness.

Following consultation with stakeholders on the report findings and recommendations, MCDEM prepared a report for the Minister of Civil Defence outlining priority areas for further work. In September 2006, the Minister endorsed the report and outlined a number of steps to be undertaken. In the shorter term the Minister has directed that a Tsunami Working Group involving a broad range of stakeholders be formed for improving the national warning system and developing public warning systems. In the longer term a commitment has been made to improve tsunami risk management, including support for developing local tsunami evacuation plans, tsunami contingency planning, and scenario modelling.



Tsunami warning signs, like this one at Castlepoint Beach, have been installed at some coastal locations around New Zealand. There is reluctance in some at-risk areas, however, to erect signs amid concerns they will alarm people and deter tourists. *Masterton District Council.*

impacts in their area and to implement response plans. There is currently a high level of uncertainty in determining wave heights and areas of inundation. Modelling tsunami inundation is currently being undertaken to define evacuation zones in some areas of New Zealand, for example Northland.

Regional source tsunamis have travel times of between one and three hours. Work is currently being carried out by GeoNet to improve detection and alert notification capabilities for these threats to New Zealand.

Local-source tsunamis may hit the New Zealand coast within minutes of an earthquake or landslide, before GeoNet can locate an earthquake, confirm a tsunami has been generated, and issue a warning. In these instances the public will need to evacuate themselves without an official warning if they have felt a strong earthquake or notice unusual changes in sea level. Public education is therefore extremely important in coastal areas of New Zealand and is the most effective readiness measure for local-source tsunamis.

Local-source tsunami warning systems that deliver warnings within three to five minutes exist in Japan but given their very high cost they are unlikely to be justifiable in New Zealand with its low population density.

Asteroids are tracked by NASA and substantial advance warning can be given before a likely asteroid impact that may cause a tsunami.

PACIFIC TSUNAMI WARNING CENTER

The Pacific Tsunami Warning Center (PTWC) in Hawaii was established in 1949 as an international programme to provide Pacific nations, including New Zealand, with tsunami warnings. The PTWC continuously monitors earthquake activity and sea levels in the Pacific region using data from participating nations.

The PTWC issues a tsunami information bulletin when an earthquake between magnitude 6.5 and 7.5 is detected within or near the Pacific Ocean basin. A tsunami warning/watch bulletin is issued for earthquakes greater than magnitude 7.5. This alerts civil defence emergency management agencies of the possibility that a tsunami may have been generated.

If an earthquake appears to be large enough to cause a tsunami and is located in an area where tsunami generation is possible, the PTWC will check water-level data from automatic tide stations near the earthquake for evidence of a tsunami. If the water-level data indicates a tsunami that poses a threat to countries around the Pacific Ocean has been generated, a Pacific-wide tsunami warning bulletin is issued. If tide stations indicate a negligible or no tsunami the tsunami warning/watch bulletin is cancelled.

Because of the time taken to analyse data and confirm or dispel the existence of a tsunami, warnings issued by the PTWC cannot be relied upon to warn against local-source tsunamis in New Zealand.

Response and recovery

Response to a tsunami begins when it is known that a tsunami has been generated (in the case of a local-source tsunami this could be when the tsunami reaches the shore), and if there is time may include organised evacuations for several hours or even days, and the provision of scientific advice to Government following generic response and recovery procedures set out in CDEM Group plans, the National CDEM Plan and the Guide to the National CDEM Plan. In addition, MCDEM is currently preparing a tsunami contingency plan.

The Earthquake Commission insures residential buildings and contents against tsunami damage, up to a certain limit, for those home owners who hold fire insurance.

FURTHER INFORMATION

GENERAL TSUNAMI INFORMATION

TE ARA ENCYCLOPAEDIA OF NEW ZEALAND

www.teara.govt.nz/EarthSeaAndSky/NaturalHazardsAndDisasters/Tsunamis/en

MINISTRY OF CIVIL DEFENCE & EMERGENCY MANAGEMENT

[www.civildefence.govt.nz/MEMWebsite.nsf/Files/tephra99/\\$file/tephra99.pdf](http://www.civildefence.govt.nz/MEMWebsite.nsf/Files/tephra99/$file/tephra99.pdf)

NATIONAL INSTITUTE OF WATER AND ATMOSPHERIC RESEARCH

www.niwascience.co.nz/rc/prog/chaz/news/tsunami

GNS SCIENCE TSUNAMI HAZARD AND RISK REPORT

MINISTRY OF CIVIL DEFENCE & EMERGENCY MANAGEMENT

[www.civildefence.govt.nz/memwebsite.nsf/wpg_URL/](http://www.civildefence.govt.nz/memwebsite.nsf/wpg_URL/For-the-CDEM-Sector-Publications-Tsunami-Risk-and-Preparedness-in-New-Zealand-Reports?OpenDocument)

[For-the-CDEM-Sector-Publications-Tsunami-Risk-and-Preparedness-in-New-Zealand-Reports?OpenDocument](http://www.civildefence.govt.nz/memwebsite.nsf/wpg_URL/For-the-CDEM-Sector-Publications-Tsunami-Risk-and-Preparedness-in-New-Zealand-Reports?OpenDocument)

GNS SCIENCE TSUNAMI PREPAREDNESS REPORT

MINISTRY OF CIVIL DEFENCE & EMERGENCY MANAGEMENT

[www.civildefence.govt.nz/memwebsite.nsf/wpg_URL/](http://www.civildefence.govt.nz/memwebsite.nsf/wpg_URL/For-the-CDEM-Sector-Publications-Tsunami-Risk-and-Preparedness-in-New-Zealand-Reports?OpenDocument)

[For-the-CDEM-Sector-Publications-Tsunami-Risk-and-Preparedness-in-New-Zealand-Reports?OpenDocument](http://www.civildefence.govt.nz/memwebsite.nsf/wpg_URL/For-the-CDEM-Sector-Publications-Tsunami-Risk-and-Preparedness-in-New-Zealand-Reports?OpenDocument)

PACIFIC TSUNAMI WARNING CENTER

PACIFIC TSUNAMI WARNING CENTER

www.prh.noaa.gov/ptwc

GEONET

GEONET

www.geonet.org.nz



Brighton Spit, Christchurch, is at risk from tsunami inundation, storm surge events and sea-level rise.

COASTAL HAZARDS

New Zealand's 18 000km of coastline is constantly changing, shaped by frequent high swells and occasional storm surges, that erode and occasionally inundate coastal land. Less frequent but potentially very damaging tsunamis also hit New Zealand's shores.

Managing the residential, recreational, and economic use of New Zealand's dynamic coastal environment is a challenge. Coastal development, particularly for residential use, has increased in recent years, placing more people, property, infrastructure and recreational facilities at risk from coastal hazards.

Swells

Wind creates waves on the surface of the ocean. Swells are series of these waves with a long distance between wave crests, which lose very little energy as they travel across large distances of up to thousands of kilometres of open ocean.

The prevailing westerly winds in the Southern Ocean create persistent southwest swells along the west coast of both islands, where the swell is rarely below 2m high. The exception is the Kapiti-Horowhenua coast, which is sheltered from this direction by the South Island. This low-lying coast can sustain serious damage, however, when subject to occasional large swells from more westerly and northerly directions.

The northeast of the North Island, on the less energetic Pacific coast, is sheltered from the southwesterly swell. However, this coastline is occasionally exposed to northeast swells of more than 4m created by tropical cyclones, which are often accompanied by storm surges.

Swells along the east coast from East Cape to Bluff are more variable in direction and height. They average 0.5m to 2m, but can occasionally rise to between 4m and 6m.



Waves crashing over a sea wall near Wellington airport on Wellington's south coast in 1998. This coast is often subject to southerly swells which can damage sea walls and boats, and deposit material over coastal roads. *The Evening Post*.

Very large swells affect various parts of the New Zealand coast several times a year, most commonly in autumn and winter. Heavy swells can damage moored boats and coastal infrastructure, and cause or contribute to coastal inundation and erosion.

WAITANGI DAY 2002 SWELL

An unusually large summer swell hit eastern New Zealand from Canterbury to Gisborne on 6 February 2002, created by a deep low to the east of the South Island. The low generated gale force southerly winds and high seas in Canterbury, which sank five boats in Lyttelton Marina. It also generated a very large swell which travelled up the east coast, striking Wellington on what was an otherwise calm and sunny morning. Thirteen metre waves were recorded on the Baring Head wave buoy at the entrance to Wellington Harbour. The southerly gale hit Wellington around noon, just as high tide approached, creating extremely high seas. Debris covered coastal roads, and waves entered the back yards of several coastal properties and damaged sea walls. Damage amounted to several hundred thousand dollars.

Further north, the log carrier Jody F Millenium attempted to leave Port Gisborne to avoid being battered against the wharf but ran aground on a sand bar outside the harbour. It took two and a half weeks and \$1.5 million to refloat the ship. This work was hampered by further big swells.

Storm surge

A storm surge is a temporary elevation in sea level during storm conditions created by two factors – low barometric pressure and wind. Low-pressure systems responsible for storms create a vacuum effect over the sea, causing the water level to rise by one centimetre for every one-hectopascal fall in air pressure below average air pressure. This 'inverted barometer' effect can cause sea level to rise by up to 0.5m above tide level.

On top of the inverted barometer effect, strong winds can pile water up against a coast creating what is known as wave set-up. This can increase sea level another 0.5m. The combination of the inverted barometer effect and wave set-up can create storm surges of up to 1m above the tide level around New Zealand. Storm surges are often caused by ex-tropical cyclones to the northeast of New Zealand. Large areas of low-lying coast, such as around the Firth of Thames (particularly the Hauraki Plains) and Tasman Bay, are most vulnerable to storm surge.

A large storm surge can cause damage at any time, but the degree of damage is highly dependent on the tide at the time. A storm surge that occurs around a very high tide is likely to be much more damaging than one arriving at low tide. Coastal inundation can be extreme if storm surge and high swells combine with an unusually high tide. This happened in March 1936 when a low-pressure system creating a storm surge on top of the highest spring tide of last century flooded much of the Hauraki Plains.

Coastal inundation and erosion during storm surges or swells is unlikely to result in deaths because adequate warnings can usually be issued. Coastal infrastructure such as ports, roads, and rail, along with buildings in coastal communities, can be damaged. Coastal land may be eroded and large areas of coastal farmland may be contaminated by salt water inundation. Storm surge may also worsen river flooding by reducing river flow into the sea.

The probability of damage from storm surges is likely to increase with sea level rise induced by climate change.

Coastal erosion

Coastal erosion is the retreat of the shoreline caused by water currents, waves, and wind. It is part of a natural process of shoreline movement that can be influenced by human activities.

New Zealand has a range of coast types dictated by geology and wave exposure. Much of New Zealand's coast is steep cliffs. Cliffs composed of young, soft, sedimentary rocks, such as those along the east coast of the North Island, erode easily. In other areas, such as Fiordland, very old, hard rocks are more resistant to erosion. Around a third of New Zealand's coastline is beach, either long stretches of open beach, like those on the west coast of both islands, or small disconnected beaches separated by rocky headlands, like those in northeastern New Zealand. Beaches go through cycles over various time scales of building up (accreting) and eroding.

Most coastal erosion occurs in large increments during storms when heavy swells, sometimes accompanied by storm surges, buffet the coast. Eroded beaches are sometimes gradually rebuilt during intervening calm periods. Several underlying factors, however, contribute to the location and severity of coastal erosion. These include the local geology, the supply of sediment to and along the coast, and the presence of artificial structures such as breakwaters and sea walls.

Human activities can disrupt sediment supply and increase erosion. Extracting sand near the shore can reduce the supply of sediment to nearby beaches. Damming and extracting water from rivers changes the flow conditions and the supply of sediment to the coast. Building port breakwaters alters sediment transport along



Rates of coastal erosion in New Zealand. About one quarter of New Zealand's coast is eroding. Adapted from Gibb, 1984.

the coast. Stormwater discharge across beaches can also contribute to localised erosion.

Large-scale coastal erosion is generally a gradual process occurring over many storm events, and areas susceptible to coastal erosion can generally be identified in advance. Ideally, coastal erosion can be planned for and the effects mitigated. However, there are periods

when coastal erosion is more rapid and severe than normal, and significant damage can occur. Deaths are not anticipated, but land and the assets on it, such as houses, roads, and recreational areas, can be damaged or destroyed.

Sea level in New Zealand has risen steadily by about 16cm over the last 100 years. This rate is likely to increase with climate change.

Rising sea level contributes to coastal erosion as each successive storm is able to encroach further inland. Climate change is also likely to cause other changes in coastal erosion drivers such as wave patterns, storminess, and other factors affecting coastal sediment supply, such as sediment input from rivers.

COASTAL EROSION IN HAWKE'S BAY

Coastal erosion and inundation are significant issues for several small settlements along the Hawke's Bay coast, particularly since the 1970s when several large storms caused erosion and inundation damage. Seawater flooded 300 hectares of coastal horticultural and urban land in East Clive in 1974. A sea-exclusion bank was built in 1976/77 to prevent further inundation but continued erosion, made worse by construction of the Hastings sewage outfall in 1979, resulted in the bank being moved further inland.

More recently, 20 Haumoana residents evacuated their seafront homes on 3 April 2002 as high seas threatened a dozen properties. The waves destroyed fences, cracked doors, and smashed windows. Further south, campers at Kairakau Beach abandoned caravans and tents as waves encroached onto the camping ground, filling some caravans with sand and pushing them 2 or 3m back with their force. The sea eroded land and inundated homes again in March 2005 and July 2006.

The shoreline is retreating at Haumoana by 0.3–0.7m each year. Increased storminess over the next few decades, associated with a positive phase of the Interdecadal Pacific Oscillation and sea level rise, are likely to increase erosion and inundation. Many residents have built their own sea walls in the past, but this piecemeal approach to protection has generally been ineffective and has disrupted natural processes. It is highly likely that more homes will be damaged or destroyed in future, and retreat away from the shoreline may be the only viable option.



Heavy seas hit Haumoana on the Hawke's Bay coast in July 2006. Erosion has been causing damage to property along the Hawke's Bay coast since the 1850s.
Hawke's Bay Regional Council.



Sea wall at St Clair beach in Dunedin. The 500m-long sea wall was built in 2004 at a cost of \$5.7 million and replaced an existing 80-year-old sea wall. *Otago Daily Times.*

Managing coastal hazards

The demand for coastal living, often in inundation or erosion-prone areas, is high, and managing coastal hazards is a complex issue. Many different approaches to coastal hazard management, usually involving a combination of measures (some more effective than others) are used around New Zealand. Direct engagement with communities affected by coastal hazards is a widely used approach to develop solutions. However, this is often a long and difficult process involving disparate points of view.

Risk reduction

STRUCTURAL PROTECTION

Structural protection measures are used in New Zealand in an attempt to prevent or lessen erosion in specific locations. Central government has not provided subsidies for structural protection since 1971 and local authorities only provide protection for public assets. Therefore structural protection for private property must now be funded by property owners. This approach has led to many ad hoc structures being placed along New Zealand's coastline, many of which are unattractive and in a state of disrepair. Private structures now require consents from the local territorial authority or regional council under the RMA.

Structural protection often creates or worsens erosion further along the coast, shifting the problem rather than solving it. It is often ineffective and can be expensive to build and maintain, particularly if it sustains frequent damage. It is often uneconomic in the long-term and is becoming a less desirable option for coastal erosion management.

BEACH STABILISATION AND RENOURISHMENT

About 1100km of New Zealand's coastline is dunes. There is growing

recognition of the role dunes play in buffering coastal land from coastal inundation and erosion. Recent years have seen a large increase in community-based projects to restore and stabilise dunes around New Zealand. Dune restoration includes planting with sand-binding native grasses such as pingao and spinifex, and restricting access across the dunes to defined walkways.

Beach nourishment involves bringing in sand to replenish beaches. Many beaches in New Zealand, for example Mission Bay in Auckland and Oriental Bay in Wellington, have been replenished. This is only a temporary solution, however, and ongoing nourishment is expensive.

LAND-USE PLANNING AND RELOCATION

Set-backs from the coast are now generally accepted as the best way to reduce risk from coastal inundation and erosion in undeveloped areas. This represents a shift away from managing beaches to managing human activities.

Knowledge of long-term coastal erosion and sedimentation trends is crucial for making land use planning decisions in coastal areas. Some coastal settlements were developed when the adjacent coast appeared to be stable or advancing, but have subsequently suffered from coastal erosion when the coastline retreated in an erosional phase. Significant research now goes into determining reasonable set-back lines for land use planning in some areas.

However, it can be difficult for territorial authorities to gain acceptance of land-use planning controls to reduce coastal erosion and inundation risk. Coastal properties now have high values and development proposals are often only resolved in the Environment Court.

Some territorial authorities require beach front houses to be relocatable so that they can be removed if they are threatened by coastal erosion. The 'do nothing' approach is also sometimes used, where houses are left to fall into the sea. This approach is often unacceptable to the individuals and communities involved.

Under the RMA, regional councils are required to prepare a regional coastal plan for their coastal marine areas. These plans address coastal issues, control the effects of activities and discharges, and identify conservation values.

New Zealand Coastal Policy Statement

The New Zealand Coastal Policy Statement (NZCPS) is the only mandatory national policy statement under the RMA. It includes policies for, among other things, avoiding and mitigating the effects of natural hazards in the coastal environment, to which local authorities must give effect. There are six policies specifically related to coastal hazard management, which focus on avoiding coastal hazards, avoiding the need for structural protection works, and promoting 'soft' options such as dune restoration above structural protection works for existing development.

The NZCPS also promotes a precautionary approach to proposed activities within the coastal marine area, particularly where there is a lack of understanding of coastal processes or of the effects of the proposed activities.

The NZCPS became operative in 1994 and a review of its ability to address coastal issues was released in 2004. The review included a report assessing the NZCPS's effectiveness in promoting sustainable coastal hazard management. The report drew attention to the many barriers to sustainable coastal hazard management and recommended more specific coastal hazard policies. The Department of Conservation is currently undertaking a full review of the NZCPS, and is aiming to have a draft revised NZCPS to Cabinet by October 2007.

Readiness

Tides are calculated well in advance and the timing of particularly high spring tides (just after the full and new moon) and perigean tides (when the moon is closest to earth), when the probability of coastal inundation is greatest, can be forecast. NIWA predicts and distributes 'red alert' and 'carefree' dates for each year. Even small storm surges could cause coastal inundation on 'red alert' days, but coastal inundation is unlikely on 'carefree' days, although it could occur in an extreme storm surge.

The state-owned MetService gathers, analyses, and provides weather information to New Zealanders. The MetService provides marine forecasts and swell warnings, and also issues advisories for abnormally high water within enclosed bays along the northeastern coast. Different areas of the New Zealand coast have different swell-warning thresholds, depending on their topography and vulnerability. For example, southeast swells of more than 3m can be destructive along the Canterbury coast, whereas swells of more than 5m pose a threat to State Highway 1 along the Marlborough coast. East coast areas from South Canterbury to Gisborne, Cook Strait, and the Kapiti Coast, are carefully monitored for swells.

Storms that are likely to cause greater than 3m swells are closely monitored and advisories may be issued several days in advance. A swell warning is issued 24 hours before the warning criteria is expected to be reached along a particular stretch of coast.

Forecasts use moored wave-rider buoys, which supply continuous information on swell height, direction, and period, and ships at sea send in six-hourly wind, sea, and swell reports. Data from the open sea was previously sparse, but satellites now use scatterometers, which measure sea surface roughness.

Response and recovery

Storm surge and coastal erosion hazards are generally localised events, and any emergency response to storm surges is likely to be managed at a local level by emergency services and local authorities. Any broader CDEM response required for storm surges or coastal inundation or erosion would follow generic response and recovery procedures set out in CDEM Group plans, the National CDEM Plan and the Guide to the National CDEM Plan.

FURTHER INFORMATION

COASTAL FLOODING, TIDES, AND STORM SURGE

NATIONAL INSTITUTE OF WATER AND ATMOSPHERIC RESEARCH
www.niwascience.co.nz/rc/prog/chaz/news/coastal
MINISTRY OF CIVIL DEFENCE & EMERGENCY MANAGEMENT
www.civildefence.govt.nz/memwebsite.nsf/wpg_URL/For-the-CDEM-Sector-Publications-Tephra-2003-Index?OpenDocument

COASTAL EROSION

TE ARA ENCYCLOPAEDIA OF NEW ZEALAND
www.teara.govt.nz/EarthSeaAndSky/OceanStudyAndConservation/CoastalErosion/1/en
www.teara.govt.nz/EarthSeaAndSky/MarineEnvironments/CoastalShoreline/1/en
NATIONAL INSTITUTE OF WATER AND ATMOSPHERIC RESEARCH
www.niwascience.co.nz/rc/prog/chaz/news/erosion
GIBB, J, 1984, 'COASTAL EROSION'. In Crozier, M and Speden, I (comp), 1984, Natural Hazards in New Zealand. New Zealand National Commission for UNESCO, Wellington.

FLOODS

A flood occurs when the amount of water in a river exceeds the capacity of the river channel and inundates adjacent land. Floods are an integral part of a river's natural cycle – they transfer sediment through the river system to floodplains and offshore.

New Zealand's early settlers lived close to rivers to take advantage of fertile soils, fresh water, and the transport links that rivers provided. The settlers, with limited knowledge of New Zealand's landscape and climate, didn't realise the high flood hazard.

Floods continue to be New Zealand's most frequent and costly natural hazard. Today, with structural protection works and monitoring and warning systems, floods claim few lives, but they still regularly cause millions of dollars' worth of damage to structures, infrastructure, and agriculture.

Factors that control flooding

The size of a flood in a river depends on the intensity, duration and total amount of rainfall, and the characteristics of the catchment and floodplain.

Widespread heavy rain

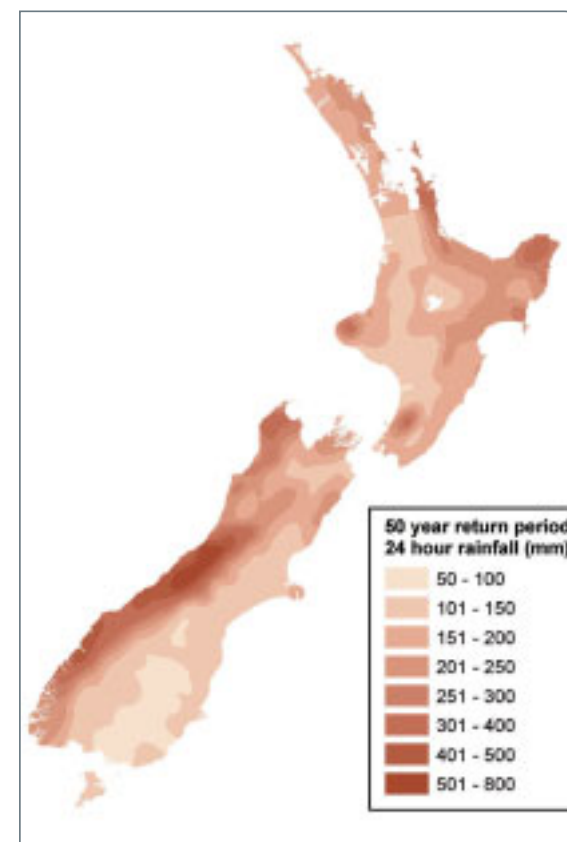
New Zealand is surrounded by ocean and lies in the zone of strong westerly winds which flow around the southern hemisphere where warm, moist air of tropical or subtropical origin meets cold, dry air from high latitudes. Topography and the angle at which the airstream hits New Zealand's ranges, along with the temperature and humidity of the air, dictate the distribution of rainfall over the country. Consequently, heavy rainfall can occur at any time of the year in any part of the country.

Widespread heavy rain occurs when air is forced upwards either within a frontal system, as moist warm air is driven up over a mass of colder air (frontal rain), or within moist air that is forced to rise over mountains (orographic rain), or as a combination of the two processes.

Heavy rainfall in the west and south of the South Island is common and is produced by a combination of fronts within west or northwest airflows and one of the highest rates of orographic uplift of air in the world. Moisture-laden air arriving from the west is forced up over the Southern Alps, rising 2500 to 3500m within 10–20km of the coast. Annual precipitation (both rain and snow) is up to 15m in the Southern Alps and rainfall of more than 600mm in one day has been recorded on the West Coast.

Heavy rainfall in the North Island and the northeast of the South Island is often associated with mid-latitude cyclones or ex-tropical cyclones that move over or past New Zealand from the north. Very strong winds often accompany ex-tropical cyclones.

Heavy rain in the southeast of the South Island may be produced by slow moving mid-latitude cyclones to the east of the island or north-south oriented fronts between a mid-latitude cyclone in the Tasman Sea and a high pressure system in the Pacific Ocean.



The 50-year return period rainfall for a 24-hour period. The west coast of the South Island, Mt Taranaki, the Tararua Range and the northeastern North Island have the highest 24-hour rainfalls. *National Institute of Water and Atmospheric Research.*

FEBRUARY 2004 STORM

The February 2004 storm was New Zealand's most widespread and damaging flood since Cyclone Bola in 1988.

Unusually wet conditions were created during late January and early February by a series of westerly airflows across central New Zealand. On 11 and 12 February a front brought northwesterly rain and winds to the lower North Island, with almost 400mm of rain recorded over 24 hours in the Tararua Range, bringing the Otaki, Hutt, and Wairarapa rivers into flood.

On 14 February a depression deepened rapidly east of the North Island, bringing further falls of heavy rain to the already saturated lower North Island and upper South Island during 15 and 16 February. Many districts in the southern half of the North Island received more than 100mm of rain, and up to 250mm fell in the Tararua and Ruahine ranges.

Rivers and streams in the Hutt Valley, Kapiti, Wairarapa, Manawatu, and southern Taranaki all flooded. The Oroua, Whangaehu and Turakina rivers in the Manawatu experienced at least 100-year return period flows. Four stopbanks burst in the Manawatu, inundating farmland, settlements, and roads. Many bridges were damaged, and water and gas lines across them cut. The Manawatu Gorge was closed for almost 3 months. No lives were lost but more than 1800 people were evacuated from their homes in the Manawatu.

The storm was the largest rainfall event in the lower North Island since major vegetation clearances of the early 1900s. Shallow landslides affected more than 16 000km² of hill country and more than 200 million tonnes of soil is estimated to have been lost from the Manawatu-Wanganui region. The soil was deposited over farmland downstream, and significantly raised riverbeds reducing flood carrying capacity.

The storm caused losses estimated at \$380 million (2006 value). This included \$195 million in agricultural losses from stock, crop, and pasture loss; milking interruption; and fence and farm building damage. Roads suffered more than \$75 million worth of damage, and flood protection schemes and rivers more than \$25 million. Insured losses totalled \$121 million.



Ngaputahi Station in the Manawatu after the February 2004 storm. Millions of tonnes of soil was washed into flooded rivers and deposited on farm land downstream. Westmount School.

Localised rain

Localised intense rain is generally associated with thunderstorms – unstable air masses formed by convective conditions as air rises and cools rapidly through solar heating, or frontal or orographic uplift. Thunderstorms can generate very intense rain, damaging winds, hail and lightning. They often develop rapidly, making them difficult to forecast accurately, but they are generally short-lived and often only affect a small area, usually less than 100km².

Thunderstorms most commonly occur in New Zealand as small, brief storms lasting for less than half an hour. Larger and longer-lived thunderstorms known as multicell line storms may last for several hours but are generally mobile and only affect individual areas for a short time. Multicell line storms, also known as squall lines, can produce intense rain, hail, strong wind gusts, and occasionally small tornadoes. Supercell thunderstorms, which bring intense rain, severe wind gusts including damaging tornadoes, and large hail (golfball-sized or larger), are also occasionally observed in New Zealand but are uncommon.

The intense rain produced in thunderstorms is the main cause of flash flooding in New Zealand. Twenty-one people were killed in 1938 at Kopuawhara Stream near Wairoa when around 130mm of rain fell in one hour, creating a flash flood that washed away 47 workers' huts. The May 2005 Matata flash flood and resulting debris flow was the result of a thunderstorm that delivered 95mm of rain in one hour in the catchments behind the village. Intense rain can produce shallow landslides, soil erosion, and debris flows, particularly in rural catchments, and surface flooding is common in urban catchments where stormwater systems may not cope.

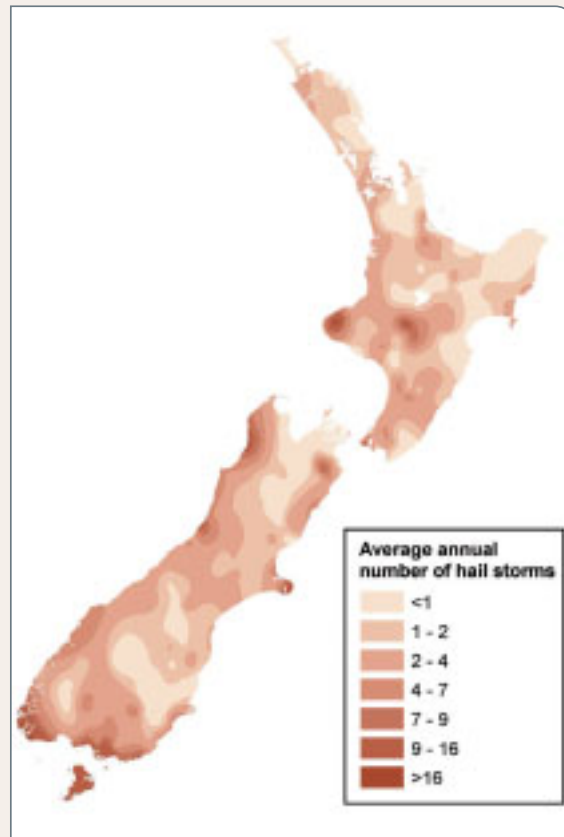
HAIL AND LIGHTNING

Along with flooding, the hail and lightning produced by thunderstorms can affect property, infrastructure and crops.

Hailstones larger than 5mm in diameter can damage fruit and vegetable crops; for example, hailstorms in 1997 caused more than \$50 million worth of damage to apple crops in Hawke's Bay. Hail can block stormwater drains and increase surface flooding in urban areas.

More than 100 000 lightning strikes hit New Zealand each year. Lightning strikes are most frequent in or to the west of the main mountain ranges, particularly in spring and summer, as air is pushed up over the mountains. The less frequent lightning strikes in eastern areas occur mostly during summer afternoons and evenings when surface temperatures are high. Lightning kills someone every 5–10 years in New Zealand, regularly disrupts electricity and telecommunications, and can also start fires.

Susceptibility to hail and lightning can be mapped at a regional scale, based on historical data. This helps with making decisions about locating crops and infrastructure. Because hail and lightning are localised events, they are unlikely to be of national significance unless they affect important infrastructure or a densely populated urban area.



Average annual number of hailstorms in New Zealand. Hailstorms most frequently occur in western areas in winter and spring, but the most damaging hailstorms occur in eastern areas during spring and summer. *National Institute of Water and Atmospheric Research.*

Catchment conditions

The size and effects of a flood are influenced by conditions within the river catchment that control the relationship of rainfall to runoff. The more permeable the ground surface, the more rainfall it can absorb before it becomes saturated and the water runs off into streams and rivers. Previous weather conditions have a large influence on the severity of a flood caused by a particular rainfall event. For example, rainfall on an already saturated catchment will lead to a more extreme flood than in a dry catchment where there is capacity for rain to infiltrate the soil.

The type of bedrock, soil, and vegetation in a catchment also influence runoff rates during rainfall. Vegetation clearance in a river catchment increases the rate of runoff causing rapid and high flood peaks. Shallow landslides and soil erosion are also much more likely on cleared hill country, causing more sediment to be fed into flooded rivers. The sediment is deposited on floodplains and raises river bed levels, reducing the flood-carrying capacity of the river.

Wetlands act as storage areas and slow the flow of water into waterways. In contrast, impermeable surfaces in urban areas increase runoff rates because rainfall is unable to infiltrate the soil.

Flooding in New Zealand

New Zealand's river catchments are relatively short and steep, compared to other countries. This makes for a short interval (from hours to a few days) between when the rain falls and when the flood peaks. Warning times are therefore short and water speeds can be high, but the flood itself is over relatively quickly.

There is no standard measure of flood hazard or risk across New Zealand. Flood-hazard maps are developed by individual regional

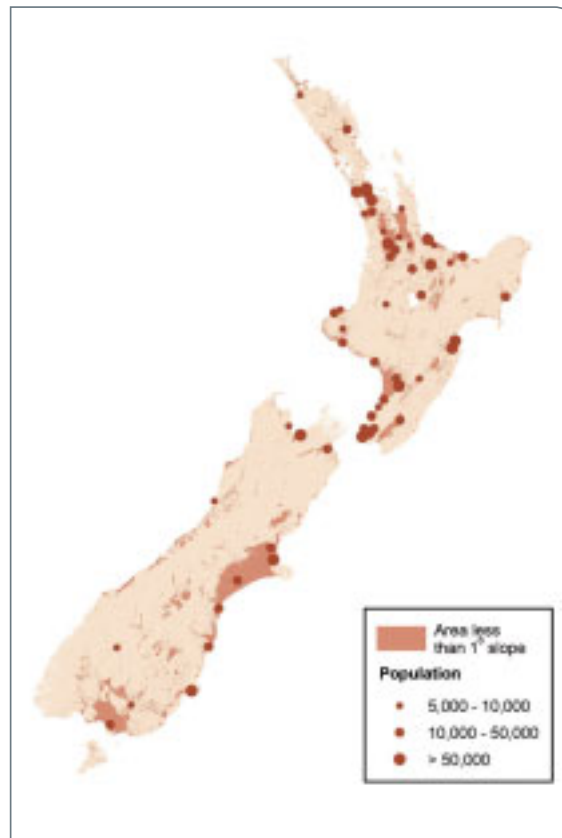
councils and do not necessarily depict the hazard from floods of the same frequency. Flood-hazard assessments are often only carried out for major rivers and in areas where significant flooding has occurred in the past. Flood hazards also depend on the existence or otherwise of protection works, which vary in design and standard across New Zealand.

The effects of a flood depend on the depth and speed of water in the flooded area. These in turn depend on the 'size' of the flood, which is measured by the amount of water involved or, more commonly, by its estimated return period.

New Zealand has a low population density and many of the country's fertile floodplains are intensely farmed. A large proportion of flood losses in New Zealand are therefore related to damage to farm infrastructure, livestock and pasture loss, and indirect economic impacts.

Floods are one of the more significant hazards for agriculture. The on-farm effects from flood events are often long-lasting with economic and social impacts continuing for several years after the event. Floods often result in livestock welfare issues.

Roading and rail infrastructure is also often damaged, particularly by rainfall-induced landslides that often accompany flooding. Scour of bridge piers is a major contributor to flood damage, and lives have been lost as a direct consequence. Flooding in urban areas leads to evacuations, damage to houses, and environmental and public health issues as water and sewerage systems are overcome and hazardous substances released. Risk to life from flooding in New Zealand is relatively low compared to other countries, but social disruption can be considerable when people are evacuated for long periods of time.



Areas of New Zealand with gentle slopes of less than 1°, giving a general indication of flood-prone land. The actual flood hazard in these areas depends on regional catchment and floodplain management, including physical flood-protection measures. These areas contain some of the country's richest agricultural land, and several towns and cities have a high flood risk, either because of the high flood hazard or the number of people and amount of assets that are exposed. *National Institute of Water and Atmospheric Research.*

Managing floods

Where and when rain falls cannot be controlled but what happens to the water once it reaches the ground can be influenced to reduce the flood hazard. Decreasing the rate of runoff into streams and containing the flood within the river channel are two measures that can be taken. However, these measures cannot eliminate flooding, and land will still occasionally be inundated. The consequences depend on how communities choose to use flood-prone land.

Risk reduction

Reducing flood risk involves managing entire river systems from the catchment to the sea.

Traditionally, flood risk reduction in New Zealand has focused on

building structures to keep water away from people. Less regard was given to non-structural measures such as land-use planning to keep people and property away from flood-prone areas, and adopting building standards to keep people and property above flood levels. Effective flood-risk reduction involves a combination of structural and non-structural measures on floodplains and managing land use in river catchments.

Regional councils and territorial authorities are both involved in managing flood risk using a variety of approaches and design standards. There is a growing interest in a more consistent approach to flood-risk reduction across New Zealand, which has generated three recent projects. The Ministry for the Environment funded the Floodplain Management Planning Guidelines, released in 2001, to guide regional councils on floodplain-management planning practice and methodology.

The 2004 lower North Island and Bay of Plenty floods prompted two further flood-risk management initiatives – the Flood Risk Management Review led by central government, and the Flood Risk Management Protocol sponsored by local government. In March 2007, the government decided that a national policy statement on flood risk management was desirable. The formal process under the Resource Management Act 1991 to develop a national policy statement is currently underway.

STRUCTURAL MEASURES

Flood protection structures – most commonly stopbanks but also including groynes and floodgates – modify river behaviour and protect people and property from floods up to a specified standard.

Design standards for stopbanks vary greatly throughout New Zealand, from protection from a flood with a 5-year return period for some rural stopbanks, to floods with 400–500-year return periods for major rivers like the Hutt and Waimakariri rivers.

Early flood protection structures were piecemeal, often deflecting flood water onto neighbouring properties. Catchment boards, established in 1941, adopted an integrated catchment and river management approach including soil conservation, with a focus on engineering works. About 3000km of central government-subsidised stopbank were built in the 1950s and 1960s to protect agricultural land and some urban areas.

Stopbanks offered a sense of security, and high-density development has occurred behind them, in areas such as in Christchurch, the Hutt Valley and the Heretaunga Plains in Hawke's Bay. Stopbanks have failed in the past in New Zealand, through poor construction, a lack of maintenance, or through floods exceeding the design capacity of the protection work. A significant residual flood risk still exists despite many flood protection schemes.

Stopbanks are costly to build and maintain. Central government subsidies for stopbank construction and maintenance ended in the

THE FLOOD RISK MANAGEMENT REVIEW AND THE FLOOD RISK MANAGEMENT PROTOCOL

The Ministry for the Environment began the *Flood Risk Management Review* in July 2005 in response to the large floods of 2004. The review, expected to be completed in 2007, focuses on three key areas:

- current flood-risk management practices and whether they are appropriate
- central and local government's role in ensuring good flood-risk management practices are adopted
- who benefits, who pays, and who can afford flood-risk mitigation.

The draft *Flood Risk Management Protocol*, an initiative sponsored by regional councils and supported by central government, gives councils a set of principles for managing flood risk. The protocol was also developed after the 2004 floods to help address increasing development pressures in flood-prone areas, the increasing cost of flood mitigation measures, increasing public expectation for protection and the limitations of some present mitigation measures.

The protocol outlines key elements and implementation principles for sustainable, integrated and holistic flood-risk management, promoting engineering, building design, land-use planning, and emergency management. The draft protocol is currently being developed into a New Zealand standard.



The Fitzherbert stopbank at Palmerston North during the February 2004 storm. The stopbank had recently been upgraded and held the Manawatu River during the flood. Had the stopbank been breached or overtopped, however, the city would have suffered major flood damage. *Horizons Regional Council.*

late 1980s. Since then local government has been solely responsible for their funding. In some areas, this cost is becoming increasingly difficult for some ratepayers to bear.

Structural measures also include maintaining the capacity of river channels through realignment or gravel extraction, and using flood detention dams, although detention dams are not often used for flood reduction alone for a variety of reasons, including costs.

All structural measures have effects on the environment. They affect sediment transport and deposition, and ecological habitats. Poorly designed structures can also increase the downstream flood hazard. Structural measures are an important component of floodplain management but the costs and benefits must be appropriately managed across social, economic, and environmental values.

NON-STRUCTURAL MEASURES

Floodplain management aims to reduce vulnerability to floods through a variety of measures, rather than by attempting to control flooding through structural measures alone.

The simplest way to reduce flooding exposure is to not develop in flood hazard areas. This is relatively easy to do at undeveloped sites where flood-prone land can be used for parks, sports fields, or car parks, rather than housing and infrastructure. However, as floodplains are often intensively farmed due to the productive soils, their potential for damage is often significant within the agricultural community. Awareness in these communities is likely the best option for risk reduction.

Discouraging further development in existing flood-prone communities is more difficult. It involves complex political, social, and economic issues. Relocation may be an option in some situations.

Flood-hazard zones are often incorporated into district plans, where rules may apply to building construction or alteration and earthworks. Accurate information on flood inundation levels and their frequency is important in mapping hazard zones. Some of this information is available, to different degrees of accuracy, for some parts of New Zealand. NIWA is currently revising flood frequency estimates for New Zealand rivers, building on work completed in 1989, to determine both river flow and floodplain inundation levels using hydraulic modelling.

Building standards, including minimum floor levels, are often used to reduce the effects of flooding. The Building Code specifies that floor levels must be above the 50-year return period flood level. Some district plans, however, set out provisions that require floor levels in flood-hazard zones to be above that specified in the Building Code.

CATCHMENT MANAGEMENT

Catchment management involves managing land use in upper river catchments to reduce the amount of sediment that goes into rivers, and therefore reduce the flood hazard. Catchment management requires long-term, multi-pronged approaches 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.

Risk-reduction initiatives by farmers and others include planting forest and other vegetation to help stabilise ground and absorb water.

Restoring wetlands in river catchments can also help reduce the flood hazard. Wetlands store water and reduce the rate at which it enters rivers.

Readiness

The MetService issues a severe-weather warning when more than 50mm of rain is expected in a widespread area within the following 6 hours, or when more than 100mm is expected in a widespread area within the following 24 hours. A severe-weather watch is generated if more than 50mm of rain in 6 hours or more than 100mm of rain in 24 hours is expected 24 to 72 hours ahead. Severe weather outlooks are issued for severe weather which could occur 3–6 days ahead. These messages are sent to local authorities and CDEM Groups.

The MetService is currently developing a warning service for small-scale intense thunderstorms and is proposing to install additional weather radars to support this.

Regional councils have primary responsibility for flood forecasting and public warnings, using MetService information and data from NIWA's and their own rainfall and river level recorders. Warning times

are relatively short because New Zealand's catchments are short and steep. NIWA is increasing its flood-forecasting capacity to complement regional council functions, using rainfall-runoff models incorporating rainfall data and river catchment conditions. It is also developing routine rainfall forecasts up to 48 hours ahead and integrating these into a rainfall-runoff model to give a longer warning time for impending floods.

Response and recovery

The Earthquake Commission (EQC) insures residential land (but not houses or contents) against storm or flood damage for those home owners who hold fire insurance. EQC will contribute to the cost of removing flood debris from under and around homes, and will cover damage to retaining walls, bridges, or culverts within 60m of a house.

Like earthquakes, more consideration could be given to pre-event recovery planning for floods – identifying in advance the land-use planning decisions that will need to be made during the recovery phase. Unlike damaging earthquakes, damaging floods often occur at the same location on a frequent basis. Recovery from recent floods, such as the February 2004 storm, has concentrated on communities regaining daily functioning rather than taking the opportunity to improve long-term resilience.

Floods are New Zealand's most common and costly natural hazard, but generally they do not affect more than one region at the same time. Particularly large floods, such as those of central New Zealand in February 2004 and those in the South Island of the mid-1980s, are of national interest and have required central government support with response and recovery.

Any coordinated local or national CDEM response to floods follows generic response and recovery procedures set out in CDEM Group

plans, the National CDEM Plan and the Guide to the National CDEM Plan.

MAF's On-Farm Readiness and Recovery Plan for Adverse Climatic Events and Natural Disasters sets out individual and community responsibility to adverse events that affect farm businesses and outlines available recovery measures for different scale events.

FURTHER INFORMATION

GENERAL FLOOD AND WEATHER INFORMATION

TE ARA ENCYCLOPAEDIA OF NEW ZEALAND

www.teara.govt.nz/EarthSeaAndSky/NaturalHazardsAndDisasters/Floods/en

www.teara.govt.nz/EarthSeaAndSky/ClimateAndAtmosphere/Weather/en

MINISTRY OF CIVIL DEFENCE & EMERGENCY MANAGEMENT

[www.civildefence.govt.nz/MEMWebsite.nsf/Files/tephra97/\\$file/tephra97.pdf](http://www.civildefence.govt.nz/MEMWebsite.nsf/Files/tephra97/$file/tephra97.pdf)

www.civildefence.govt.nz/memwebsite.nsf/wpg_URL/For-the-CDEM-Sector-Publications-Tephra-2001-Index?OpenDocument

www.civildefence.govt.nz/memwebsite.nsf/wpg_URL/For-the-CDEM-Sector-Publications-Tephra-2003-Index?OpenDocument

MOSLEY, M P AND PEARSON, C P (EDS), 1997, FLOODS AND DROUGHTS. New Zealand Hydrological Society, Christchurch.

FLOODPLAIN MANAGEMENT PLANNING GUIDELINES

MINISTRY FOR THE ENVIRONMENT

www.mfe.govt.nz/withyou/funding/smf/results/9035_floodplain

[_management_planning_guidelines.pdf](#)

FLOOD RISK MANAGEMENT REVIEW

MINISTRY FOR THE ENVIRONMENT

www.mfe.govt.nz/issues/land/natural-hazard-mgmt/flood-risk-review.html

FLOOD RISK MANAGEMENT PROTOCOL

CENTRE FOR ADVANCED ENGINEERING

www.caenz.com/info/MFR/MFR.html

METSERVICE WARNINGS

METSERVICE

www.metservice.co.nz/default/index.php?alias=weatherwarningcriteria

SEVERE WINDS

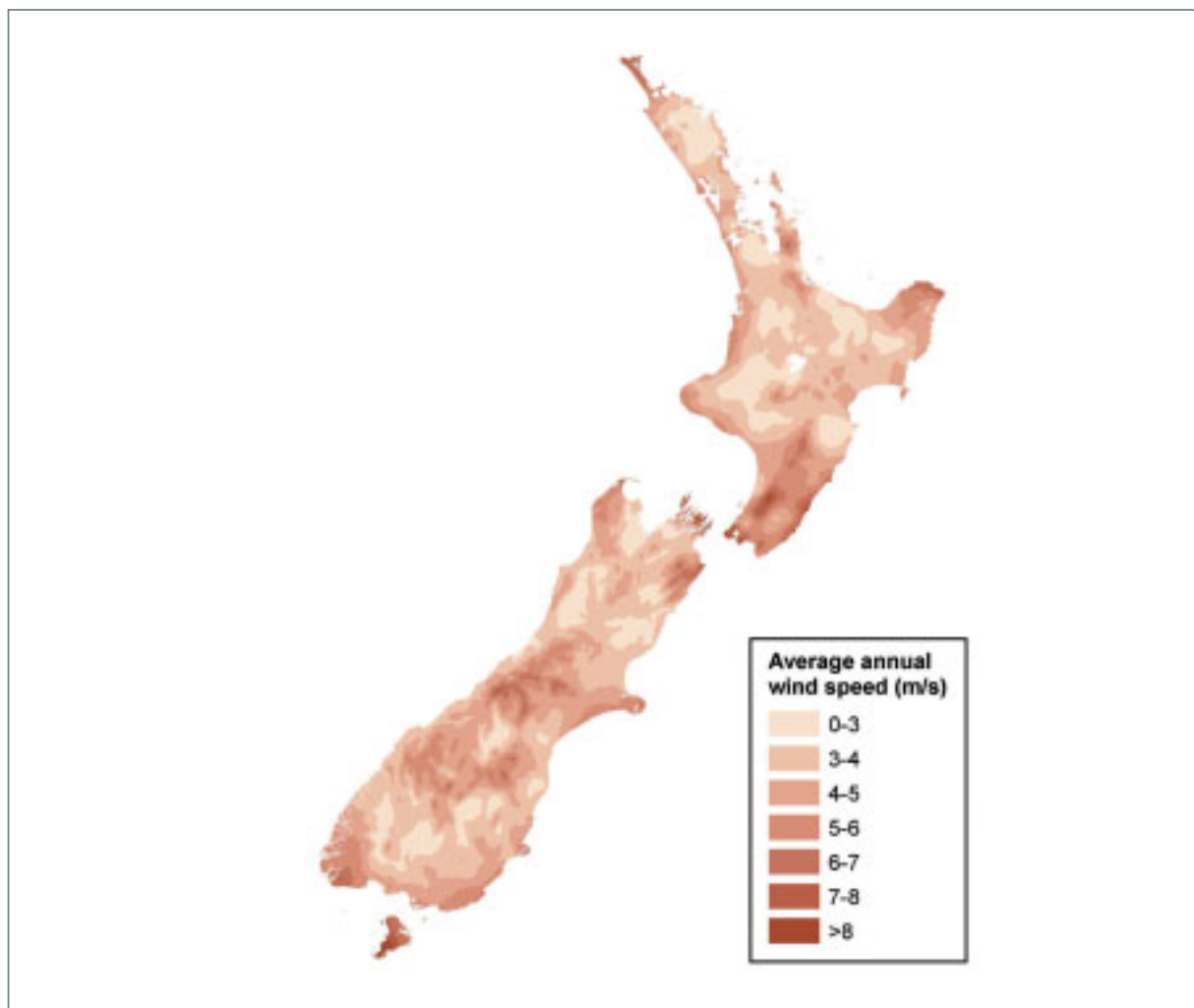
New Zealand lies in the path of the strong mid-latitude westerly winds, known as the 'roaring forties', and frequently experiences strong winds that can be extremely damaging.

New Zealand's predominant winds are from the west quarter – between northwest and southwest. When stable westerly airstreams hit the mountains they are forced up, over, and down into the lee of the ranges, creating strong eddies and downstream winds in areas such as Canterbury, Wairarapa, and southern Hawke's Bay. Winds are also funnelled through gaps in the ranges, such as the Manawatu Gorge, Cook Strait, Waitaki Valley and Foveaux Strait, making the surrounding areas particularly windy. Westerly winds are strongest in spring when the temperature difference between the equator and the South Pole is greatest.

The north and east of the North Island can also be affected by strong winds from the remnants of tropical cyclones moving down from the tropics during the summer. Localised wind gusts and tornadoes are often experienced with thunderstorms, most commonly in the west and north of the country.



Average annual wind speed in New Zealand. The values are for 10m above the ground surface and do not take into account small-scale topographic effects. *National Institute of Water and Atmospheric Research.*



Downslope wind storms

Wave motions are generated in the atmosphere in the lee of mountain ranges, which can cause strong downslope winds. The nature of these wave disturbances depends on the strength of the airflow over the mountains, how stable the atmosphere is, and topography.

Downslope wind storms occur in Canterbury in the lee of the Southern Alps, and in Wairarapa in the lee of the Tararua Range in strong northwesterlies. They have also occurred in Te Aroha in the lee of the Kaimai Range during strong easterlies.

Downslope wind storms can be relatively localised and do not generally bring rain, because most of the rain falls on the windward side of the mountains. Strong winds blew down power lines in Canterbury in October 1988, even though no high wind speeds were recorded at any monitoring stations. The behaviour of wind in the lee of mountains – the strength, duration and location of wave activity – remains difficult to forecast, although developments have been made recently in refining wind models.

1975 CANTERBURY WIND STORM

The Canterbury wind storm of 1 August 1975 was generated by a front moving over New Zealand between 31 July and 1 August with a strong northwesterly flow ahead of it. The situation was worsened by a stationary high-pressure system to the north of the country.

The storm affected areas from Southland to Wairarapa but was most intense in Canterbury. Lee waves formed to the east of the Southern Alps, producing bands of strong gusty winds along the Canterbury Plains. The period of highest winds only lasted one to two hours but caused severe damage. Northwesterly winds in Timaru reached 130km/h (70 knots) gusting to 165km/h. At the peak of the storm winds in Christchurch reached 130km/h (70 knots) gusting to 190km/h.

The strongest gust of 195km/h was recorded in Kaikoura. Roofs were blown off many buildings, aircraft were damaged, and garages and sheds were destroyed. Many electrical fires were ignited by falling power lines. Many trees were blown down or uprooted – Temuka lost 300 trees, some 80–100 years old, from its domain.

Eleven thousand hectares of plantation forest were damaged. Most of the pine plantations beside State Highway 1 north of Rakaia were flattened and there was widespread damage in the Eyrewell, Ashley, Balmoral, and Hanmer forests in North Canterbury.



Glasshouses damaged in the 1975 Canterbury wind storm. The return period of the storm was estimated at more than 100 years and insured damage was around \$55 million (2006 value). *The Christchurch Press.*

Tornadoes

In certain circumstances, rotation inside a thunderstorm produces a tornado – a narrow, tightly spinning funnel of air which extends below the cloud. Wind speeds within a tornado can be up to 300km/h, but tornadoes in New Zealand are mostly small and short-lived, unlike the very destructive tornadoes of the United States.

Around 20–30 tornadoes are observed in New Zealand each year, most lasting less than 15 minutes. They are most frequent in the west and north of the country, particularly the Waikato, Bay of Plenty, and Westland. Damage paths are 10–20m wide and usually less than 5km long.

New Zealand's worst tornado killed three people in Hamilton in 1948. More recently, two Taranaki people were killed in August 2004 when their house was destroyed by a tornado, and a tornado swept through Greymouth in March 2005 causing \$9.6 million worth of damage (2006 value).

The passage of squall lines associated with thunderstorms can also produce the sudden onset of very strong wind gusts followed by a gradual decrease in intensity over several minutes. Squall lines have been responsible for some of the highest wind gusts recorded – up to 145km/h – in northern New Zealand. Squalls can also be experienced within tropical cyclones and more commonly with southerly changes along the east coast of the country. Downbursts (plummeting downdraughts of cold, heavy air out of thunderstorms) pose a major risk to aviation.

1948 FRANKTON TORNADO

New Zealand's worst tornado struck Frankton and other parts of Hamilton on 25 August 1948. The tornado, which was accompanied by heavy rain, originated in the northwest of Frankton and swept through the village before travelling through Hamilton West and over the Waikato River into Hamilton East.

The tornado demolished most commercial buildings along the main street of Frankton and damaged 163 houses. It uprooted trees and threw corrugated iron, timber, and other debris into the air. It killed three people and badly injured seven. Damage was estimated at \$60 million (2006 value).



Damage to houses from the 1948 Frankton tornado. The tornado was New Zealand's deadliest, killing three people. *Hamilton City Library.*

Ex-tropical cyclones

Ex-tropical cyclones and depressions of subtropical origin are the most common source of widespread high wind in the northern half of the North Island, especially Northland, Auckland and the Bay of Plenty, and they are often accompanied by heavy rain causing flooding. New Zealand's most memorable storms have been ex-tropical cyclones – the 1936 storm, the Wahine Storm in 1968, Cyclone Bernie in 1982, Cyclone Bola in 1988 and Cyclones Drena and Fergus in the summer of 1996/97.

Between November and April tropical cyclones, containing belts of sustained strong winds rotating around an area of low pressure, form in the tropics to the north of New Zealand, at around 10 to 20 south. The heaviest rain and highest winds of a tropical cyclone, sometimes more than 200km/h, are mostly confined to a belt 10–20km wide around the centre or 'eye' of the storm.

Tropical cyclones are fuelled by warm water and either weaken or change their structure as they travel over increasingly cool seas away from the tropics. Sometimes, as ex-tropical cyclones head south toward New Zealand, they can evolve into large, damaging mid-latitude storms with the infusion of colder air. However, they retain the circulation pattern and the large amounts of moist air of the former tropical cyclone. Of the 10 or so tropical cyclones that form on average each year in the tropical southwest Pacific, only one or two are likely to affect New Zealand as ex-tropical cyclones.

The frequency of tropical cyclones is unlikely to increase with climate change. However, the rise in average sea surface and air temperatures will provide tropical cyclones with more energy, so ex-tropical cyclones affecting New Zealand are likely to be more intense in future.

1936 STORM

The 1936 storm has been described as the North Island's worst storm of the twentieth century. It caused widespread wind and rain damage from Northland to Marlborough. The storm initially formed in late January as a tropical cyclone near the Solomon Islands. As it moved south it joined a cold front over the north Tasman Sea and redeveloped into an intense mid-latitude storm.

The storm crossed the North Island on 2 February causing most rivers to flood resulting in widespread damage. Winds generated by the storm destroyed buildings from the Bay of Plenty to Taranaki and Manawatu, blew fruit off trees, and flattened crops.

The Manawatu was particularly hard-hit. Many houses lost roofs and the grandstands of the A&P Association, the Awapuni Racecourse, and the sports ground were demolished. A man was killed when he was blown off his roof while repairing it. The Longburn Anglican church was scattered over the adjacent road and railway line. The Feilding Aero Club hangar and two planes were destroyed. Trees were uprooted from ridges in the Tararua Range and thrown into valleys.

More than 40 boats were blown from their moorings in the Waitemata and Manukau Harbours in Auckland, and the ferry *Rangatira* hit rocks at the mouth of Wellington Harbour with 800 people on board. In today's dollars, this storm is estimated to have cost New Zealand \$800 million.



The A&P showground grandstand in Palmerston North, demolished in the 1936 storm. The storm was possibly New Zealand's worst storm of the twentieth century. *Palmerston North City Library.*

Severe wind impacts

Widespread strong winds can be produced by different large-scale weather systems over New Zealand. However, wind speed experienced at a particular site on the ground is highly dependent on local topography. Wind accelerates over ridges, hilltops and coastal escarpments – the steeper and nearer the top of the slope, the greater the wind speed. Factors such as whether the site is surrounded by substantial buildings or trees, and whether the site is urban or rural, also influence wind speed but to a lesser degree.

The most common effects of high winds are damage to buildings, particularly roofs, and infrastructure such as power lines. Driving can be difficult and Cook Strait ferry crossings are sometimes cancelled due to high winds and associated swells in the strait.

Exotic plantation forests are particularly susceptible to wind damage during downstream wind storms and tropical cyclones, especially where trees are of an even age. Windthrow is one of the most significant risks to forestry investments, and there is evidence that wind can affect wood quality. Also, dead wood debris left after wind damage to forests increases the wildfire risk.

Managing severe winds

Risk reduction

The design and construction of buildings and infrastructure has a large influence on their resilience to severe winds. New Zealand's Building Code has provisions that ensure wind loading is taken into account during design and construction. Wind zones, which consider local topography, site exposure, ground roughness, and wind region, dictate a structure's bracing requirements.

While severe wind is generally not addressed in district plans, several urban territorial authorities have provisions that aim to avoid or mitigate local effects such as wind tunnelling in high-rise streets.

Probabilistic wind analyses have been undertaken as part of local or regional engineering lifeline projects. This information enables lifeline utilities to design and site infrastructure to minimise the risk of severe wind damage.

The risk of wind damage to forestry can be reduced by selecting low-wind condition sites for planting and employing particular planting, pruning and felling regimes.

Readiness

The MetService issues a severe weather warning when widespread (over a 1000km² area) gales with a minimum wind speed of 90km/h, or frequent gusts exceeding 110km/h, are expected within 24 hours. A severe-weather watch is generated if these conditions are expected to occur 24–72 hours ahead.

Response and recovery

A widespread severe-wind event can cause significant damage in several regions. However, most wind events are able to be managed at a local level, or are often part of a larger flood event response. Tornadoes are localised events and, unless they impact on a critical area, infrastructure, or building, are unlikely to require a regional or national response.

MAF's On-Farm Readiness and Recovery Plan for Adverse Climatic Events and Natural Disasters sets out individual and community responsibility to adverse events that affect farm businesses and outlines available recovery measures for different scale events.

Any CDEM response to severe winds follows generic response and recovery procedures set out in CDEM Group plans, the National CDEM Plan and the Guide to the National CDEM Plan.

FURTHER INFORMATION

GENERAL WIND INFORMATION

TE ARA ENCYCLOPAEDIA OF NEW ZEALAND

www.teara.govt.nz/EarthSeaAndSky/ClimateAndAtmosphere/Weather/en

MINISTRY OF CIVIL DEFENCE & EMERGENCY MANAGEMENT

[www.civildefence.govt.nz/MEMWebsite.nsf/Files/tephra97/\\$file/tephra97.pdf](http://www.civildefence.govt.nz/MEMWebsite.nsf/Files/tephra97/$file/tephra97.pdf)

[www.civildefence.govt.nz/memwebsite.NSF/Files/TephraVol20%20complete/\\$file/TephraVol20%](http://www.civildefence.govt.nz/memwebsite.NSF/Files/TephraVol20%20complete/$file/TephraVol20%)

METSERVICE LEARNING CENTRE

www.metservice.co.nz/default/index.php?alias=learningcentre

METSERVICE WARNINGS

METSERVICE

www.metservice.co.nz/default/index.php?alias=weatherwarningcriteria

WIND DAMAGE TO FORESTRY

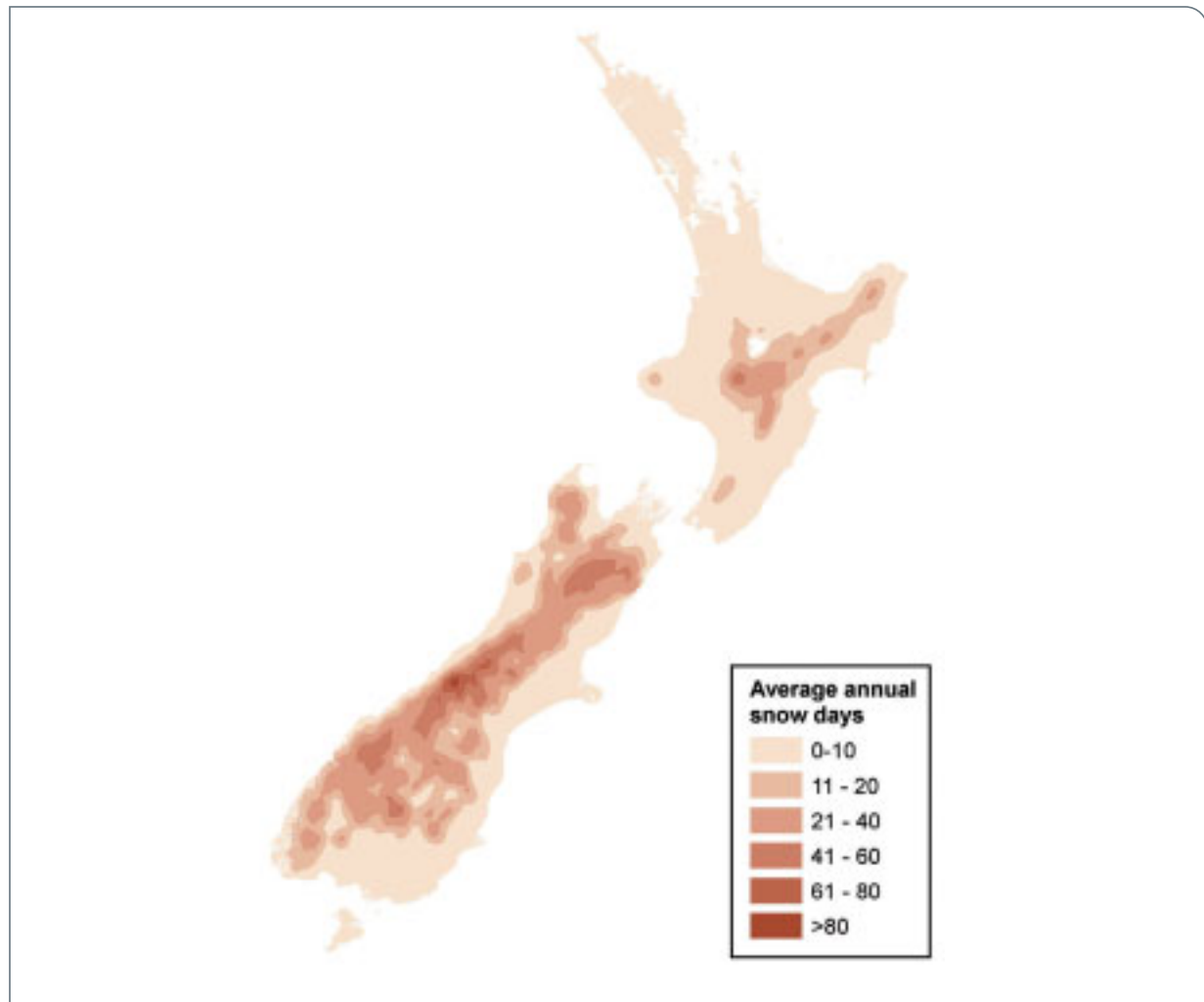
MCFARLANE, P, PEARCE, G, AND MOORE, J, 2001,

FORESTRY AND RISK MANAGEMENT – NEW ZEALAND IN A GLOBAL CONTEXT. Risk Management and Sustainable Forestry, 8 September 2001, Bordeaux, France.

SNOW

Winter snowfall is common above 1000m in the Southern Alps and the North Island ranges. Heavy snowfalls below 1000m altitude are less common and mostly affect rural areas of Canterbury, Otago and Southland and high-altitude roads in both the North and South Islands. Snow occurs only occasionally at sea level in the south and east of the South Island and in the hill country of the Wairarapa and Hawke's Bay. It rarely falls to sea level in the west and north of the South Island or the North Island.

Snowstorms in New Zealand may bring snow to low levels but they are not accompanied by sustained periods of intense cold as in some Northern Hemisphere countries. They can, however, cause significant disruption simply because they are unusual and not normally planned or designed for. Damaging snowfalls are usually confined to parts of one or two regions at a time. They can vary significantly over relatively short distances – snowstorms can severely affect one part of a region and produce little or no effect in other parts.



Average annual number of days on which snow falls.
National Institute of Water and Atmospheric Research.



JUNE 2006 CANTERBURY SNOWSTORM

The 12 June 2006 snowstorm was generated by a depression that deepened as it moved southeast over the South Island from the Tasman Sea. The precipitation associated with the depression fell as heavy, 'wet' snow as the warm air mass was undercut by a very cold southwesterly airstream.

Up to 30cm of snow fell at sea level between Temuka and Rakaia, increasing to 80cm in the foothills. North of the Rakaia River 20–30cm fell at Lincoln, 10–15cm in Amberley and around 5cm at sea level in Christchurch. Inland South Canterbury, around Fairlie, had snow depths greater than 70cm, and 40–50cm fell in the Mackenzie Basin. Snow depths were the highest in 60 years over large parts of the Canterbury Plains and foothills. Ashburton experienced its greatest snow depth on record – 38cm.

Many kilometres of power lines collapsed under the weight of snow, snapping or bending power poles. This caused widespread loss of electricity in South Canterbury for up to 4 weeks in isolated areas and loss of telecommunications for up to 11 days. Trees and fences collapsed, as did some buildings including a piggery near Methven and three large buildings in Timaru and Temuka.

Farmers were forced to use winter stock feed much earlier than usual, which had a medium-term economic impact on farmers. The Ministry of Agriculture and Forestry appointed rural coordinators to facilitate ongoing support to rural communities.



Pleasant Point near Timaru after the June 2006 snowstorm. Roads took many days to clear in some areas. *Jeff Tollan.*

Snowstorms

Cold southerlies

Snow is usually produced by slow-moving, deep depressions within cold southerly airstreams travelling north from the Antarctic. These systems often deposit snow on the mountains of the South Island and southern central North Island. They occasionally bring snow to sea level in the south and east of the South Island and the hill country of the southeastern North Island. Snow generated by southerly airstreams often covers a large area but is relatively light, 'dry' snow. Cold air does not hold much moisture and so large accumulations are unlikely.

In an extreme event, a series of cold southerly outbreaks between June and August 1939 covered much of the country, even as far as Northland, in snow. Estimates place it as a 100-year return period event at that time, but with climate change such snowfall would now be considered even rarer.

Warm advection snow

The most damaging snowstorms in New Zealand are formed when warm, moist airstreams travelling down from the north are pushed up over colder, denser airstreams from the south. This process is known as warm advection. As the moist air is forced up, the water vapour it contains cools directly into ice crystals which fall as snow.

Snow generated through warm advection usually falls over a relatively small area because the warm airstreams involved are often only tens of kilometres wide. They are more damaging though, because warm air can hold three times as much moisture as cold air, and the snow produced in this manner is wetter, heavier, and thicker than snow from cold southerly airstreams.

Warm advection has been responsible for heavy snowfalls in the South Island in 1945, 1996, and 2006.

Snowstorm impacts

Heavy snowstorms commonly disrupt electricity and telecommunications as lines collapse under the weight of snow. The combination of electricity outages and cold temperatures can create welfare issues for vulnerable members of communities such as the sick and elderly. Road, rail, and air transport may be disrupted, but snow is usually cleared from main roads within a few days. Occasionally, buildings are damaged or collapse from the weight of snow. The density of snow in New Zealand can be as high as 500kg/m^3 , with the potential to cause significant damage to forestry plantations and in particular radiata pine.

Snowstorms, particularly in early spring during lambing, can result in stock losses through cold, lack of access to water supplies, and lack of feed in the short and long term. During the 1992 Canterbury snowstorm stock losses were particularly high, with estimates of a million lambs lost and a half-million ewe deaths. Estimates of financial cost to the Canterbury region have been as high as \$100m.



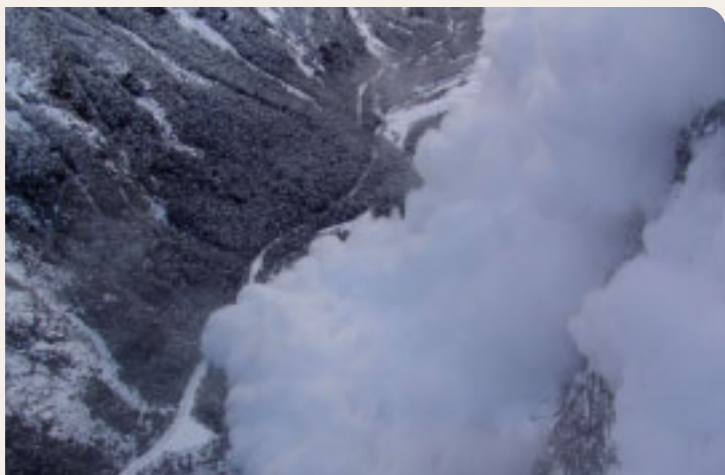
Snow on the hills at Clevedon near Auckland in 1939. Snow fell the length of the country during this snowstorm, and caused serious disruption in the southern South Island. *New Zealand Herald*.

THE MILFORD ROAD

The Milford Road in Fiordland, linking Te Anau with Milford Sound, is a unique avalanche hazard area in New Zealand. The road is one of the highest alpine roads in the country. It is surrounded by very steep terrain and high snow basins, and a 29km stretch of it can be affected by avalanches from June to November.

The road was constructed in the 1930s and 1940s, and during this time avalanches killed several construction workers and damaged the road, bridges and the east Homer Tunnel portal. When it was completed in 1952 the road was only open during summer to avoid the avalanche hazard. It opened all year round in the 1970s following increased pressure from the tourism industry. The death of a road maintenance supervisor in a large avalanche in the early 1980s, however, prompted the formation of an avalanche monitoring and control programme.

The Milford Road avalanche monitoring programme aims to minimise road closures and maximise avalanche safety. An avalanche control team, funded by Transit New Zealand, monitors the avalanche hazard using data on snow pack and local weather conditions, and site specific forecasts from the MetService. The avalanche risk is managed passively, by not allowing traffic to stop within avalanche areas or by closing the road completely, or actively, by using explosives to trigger avalanches when the road is closed.



A controlled avalanche on the Milford Road, triggered by explosives while the road is closed. There have been no avalanche deaths on the Milford Road since the avalanche monitoring and control programme was instigated in the early 1980s. *Wayne Carran, Works Infrastructure.*

Snow avalanches

Snow avalanches are triggered by increased loading on a weak layer or sliding surface within the snow. The increased loading can be caused by gravity, new snow or rain, or human activity such as backcountry skiing, snowboarding or active control with explosives.

New Zealand has a large amount of avalanche-prone terrain. The winter snowline ranges from 1000m in Fiordland to 2000m in the North Island. Snow covers steep slopes on approximately 35 per cent of the South Island and five per cent of the North Island during the winter.

New Zealand's alpine areas are sparsely populated, and many are within national parks or reserves, so the risk to infrastructure, residential buildings, and people is relatively low compared to more densely populated alpine areas overseas. However, many people are exposed to avalanche risk each year in New Zealand through recreational activities, especially skiing, snowboarding, and mountaineering. These risks are managed by education programmes and by the owners of ski field facilities.

There were 140 reported avalanche deaths between 1863 and 2005, including 40 gold miners who died in a Central Otago avalanche in 1863. Deaths in the late 1800s and early 1900s were rare and mostly work-related. However, recreational deaths have increased since 1940, as alpine recreation has become more popular. Ninety-five percent of avalanche deaths have occurred in the South Island, a reflection of the terrain and snow cover.

Over the last decade at least 250 people have been caught in avalanches and 16 have died as a result. Most of these people were mountaineering, skiing, snowboarding, or on avalanche training courses at the time. Most avalanche deaths occur in July, August, and September, when avalanches are most common, and in December and January, when many mountaineering trips are undertaken.



Christchurch during the August 1992 Canterbury snowstorm.

DROUGHTS

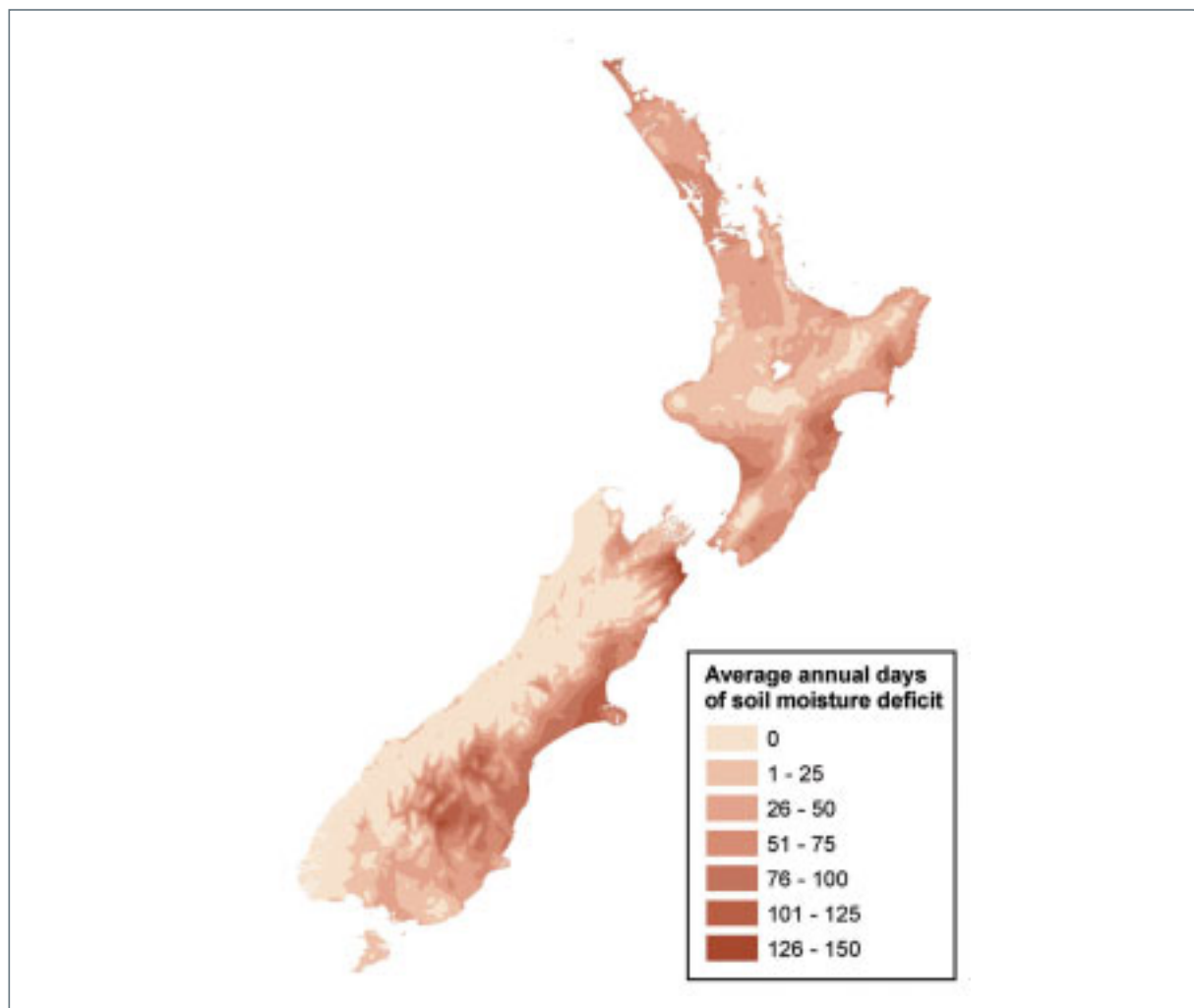
Drought, from a hazard management perspective, is a prolonged period when rainfall is lower than normal for a specific locality. As a result soil moisture levels are much lower for longer than communities normally experience, sometimes being insufficient for plant growth, and restrictions are often placed on water supply for domestic use, stock, and irrigation.

Drought is a natural phenomenon. It becomes a hazard when the effects of a continuing dry period become greater than people who live and work in the area are used to managing. For example, the management of high stock numbers is adjusted in response to expected dry periods, but at some stage when the dry period becomes a drought, the farmer starts to incur high losses from lower-yielding crops or from having to sell stock early or pay more for feed.

Droughts are one of New Zealand's most common and costly hazards, because they can affect a very large area and the effects linger for several years afterwards.



Average annual number of days of soil moisture deficit. Days of soil moisture deficit measures the number of days that plant growth is restricted by insufficient moisture in the soil. *National Institute of Water and Atmospheric Research.*



Drought conditions

Dry periods in New Zealand usually last for 3–4 months and are most common from December to March. As a dry period continues it becomes a drought at some point that is not easily defined, and may run over more than one summer or one year. Droughts therefore develop over time.

Although the start of a drought is not easy to identify, its end may be clear, if it is broken by heavy rain or a period of sustained rainfall. Even once broken by rain, the effects on production, and therefore on communities, continues for several years as farmers need to restock and recover financially.

The occurrence of drought in New Zealand, like that of heavy rain, is related to topography. Although any part of the country can be affected by drought, the most susceptible areas are those in the lee of the main ranges subject to dry winds – Hawke’s Bay, Wairarapa, Marlborough, Canterbury and Central Otago. Particularly drought-prone areas are also likely to have soils with low moisture-storage potential and to have little or no irrigation available. Severe droughts have occurred in these areas at least once every decade. There is a point, however, where a series of droughts becomes ‘normal’ for a location and therefore ceases to be described as unusual. Again, this point is not easily defined.

The severity of a drought is often described using potential evapotranspiration deficit (PED), a measure of the gap between the water demand of plants and what water is actually available. PED is measured in millimetres and can be thought of as the amount of water that would need to be added, by rainfall or irrigation, to keep pasture growing at an optimum rate. Typical New Zealand pasture requires around 5–6mm of water per day in summer so, for example, a PED of around 35mm represents one week’s reduced growth.

Marlborough recorded a PED of 835mm during the severe 1997/98 drought, representing more than 6 months of low or no plant growth.

The occurrence of droughts is influenced by El Niño cycles and the Interdecadal Pacific Oscillation. Droughts in eastern areas are more common during El Niño periods when northwesterly winds followed by southwesterly winds predominate. Climate change is likely to accentuate existing rainfall patterns. East coast regions from Hawke’s Bay to Otago are likely to become drier with an increasing frequency of droughts.

1997/98 EL NIÑO DROUGHT

The 1997/98 drought, associated with a strong El Niño event, severely affected eastern regions from Hawke’s Bay to Central Otago. The drought was predicted soon after the rapid development of the El Niño event between March and July 1997.

The El Niño resulted in more frequent or stronger southwesterlies and westerlies in the following spring and summer. In general, western areas were wetter than usual and eastern areas were drier. In some areas, however, there were significant departures from typical El Niño patterns. The very high summer temperatures recorded in many regions were unusual for an El Niño and may have contributed to drought conditions in places.

Marlborough was the worst-hit region. The potential evapotranspiration deficit measured there during the drought was 835mm, representing more than 6 months of low or no growth and estimated to have a 60-year return period. The Wairau, Awatere, and several smaller rivers experienced low flows, and groundwater levels were so low that water had to be trucked in from elsewhere.

North Canterbury, parts of the Wairarapa and Hawke’s Bay also experienced reduced pasture growth. High rainfall in the Southern Alps, however, kept flows in Canterbury’s alpine-fed rivers high.

Economic losses were estimated at \$750 million (2006 value), or 0.9 per cent of GDP, and stress and hardship took a large toll on New Zealand’s farming community. However, changes in farming practices over the previous decade, resulting in generally lower stocking rates, had reduced the farming community’s vulnerability to drought and feed shortages. Also, the fact that the drought was anticipated some months in advance led to early action by many farmers, such as selling stock and moving animals to other regions, which reduced farmers’ exposure.

The 1997/98 El Niño also contributed to droughts and wildfires in Australia and South-East Asia, and shifted tropical cyclones in the South Pacific eastwards towards the Cook Islands and French Polynesia.



A dry stock pond near Gisborne during the 1997/98 El Niño drought.
PhotoNewZealand.

Drought impacts

Droughts often affect the rural sector, through crop failure and lack of stock feed, with predominantly regional economic impacts. Farmers may need to sell stock or temporarily move them to other non-affected regions. The economic impact generally has a lag effect whereby it is not felt in the year of the drought, when farmers may be cash-rich from stock sales, but rather the following years as farmers restock at higher prices due to shortages in a sellers' market. Animals that have been carried through a drought may be out of condition and have a lower reproductive performance in the following year. National economic impacts tend to be lower than the local impacts because stock are often moved to other locations within New Zealand or are processed earlier than they would have been under normal conditions.

Droughts can have significant psychological and social impacts on farming communities. Difficult farm management decisions are made in pressured situations as droughts develop and the financial effects continue well beyond the end of the drought.

Droughts also cause water shortages or restrictions, and irrigation supplies can be affected, although this is not always the case. In most of Canterbury, for example, northwesterly winds that dry out the plains also provide more water for the alpine-fed rivers. Private domestic water supplies along with large urban water supplies can run low. Hydroelectric generation capacity, accounting for around two-thirds of New Zealand's electricity generation, can be affected.

Wildfire risk increases during dry periods and droughts. This is particularly so when a sudden dry period follows a period of good rainfall, as the vegetation that has grown well dries and becomes easily combustible. Dry periods in eastern areas of the country are often accompanied by warm, and potentially strong, northwesterly winds that can help fires spread quickly. The wildfire hazard can eventually decrease during prolonged droughts as the amount of vegetation available to fuel fires declines, but then there is often less water readily available to fight a fire if one does occur.

1991/92 HYDROELECTRIC DROUGHT AND THE 1993/94 AUCKLAND WATER SUPPLY DROUGHT

The 1991/92 hydroelectric drought led to electricity shortages through the winter of 1992. Persistent, cool southwesterly weather brought low rainfall to the central Southern Alps and low flows into the hydroelectric storage lakes from November 1991 to May 1992. The situation was likely worsened by cooler temperatures, caused by ash in the atmosphere from the Pinatubo eruption in the Philippines, which lowered the snow level in the Southern Alps during the 1992 winter, locking up water. The then Electricity Corporation of New Zealand had to rely heavily on thermal and geothermal generation, and households and businesses conserved energy where possible. Estimates place the direct impact on the economy at more than \$600 million. Indirect impacts included a loss of overseas investor confidence.

Following the hydroelectric drought, low rainfall in Auckland during 1993 and 1994 led to low water levels in the region's 10 storage reservoirs in the Waitakere and Hunua ranges. Water use was restricted in the last few months of the drought before it broke in July 1994. A drought plan was prepared during the drought and an emergency proposal to pipe water from the Waikato River to Auckland was put to Parliament. A pipeline supplying water from the Waikato River was eventually completed in 2002 and now provides additional capacity should the region experience another water supply drought.

These two droughts highlighted New Zealand's dependence on regular rainfall and led to the first in-depth studies of the relationship between the El Niño Southern Oscillation and low rainfall and river flows in New Zealand. The 1991/92 hydroelectric drought helped prompt the formation of the Electricity Commission, whose functions include ensuring security of electricity supply during dry years.



Upper Huia Dam in the Waitakere Range during the 1993/94 Auckland water supply drought. *Watercare Services.*

Managing droughts

Risk reduction and readiness

Farming in drought-prone areas carries with it more risk of variable returns and higher costs from having to maintain feed buffers, use irrigation, or plan for variable crop yields. Due to the nature of drought (having a slow onset), considerable time is available to manage this hazard and communities are expected to mitigate its effects where possible. Reducing risks from drought focuses on good farm management and irrigation where it is available. Strategies for coping with drought where irrigation is not available include using drought-resistant pasture species, preventing over-grazing, having more flexible stocking strategies, early lambing, building small farm dams and buying in feed where necessary.

Droughts are not easily predicted. NIWA produces monthly climate outlooks for the following 3 months based on rainfall, river flow and soil moisture data, and likely climate patterns (such as the El Niño Southern Oscillation). These outlooks assist farmers and water users to make early decisions and prepare for the possibility of a drought. Some regional councils, for example the Greater Wellington Regional Council, have developed regional drought-prediction models based on the El Niño Southern Oscillation that may assist in drought management planning.

Local authorities monitor water levels, which assists in identifying at-risk water resources and allocation limits for sustainable water management.

Response and recovery

Effective response to droughts is different from many other hazards because droughts develop over a longer time, and response and recovery issues can be addressed as the situation evolves. Rural communities have time to make business decisions to ensure, for example, animal welfare needs are met. Severe droughts may eventually involve coordinated efforts by many organisations and the affected communities.

The Ministry of Agriculture and Forestry (MAF) may assist drought-affected rural communities with livestock disposal, rural recovery coordination, labour, and deployment of Defence Force personnel to assist in water

supply or supplementary feeding. MAF's On-Farm Readiness and Recovery Plan for Adverse Climatic Events and Natural Disasters sets out who is responsible for responding to adverse events in rural areas and outlines available assistance. Early farm management decisions are required during droughts, particularly around the timing of stock sales.

Emergency water can be brought into drought-affected areas but this is costly, especially if the drought is across a wide area. Water is more likely to be rationed by local authorities.

Any CDEM response to droughts follows generic response and recovery procedures set out in CDEM Group plans, the National CDEM Plan and the Guide to the National CDEM Plan.

FURTHER INFORMATION

GENERAL DROUGHT INFORMATION

NATIONAL INSTITUTE OF WATER AND ATMOSPHERIC RESEARCH

www.niwascience.co.nz/edu/students/faq/drought

MOSLEY, M P AND PEARSON, C P (EDS), 1997, FLOODS AND DROUGHTS. New Zealand Hydrological Society, Christchurch.

EL NIÑO AND ITS INFLUENCE ON NEW ZEALAND'S CLIMATE

NATIONAL INSTITUTE OF WATER AND ATMOSPHERIC RESEARCH

www.niwascience.co.nz/rc/atmos/clivar/el_nino

1997/98 DROUGHT

MINISTRY OF RESEARCH, SCIENCE AND TECHNOLOGY

web.archive.org/web/20000830105821/

http://www.morst.govt.nz/pubs/el_nino/index.htm#21



Canterbury drought, 1987/88. There is, on average, one significant drought every six years in Canterbury. The consequences of severe drought are generally widespread with significant economic impacts beyond the directly affected areas.
The Christchurch Press.