8. Cyclone

8.1 Hazard Characteristics

Tropical cyclones are severe low pressure systems that form in the tropics. These revolving storms gain their energy from heat that is released when water vapour evaporated from the warm ocean surface condenses into rain, releasing latent heat. The main hazard characteristics of tropical cyclones are damaging winds, high seas and heavy rainfall. Storms of this type are often called hurricanes in the North Atlantic and eastern Pacific and typhoons in South East Asia and China. They are typically called tropical cyclones in the southwest Pacific and Indian Ocean region.

As tropical cyclones migrate into New Zealand waters they tend to weaken or decay when moving over cooler seas and land. Some tropical storm systems can re-intensify in the extratropics to become potent mid-latitude storms ("ex-tropical cyclones") capable of inflicting loss of life and severe property damage. The worst cyclones tend to occur from December to April with at least one ex-tropical cyclone passing within 500 km of New Zealand in most years. The severity of these storms (and associated damaging winds, high seas and heavy rain) depends on their location and phase of the El Niño/La Niña cycle.

There are several favourable environmental conditions that must be in place before a tropical cyclone can form. These are:

- Warm ocean waters (at least 27°C) throughout a depth of about 50 m.
- An atmosphere which cools fast enough with height such that it is potentially unstable to moist convection.
- Relatively moist air near the mid-level of the troposphere (4,900 m).
- A minimum distance of at least 480 km from the equator.
- A pre-existing near-surface disturbance, such as a cyclonic circulation.
- Low values (less than about 37 kph) of vertical wind shear between the surface and the upper troposphere. Vertical wind shear is the change in wind speed with height.

As sea surface temperatures need to be at least 27°C for tropical cyclones form, it is natural that they form over the tropical oceans. In only the rarest occasions these storms form within 5° latitude of the equator. This is because the rotation necessary for cyclone formation comes from the Coriolis force, a consequence of the earth's rotation. The vertically-pointing component of the Coriolis force is zero along the Equator and becomes strong enough to affect storm formation only outside of ~5° latitude.

8.2 Location, Frequency and Magnitude

8.2.1 Tropical Cyclone Classification

In the Southwest Pacific, tropical thunderstorms with a defined circulation, and maximum sustained winds of 61 kph or less are called "tropical depressions". Once the system reaches winds of at least 63 kph they are called a "tropical storm" and assigned a name. The severity of a tropical cyclone is described in terms of categories ranging from 1 to 5 in relation to the zone of maximum winds (see Table 8.1). An estimate of cyclone severity is included in all tropical storm warnings. Using this severity scale, communities are able to assess the degree of cyclone threat and take appropriate action. The category does not refer to the amount of flooding or storm tides. If a storm tide is expected it will be mentioned separately in the cyclone warning.

Table 8.1 Tropical Cyclones Classification in the Southwest Pacific.

Category	Strongest gust (km/h)	Typical effects
1 = Tropical Cyclone	Less than 125 km/h Gales	Minimal house damage. Damage to some crops, trees and caravans. Boats may drag moorings.
2 = Tropical Cyclone	125 - 164 km/h Destructive winds	Minor house damage. Significant damage to signs, trees and caravans. Heavy damage to some crops. Risk of power failure. Small boats may break moorings.
3 = Severe Tropical Cyclone	165 - 224 km/h Very destructive winds	Some roof and structural damage. Some caravans destroyed. Power failure likely.
4 = Severe Tropical Cyclone	225 - 279 km/h Very destructive winds	Significant roofing and structural damage. Many caravans destroyed and blown away. Dangerous airborne debris. Widespread power failures.
5 = Severe Tropical Cyclone	More than 280 km/h Extremely destructive winds	Extremely dangerous with widespread destruction.

As tropical cyclones move from the equatorial region (where they form in the Southwest Pacific between 5°S and 20°S) towards higher latitudes they transform into ex-tropical cyclones, losing the warm core typical of tropical storms and taking on the cold-core characteristics of mid-latitude storms. Such ex-tropical cyclones can affect northern New Zealand in particular.

8.2.2 Frequency and Magnitude

On average, about ten or eleven tropical cyclones form in the Southwest Pacific per year, although in any one season the frequency can range between approximately 2 and 16. During La Niña events, atmospheric and oceanic conditions are more favourable for tropical cyclone formation in the Coral Sea instead of further east, so the likely track may come closer to northern New Zealand. While the track of tropical cyclones in the tropics is affected by the El Niño-Southern Oscillation (ENSO) cycle, the chance of ex-tropical cyclone activity near northern New Zealand does not change significantly with the ENSO cycle. The average risk over a cyclone season for northern New Zealand is approximately 80 percent, i.e. one storm comes within ~500km of the New Zealand coast in 4 years out of 5, on average.

Some of Auckland's highest wind gusts have occurred with ex-tropical cyclones. As these, move poleward, they encounter colder seas, and couple with a vigorous upper level trough to form a cold-cored, broader scale mid-latitude depression (Sinclair, 2002 [1]). Wind storms such as those resulting from cyclones Bola (March 1988) and Giselle (April 1968, the "Wahine storm") are examples of tropical cyclones that transformed into intense mid-latitude systems, causing damage from extreme winds. The former produced gust speeds of 107 kmh^{-1} in Auckland (Sinclair et al. 2005 [2]).

In the last 15 years, the worst storms affecting the Auckland region have been: Cyclone Fergus in December 1996, which brought heavy rain also to Northland and Auckland (44mm of rain recorded at Auckland, Owairaka on 31/12/1996); and Cyclone Drena in January 1997 (Figure 8.1), causing more wind damage than Fergus but bringing less rain. One man was electrocuted by a fallen power line. The early warning of Cyclone Fergus during the Christmas holiday season allowed people to evacuate from beachside campsites, preventing loss of life (Figure 8.2).

Figure 8.1 Trajectories of ex-tropical cyclones during summer 1996-1997 (left), tropical cyclone Drena in January 1997 (centre) and tropical cyclone Fergus in December 1996 (right). *Source: Bureau of Meteorology of Australia, 2008* [3].

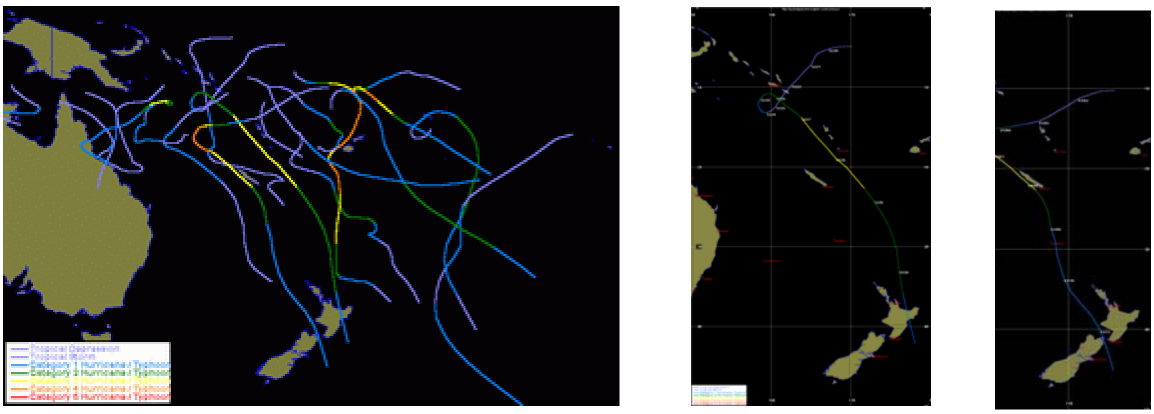
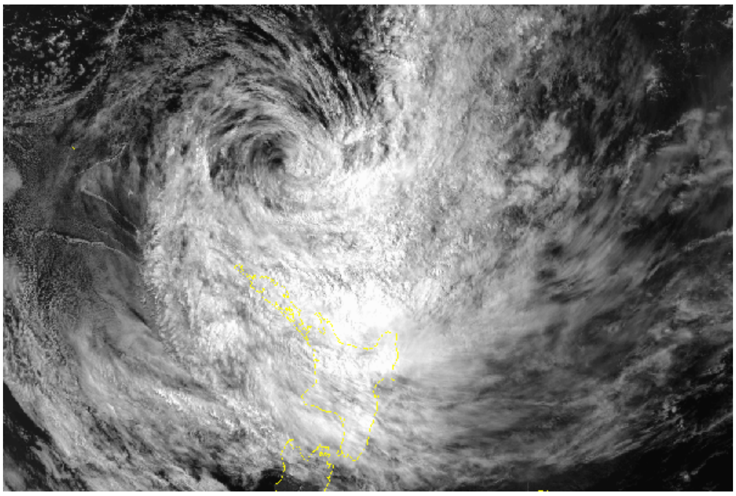


Figure 8.2 Satellite image shows the position of the cyclone Fergus centred just north-east of the North Island, 31 December 1996. Source: NOAA/NGDC, 1996 [4].



8.3 Key Vulnerabilities and Potential Impacts

Tropical cyclones normally have three major meteorological hazards; heavy rainfall, high winds, and storm surge. Ex-tropical cyclones are often the cause of Auckland's most extreme weather leading to extensive flooding and wind damage, and this damage (and the naming of the storms) leads to them being well-remembered by the public (e.g. Cyclone Fergus). Ex-tropical cyclones pose a hazard in that they bring both intense rainfall and wind, which can cause major damage. Far from being confined to wind damage and flooding, there is also the potential for storm surges and waves to exacerbate the damage potential in coastal areas.

Ex-tropical cyclones can generally be forecast quite reliably, usually allowing for a number of days warning before they reach northern New Zealand. Amelioration measures for these cyclones are the same as for intense rainfall and floods, coastal flooding, and severe winds. Damage to property and infrastructure will vary depending upon factors such as:

- Distance from the zone of maximum winds;
- Exposure of the location;
- Building standards;
- Vegetation type; and
- Resultant flooding.

General impacts on property and people include those resulting from high winds and flooding, such as uprooted trees damaging buildings and utility infrastructure, injuries from airborne debris, boats blown onto shorelines, disruption to civil aviation, slips blocking roads and threatening houses, residential flooding on low lying coastal areas and flood plains and coastal inundation and erosion.

Wind is often one of the first weather impacts from cyclones. While the wind speed alone can cause considerable damage, it is the debris in the wind that results in the most destruction. Flying objects cut power lines, break windows and break branches that themselves become flying missiles. Tropical storm-force winds are strong enough to be dangerous to those caught in them. For this reason, emergency managers plan on having their evacuations complete and their personnel sheltered before the onset of tropical storm-force winds.

'Hurricane-force' winds can easily destroy poorly constructed buildings and mobile homes. Debris such as signs, roofing material, and small items left outside become flying missiles in hurricanes. Extensive damage to trees, towers, water and underground utility lines (from uprooted trees), and fallen poles cause considerable disruption. High-rise buildings are also vulnerable to hurricane-force winds, particularly at the higher levels since wind speed tends to increase with height. It is not uncommon for high-rise buildings to suffer a great deal of damage due to windows being blown out. Consequently, the areas around these buildings can be very dangerous.

Flooding can be a major threat to communities located on floodplains and low lying coastal land. Intense rainfall is not directly related to the wind speed of cyclones. In fact, some of the greatest rainfall amounts occur from weaker storms that move slowly or stall over an area. Coastal flooding can be cause by storm surge. Battering of waves and floating debris results in weakening or destruction of structures both in the coastal marine area and on land.

8.3.1 Auckland Region Cyclone Scenario

The 'one in a hundred year' cyclone to affect Auckland was hypothesized in a study by Salinger et al. (1997) [5]. This hypothetical ex-tropical cyclone event with 1% annual exceedance probability named cyclone 'Grief' had a similar strength to cyclone Bola (March 1988) but passed directly through the Auckland region with a southward direction of travel. The cyclone event had a duration of four days.

Wind and rainfall varied throughout the Auckland Region. The wind speeds predicted for cyclone Grief are listed in Table 8.2. The sustained wind speed was estimated at 67% of the gust speed predicted by Salinger et al. (1997). Table 8.3 shows rainfall predicted for the cyclone event while Table 8.4 shows flood flow estimates for Auckland City based on 100 year return period rainfall data.

Table 8.2 Cyclone 'Grief' wind speeds.

Direction	Gust wind speed (km/hour)		Sustained wind Speed (> 1hour; km/hour)
	Auckland City	Regional Range	
North/ North-East	50	45 to 80	35
East	120	115 to 140	80
South-East	100	80 to 120	65
South-West	140	85 to 170	95
Note: Sustained wind speed taken at 0.67 of gust speed			

Table 8.3 Cyclone 'Grief' rainfall.

Duration	Rainfall (millimetres)	
	Auckland City	Regional Range
20 minutes *	40	--
1 hour	60	~ 50 to 85
2 hours *	80	--
6 hours *	110	--
24 hours	125	~ 80 to 170
4 days	320	230 to 415
* Derived from regional values		

Table 8.4 Flood flow estimates for Auckland City.

Catchment size	Response time (hour)		Peak flood flow (m^3/sector/hectare)	
	Urban	Rural	Urban	Rural
10 hectares	0.2	0.4	0.30	0.20
100 hectares	1.0	2.0	0.16	0.11
1000 hectares	2.0	4.0	0.10	0.07

Note:

- For urban catchments the effective runoff coefficient is 0.8
- For rural catchments the effective runoff coefficient is 0.6
- Assume clay type soils

Storm surge scenarios for the Auckland region have been investigated de Lange (1997) [6] showing that during a tropical cyclone, the combination of low atmospheric pressure and wind stress on the ocean surface will produce a storm surge. During the two days the cyclone is closest to Auckland, the regional atmospheric pressure at sea level was 970 hPa. The inverse barometer effect associated with this low pressure would be 0.44m. The resulting storm surge from the wind was 0.90m on the east coast. This surge, in combination with the tide and seasonal sea level variations and wave set-up effects in exposed locations, was estimated to produce a maximum still water level of 4.8m above Chart Datum (i.e. 3.0m above Mean Sea Level).

Overall, the impact on Auckland was expected to be limited, with most consequences occurring over the storm duration. Potential damage would likely include:

- Airport flights being excessively delayed due to high winds;
- Auckland harbour bridge being inoperable due to high winds;
- The Ports of Auckland not being operational due to high winds and waves and spray wash over the terminal;
- Sewage treatment plants may have their treatment processes affected by an influx of saline water;
- Sections of the northwestern and northern motorways being inundated or subject to wave overtopping due to storm surge and wave action. Tamaki drive would experience heavy spray and occasional wave overtopping. Alternative inland road routes would need to be used;
- Any critical service in a low lying area near a catchment outlet would be potentially flooded;

Personnel involved in emergency services could be affected by:

- Their residential property being subject to wind damage and/or flooding;
- Taking alternative road routes to their place of work, and at time being unable to drive because of high winds and intense rainfall

Since tropical cyclones are not well resolved by global or regional climate models, there remains considerable uncertainty about future projections of cyclone frequency, magnitude and impacts affecting the Auckland region. Despite this, tropical cyclone impacts on the region will be similar to those from sea level rise and coastal flooding, and high intensity rainfalls that produce flooding.

8.4 References and Additional Reading

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9. Drought

9.1 Hazard Characteristics

Drought is a normal, recurrent feature of climate[1]. It occurs almost everywhere though its features vary from region to region. Defining drought is difficult as it depends on need, physical differences in regions, and varying disciplinary perspectives. In the most general sense, drought originates from a deficiency of precipitation over an extended period of time, usually a season or more[2], resulting in a water shortage for some activity, group, or environmental sector.

In contrast to natural hazards, such as floods and earthquakes, the onset of a drought can be slow and unspectacular[3]. Nevertheless, its effects can be severe as has been seen over the last decade on urban water supply, energy generation and the pastoral industry (Henderson, 2003 [1]). Droughts tend to break when there is substantial rainfall to recharge the moisture levels in the rivers, lakes and soils. Recent droughts and their impacts across New Zealand include:

- winter 1992 in the hydro-electric catchments: reduced GDP by $1,000 million.
- 1993–94 in Auckland water supplies: prompted construction of the Waikato pipeline (2001) at a cost of $171 million.
- 1997–98 on North Island and South Island east coasts: reduced GDP by $618 million.
- 1998–99 in North and Central Otago: reduced GDP by $539 million.
- 2001 in South Island hydro-electric catchments: Natural Gas Corporation lost $302 million.
- Widespread drought over the past two years in many parts of the country, estimated to have cost farmers in excess of $1 billion.

Drought should not be viewed as merely a physical phenomenon or natural event. Its impacts on society result from the interplay between a natural event (less precipitation than expected resulting from natural climatic variability) and the demand people place on water supply (Mosely and Pearson, 1997 [2]). Human beings often exacerbate the impact of drought. Recent droughts in both developing and developed countries and

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1 Many people erroneously consider it a rare and random event.

2 Drought is a temporary aberration; it differs from aridity, which is restricted to low rainfall regions and is a permanent feature of climate.

3 Droughts tend to be prolonged events in comparison to other extreme events which may cause a similar magnitude of havoc yet be over within a few hours or days.

the resulting economic and environmental impacts and personal hardships have underscored the vulnerability of all societies to this "natural" hazard.

According to Wilhite and Glantz (1985) [3], there are two principal ways of defining drought: conceptual and operational. Conceptual definitions, formulated in general terms, help people understand the concept of drought. For example, drought may be defined as a prolonged period of deficient precipitation resulting in extensive damage to crops and loss of yield or a drought is a sustained period of low rainfall so that soil moisture is insufficient for plant growth. These definitions may be important in establishing drought policy. In contrast, operational definitions help people identify the beginning, end, and degree of severity of a drought. To determine the beginning of drought, operational definitions often specify the degree of departure from the average of precipitation or some other climatic variable over some time period. This is usually done by comparing the current situation to the historical average, often based on a 30 year period of record. The threshold identified as the beginning of a drought (e.g., 75% of average precipitation over a specified time period) is usually established somewhat arbitrarily rather than on the basis of its precise relationship to specific impacts.

There are many ways of measuring or defining 'operational' droughts:

Agricultural drought is a period when the soil is estimated to be in 'moisture deficit'. It is often based on modelled estimates of soil moisture balance, where drought is said to occur when there is insufficient soil moisture to sustain plant growth. Crops become stressed as the readily available water capacity of the pasture root-zone becomes depleted and incipient wilting occurs. The drought ends when rainfall finally restores the soil moisture levels.

In contrast, a hydrological drought is when the effects of low precipitation affect hydrological systems and is usefully defined as a recurrence value of 'one-in-x-years' for a fixed period such as a season. This usually occurs when rainfall is well below expected levels in any large catchment area for an extended period of time. A hydrological drought can result in a water supply shortage although storage capacity and demand are also important factors.

Climatological or meteorological drought is an 'above the ground' definition of drought, and typically involves a variety of statistical descriptions. For example, hazard conditions might be said to occur when at least the seasonal (3-month) rainfall in the area affected falls below the ten-percentile value, and a severe event falls below the five-percentile value, i.e. an event that occurs on average less than once in twenty years. In New Zealand, meteorological droughts were initially defined in terms of the duration of days without rain (Bondy, 1950[4]) i.e., a period of 15 days with no measurable rain (<0.1 mm /day), and a dry spell was defined as a period of 15 days with no more than 1 mm of rain each day. In practice however the onset of drought is not easy to define.

Drought indices have been designed to evaluate the severity of drought. A drought index value is typically a single number, which can be evaluated more easily than raw observational data for decision making. There are several indices that measure how much precipitation over a given period of time has deviated from historically established norms, and some indices are better suited than others for certain uses. Among others, the most used are:

- Standardized Precipitation Index (SPI) is an index based on the probability of precipitation for any time scale.
- Palmer Drought Severity Index (The Palmer; PDSI) is a soil moisture algorithm calibrated for relatively homogeneous regions.
- Crop Moisture Index (CMI) is a Palmer derivative; the CMI reflects moisture supply in the short term across major crop-producing regions and is not intended to assess long-term droughts.

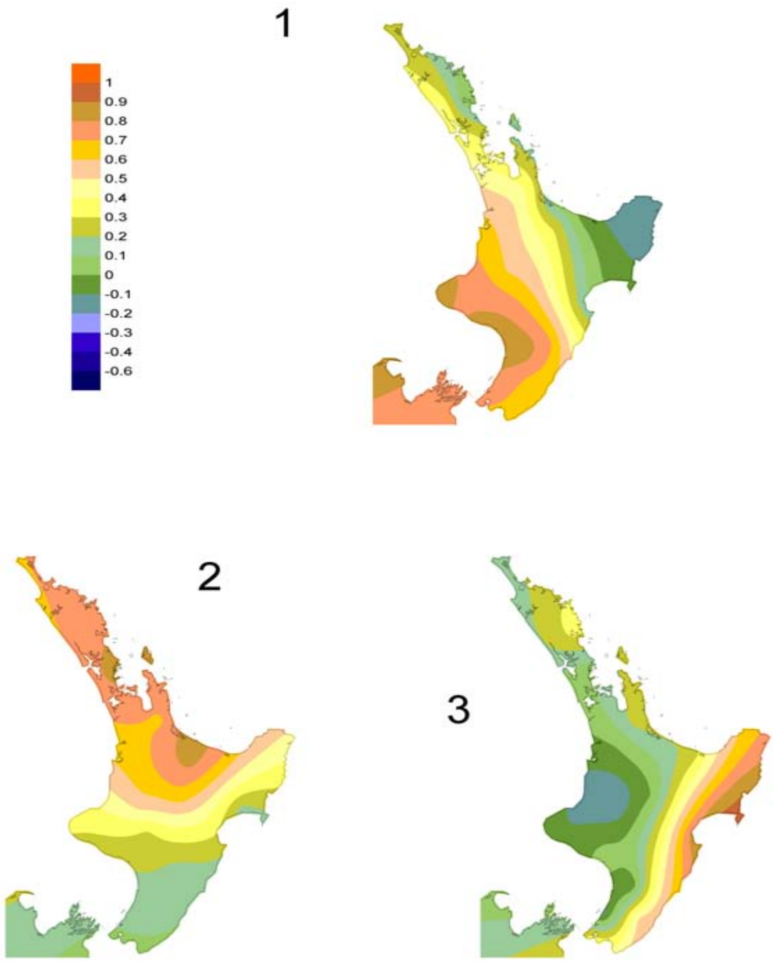
9.1.1 Potential Evapotranspiration Deficit or PED

The 'potential evapotranspiration deficit' (PED) can be used as a measure of drought and is a useful means of ranking the severity of dry periods from a meteorological viewpoint, but based on a water balance application that takes soil moisture deficiency into account. The choice of whether a dry period takes on the more sinister term of 'drought' might then be made on how often a given level of dryness (as defined by PED) might occur or be exceeded. This measure incorporates all three of the above climatic factors. Accumulated PED is the amount of water that would need to be added to a crop over a period, (for example a year), to prevent loss of production due to water shortage. For pastures not receiving irrigation, an increase in accumulated PED of 30 mm corresponds to approximately one additional week of pasture moisture deficit (reduced grass growth). In New Zealand, the accumulated PED is typically calculated over a July to June 'growing year', from daily information stored in NIWA's climate database, although comparisons of drought severity are also made on sub-annual (e.g. spring) or multi-annual time scales.

Droughts are typically produced by persistence in circulation or increased frequency of a weather type interacting with New Zealand's topography. Increased frequencies of anticyclones are a common thread for higher than normal PED; wetter seasons typically occur when more troughs than usual occur. Drought over extensive areas is evidence of seasonal persistence of atmospheric circulation and anticyclonic weather types. The two regionally significant hazards produced by drought and dry periods are agricultural drought and water supply storage.

In the North Island three patterns of drought have been identified and associated with different weather patterns (Figure 9.1). The three North Island patterns respectively account for 29%, 30% and 13% of the total variability in PED over the country. Dry conditions experienced in the Auckland region occur in during south to southwest wind flows (2). Persistent periods of south to southwest flows typically produce drought. Conversely, wet conditions typically occur in the region during northeast flows (1).

Figure 9.1 Drought patterns in the North Island associated with specific atmospheric circulation patterns. *Source: Salinger and Porteous, 2006* [5].



9.2 Location, Frequency and Magnitude

Drought impacts on the Auckland region can be severe. For example, the summer of 1997-1998 was associated with an El Niño climate pattern, and this was also a summer of water shortages for the Auckland region. Drought during this period was related to the timing (i.e., season, delays in the start of the rainy season, occurrence of rains in relation to principal crop growth stages) and the effectiveness of the rains (i.e., rainfall intensity and number of rainfall events). Other climatic factors such as high temperature, high wind, and low relative humidity also influenced the severity of this drought. The impact of this drought illustrated our continuing and perhaps increasing vulnerability to extended periods of water shortage[4].

9.2.1. Water Supply Drought in Auckland

Perhaps the most notable region drought for Auckland was the 1994 - 1995 water supply crisis. The first public warning of a water supply problem came on January 12 1994 with Water-care's advertising campaign to promote water conservation. Intimations of a crisis surfaced on February 26 with the announcement that water restrictions would begin. Regular news releases of falling dam levels began - 43% by March 29, 41% by April 6, 40% by April 8. On April 13 in Auckland a total ban was imposed on the use of water sprinklers. By May 22 Auckland dam levels had fallen to 32.7%. Pictures of dried up lake beds appeared in newspapers and on television. However, the drought ended in September when more than double the normal rainfall occurred. The return period for this event, based on 12 month cumulative rainfall totals, was 1 in 25 years (AELG, 1997[7]).

As a result of this event (and the dry 1997 - 1998 summer), Auckland's water supply was redesigned in 2002 to endure a drought event with a low rainfall recurrence interval of 200 years.

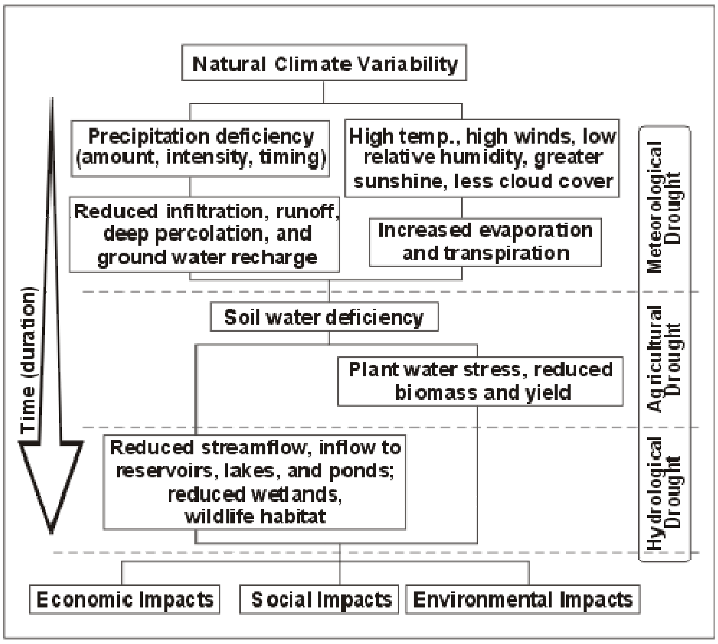
9.3 Key Vulnerabilities and Potential Impacts

Drought, especially prolonged multi-year drought, has tremendous societal and economic impacts. The integrated nature and sequence of drought impact is presented in Figure 9.2. Drought risk is based on a combination of the frequency, severity, and spatial extent of drought (the physical nature of drought) and the degree to which a population or activity is vulnerable to the effects of drought. The degree of a region’s vulnerability depends on the environmental and social characteristics of the region and is measured by the ability to anticipate (prepare), cope with, and recover from drought. Society’s vulnerability to drought is affected by (among other things) population growth and shifts, urbanization, demographic characteristics, technology, water use trends, government policy, social behaviour, and environmental awareness. These factors are continually changing, and society’s vulnerability to drought may rise or fall in response to these changes. For example, increasing and shifting populations put increasing pressure on water and other natural resources—more people need more water. Understanding and reducing these vulnerabilities is essential in preparing for and dealing with drought.

[4] The New Zealand Institute of Economic Research estimated that the associated drought resulted in a loss of $618 million (0.9%) to GDP. This was largely caused by a decline in agricultural production due to less livestock production, lower livestock weights, higher feed costs, and other associated impacts.

One important aspect of reducing vulnerability in the Auckland region is to understand the impacts of drought. Each drought produces a unique set of impacts, depending not only on the drought's severity, duration, and spatial extent but also on changing social conditions. These impacts are often symptoms of other underlying vulnerabilities. In order to understand vulnerability, a good place to start is to investigate varying drought climatologies and drought impacts. Understanding trends in drought occurrence and impacts over time is important for projecting potential future impacts and understanding our changing vulnerabilities. With a good understanding of drought impacts and the probability of recurrence at various levels of severity, the most significant impacts can then be identified for further review by conducting a drought impact assessment. Once the most significant drought impacts have been identified, it is important to understand why the impacts occur so the causes of vulnerability can be addressed. Planning ahead to mitigate drought clearly gives decision makers the chance to relieve the most inconvenience or suffering at the least expense.

Figure 9.2 The integrated nature and sequence of drought impact. Source: National Drought Mitigation Centre, 2008 [6].



The potential impacts from drought are listed in Table 9.1. Drought can significantly impact Auckland's agricultural and horticultural industries, including:

- reduced number of breeding sheep and cattle and resultant economic losses
- financial disruption and lost production to the horticultural industry
- increased risk of losses due to fire.

For water supply, drought events with a recurrence exceeding 200 years will result in water supply restrictions with implications for sanitation and business activities. Finally, regular reporting and monitoring of rainfall and its relationships to ENSO characteristics play an important role in improving drought prediction, and mitigating potential hazards caused by drought, by assisting people and organisations to become better prepared for drought and its consequences.

Table 9.1 Drought Impacts.

Type	Impacts
Environmental	• damage to plant and animal species, wildlife habitat, and air and water quality • forest and range fires, degradation of landscape quality • loss of biodiversity, and soil erosion
Social	• public safety • health, conflicts between water users • inequities in the distribution of impacts and disaster relief
Economic	• economic impacts occur in agriculture and related sectors, • losses in yields in both crop and livestock production • drought is associated with insect infestations, plant disease, and wind erosion • forest and range fires increases substantially • reduced income for farmers and retailers and others who provide goods and services to farmers • prices for food, energy, and other products increase as supplies are reduced

9.4 References and Additional Reading

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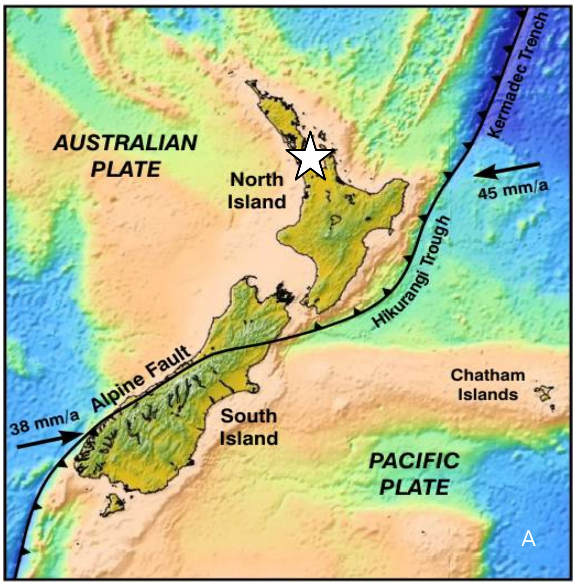
10. Earthquake

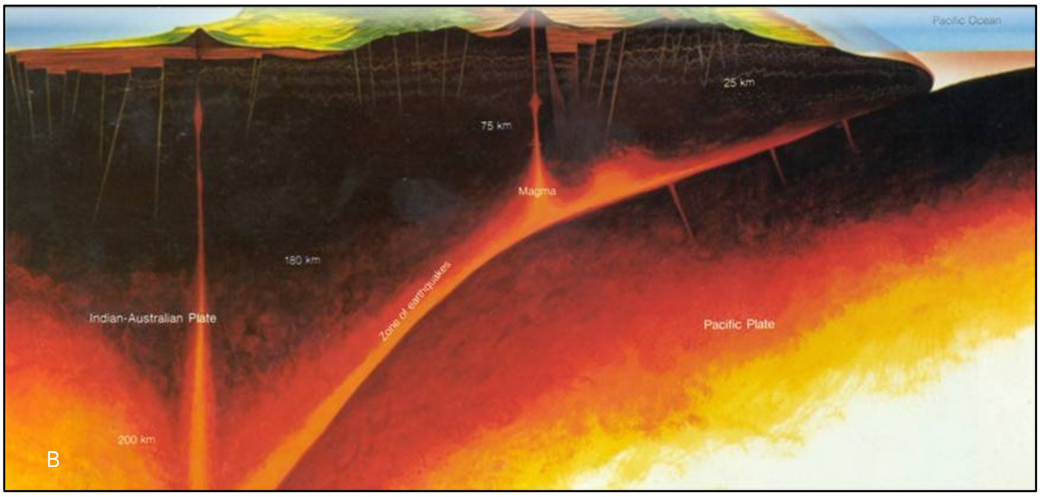
10.1 Hazard Characteristics

Situated across the boundary between the Australian and Pacific tectonic plates, New Zealand is a seismically active country with over 15000 earthquakes detected each year by GeoNet, New Zealand's geological hazard monitoring agency. Of the thousands of earthquakes detected, around 250 each year will be large enough to be felt.

Seismicity is governed by tectonic plate movement. The Pacific Plate is subducting under the Australian Plate below the North Island; the Australian plate is subducting under the Pacific Plate below the south of the South Island; and along the centre of the South Island the plates are converging with the resulting collision currently building the Southern Alps (Figure 10.1a and b).

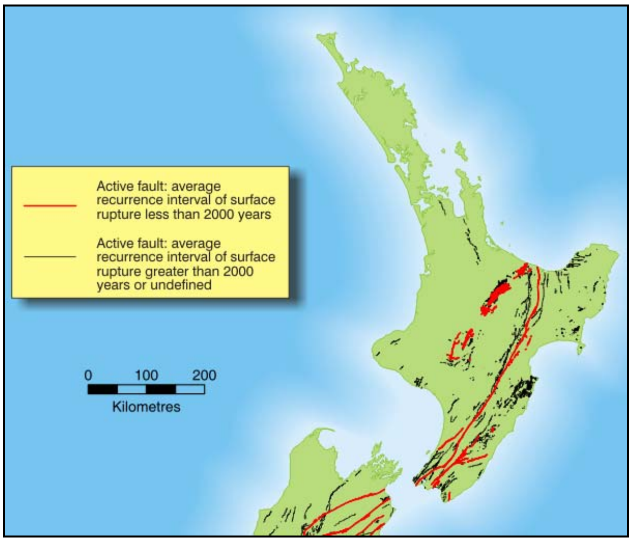
Figure 10.1 A: Motion of the Pacific Plate eastwards (relative to the Australian Plate) creates subduction zones under the North Island and Fiordland where denser oceanic crust of one plate sinks beneath the lighter continental crust of the other plate. The Southern Alps are produced by uplift driven by continental collision. The location of Auckland is indicated by the star. B: Cross section of the North Island subduction zone. The heat and stresses generated by the subduction of the Pacific Plate beneath the Australian Plate creates earthquakes and areas of melting which are manifested at the ground surface as earthquake shaking and volcanoes. *Source: Wallace, 2008* [1].





Movement of the plates creates faulting at the ground surface. These are zones of weakness in the Earth's crust which move and potentially rupture, causing earthquakes. Faults are considered to be active if they have moved in recent geological time. The land area of the Auckland region has two faults that have been classed as active in differing databases or studies. These are the Wairoa North Fault classed as active in Edbrooke (2001) [2] and in the Active Faults database (GNS, 2008[3]) and the Drury Fault which was classed as active in a study by BECA (2005) [4]. However, neither has been active in the last 10,000 years or more and neither has a recurrence interval of less than 2000 years. More information on the location of active faults and the Auckland seismic hazard is in Section 10.2.

Figure 10.2 Active faults in the North Island - only the Wairoa North Fault is visible in the Auckland region (note: this map only shows onshore faults). *Source: GNS Science Active Faults Database, 2008*.



Because of the differing styles of faulting and rates of deformation throughout New Zealand, seismicity varies across the country in terms of depth, magnitude and frequency of earthquakes. Figure 10.3 shows a ten year record of seismicity for shallow (<40 km depth) and deep earthquakes in New Zealand (>40 km depth) for earthquakes over Magnitude 3.0. Earthquakes may also be caused by other processes apart from fault movement (e.g. volcanism).

Figure 10.2 Earthquakes recorded between 1990 and 1999 ≥ Magnitude 3. Note that Auckland region is low activity zone compared to the rest of the North Island.

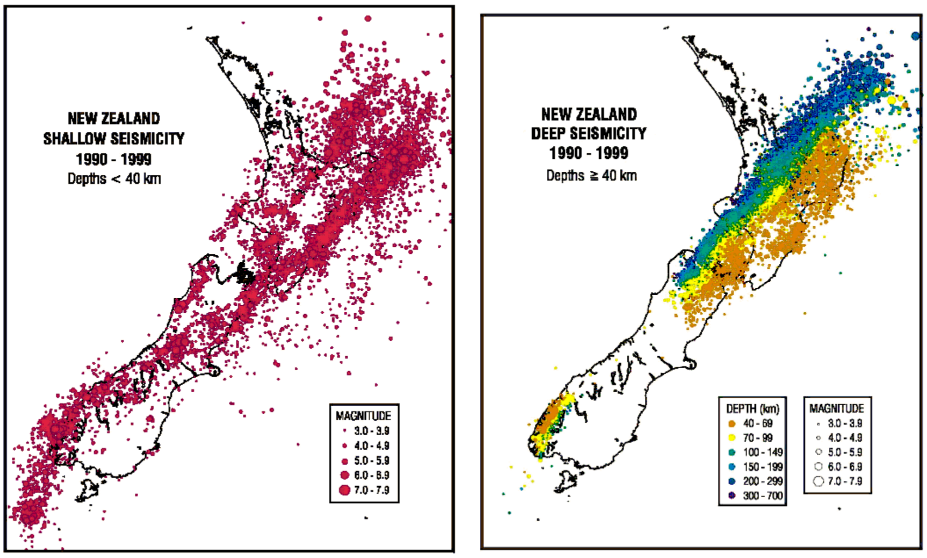
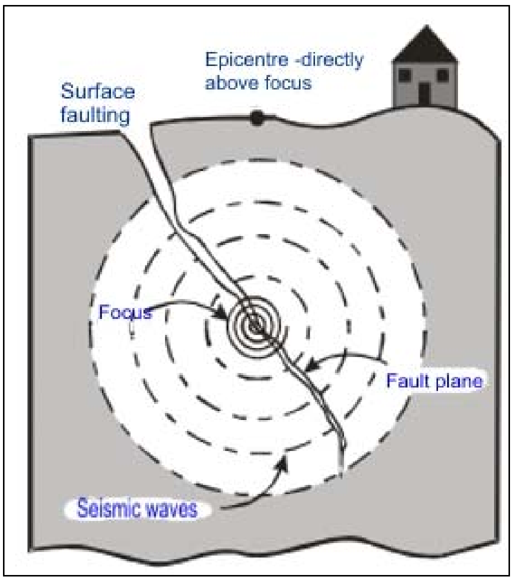
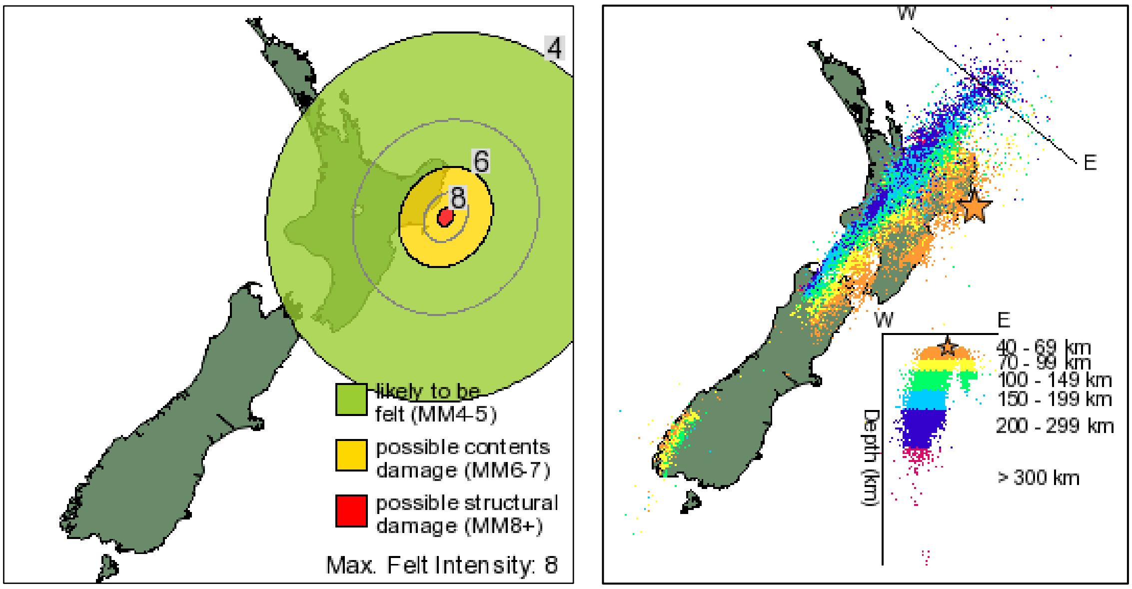


Figure 10.4 Earthquake features and nomenclature.



A measure of earthquake energy release is its magnitude (commonly referred to as Richter Magnitude; though there are numerous other magnitude scales). Because many earthquakes occur well below the ground surface, material between the earthquake focus (Figure 10.4) and the ground surface can dampen the energy felt. For example, a magnitude seven earthquake (M 7) that occurs only 5 km below the surface will feel much stronger than a magnitude seven earthquake that occurs 50 km below the surface even though energy released is the same. Therefore scientists also use an alternate way of describing earthquake size that reflects the level of shaking that is felt at the surface; the Modified Mercalli Intensity scale (MMI). In New Zealand the MMI scale ranges from MMI I to MMI X, with the higher the number reflecting a greater amount of shaking and damage. The MMI scale reflects the fact that earthquake shaking dissipates the further form the source you are. For instance, during the M 6.8 Gisborne earthquake of December 2007 for people living in Gisborne it was difficult to stand and structural damage to buildings and contents resulted (MMI VIII = highly damaging) but for people living in Wellington it was experienced by the people who felt it as being slightly damaging (MMI VI) to merely being observed (MMI IV = mild shaking felt with light fittings swaying etc).

Figure 10.3 A MMI intensity map of the December 2007 Gisborne earthquake and a location and depth (epicentre indicated by a star) map showing the earthquake occurred off the coast of Gisborne at about 40 km depth.



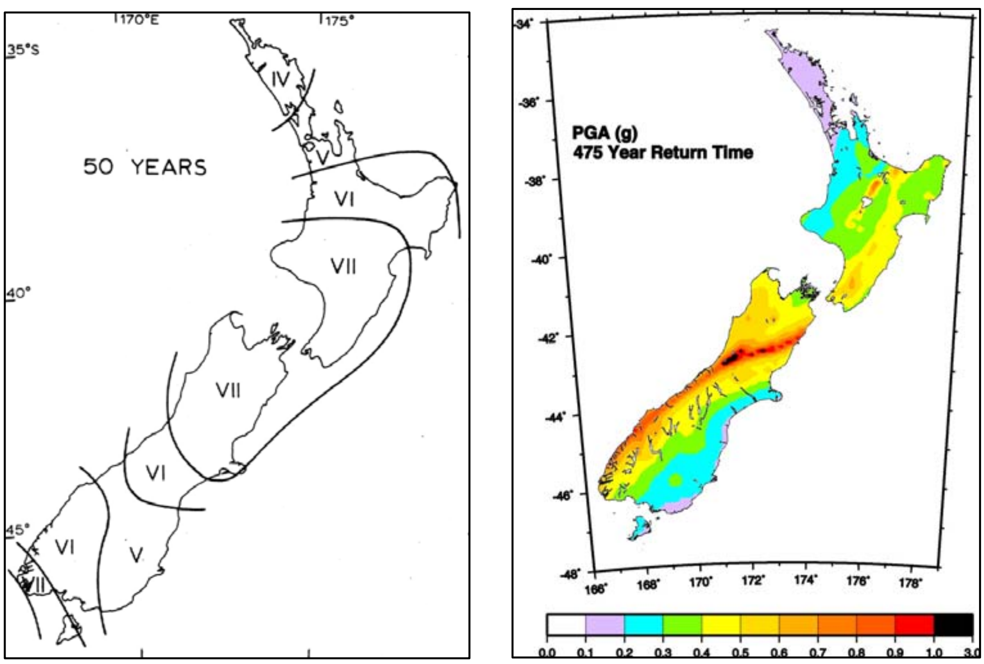
New Zealand has considerable variance in seismicity (including style and rate of faulting) which can be divided into a series of seismic hazard zones. These zones have undergone adjustment as modelling techniques and earthquake science have improved but maps produced (Figure 10.6) using two different methods from 1976 and 2000 show that the relative hazard level for Auckland region remains amongst the lowest in the country. Smith's 1976 hazard zones show shaking intensities with a 10% probability of occurrence within a 50 year period and is based on historical records, and Stirling's probabilistic seismic hazard model from 2000 shows expected peak ground accelerations (the maximum velocity in m/s^2 the ground can be expected to move) from all sources over a period of 475 years (Stirling, 1998[5]). Despite being in the lowest hazard zone, the Auckland region (like all of New Zealand) is still at risk from earthquakes, though to a lesser degree than other parts of the country.

Earthquake hazards include the following:

- Strong ground shaking (dependent on factors including earthquake size, distance from earthquake, and composition and geometry of near surface materials)
- Fault rupture and permanent ground tilt
- Liquefaction (certain saturated soils under strong shaking lose strength and behave materially more like liquids than solids)
- Earthquake-induced landslides (See Chapter 12, Land Instability)
- Tsunami (See Chapter 7, Coastal Hazards: Tsunami)

Not all earthquakes produce every single one of the above hazards. Many earthquakes occur with no rupture of the ground surface though can still cause damage and harm. All earthquakes produce some form of ground shaking with liquefaction only occurring in certain types of saturated poorly consolidated soils. Earthquake induced landsliding occurs when earthquakes are of sufficient magnitude (usually MMI shaking greater than VII is required) and is also dependent on rock and soil strength. A tsunami may occur when a part of the ocean floor is displaced and generation is also dependent on the orientation and behaviour of faults (Hull et al. 1995[6].

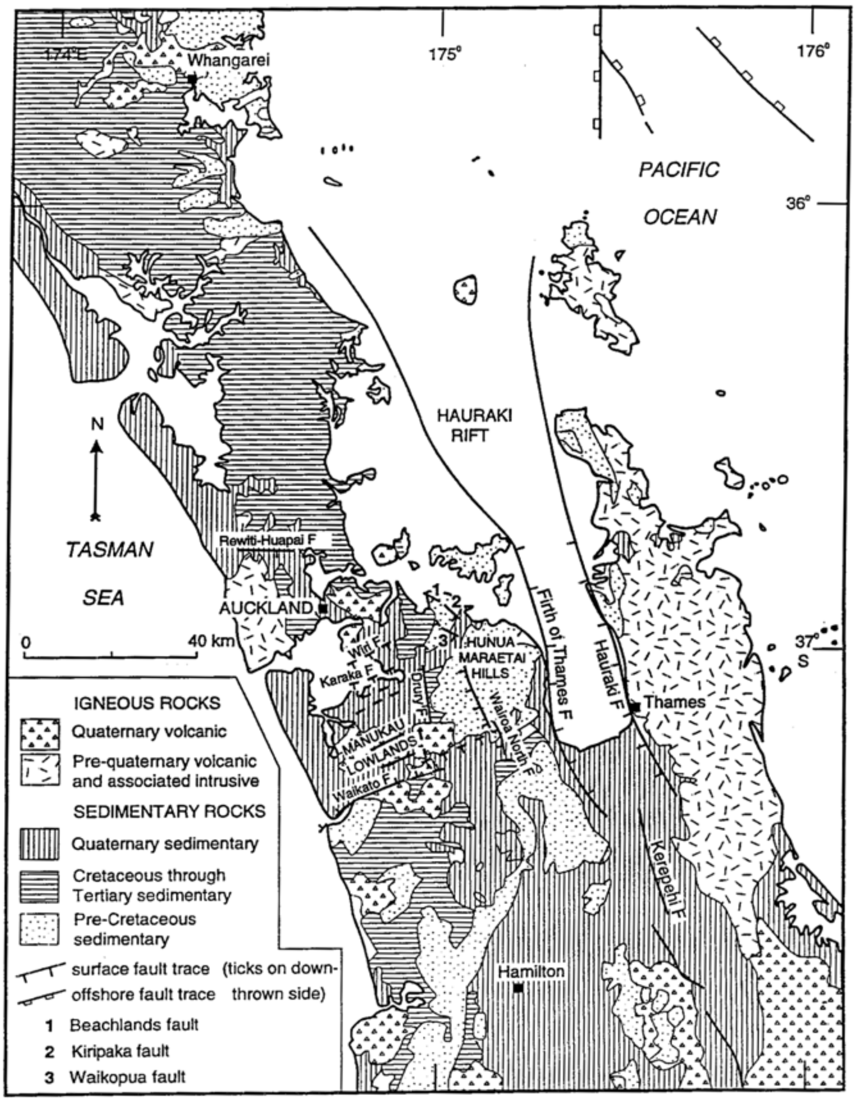
Figure 10.4 The evolution of seismic hazard models - hazard to Auckland remains among the lowest in the country but is still present; Smith's model is on the left and Stirling's on the right. *Source: Stirling, 1998* [5].



10.2 Location, Frequency and Magnitude

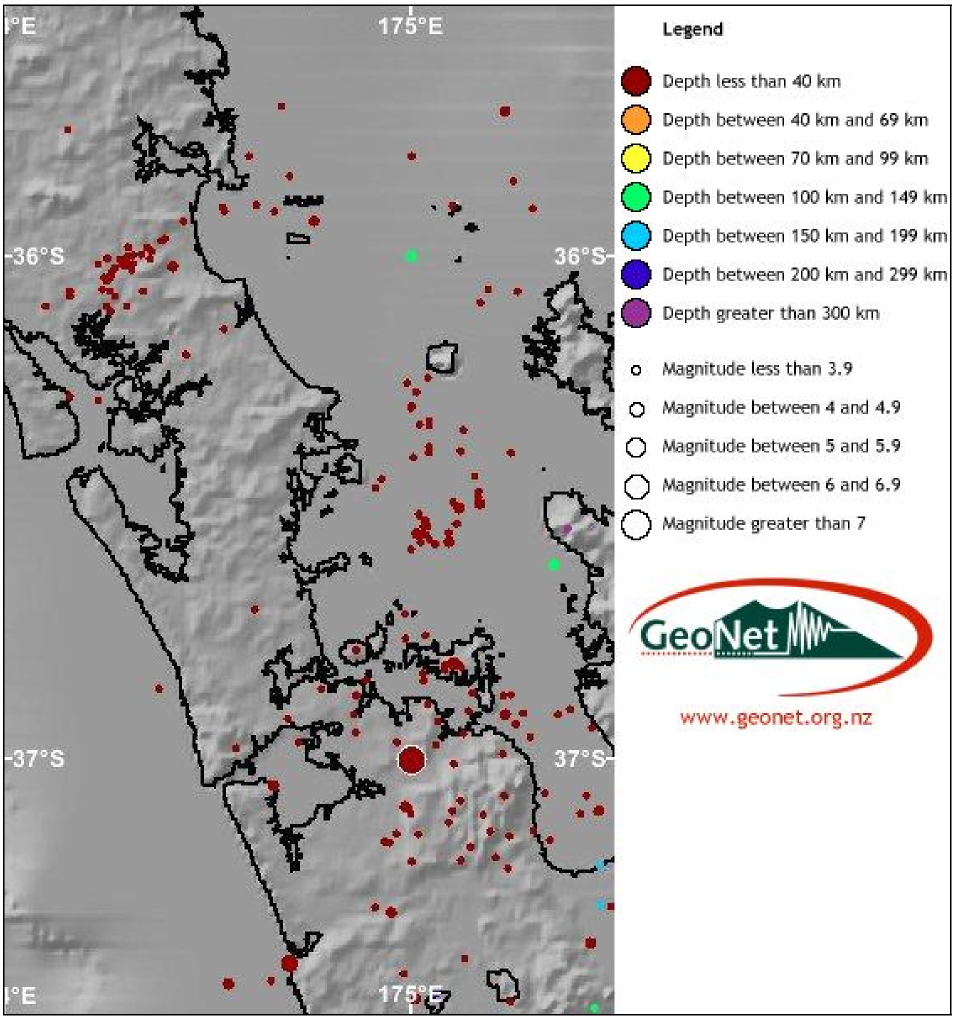
Figure 10.7 shows key features relating to Auckland seismicity both pre-historic and active sources: the Wairoa North Fault extends through the Hunua Ranges and the Drury Fault is situated near Papakura, west of the Hunua Ranges. The Kerepehi Fault outside the region has been identified as being a potential source of damaging earthquake for the Auckland region (Hull et al. 1995; Edbrooke et al. 2003 [7]) Felt earthquakes in the Auckland region have been situated as far away as Otira in the Southern Alps of South Island (a 1929 event is discussed by Eiby (1955) [8]), but the majority of Auckland's felt earthquakes of significant magnitude originate within or close to the region. Only two events have been recorded as inducing building damage and/or injury, both in the 19th century.

Figure 10.7 Geology and location of faults in the Auckland region. This map provides good geological context and shows faults of significance outside the region (in particular the Kerepehi Fault). *Source: Hull et al. 1995.*



Very few earthquakes of considerable magnitude have occurred in Auckland region since the 1891 Waikato Heads event (Figure 10.8) (Hull et al. 1995). To create hazardous effects for people and assets, earthquake shaking intensities generally need to reach MMI VI, when objects fall, difficulty can be experienced in walking, furniture may overturn, and minor building damage can occur. Hull et al. (1995) lists three earthquakes that have been felt in the Auckland region with shaking intensities ≥MMI V; an event in 1834-35 (exact date unknown but GeoNet lists it as 1935) which was felt and recorded in a time when only a few missionaries were keeping written records in the area, and location and details are somewhat sketchy; the 1891 Waikato heads event; and the Te Aroha event in 1972 which had an epicentre 200 km from Auckland City but was of sufficient magnitude to produce MMI V shaking in Auckland City and Manurewa.

Figure 10.8 Earthquakes detected and located from historical records in the Auckland area. The display shows depths and magnitudes; the largest event is the Waikato Heads earthquake of 1891 for which magnitude was inferred from damage reports. Source: *GeoNet, 2008* [9].



Both the Wairoa North and Drury Faults have not been active in the last 10,000 years though investigations of earthquake hazard for the region have identified both faults, along with the Kerepehi Fault outside Auckland region as potential earthquake hazard sources (BECA, 2005). Edbrooke et al. (2003) state that while several faults in the Auckland region have been active over the last two million years, the greatest potential for future displacement and subsequent moderate to large earthquakes exists along faults in the Hauraki plains and South Auckland. The authors determined the estimated probability of Auckland region experiencing shaking of MMI VI or greater as approximately once every 90 years, and the probability of shaking intensity of MMI VIII or greater as once every 5400 years.

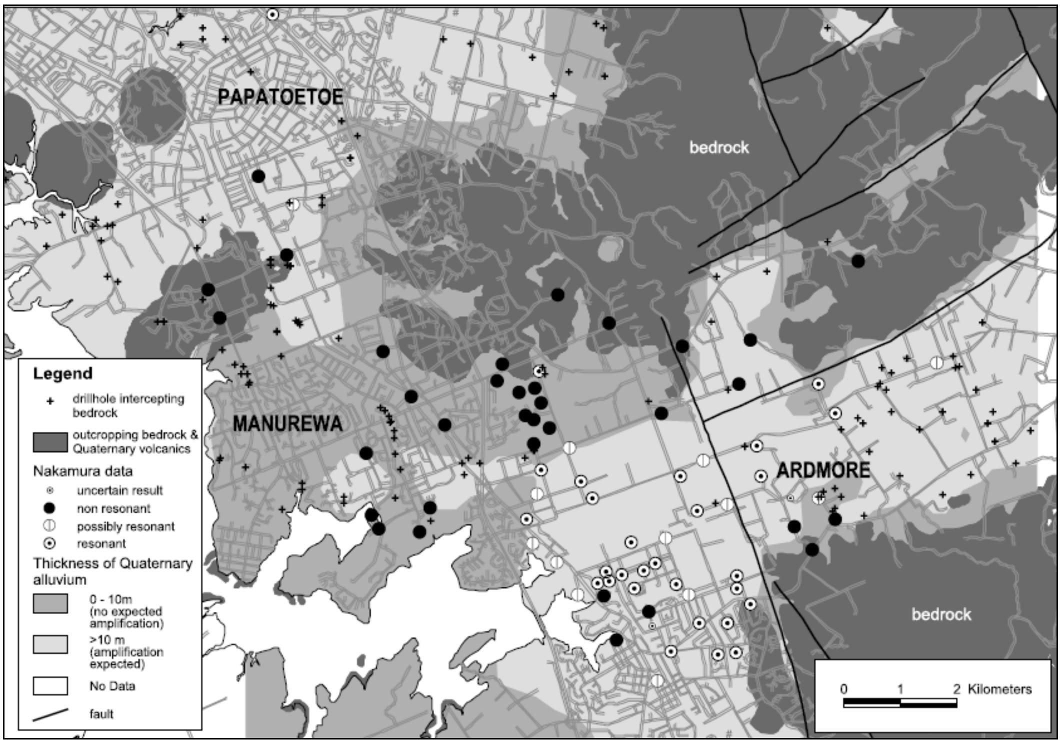
10.3 Key Vulnerabilities and Potential Impacts

Dowrick and Rhoades (2000) [10] state that over 80% of all earthquake-related deaths in New Zealand since 1840 have been due to building damage and mostly at very high shaking intensities (MMI IX-X). The second greatest cause of death after this is earthquake-induced landsliding (6%). Auckland's geological setting means building and infrastructure damage is the primary earthquake risk. However, as the probability of shaking intensities causing structural damage or collapse of buildings is very low, the greatest risk to people would be from falling objects or failure in un-reinforced parapets or masonry of older buildings. Building standards in New Zealand are such that post-1970's buildings are, in general, seismically robust, and while structural damage may occur, they are unlikely to collapse even when subjected to maximum shaking intensities. Older buildings of unreinforced masonry, brick, or sub-standard construction are more susceptible.

Reducing earthquake hazard vulnerability should include focusing on key assets that must meet stricter building standard criteria than residential dwellings such as bridges, hospitals, emergency management operation centres and lifeline infrastructure networks and facilities. As key infrastructure facilities are essential for response and recovery from potentially damaging earthquake events they need to meet the expectation of continuing operation during times of crisis.

Consideration should (and has) also be given to local conditions that may increase earthquake risk. To this end, studies on the potential for amplification of shaking by soft soils in the region have been undertaken. The Auckland region has large lowland areas on soft poorly consolidated sediments, such as the Manukau Lowlands and other Quaternary soft sediment areas (see Chapter 2), which are intensively developed with industrial, residential, commercial and lifeline utility infrastructure (Edbrooke et al. (2003); Stephenson et al. 1998[11]; Stephenson et al. 1997[12]). Stephenson et al. 1998 found that the presence or absence of soft soils was not on its own sufficient to class areas into hazard zones and that the thicknesses of sediments along with the nature of underlying geology also affects amplification. The study concludes that in areas of soft sediments, on-site testing of resonant properties should be carried out as there are considerable variations in amplification response and therefore any potential hazard. With a better understanding of amplification, hazards can be mitigated against appropriately.

Figure 10.9 Stephenson et al. (1998) microzoning work in the South Auckland area, most resonant sites are south west of Ardmore. Source: Edbrooke et al. 2003 [7].



Some key assets and infrastructure in the Auckland region have been seismically retrofitted to reduce earthquake risk. The Auckland Town Hall, a significant heritage building constructed in 1911, was found to be a considerable earthquake risk and retrofitting work has now been completed (Robertson, 2000[13]). Of greater importance to life, safety and the economy of Auckland, the Auckland Harbour Bridge has also undergone seismic strengthening (Beamish and Billings, 2000 [14]). The bridge has been strengthened to withstand shaking from a 2000 year return period event to the degree that immediate access to four lanes of traffic can be re-established. The seismic performance standards for the Auckland Harbour Bridge are listed in Table 10.1; MCE stands for maximum credible event, a term often used for hazard and risk planning.

Table 10.1 Seismic performance standards for Auckland Harbour Bridge. *Source: Beamish and Billings, 2000.*

Ground Motion considered	Performance Required	Assessment Basis
Objective 1: 200 year return period motion	• Minimal damage • Immediate service to eight lanes	• Design strength • Serviceability
Objective 2: 2,000 year return period motion	• Low risk of loss of life • Repairable damage • Immediate access to four traffic lanes • Fully re-opened to traffic in a few days	• Nominal strength • Limit demand/capacity
Objective 3: MCE at mean plus 1.5 standard deviations.	• Low risk of collapse and major loss of life • Closure for an extended period is acceptable	• Probable strength • No collapse

McClure (2008) [15] states that it is not the earthquake that kills people but the collapse of unsafe buildings. Because earthquakes are constantly displayed via media as totally devastating with images of total collapse, people confuse the event with its consequences. The majority of earthquake damage and loss can be mitigated against and consequently, potential losses form earthquakes will be determined by a number of factors.

Potential impacts from a damaging earthquake in the Auckland region are likely to vary depending on:

- the magnitude and shaking intensity of the event,
- the location of the earthquake epicentre,
- time of day the event occurs (at night casualties will be lower as New Zealand structures are generally of sufficient strength to withstand even large earthquakes without collapse, while in the day more people are in the street where falling objects or masonry could hit them),
- the amplification of shaking intensities by soft soils,
- whether critical assets on these soils have been protected sufficiently,
- whether any critical infrastructure or facilities are damaged beyond use (e.g. hospitals, emergency operations centres),
- whether key transport routes are still usable,
- whether lifeline utilities are still functioning and also the interdependencies of those lifelines (e.g. many other lifelines are reliant on uninterrupted electrical supply),
- secondary hazards e.g. rupturing of gas pipes (potential fire hazard), and
- earthquake-induced landsliding.

While unlikely in terms of probability, consequences of a large damaging earthquake impacting the Auckland region could potentially include:

- physical harm and casualties,
- damage to buildings and structures resulting in financial loss and loss of function,
- displaced persons,
- insurance payments including EQC payments,
- interruption to businesses, including loss of employment (temporary and permanent),
- clean up costs of debris,
- potential pollution of waterways from ruptured pipelines or spilled chemicals,
- downturn in tourist numbers,
- psychological effects on populations,
- increase in building and recovery activity creating employment and bringing wealth into the region.

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11. Flooding

11.1 Hazard Characteristics

Flooding is the most common natural hazard in New Zealand[1]. According to GNS (2005) [1] "the average annual cost of damage from flooding in New Zealand exceeds the average annual cost of damage from earthquakes and volcanoes put together". The occurrence of flooding is dependent on several factors including: rainfall intensity, rainfall duration, antecedent soil moisture conditions, local river levels; as well as the physical characteristics of a catchment (e.g. soil type, slope, and vegetation cover) among other local factors. Areas prone to flooding may include: low-lying flood plains with active river systems; valley floors of steep river catchments that are susceptible to intense rainfall and ex-tropical storms; and low-lying areas near sea-level and the coast.

Across New Zealand, river flooding hazards pose the greatest risk in terms of potential loss of human life, social disruption, economic cost and infrastructure damage. Depending on the physical setting, how deep the water is and how fast it is moving, the amount of damage that a flood may cause will vary. For example, the ponding of water from a blocked stormwater drain is less likely to cause as much damage as an overflowing stream or river. On the other hand, floodwaters contaminated by sewage can cause substantial environmental, material and property damage as the water becomes unsanitary.

An assessment of the frequency of extreme rainfall for a range of durations from 10 minutes to 72 hours is important in determining the risk of flooding, both under present and future climate conditions. For every degree increase in air temperature the water holding capacity of the air increases by about 8%. In absence of any counteracting change in the atmospheric dynamics this results in an increased precipitation potential and a consequential increase in the risk of extreme rainfall on all timescales. Heavy rainfall is meteorologically defined as an event where "greater than 100 mm of rain falls within 24 hours, or a pro rata amount" (Thompson, 2006[2]).

Flood magnitude is usually defined in terms of the average recurrence interval (ARI) or the annual exceedance probability (AEP). The ARI is the average period of time between floods of similar magnitude whereas the AEP is the probability of a specific flood occurring during a specific time period. ARIs of greater than 10 years are very closely approximated by the reciprocal of the AEP.

[1] Floods are also the most common cause of a Civil Defence Emergency.

Local authorities use records of local river flows and rainfall to calculate how frequently floods of different magnitudes occur. The extents of different magnitude floods are then determined either by mapping previous events or by inputting the flood height data into a digital terrain model. For example, the 100-year (or 1 in 100 year) flood zone is the area that has a one-percent or more chance of being flooded in any given year. Flood levels would be expected to reach this extent, on average only once in a hundred years. Over the course of 1,000 years, these events would be expected to occur 10 times. However, it is still possible to have several "100-year floods" in a relatively short period. Changes to the rivers and catchments may also change the frequency of floods of various magnitudes.

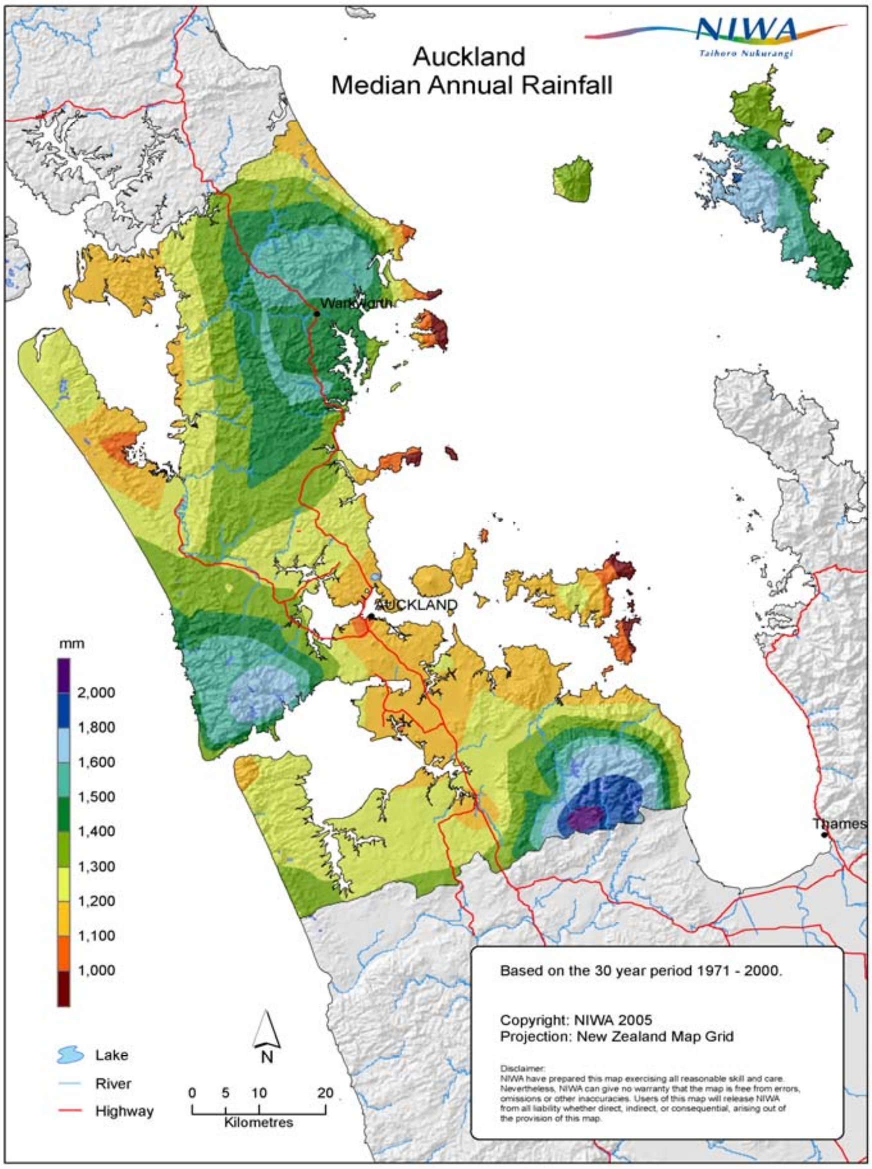
11.2 Location, Frequency and Magnitude

In terms of the broad-scale climate setting, between the tropical belt of travelling anticyclones to the north, and westerly wind flow to the south, the Auckland region extends into the subtropical anticyclonic belt. The prevailing winds are south-westerly which can include long periods of lighter winds. However, Auckland is exposed to northerly quarter winds which bring relatively warm conditions with high humidity. The region is loosely bounded by the ocean and as a result land temperatures are largely controlled by sea surface temperatures. The mean annual temperature varies between 15 and 16°C in the city.

Auckland's heaviest rainfalls occur during warm moist north or north-easterly wind flows, depressions from the north or northwest, and from slow-moving anticyclone to the east. These flows produce about 60% of the annual rainfall total in any one year. In contrast, south-westerly flow produces showery weather, especially in winter. Stormy westerlies also produce rainfall, and may be accompanied by thunderstorms, and sometimes tornadoes. Normal (1971-2000) annual rainfall in the Auckland area ranges from just under 1000 mm to about 2000 mm (Figure 11.1).

Shorter-duration rainfalls in Auckland are often very localised, associated with the interaction of small scale meteorological phenomena with Auckland's complex coastline and topography. Localised falls can often occur during mid-afternoon in summer when sea breezes from the main east and west coasts sweep inland and converge over Auckland City. Heavy rainfalls can also occur in moist and unstable northeast airflows, with embedded thunderstorms. An example of such an isolated event occurred at Whenuapai on 18 February 1988 when 148 mm of rain fell in a 3.5 hour period. Rainfalls a few kilometres away were much lighter and no rain was recorded 8 km away.

Figure 11.1 Auckland mean annual rainfall (1971-2000).



11.2.1 Recent flood events in the Auckland Region

Auckland City Flood: 1997

Heavy rain flooded a number of homes in western and southern suburbs of Auckland City during the morning of 24 May, and caused chaos on the roads. The Fire Service received 230 emergency calls between midnight Friday the 23rd and 1pm Saturday the 24th, when on average 15 calls are made in that time. The meteorological maps for the event show a classic "blocking" pattern. A broad ridge of high pressure extended from a high in the south Tasman Sea to another high east of New Zealand, cradling a shallow low in the central Tasman.

The Pukekohe Flood: 1999

In January 1999, 145 mm of rain fell in 6 hrs causing flooding in Pukekohe, south of Auckland. During this flood event, flood waters rose to 1.5 m in some houses and resulted in:

- flooding of residential homes and consequent evacuation of a number of Pukekohe residents. Evacuation required assistance from emergency services and created stress for residents,
- many roads being made impassable,
- extensive damage to land and buildings from sediment deposition, and
- contaminated water supply due to the infiltration of sewer overflows represented a potential health risk to local communities. This was a concern for weeks after the event.

The Leigh Flood: 2001

On 29-30 May 2001, 132 mm of rain fell in 24 hours over the Leigh Township, north of Auckland. Between 1:40-2:40am on 30 May, 109.4 mm of rain fell, creating a new 1 hour rainfall record for New Zealand. Analysis of the event confirmed it was genuinely exceptional, with a return period far in excess of 100 years. This event caused significant damage in Leigh and surrounding farmland. One family lost about 200 sheep and fences were flattened. Houses were flooded to a depth of well over 1m. On two properties cars, parked outside were moved by flood waters. In one case a car broke through a ranch-slider and then bounced around the living room while the terrified family watched from upstairs. Slips were also common on adjacent farmland. A nearby footbridge, stretching across the Kohuroa Stream, broke in two. Large amounts of debris were deposited. For several days, whole trees placed just off-shore prevented local fishermen putting to sea at night for fear of running into them. The Rodney District Council estimated $700,000 worth of damage mainly to the Leigh and Mangawhai districts.

11.2.2 Regional Analyses of Extreme Rainfalls in Auckland using HIRDS.

The most comprehensive framework for estimating the duration and frequency of extreme rainfalls in New Zealand is High Intensity Rainfall Design System (HIRDS) (Salinger et al. 2007[3]; Thompson, 2002[4]). Regional frequency analysis uses data from sites within a defined region to estimate the design variable (e.g. river flows or rainfall) at each site. Table 11.1 show HIRDS analyses of extreme rainfall for Auckland Airport. The data are displayed in the form of total rainfall in millimetres (depth-duration-frequencies, top) and in terms of rainfall intensity in millimetres per hour (intensity-duration-frequencies, bottom).

At Auckland Airport, the one-hour (60-minute) rainfall total with an ARI of two years is 24 mm. The corresponding 50-year value is 51 mm. Over 24 hour duration, the 2-year ARI rainfall is 73 mm, while the 50-year ARI rainfalls is 168 mm. Furthermore, a 24-hour rainfall intensity of 5 mm h^{-1} can be expected on average approximately once every 10 years. However, an intensity of 5 mm h^{-1} sustained over 48 hours occurs only once every 80 years on average.

Table 11.1 High Intensity Rainfall System results for Auckland Airport.

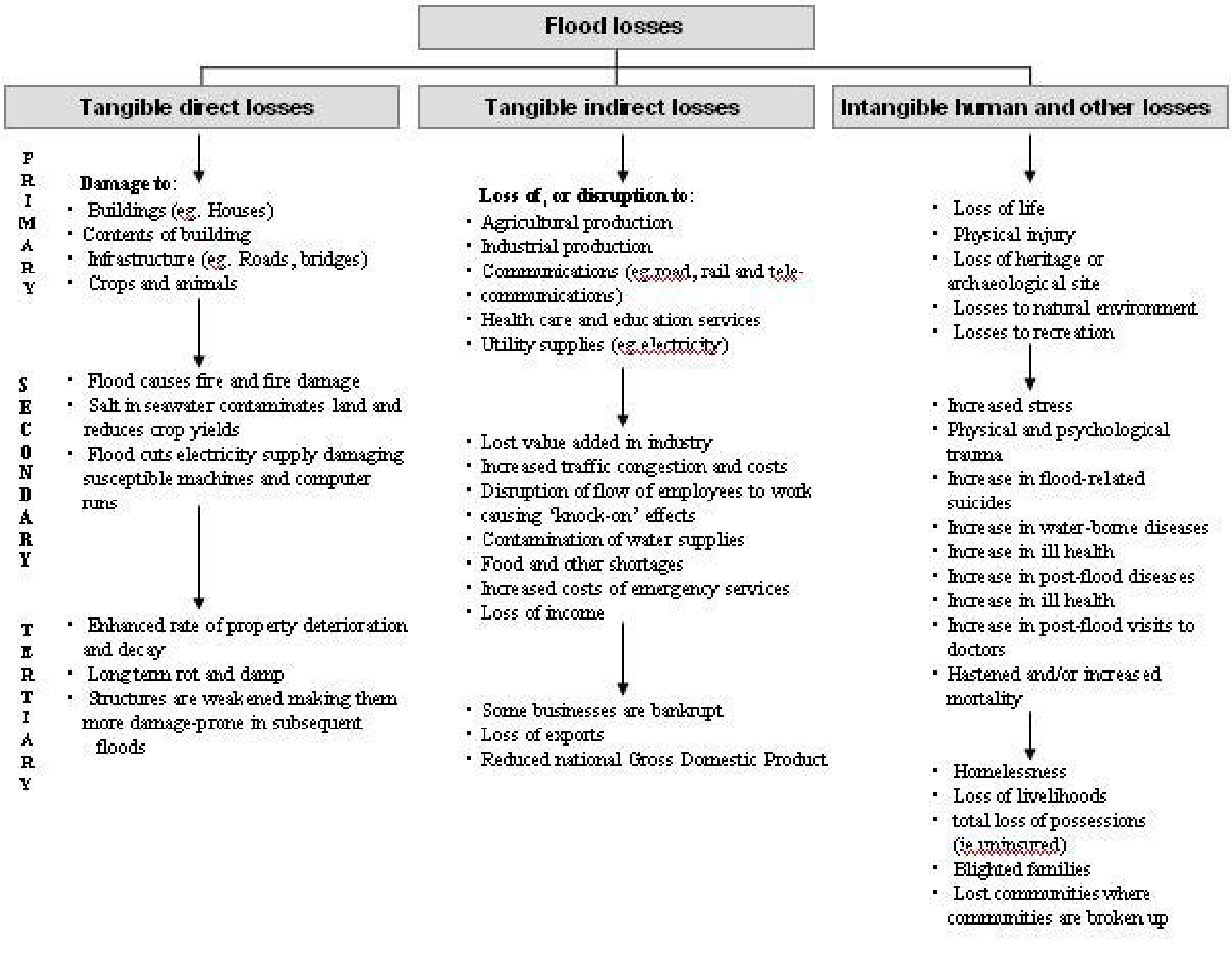
Depth – Duration – Frequency table derived from HIRDS (High Intensity Rainfall System) version 2'), mm h^{-1} m = minutes, h = hours										
ARI	10m	20m	30m	60m	2h	6h	12h	24h	48h	72h
2	10.1	14.4	17.4	24.0	31.0	44.9	56.5	72.9	85.6	94.0
5	13.1	19.0	23.2	32.1	41.6	60.2	75.8	97.8	115.3	127.5
10	15.2	22.1	27.1	37.8	49.1	71.3	89.9	116.4	137.7	153.3
20	17.1	25.2	31.1	43.5	56.7	82.6	104.5	135.9	161.5	181.0
30	18.2	26.9	33.4	46.8	61.2	89.4	113.4	147.9	176.4	198.5
40	19.0	28.2	35.0	49.2	64.5	94.4	120.0	156.7	187.4	211.5
50	19.6	29.2	36.3	51.1	67.1	98.4	125.2	163.8	196.2	222.0
60	20.1	30.0	37.4	52.7	69.2	101.6	129.5	169.7	203.6	230.8
80	20.9	31.2	39.0	55.2	72.7	106.9	136.5	179.3	215.7	245.2
100	21.5	32.2	40.3	57.2	75.4	111.1	142.1	187.0	225.4	256.9
Intensity – Duration – Frequency table derived from HIRDS (High Intensity Rainfall System) version 2										
ARI	10m	20m	30m	60m	2h	6h	12h	24h	48h	72h
2	61	43	35	24	16	7	5	3	2	1
5	79	57	46	32	21	10	6	4	2	2
10	91	66	54	38	25	12	7	5	3	2
20	103	76	62	44	28	14	9	6	3	3
30	109	81	67	47	31	15	9	6	4	3
40	114	85	70	49	32	16	10	7	4	3
50	118	88	73	51	34	16	10	7	4	3
60	121	90	75	53	35	17	11	7	4	3
80	125	94	78	55	36	18	11	7	4	3
100	129	97	81	57	38	19	12	8	5	4

11.3 Key Vulnerabilities and Potential Impacts

A large range of factors are important in determining the vulnerability of activities to flooding. Sensitive activities can be defined as those activities that are inundated and disrupted or impaired by flood waters. They include agricultural, horticultural, transportation and urban activities.

Impacts of flood losses are shown in Figure 11.2. Economic impacts include the cost of damage to a property by a flood, the costs of clean-up, (e.g. paying for the house to be dried out), the costs of living in temporary accommodation, and possibly the costs of having a house that is harder to re-sell. With respect to demographic variables associated with economic impacts of flooding, people least likely to be insured live in disadvantaged urban neighbourhoods.

Figure 11.2 Potential impacts and losses from flooding events.



Health effects caused by a flood event may result from: the event itself; the disruption and problems arising from trying to recover; and from the worry or anxiety about the risk of flood re-occurring. The potential health effects can be considered at three time periods:

- immediate: death by drowning, injuries due to being knocked over by flood waters or struck by falling trees, over-exertion during the event, hypothermia, electrocution, exposure to contaminants, the stress of the event itself,
- medium term: gastrointestinal illnesses, cardiovascular disease from over-exertion during recovery/clean-up processes, lacerations, sprains/strains, dermatitis, respiratory illnesses, carbon monoxide poisoning, and
- long term: psychological effects.

Sewer flooding and the health issues associated with that are a key issue for urban flooding, whereas concern is growing over the effects of diffuse pollution in rural flooding.

Flooding in rural catchments is dependent on wet antecedent conditions, that is, maximum flow occurs when the soil is saturated before the onset of heavy rainfall. High intensity rainfall for durations of around 24 hours or more are most likely to cause flooding in rural areas. In both rural and urban areas there is likely to be pressure on services to aid the clean up of the flooding. In urban areas, if a large area has been flooded then there may be difficulties in finding workmen to repair flood damage. However, if there are large numbers of people flooded, then networks of knowledge can emerge and there can be support for people in terms of helping to organise an emergency response.

Increasing the predictability of heavy rainfall or improving real-time monitoring of heavy rainfall events would have benefits in terms of reducing the risk of the hazards discussed above. Although times of concentration for urban and rural catchments in Auckland are relatively short, flood forecasting is a useful tool in very larger catchments where heavy rainfall can precede flooding by many hours. However, for many of the urban catchments in the region, this time lag would be less than one hour. In cases where heavy rainfall can be forecast several hours in advance, mitigation action can be taken. Current knowledge about warning benefits is limited, indicating a need for further research especially as the benefits of flood warnings are likely to increase. Most is known and capable of monetary estimation in the category of primary, tangible benefits (Figure 11.2), particularly in the residential sector where data on warning response variables is accumulating. Research reveals the importance of primary intangible (protection of life) and secondary intangible (e.g. health) warning benefits, although our ability to estimate the latter remains limited. In rural catchments, such as the Kaipara, heavy rainfall forecasting is useful as it enables stock to be moved. Enhancing heavy rainfall predictability is therefore likely to have application over the whole region.

In summary, flooding is the Auckland region's most frequently occurring hazard and its effects include:

- flooding of residential homes and consequent evacuation of residents
- injury or death by drowning
- roads may become impassable
- extensive damage to land and buildings from sediment deposition
- contamination of the water supply due to the infiltration of sewer outflows

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12. Land Instability

12.1 Hazard Characteristics

Auckland Regional Council has identified that land instability and its effects create significant impacts in parts of the Auckland region (ARC, 1998[1]; ARC, 1996[2]; Williams, 1996[3]). An understanding of regional land instability must be based on familiarity with the location and properties of geological units because of the diversity of rock and soil types in the region. As discussed in Chapters 4 and 5, the geology and geomorphology of the Auckland region are the key contributors to land instability hazards. Landslides and erosion occur readily in soft, weak, less consolidated sediments and rock, of which most of the regions geology is comprised. Alongside this, areas of hard rocks that have been weathered develop a thick mantle of regolith (soil produced from *in situ* weathered rock) and are also susceptible to instability.

Examples of landsliding styles in the Auckland region are shown in Figure 12.1. The nature of landsliding is dictated by geotechnical properties of the source rocks and soils, slope angle, and the degree of saturation of the slope. Land instability styles and behaviour include:

- landsliding (mass movement downslope of material under the influence of gravity), including: rotational slides, translational slides, slumps, flows, and falls,
- subsidence (can occur on flat terrain as well as sloping, usually the result of draining or overloading weak soils),
- tunnel gulley erosion (tunnels form below the slope surface and eventually collapse),
- stream and river bank erosion (e.g. scouring and avulsion)
- coastal erosion (see Chapters 4 and 5),
- topsoil erosion: sheet erosion (layers of soil particles dislodged by rain and transported by overland flow runoffs), rill erosion (channels dug in soil by rainwater flow), and aeolian (wind transported soil particles).

Tunnel gully and topsoil erosion while contributing to economic loss and environmental degradation, are not considered in-depth in this chapter as the hazards associated with these types of instability are minor compared to the effects of landsliding, subsidence, stream and river bank erosion, and coastal erosion. Hazard impacts associated with landsliding, subsidence, stream and river bank erosion, and coastal erosion are discussed in Section 12.3.

Figure 12.1 Styles of landslides around Auckland. Top left coastal cliff instability in Quaternary sands at Awhitu Peninsula; top right slumping and flow in Miocene mudstone and sandstone sedimentary rock; bottom left multiple scarps in volcanic ash-derived soils; and bottom right coastal landsliding in Miocene sedimentary coastal cliffs at Mellons, Bay, Howick. *Source: GNS Science, 2008* [5]*; and Williams, 1996*.

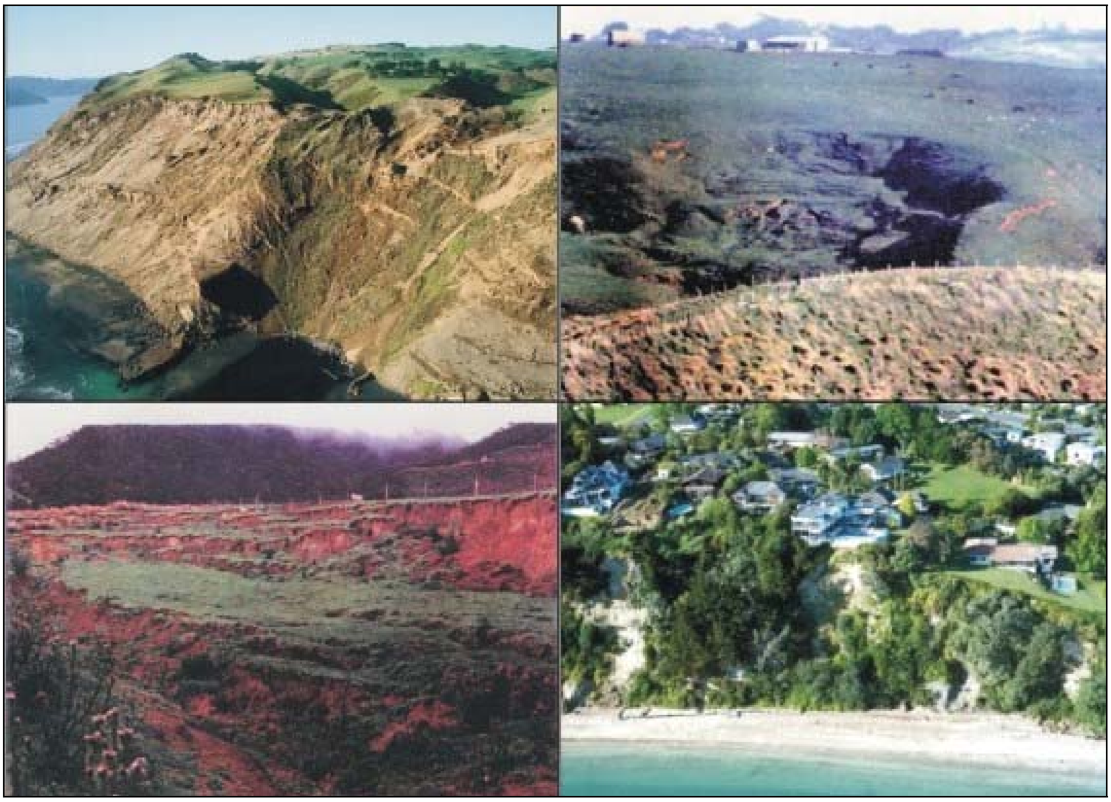


Figure 12.2 Main types of damaging landsliding. A) Block fall. B) Translational slide. C) Flow. D) Rotational slump. *Source: Kermode, 1992* [10].

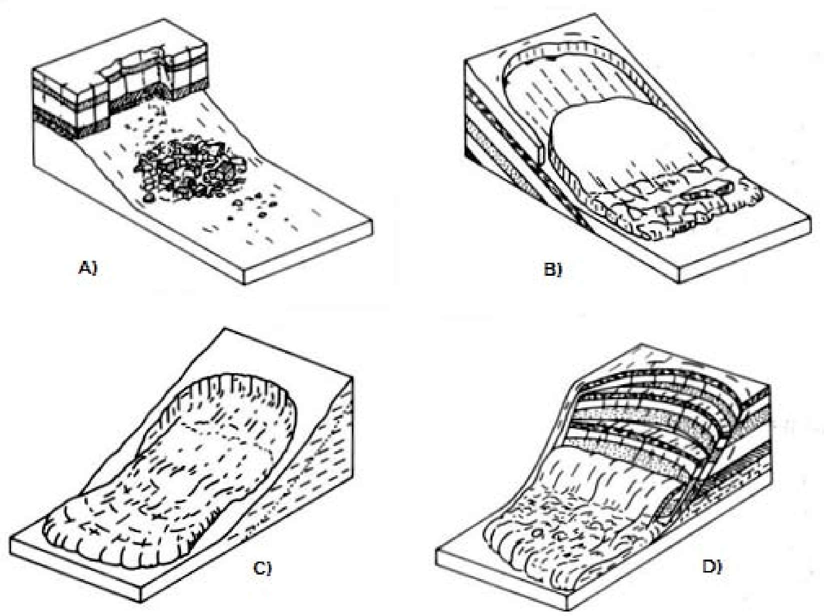
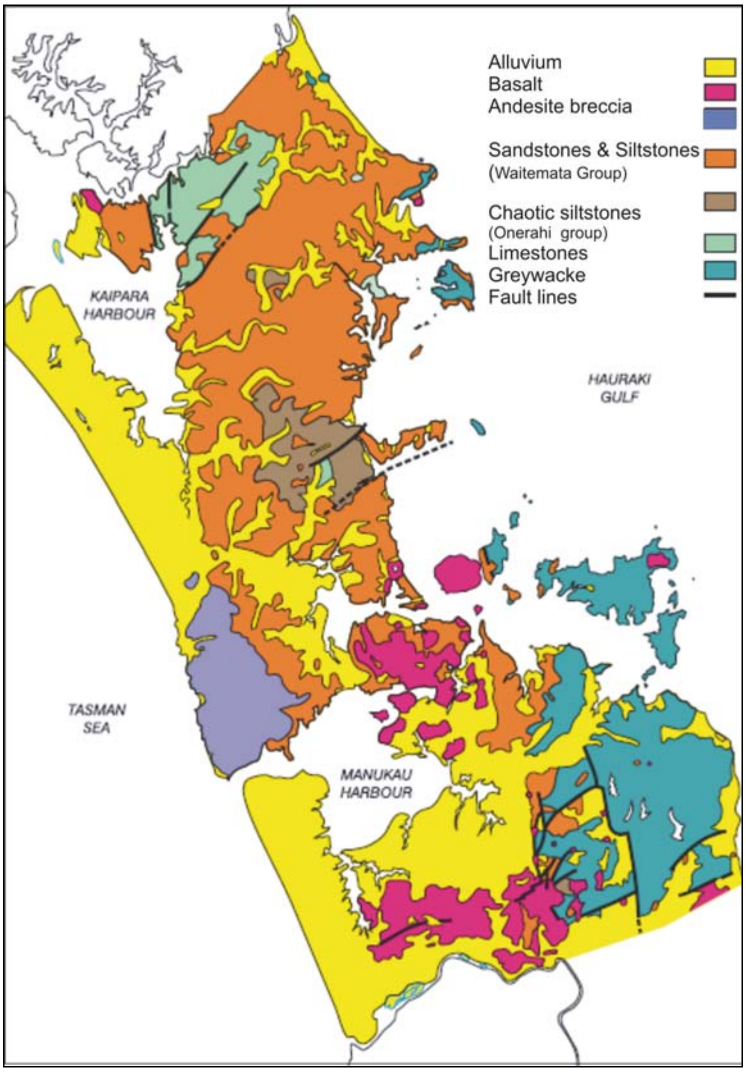


Figure 12.3 Surface geology of the Auckland region: scale is from youngest to oldest sediments. Onerahi Chaos is another name for the Northland Allochthon. Alluvium refers to Tauranga Group sediments/rocks. *Source: Auckland Regional Council, 2002* [6].



Different landslide and erosion styles are possible in the Auckland region because of the diverse geology and geomorphology. In parts of the region greywacke rocks are exposed at Tawharanui Peninsula, Kawau Island, Great Barrier Islands and Waiheke Islands, Hunua Ranges (Figure 12.3) and south of Port Waikato. These 'old' sandstones and mudstones weather to soft clays and form long and straight hill slopes with closely spaced stream channels. Unweathered greywacke rocks are hard to very hard though where rock mass defects (i.e. joints and shear zones) are present, block or wedge failures may be produced. These rocks can be weathered up to 20m depth creating a weaker sandy clay regolith. Small shallow rotational slides and soil creep are common in this weathered rock.

Figure 12.4: A)The hard rocks of the Waipapa Terrane in the Hunua Ranges. Where vegetation cover is dense, Hills appear free of landsliding. Shallow landslide scars can be seen in the pasture hills in the top right of the image. B)Te Whau Point in Blockhouse Bay, Miocene sedimentary rocks of the East Coast Bays formation. *Source: GNS Science, 2008; Blockhouse Bay Historical Society, 2008* [8].

Waitemata Group rocks are comprised of sequence of coarse marine sediments, sandstones, mudstones, conglomerates and volcanic rocks. Outcrops of these moderately soft to moderately hard rocks can be found in the Auckland Isthmus and north of Manukau Harbour, and in the north east of the region from the north shore of the Waitemata Harbour to the region's northern boundary (Figure 12.3). These rocks are susceptible to mass movement failures especially on weathered cliffs, in jointed and faulted rock, and where bedding planes are parallel to the hill slope.

The Northland Allochthon sedimentary rocks outcrop in the north of the region though can be found as far south as Albany. These rocks have high densities of rock mass defects and weather rapidly (Edbrooke, 2001 [7]). The Northland Allochthon rocks form gently rolling hummocky hills with a characteristic 'slumped' topography due to old landsliding events.

Andesitic and basaltic volcanism have formed parts of Auckland's geological landscape such as the Waitakere ranges and Great Barrier Island. Volcanic areas are characterised by steep hill slopes and short steep rivers and streams. Geologically recent volcanism produced the distinctive basaltic volcanic landforms (basaltic scoria cones, lava flows and maar craters (Smith and Allen, 1993[9]) of the Auckland and South Auckland Volcanic Fields (see Chapter 14.1). Differing degrees of strength are associated with volcanic rocks and depend on the type of volcanic feature (e.g. volcaniclastic ranges, scoria cones (Figure 12.4), lava flows). Topographic features include explosion craters (maars and tuff rings), ash deposits, scoria cones, lava flows, lava caves and tunnels. Lava flows are generally strong but scoria cones (when over steepened) and tuff and ash deposits are prone to slumping (Edbrooke et al. 2003).

Figure 12.5 Mt Wellington a scoria cone of the Auckland Volcanic Field, note the slumping of the steep face above the buildings. *Source: GNS Science, 2008*.

The youngest rocks and sediments of the Auckland region are soft coastal sands, alluvial sands and muds, pumice, and peats. These sediments are generally very weak materials, poorly consolidated or unconsolidated (not compacted), especially when saturated (Edbrooke et al. 2003). Erosion types for these sediments include flows and soil creep on shallow slopes, and subsidence when drained or overloaded.

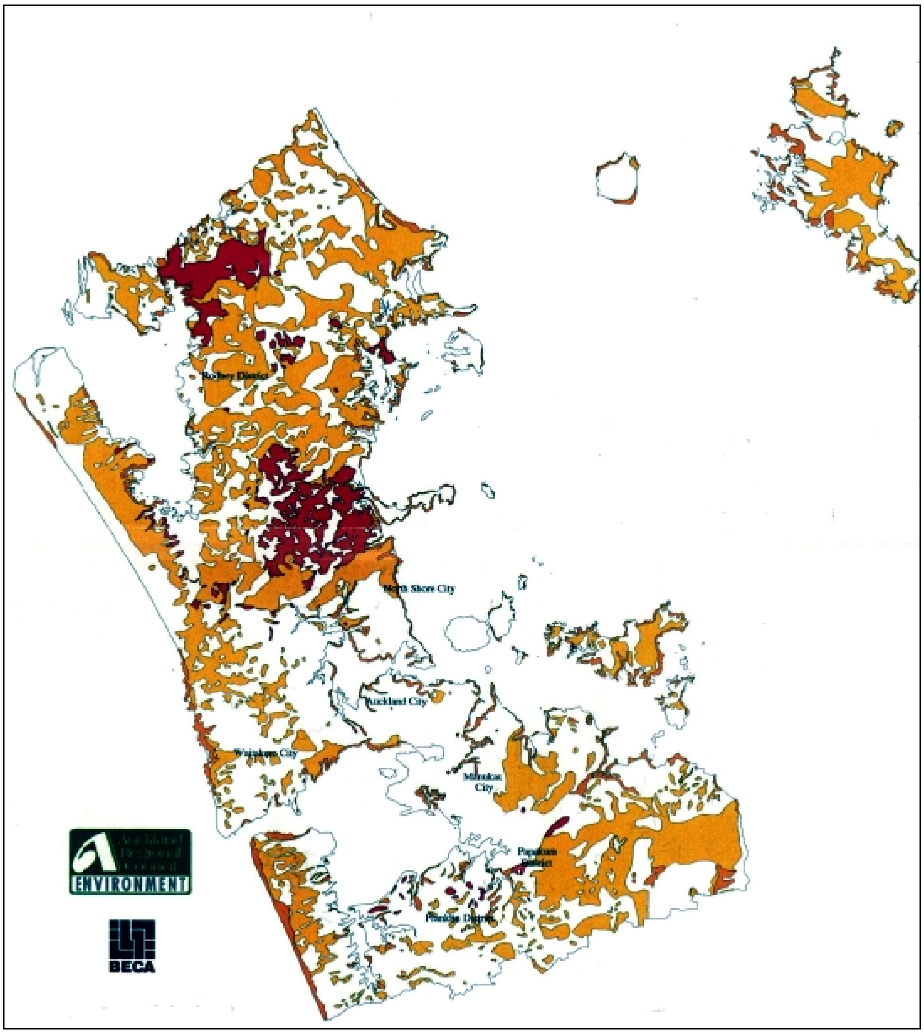
12.2 Location, Frequency and Magnitude

Edbrooke et al. (2003) identifies several factors within the Auckland region that increase slope instability hazards. These are: slopes formed on rocks of the Northland Allochthon; inland slopes greater than 20°; coastal cliffs in Waitemata and Tauranga Group sediments; bedding-parallel clay seams present in Waitemata group (form a thin, very weak layer between harder layers which can result in the upper layer sliding on the weak clay layer); and sensitive pumiceous deposits in Tauranga Group sediments (see Figure 12.3 for rock group locations).

Williams (1996) used the geological and geomorphic properties of rocks and soils in the Auckland region to class them according to geotechnical characteristics related to instability hazards. Classes relate not only to the surface geology but also to the geology of the underlying units. These geotechnical classes were then overlain with slope angle, and a layer representing areas of known instability (Figure 12.6) to produce a land instability map for the Auckland Region (Figure 12.7).

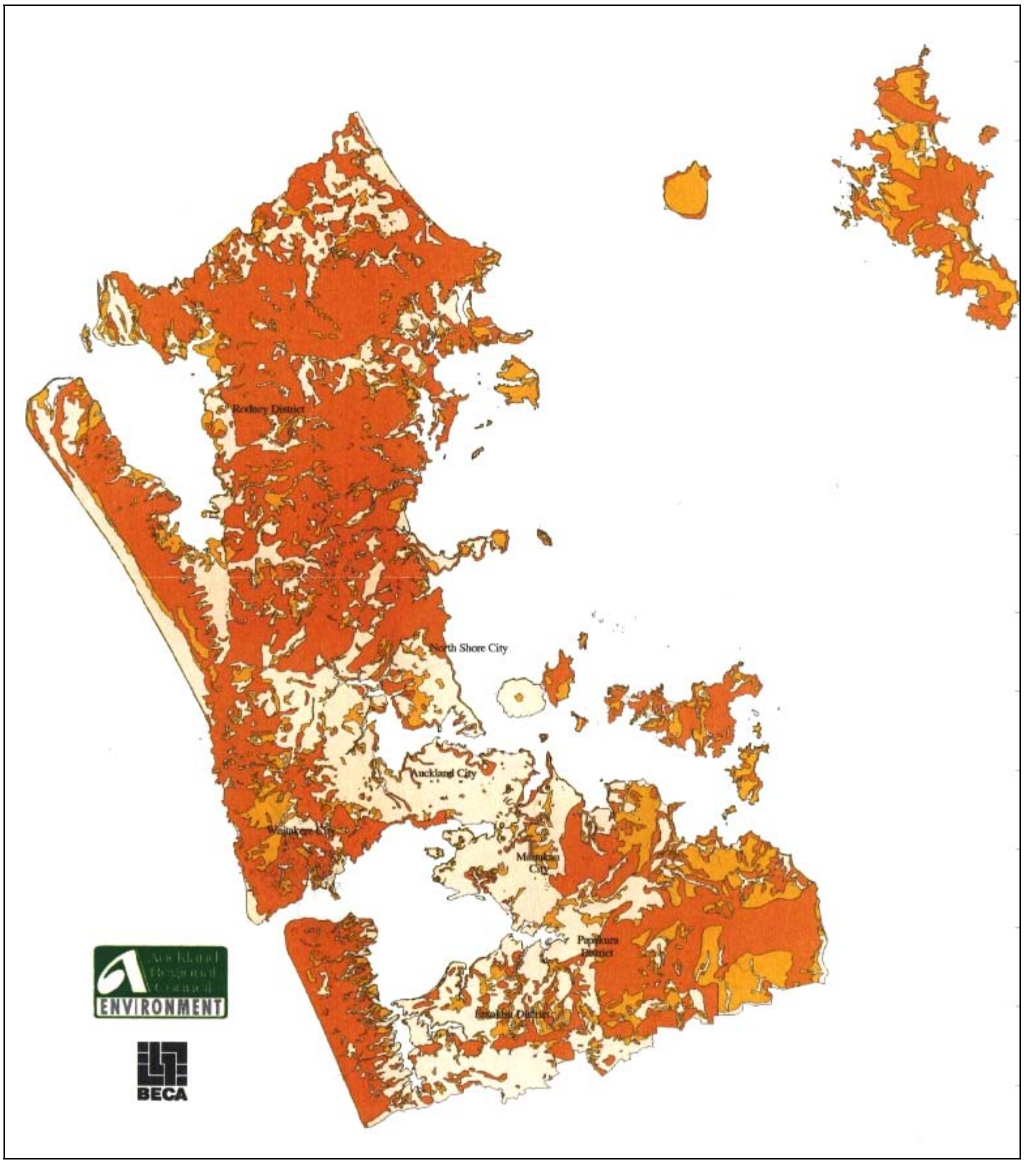
Assessing the frequency and magnitude of landslide events in the region is problematic due to the difficulty in collecting or accessing data that are relevant over medium to long term timescales (Claessens et al. 2006[11]). Longer term studies often use large inventories of aerial photographs taken decades apart and analysis based on assumptions of area/volume relationships. Other types of frequency-magnitude analysis look at large multiple landslide events often considered as the most significant contributor to a catchment's sediment budget for a given period of time and location (Hancox and Wright, 2005[12]). There are very few magnitude frequency studies for slope instability available for the Auckland region (Kermode, 1992); most reports focus on specific events (Adhikary, 2004[13]) or erosion styles (ARC, 1996). Claessens et al. (2006) examined a catchment of the Waitakere Ranges which typically loses most sediment during high magnitude/low frequency events, such as high intensity rainfalls. From observing a 1000 year record of lake sediments the authors identified four distinct high-magnitude landslide events contributing between ~70,000 m^3 and ~210,000 m^3, and other lesser events with a total of ~5,550,000 m^3 sediment lost from the study catchment overall.

Figure 12.2 Areas of known slope instability. dark red: unstable even on gentle slopes; dark orange: coastal cliffs, river banks and gullies; orange: moderate to steep inland slopes. *Source: Williams, 1996*.



Page (2008) [14] has compiled a bibliography of "rainfall-induced" landslide studies for New Zealand. Several of the reports listed include frequency/magnitude analysis for the entire country so information about Auckland landsliding events could be extrapolated from these. The author also makes reference to the Erosion Terrain Classification System developed by Landcare NZ. This system compiles information on landslide types found in certain areas, landforms and terrain types. This data is not publicly available, however the information on landslide characteristics in the Auckland region is worth consideration, and councils should seek further information on location, frequency, magnitude and landslide types.

Figure 12.2 Slope instability map for the Auckland Region determined from rock and soil geotechnical characteristics and slope angle. Dark orange: high susceptibility/unstable slopes; light orange: moderate susceptibility where critical local factors need consideration; pale orange: low susceptibility to slope instability. *Source: Williams, 1996*.



Useful information on the magnitude and frequency of landslide hazard risk could be assimilated from council property information files, resource consents, Earthquake Commission (EQC) and insurance claims, however much of this information is confidential at present. Storing landslide hazard information from council records specific to properties in a GIS is a useful method to determine landslide location, magnitude, frequency and behaviour in Auckland region. GNS Science collates a large landslide database to store information on landslides over a threshold magnitude. Information is sourced from field research, media reports, and analysis of topographic maps and aerial photographs. The GNS Science landslide catalogue contains over 34 landslide events that have occurred in the Auckland region over the last ten years. This list is known to be grossly incomplete as generally only landslide events which are "newsworthy" are reported and thus recorded in the catalogue.

12.3 Key Vulnerabilities and Potential Impacts

All the geological units in the Auckland region have an angle at which they are stable. Slope angle is a critical factor in slope stability and any modification of a slope that over-steepens it will result in increased vulnerability to properties, infrastructure and people on or near the slope. Cut slopes increase likelihood of landsliding and vulnerability of assets and people in the immediate vicinity. Two fatalities have occurred nation in the last 10 years from cut slope collapse though these were not reported from the Auckland region. Nevertheless, increasing popularity to building in rural (e.g. northern Rodney District) or steepland (e.g. Waitakare Ranges) areas will increase the vulnerability of people and property to landslides as hill slopes and gullies are cut and filled to create building platforms.

The Auckland Engineering Lifelines Group (2007) [15] undertook a study identifying "hotspots" for utility lifeline infrastructure. Hotspots were identified where key facilities or nodes of one or more lifeline utilities was likely to be impacted by a variety of hazards that may cause disruption to other key lifeline infrastructure, and therefore the Auckland population. For instance, the destruction of a strategic bridge carrying gas, stormwater and potable water supplies would have considerable adverse flow-on effects. One lifeline Hotspot was identified at "high risk" from slope instability hazards and two were at "moderate risk". The hotspots report contains information that is commercially sensitive so locations are not described here. However, as slope stability hazard can often be mitigated by best practice engineering the identification of vulnerable lifeline utilities provides utility companies with information to undertake risk mitigation for structures and networks.

The Auckland region has intensively urbanised areas that are subject to slope instability, particularly near coastal cliffs. Urban properties vulnerable to instability include the north coast of the Manukau Harbour; the east coast north of Milford and east coast of Auckland City between Bucklands Beach and Omana. As coastal cliff recession is an ongoing natural process (see Chapter 5) the vulnerability of people, property or infrastructure activities to landsliding can be reduced through site-specific geotechnical and hazard investigations. This information can direct persons and consent authorities on where dwelling and infrastructure placement is safest.

The vulnerability of people, structures, and networks cannot be solely determined by the natural geological and geomorphological setting. Where rock and soil has been removed, transported and compacted to form flat areas for development (i.e. cut and fill operations) geotechnical weakness can result if these sites are poorly designed or monitored during development. Areas of cut and fill require geotechnical design and monitoring to ensure they are not weaker and more easily saturated than surrounding materials. Poorly placed fills are known to fail on or near urban properties after triggers such as heavy or prolonged rainfall.

Some potential hazards and losses associated with land instability in the Auckland region are:

- danger to life in the case of sudden onset landslide events (danger exists both at the head (active failure surface) and the toe (debris deposit area) of the landslide),
- damage or destruction of buildings and structures either in the head or toe area of the landslide,
- damage or destruction of lifeline infrastructure such as water, sewerage and gas pipes, or above ground features in the impacted zones such as roads, power transformers, network lines, etc,
- loss of land potentially resulting in an active hazard feature migrating closer to buildings/infrastructure,
- loss of land resulting in a reduction in property value,
- destabilisation of neighbouring slopes/properties,
- psychological impacts for people affected either physically or economically,
- clean-up costs for debris removal,
- environmental impacts of sedimentation in debris-receiving waterways,
- pollution of land and water where toxic substances form part of landslide debris (e.g. sewerage, paint, oil, garden chemicals),
- secondary hazards such as leaking gas or water from broken pipes,
- costs associated with mitigation or remedial works,
- costs to insured people through increases in premiums.

In a planning context, whether land instability should be considered during development can be determined by a series of factors both site-specific and on a larger scale. Relevant questions to ask include:

1. Is the geology of the location likely to result in increased risk? Is the location on rocks and soils known to be weak and prone to instability? Are there any available geotechnical assessments for the location?

2. Is the geomorphology (slope angle, aspect, drainage and existing features) of the location likely to result in increased risk?
3. Has there been any human modification of the location, particularly cut and fill or over-steepening of slopes? Is there evidence of vegetation removal, loading, drainage modification?
4. Have there been any instability issues in the neighbouring properties or nearby areas?
5. What effects, both individual by site, and cumulative by area are likely? How do these effects relate to points 1-5 above?
6. if mitigation measures are proposed what is the residual risk [16]?

Guidance for planners and policy makers whose work includes assessment of landslide (including debris flow) prone land have been developed by the Ministry for the Environment. The guidelines include information on landslides characterisitcs and behaviour, risk assessment, legislative framework and how to assess consent applications amongst other tools for planners (Saunders and Glassey, 2007 [16]).

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13. Tornado

13.1 Hazard Characteristics

A tornado is a rapidly-rotating vortex or narrow column of air, extending from the base of a cumulonimbus cloud (or thunderstorm) to the ground (AMS, 2007[1]; Houze, 1994[2]). On a local scale the tornado is the most intense of all atmospheric circulations. Visible parts of the vortex are the condensation funnel and the debris cloud (this is near the ground, and may consist of dust, leaves, and other airborne missiles – i.e. twigs, branches, and metal. The circulating winds of a tornado can attain extremely high speeds which are hazardous to property and life, at the ground and in the air.

The origin of tornadoes is often associated with well-developed thunderstorm cells on cold fronts. For example, at the gust-front boundary an advancing mass of cold air overruns and displaces pre-existing warmer humid air. Within a thunderstorm cell a strong persistent updraft of warm moist air is maintained as air enters the forward right flank at lower latitudes. As the air ascends it is forced to turn due to the variation of wind speed with height (known as vertical wind shear) and due to its proximity to a downdraft of drier cold air. By this means, the buoyant warm updraft acquires rotation in an anticlockwise direction as it undergoes local stretching in the vertical. The spinning, spiralling effect gradually extends along the length of the updraft, and the speed of rotation or 'twisting' increases as the effective column diameter diminishes.

Given enough time and a high enough rate of spin and stretching, the tornado's funnel lengthens to the ground, creating high velocity winds. Winds in the middle of the funnel are light at the epicentre similar to the eye of a tropical cyclone. In the USA and Europe two tornado wind-speed scales determine tornado intensity. These are the international decimal T-Scale with an intensity range from 0 to 9 and the American F-Scale with a range of 0 to 5[1]. In the severest tornadoes wind speeds may reach 130m/s or 480 kph. Such an event would register T10 or EF5 respectively on the aforementioned intensity scales. Tornado tracks commonly range 1 to 100km and extend from 10s to 100s of metres in diameter. Some tornadoes form out at sea as strong waterspouts, which sometimes cross the coast and may become a tornado as the twisting funnel moves from land to sea (and vice-versa). Tornados characteristically last for a few minutes, track across the land for 2 to 5km with a diameter of 20m to 100m and generate wind speeds of 115 to 180 km/h. Larger events may attain wind

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[1] The Beaufort wind force scale and the Fujita-Pearson scale can be found on the National Oceanic and Atmospheric Administration's website (NOAA, 2008a[3]; NOAA, 2008b[4]). The Fujita scale (F-Scale), or Fujita-Pearson scale, is a scale for rating tornado intensity, based on the damage tornadoes inflict on human-built structures and vegetation. The official Fujita scale category was determined by meteorologists (and engineers) after examining damage, ground-swirl patterns, radar tracking, eyewitness testimonies, media reports and damage imagery, as well as photogrammetry/videogrammetry if video was available.

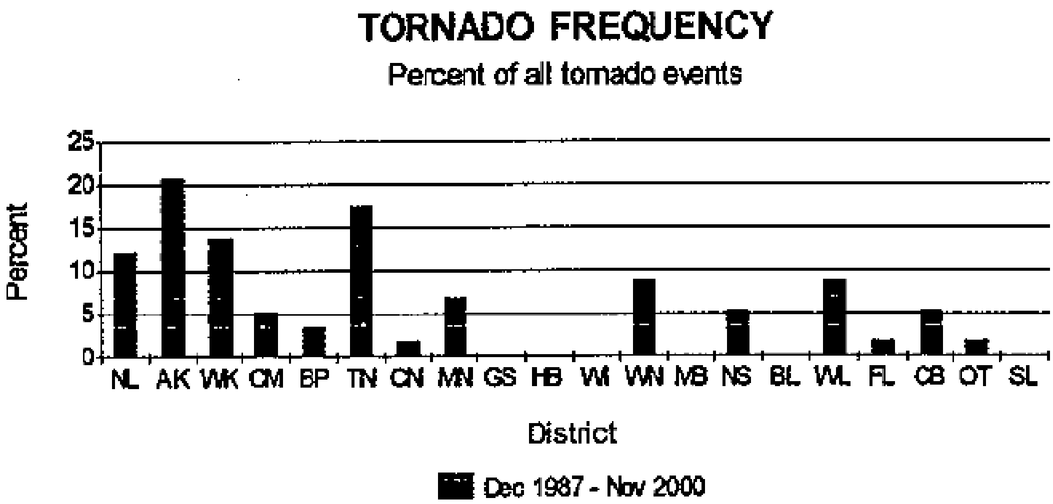
speeds up to 480 km/h and track a distance over 100 km, though such events are very rare.

11.2 Location, Frequency and Magnitude

13.2.1. Tornadoes in the Auckland Region

Tornado's occur infrequently in the Auckland region and typically produce narrow and short tracks. The magnitude of historic events have resulted in damage paths of 10 to 30m wide and tracks between 1 and 5 km. Monthly event distribution is fairly even though daily patterns show the major of recorded events occur in the early afternoon (Seelye, 1945[5]; Tomlinson and Nicol, 1976 [6]). From 1961 to 1975, 17 tornados were observed between Bay of Plenty (38°S) to Auckland [6], while more recently between 1987 and 2000, 21 tornados were reported in the Auckland region equating to a frequency of 1 to 2 events annually (Figure 13.1). The infrequency of events means detailed tornado research undertaken in the Auckland region is minimal.

Figure 13.1 Regional tornado frequencies in New Zealand from December 1987 to November 2000. *Source: Neale, 2001* [7].



13.3 Key Vulnerabilities and Potential Impacts

In the United States, where tornadoes can last considerably longer than an hour and cause large-scale devastation, there is a comprehensive network of powerful Doppler weather radars that makes it possible to detect the formation and track of individual tornadoes. Even so, specific communities may only receive about 20 minutes warning of a touchdown. In Auckland, a tornado's short lifespan and their tendency to form offshore means detecting their formation is almost impossible. The inability to predict events means people in the path of a tornado are highly vulnerable to injury or even death. Most tornado injuries or deaths relate to airborne debris or building collapse. Public education is the only cost-effective option available to safeguard people from tornado hazards.

In Auckland, tornadoes have historically caused damage to:

- buildings and power lines,
- fences and trees,
- vehicles (overturned),
- one life is known to have been lost in a tornado event in Auckland.

This damage is extremely localised. Recent tornado episodes causing damage in Auckland include:

- 31 October 2001: Parts of Auckland city experience fallen trees, and at least 10 houses had damaged roofs, associated with the passage of a 'vortex' and wind gusts to about 150 km/h.
- 25 October 2002: Tornado-like winds ripped roofing iron off a house, and toppled fences in Blockhouse Bay, Auckland City.
- 22 December 2004: Winds associated with a small tornado that occurred in Penrose and Mt Wellington caused damage to six houses, and was strong enough to shift a truck from a stationary position.
- 25 June 2005: Two mini-tornadoes formed near Ardmore aerodrome causing minor damage to some buildings.
- 4 July 2007: A tornado caused damage to at least 30 homes in southeast Auckland. Wind gusts removed tiles from houses in the Botany Downs, Golflands and Somerville areas. Two people were taken to Middlemore Hospital with injuries.

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14. Volcanic Hazards

14.1 Auckland Volcanic Field

14.1.1 Hazard Characteristics

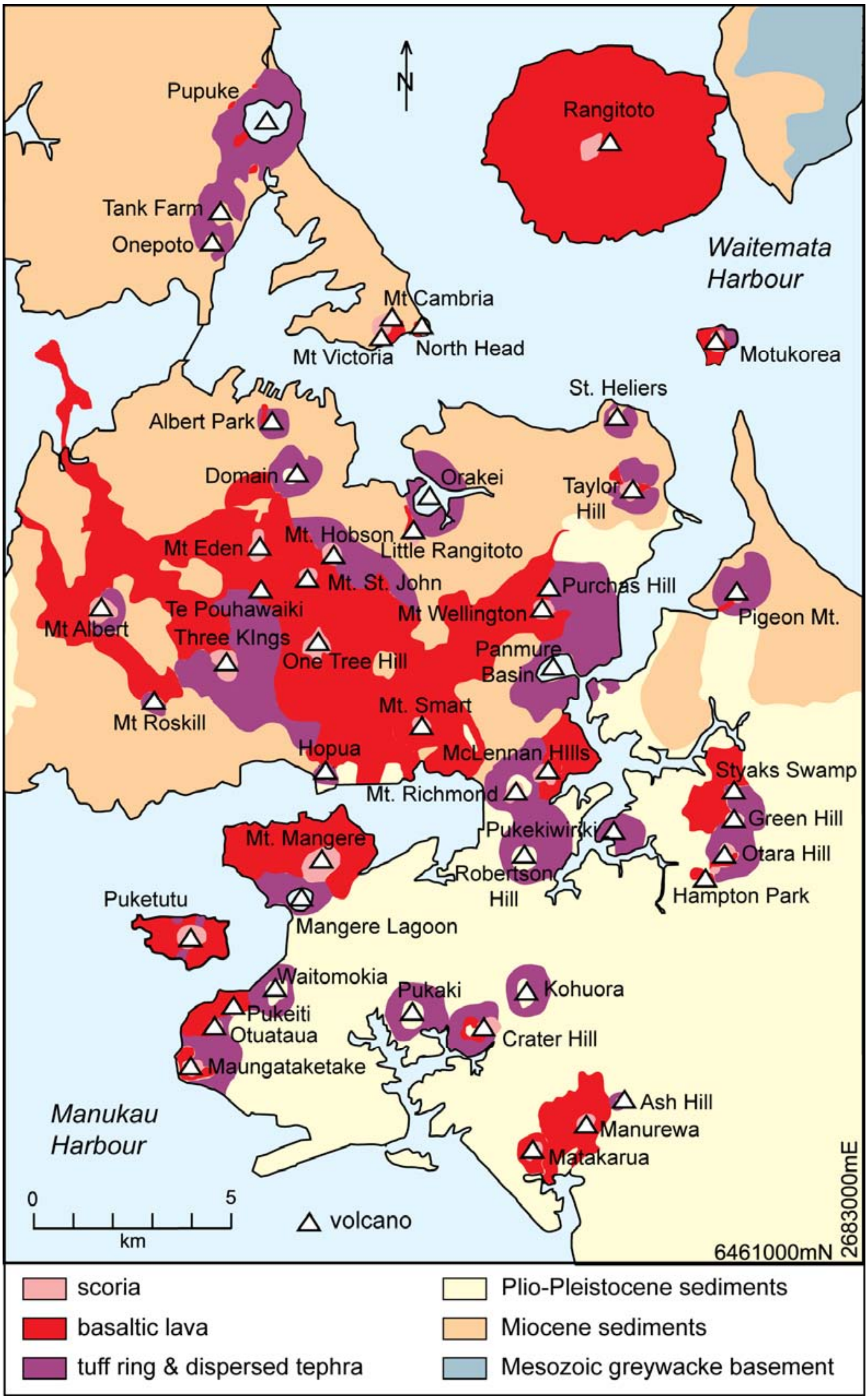
Auckland is built directly on the Auckland Volcanic Field (AVF), and the many small volcanic cones of the field form distinctive landmarks in and around the city. Although the volcanoes are small and their eruptions have been infrequent, the risk associated with future activity is very high, given the high physical and economic vulnerability of Auckland City. Auckland is also at risk from ash fall from eruptions at large volcanoes in the central North Island and Taranaki; this is discussed in Chapter 14.2.

The AVF covers an area of 360km^2 and comprises a minimum of 49 scattered volcanic centres in the form of maars, tuff rings, scoria cones and associated lava fields (Figure 14.1.1). The earliest activity may date back to 250,000 (Shane and Sandiford, 2003[2]) and the youngest eruption, forming Rangitoto Island, occurred about 700 years ago and was witnessed by early Maori living on Motutapu Island (Brothers and Golson, 1959[3]). The volcanoes in the field typically take the form of explosion craters with associated tuff rings, or scoria cones with or without associated lava flows. Many centres display a combination of these two forms.

Past eruptions in Auckland have typically started with an explosive phreatomagmatic phase, resulting from the fragmentation (blasting apart) of magma due to interaction with sea water or groundwater. The resulting explosions generated vertically directed dark plumes of lithic (non-magmatic) rock fragments and ash, base surges and convecting ash columns, and led to the formation of an explosion crater (e.g. Lake Pupuke, Orakei basin, Onepoto). When magma became isolated from water, lava spatter from fire-fountaining and fall out of ash and scoria from sub-plinian eruption columns led to the development of a scoria cone (e.g. Mt. Wellington, Mt Eden, Motukorea, Three Kings). The latter stages of some Auckland eruptions are charactersied by extensive lava flows (e.g. Rangitoto, Three Kings, Mt. Eden, Mt. Wellington). Individual vents often display several different eruption styles (Smith and Allen, 1993[4]; Houghton et al. 1996[5]).

Similar volcanic fields in New Zealand (e.g. South Auckland Volcanic Field) and elsewhere (e.g. Cheju volcanic island, Korea) have had life-spans of more than a million years. This, together with a mantle anomaly at depths of about 70-90 km beneath Auckland, has been interpreted as a possible source for Auckland magmas (Horspool, 2006[6]), indicating that the AVF could still be active.

Figure 14.1.1 Geological sketch map of the Auckland area showing the volcanoes (triangles) and volcanic deposits of the Auckland Volcanic Field. Modified from: Kermode, 1992 [1].



14.1.2 Location, Frequency and Magnitude

14.1.2.1 Location of a future eruption

Although evidence suggests that Rangitoto may have formed by several eruptions over a number of decades (Horrocks et al. 2005[7]), eruptions at similar volcanic fields elsewhere (e.g. Michoacán Guanajuato volcanic field, Mexico; Wudalianchi volcanic group, NE China) have not lasted longer than a few months or years (Blake et al. 2006[8]; Sherburn et al. 2007[9]) so it seems unlikely that Rangitoto will erupt again. A future eruption is likely to produce a new volcano, but it is not known where the next eruption will occur. Some attempts have been made to determine patterns in vent alignments in the AVF and predict future ones (Magill et al. 2005[10]). However, poor age-control limits the interpretation of any spatial trends, making it almost impossible to predict the location of a future vent.

14.1.2.2 Frequency of past activity

There is generally very poor age control on the volcanism in the AVF. The use of radiocarbon (^{14}C) dating is limited because carbonised material is rare, and some of the field is older than 40,000 years (the upper limit of the technique). Early attempts at dating Auckland lavas using K-Ar techniques revealed excess argon, giving anomalously old ages. More recent attempts at dating the field have used the ^{40}Ar-^{39}Ar technique (Cassata et al. 2008[11]), which is giving promising results.

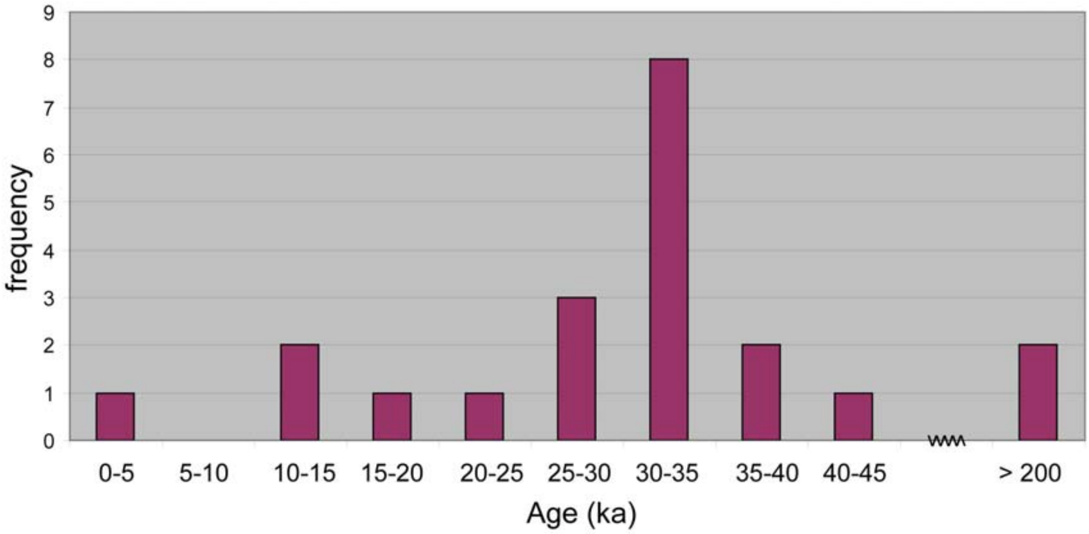
Despite a catalogue of over 120 radiometric age determinations for the AVF, reliable age estimates can be given for less than half of the centres (Table 14.1). The other centres have unreliable, inconsistent or only minimum ages, or no ages at all. This lack of good age-control places severe limitations on any probabilistic hazard modelling in Auckland, and a comprehensive dating programme is needed to fill the gaps and provide reliable and robust data for improved hazard assessment. An indication of the range in ages for dated AVF centres is given in Figure 14.2.

Urban development, in particular quarrying and covering of volcanic outcrops (and even some entire centres) has destroyed much of the surficial record of volcanic eruptions. This, together with the general lack of reliable radiometric ages, has limited studies of the frequency of past activity in the AVF. However, recent investigations of tephra layers interbedded with laminated lake sediments cored from Auckland maars (Shane and Hoverd, 2002 [12]; Molloy et al. submitted [13]; Molloy, 2008 [14]) have revealed that Auckland has been impacted by significant ash fall (represented by >0.5 mm of preserved ash) from a local eruption, on average at least once every 3,500 years over the last 80,000 years. Given that not all eruptions will have left a record in the cored localities (ash fall can be quite localised), and that small eruptions may in fact leave < 0.5 mm of ash or even no record at all, the actual frequency of local ash-fall could be higher than what is represented in the cores. Furthermore, the tephra record gives explosive frequency but little information about past volumes, making it difficult to assess magnitude-frequency relationships.

Table 14.1.1 Age estimates for Auckland Volcanic Field volcanoes, with the most reliable ages shown in bold. ^{14}C Ages are presented as calibrated years before present. Table is based on unpublished data from Lindsay and Leonard, in preparation [20].

Volcano	Age
Centres with radiometric ages	
Rangitoto	**800**
Mount Wellington	**10,000**
Purchas Hill	**10,000**
Mount Saint John	19,500
One Tree Hill	20,000
Mount Eden	28,400
Three Kings	**28,600**
Hampton Park	26,600
Mount Richmond	30,000
Wiri Mountain/Manurewa	**31,000**
Puketutu Island	**31,500**
Pukeiti	32,000
Panmure Basin tuff ring	**32,000**
Crater Hill tuff ring	**32,100**
Kohuora	33,000
Otuataua	33,000
Mangere Mountain	35,000
McLennan Hills	**39,100**
Maungataketake	45,000
Pupuke tuff ring	**200,100**
Onepoto	**250,000**
Centres with minimum ages	
Mount Albert	>30,000
Hopua Basin	>29,000
Auckland Domain	>50,000
St Heliers tuff ring/Glover park	>50,000
Orakei tuff ring	>85,000
Pukaki tuff ring	>125,000

Figure 14.1.2 Best estimate ages for 21 centres in the Auckland Volcanic Field (from Table 15.1). Note that at least 8 centres in the AVF appear to have formed between 30 and 35 ka (thousand years) ago.

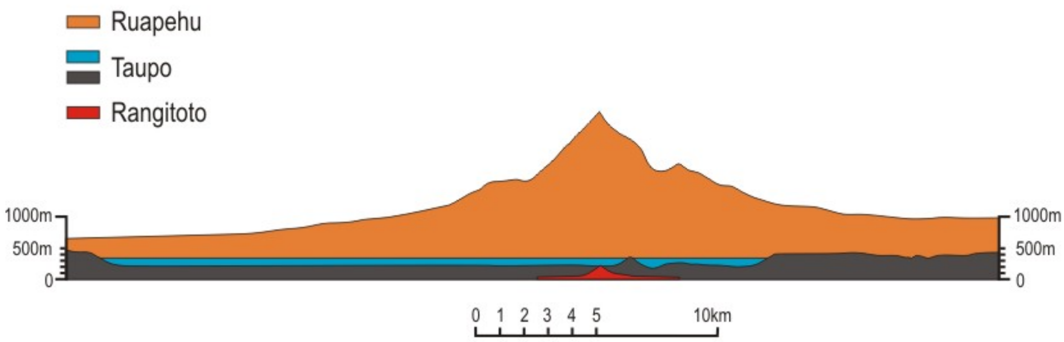


The tephra record also shows that past activity has been episodic. In fact, 16 out of the 24 AVF ash layers identified in Auckland cores were deposited between 35 to 24 thousand years ago, with a major flare-up of widespread ash at 32 ± 2 thousand years 9 (Molloy et al. submitted). This flare-up is also recorded in combined paleomagnetic and ^{40}Ar-^{39}Ar age data, which indicate that five of the volcanoes in the AVF appear to have formed within a period of only 50-100 years or less, about 30,000 years ago (Cassata et al. 2008; Cassidy, 2006[15]). It is also consistent with a clustering at around 32 thousand years of (mainly radiocarbon) ages in the literature (Figure. 14.1.2). In contrast, only three tephra layers have been found that are younger than 20 thousand years; two of these correlate to the youngest centres in the field, Mt Wellington (10,000 years old) and Rangitoto (700 years old) (Molloy et al. submitted). The strong evidence for time clustering of past activity in the AVF makes determining probabilistic hazard challenging.

14.1.2.3 Size and duration of a future eruption

Auckland's volcanoes are small by comparison with many of the world's volcanoes, with most <150 m in height and with volumes of <0.1 km^3 ($10^6 m^3$) [4]. Tuff rings and maars are typically <1 km in diameter. The youngest centre, Rangitoto, has produced the largest volume of lava erupted in the AVF (~2 km^3), and at present it is unknown whether this represents an anomaly, or the start of a period of larger eruptions in the field. A size comparison between Rangitoto and the much larger Ruapehu and Taupo volcanoes is shown in Figure 14.1.3. The size and duration of an Auckland eruption will depend on magma supply: small magma batches may result in short-lived eruptions that stop after generating a phreatomagmatic explosion crater and tuff ring, whereas larger magma batches will generate longer-lived eruptions that may also produce a scoria cone and lava flows.

Figure 14.1.3 Schematic cross sections showing a size comparison between Rangitoto, Ruapehu and Taupo volcanoes (from Wilson and Houghton, 2004 [21]). Rangitoto is the largest AVF volcano; other AVF centres would be significantly smaller on this diagram.



Historical eruptions in similar fields elsewhere have ranged in duration from a few hours (e.g. Teishi Knoll, Higashi-Izu volcanic Field, Japan) to as long as a decade (e.g. Jorullo volcano, Michoacán Guanajuato volcanic field, Mexico); with the longer-lived eruptions forming a combination of features such as cinder cones, tuff rings, satellite cones, fissure vents and lava fields (e.g. Jorullo volcano) (Sherburn et al. 2007). Evidence from past eruptions suggests that the AVF has followed this pattern. Most of the volcanoes in Auckland are thought to have grown by eruptions lasting a few months or possibly a few years (Smith and Allen, 1993), although the entire volume of Crater Hill may have been erupted in less than 12 days (Blake et al. 2006). Several volcanoes in the field (e.g. Rangitoto, One Tree Hill, Mt. Eden, Pupuke, Mt Wellington) comprise numerous volcanic features and/or satellite cones, indicating that the eruption may have been relatively long-lived (perhaps months), with several eruptive episodes possibly separated by time breaks (Spargo, 2007 [16]; Hayward, 2006[17]).

14.1.3 Key Vulnerabilities and Potential Impacts

14.1.3.1 Short lead-in time

One of the key vulnerabilities associated with a future AVF eruption is the expected short warning period (days rather than weeks). Auckland's volcanoes erupt basalt magma that originates in the mantle approximately 50 – 100 km below the earth's surface. Basalt magma is expected to rise quickly through the upper mantle and crust [8] – about 0.1 – 2.2 km per hour – indicating that magma will take between one to 19 days (from 50 km depth), or between two and 38 days (from 100 km depth) to reach the earth's surface. Ascent rates may, however, vary with depth, and magma may stall for a while at the base of the crust before continuing its journey to the surface.

Assuming the latter scenario, the first sign of seismic unrest would be a series of earthquakes occurring when the magma reaches a depth of about 30 km, near the base of the crust (Blake et al. 2006), starting between 14 hours and 11 days prior to eruption. Earthquakes may increase in magnitude and frequency leading up to the eruption, and several hundred may be felt in the hours before an eruption begins. Eruptions from similar volcanoes typically display several days to weeks of precursory seismicity.

14.1.3.2 Uncertainty in vent location

A future eruption in Auckland could occur anywhere within the Auckland Volcanic Field, making land-use planning for this hazard impossible. In a lead up to an eruption, epicentres associated with precursory activity may plot in a diffuse zone around, or even be displaced some distance from, the eventual point of outbreak, making it difficult to pinpoint the exact vent location and thus identify vulnerable areas to evacuate. Furthermore, as magma rises beneath Auckland there is also the possibility that it may stop several kilometres beneath the surface and not culminate in an eruption. Such stalled magma ascent has happened in analogous basaltic fields elsewhere in the world (e.g. Higashi-Izu volcanic field, Japan, 1989) where it resulted in earthquake swarms but no eruption (Blake et al. 2006).

14.1.3.3 Possible impacts

Despite their relatively small size, the effects of a future eruption are likely to be serious, given that Auckland city is built on and around potential eruption sites.

Hazardous phenomena expected during a future eruption include tephra falls (including ash and larger fragments), ballistic ejecta (including blocks from explosions and bombs from fire-fountaining), pyroclastic surges, lava flows, volcanic gases, volcanic earthquakes and atmospheric effects (e.g. lightning strikes from ash clouds). Secondary effects such as flooding due to damming of waterways and blocked drainages will also occur. Within a few kilometres (<5 km) of the vent, volcanic activity is likely to destroy structures and present a high risk to life.

Further away from the vent (>5 km), falling ash will be the most widespread hazard (Houghton et al. 2006[18]). The extent and thickness of ash will depend on eruption style and duration, wind direction, and distance from the vent, but could be dispersed 10 km or more downwind. However, this may occur in a narrow corridor, leaving parts of the city unaffected. Even a few millimetres of ash will disrupt transportation, electricity, water, communications, and sewerage and stormwater systems. The secondary impact of utility failure will affect a much greater area of Auckland than the direct impacts themselves. Earthquakes up to magnitude 4.5-5.0 could occur in the lead up to an Auckland eruption, and also during the early stages of the eruption. These would be widely felt across Auckland, and could cause items to fall off shelves as well as some damage to buildings and infrastructure.

Some of the possible impacts on organisations resulting from a volcanic eruption are listed in tables 14.1.2 – 14.1.4 (modified from Lindsay and Daly, 2008[19]).

Table 14.1.2 Economic Impact on Businesses/Agencies/Organisations

Financial systems	• Auckland would experience a 47% reduction in GDP. • New Zealand would experience a 14% decline in GDP (two times greater than the 1930's great depression.
Costs	• Emergency funding for response and recovery. • Emergency benefits for displaced individuals. • Cost of damage (repairs, replacement and clean-up). • Insurance.
Business	• Loss of business during response and recovery phases. • Business continuity arrangements, including those for loss of utilities, damage to assets, relocation options, possible economic down-turn. • Loss of workforce (due to evacuations). • Skills shortages. • Possible closure of international airport: - Loss of revenue from tourist dollar, - Disruption to import/export market, - Disruption to travel.

Table 14.1.3 Social Impact on Businesses/Agencies/Organisations

Jobs	• 48% of jobs lost in the Auckland Region. • 14% of NZ-wide jobs lost.
Health	• Direct and indirect injuries and illness, particularly respiratory illnesses. • Disruption, possible closure of health services (due to disruption to utilities and lack of workforce). • Widespread community concern; psychosocial issues.
Evacuation	• Logistics of large-scale evacuation. • Traffic congestion. • Community concern. • Welfare provision. • Animal welfare.
Food supply	• Disruption to fast moving consumer goods sector. • Possible food and groceries shortages. • Panic buying, law and order issues.

Table 14.1.4 Physical Impact on Businesses/Agencies/Organisations

Roads	• Road closures due to damage. • Diversions due to evacuation zones. • Hazardous driving conditions due to ash on roads. • Traffic congestion.
Utilities	• Degradation of mechanical equipment due to ash abrasion. • Stormwater systems blocked due to ash runoff. • Disruption to sewage treatment due to ash. • Contamination of drinking water. • Electrical disturbance; short circuit of power. • Overloading of telecommunications systems.
Buildings	• Complete devastation within blast zone. • Structural concerns about buildings due to ash on roofs.

The following gaps in our knowledge need to be filled in order to better understand the hazard to Auckland from a local AVF eruption and thus reduce Auckland's vulnerability to such an event:

- A better understanding of the crustal structure beneath Auckland and the magma system in general is needed to better predict the rise speeds of magma and its possible pathways (and thus likely vent areas) as well as the timing, nature and depth of precursory seismicity.

- Better age-control is needed to determine magnitude-frequency (distribution in space and time) relationships for the AVF. This is the fundamental data set needed for any probabilistic modelling in the AVF.
- In order to appreciate where Auckland is in its lifespan, and to gain insight into its possible future evolution, it is critical to compare it with analogous volcanic fields, such as those in Northland and South Auckland, as well as elsewhere (e.g. Cheju volcanic field in Korea).
- Detailed vulnerability assessments for Auckland need to be carried out and developed into an exposure database for sound risk assessment.
- Further development of the warning system is needed, by improving our understanding of the potential timing and sequence of geophysical warnings (from GeoNet) and their links to the decision-making processes in the emergency responses.
- Also valuable would be an improved understanding of the potential options for an efficient recovery, and for strategies for managing the recovery process.

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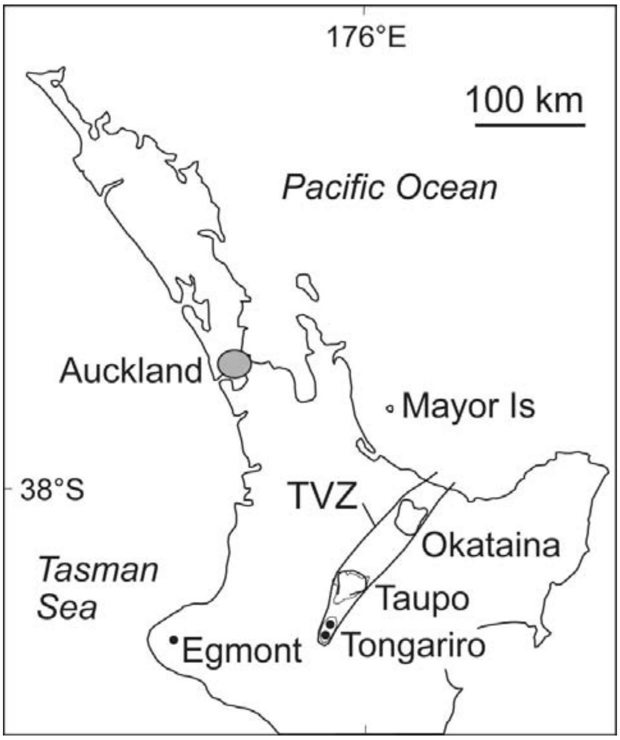
14.2 Distant North Island Source

14.2.1 Hazard Characteristics

In addition to the risk posed by a local eruption in the Auckland Volcanic Field (AVF) (Chapter 14.1), Auckland is at risk from ash fall from eruptions at several large and frequently active andesitic and rhyolitic volcanoes in the central North Island, 140-280 km to the south and southeast (Figure 14.2.1), as well as from any reawakening of volcanic activity in Northland. Numerous and widespread layers of volcanic ash originating from Egmont, Taupo, Okataina, Tongariro and Mayor Island have been found throughout the Auckland region (Sandiford et al. 2001[1]; Shane and Hoverd, 2002[2]; Shane, 2005[3]. Although there is no geological evidence for past eruptions from the Northland Kaikohe-Bay of Islands or the Whangarei volcanic fields impacting Auckland, future activity combined with northerly winds could see ash reach Auckland.

Figure 14.2.1 Volcanic centres of the central North Island that have been active during the late Quaternary and that have deposited ash in Auckland. TVZ = Taupo Volcanic Zone.



About one million years ago, an extremely violent phreatomagmatic eruption in the Taupo Volcanic Zone (TVZ) generated a pyroclastic flow (a devastating flow of hot ash, fine pumice and gases) that traveled for more than 385km and left an extraordinarily widespread deposit known as the Kidnapper's Ignimbrite (Wilson et al. 1995[4]).

Reworked portions of this ignimbrite are up to 9 m thick in parts of Auckland, and can be clearly seen in the banks of the Tamaki Estuary below St. Kentigern College. Although such pyroclastic flows have clearly impacted Auckland in the past (see Alloway et al. 2004 [5] for other examples), over the past million years crustal faulting, together with volcanism in the South Auckland Volcanic Field, has led to numerous hills and ridges south of Auckland that would act as a topographic barrier to these very infrequent but devastating flows today. Thus the main hazard associated with distant volcanoes is ash fall and associated aerosols; past ash fall deposits range in thickness from 1mm to 0.6m in Auckland (Shane and Hoverd, 2002).

14.2.2 Location, Frequency and Magnitude

In contrast to the Auckland Volcanic Field which is characterized by low-frequency, low-magnitude basaltic eruptions, the central North Island volcanoes are characterised by relatively high-magnitude, high-frequency eruptions. Eruptions from New Zealand stratovolcanoes such as Ruapehu and Egmont occur, on average, every 50 to 300 years from approximately the same vent area, and are typically characterised by a succession of small to moderate-sized eruptive episodes over a long period of time (weeks to months) (Johnston and Becker, 2001[11]). Activity at caldera volcanoes is characterised by far less frequent (on average every 1000 to 2000 years) moderate to large-sized eruptions. These eruptions are capable of generating huge volumes of material that can be distributed over wide areas many hundreds of kilometers downwind. Whether or not ash from any given distant eruption will reach Auckland, and the thickness of any associated ash fall deposit, will depend on a number of factors including the style of the eruption, the direction of the blast and orientation of the vent, the properties of the source magma, the degree of magma-water interaction, the height of the eruption column, the volume of erupted material, whether or not pyroclastic flows are generated, the duration of the eruption, and importantly, the wind direction (Newnham et al. 1999[6]).

Our best source of information on the frequency of ash fall in Auckland from distal volcanoes is a series of cores of ancient lake sediments retrieved from maars (volcanic craters) of the AVF (Sandiford et al. 2001; Shane and Hoverd, 2002). These laminated sediments contain numerous tephra (ash) layers from both local AVF volcanoes and distant volcanoes. The well-established stratigraphy, mineralogy and glass chemistry of most rhyolite tephra layers from Okataina and Taupo volcanoes in the TVZ allows them to serve as stratigraphic marker horizons for correlating tephra layers between the different cores.

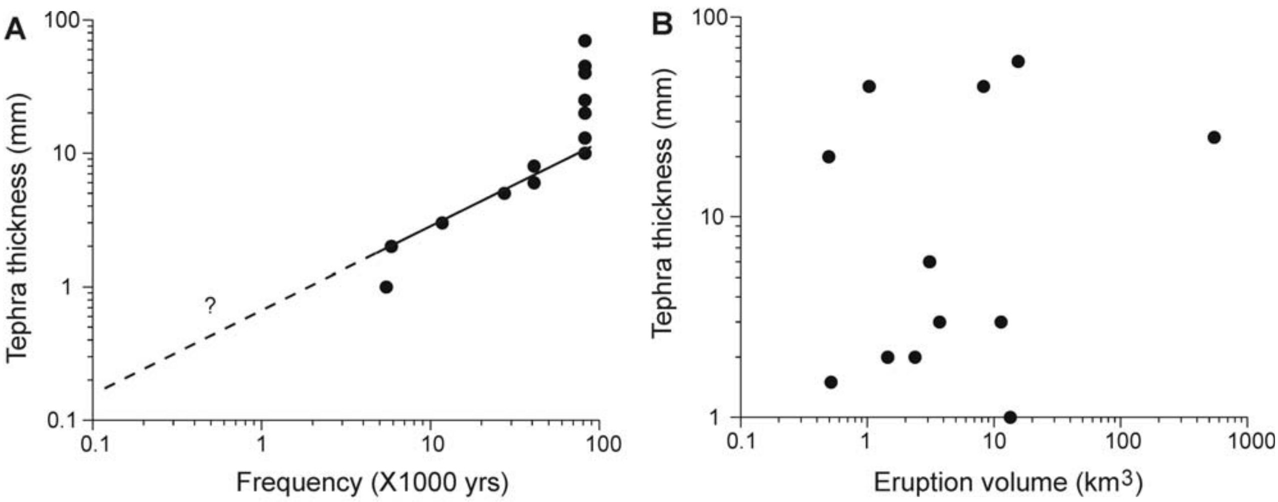
Over the last 80,000 years, eruptions from distant volcanoes have deposited at least 82 different tephra layers >0.5 mm thick in the Auckland area (Molloy et al. submitted [7]). The majority of these are from Egmont volcano (52), with the remainder deriving from Okataina and Taupo (21), Tongariro (7) and Mayor Island (2). Over the same time period, local AVF eruptions have produced 24 tephra layers. These numbers can be converted to the fall out frequencies shown in Table 14.2.1.

Table 14.2.1 Average ash fall out frequencies over the past 80,000 yrs in Auckland. *Source: Molloy et al. submitted*.

Egmont	1 per 1,500 years
TVZ rhyolite (Taupo and Okataina)	1 per 3,800 years
Tongariro	1 per 11,400 years
Mayor island	1 per 40,000 years
AVF	1 per 3,500 years
Frequency of distal events	1 per 980 years
Frequency of local events	1 per 3,500 years
Total combined frequency	1 per 750 years

Note that these fall-out frequencies are based on tephra layers that are >0.5 mm thick in cored locations. However, we know that Auckland has been impacted by ash from distant volcanoes without ash being preserved in the geological record (e.g. Ruapehu 1995/1996). The actual frequency of ash fall impacting Auckland in the past is therefore likely to be higher than those indicated in Table 14.2.1. A plot showing the frequency of tephra layers of a given thickness suggests a 0.1mm thick ash layer could occur in Auckland about every 100 years (Figure 14.2.2 A). Further study of microscopic tephra layers in existing cores should greatly enhance our understanding of the low-magnitude, high-frequency end of the distal ash fall spectrum.

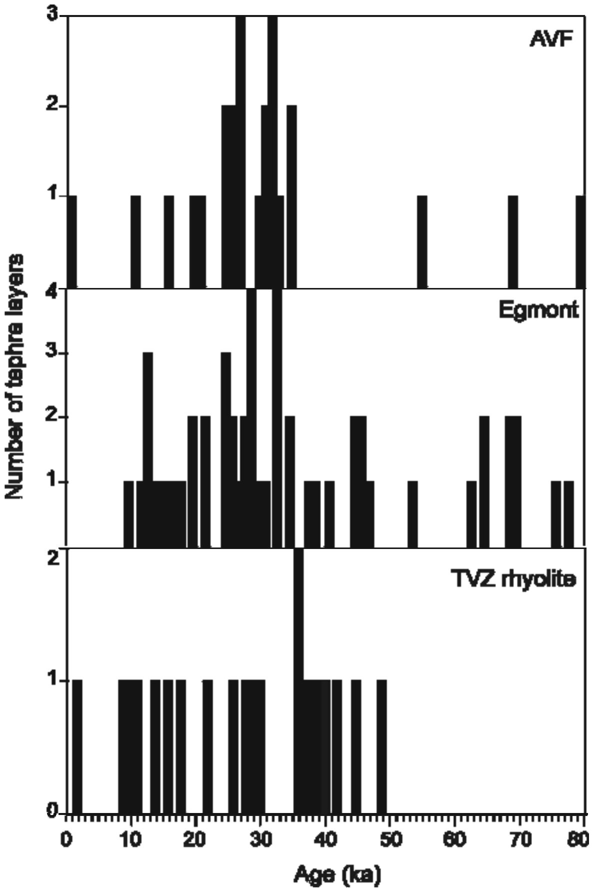
Figure 14.2.2 (A) Thickness-frequency relationship for TVZ and Egmont-sourced tephra in the Auckland area and (B) Thickness of TVZ rhyolite tephra at Auckland compared to known volume of the eruption. *Source: Molloy et al. submitted*.



Interestingly, studies of the deposits of past eruptions reveal that there is no correlation between the size of the distant eruption and the thickness of the associated ash layer in Auckland. For example, rhyolite eruptions from the TVZ that are known to have produced about 10km^3 of material are represented in Auckland by deposits ranging in thickness from 1 mm to >70 mm (Figure 14.2.2 B). Clearly, some of these thickness variations may be related to the wind direction, which will influence whether Auckland lies on the axis of dispersal, but much of the thickness variation is thought to be due to local reworking (Molloy et al. submitted). The fact that the thickness of a given deposit in Auckland may be influenced more by local sedimentary processes, rather than the nature of the source eruption, makes it very difficult to discuss magnitude-frequency relationships (based on the geological record) in any detail.

As mentioned in Chapter 14.1 there is a strong clustering in time of local AVF eruptions. Frequency of ash fall from distant volcanoes appears more uniform (Figure 14.2.3), although andesitic ash from Egmont appears to have been deposited in Auckland most frequently 25 to 35 thousand years ago. Furthermore, no Egmont ash younger than 10,000 years has been found in Auckland cores, although we know that this volcano has been continuously and frequently active during this time period (Shane, 2005). This has been attributed to climatic controls, whereby a more northerly dispersal of tephra is promoted during glacial periods. Between 30,000 and 18,000 years ago southerly winds promoted the more northerly dispersal of ash from Egmont, whereas climate conditions over the last 10,000 years have not promoted such dispersal. Rhyolite ash from Okataina and Taupo appears to have reached Auckland fairly regularly over the last 50,000 years. Note that decadal scale ENSO (El Niño) cycles can influence dominant wind direction in New Zealand and thus likelihood of ash fall during a particular period.

Figure 14.2.3 Distribution in time of tephra layers from local AVF centres, Egmont, and TVZ rhyolite centres (Okataina and Taupo) found in sediment cores in Auckland. Source: Molloy, 2008 [8].



14.2.3 Key Vulnerabilities and Potential Impacts

The effects of a distal eruption in Auckland were highlighted in 1996 when ash from the Ruapehu eruption resulted in the overnight closure of Auckland airport for several days (Johnston et al. 2000[9]). The 1996 Ruapehu ash is not preserved in the geological record, illustrating that even small magnitude events can cause significant impacts on Auckland's infrastructure and economy.

Impacts from a distal eruption will strongly depend on the amount of ash fall and the duration of the event (a sustained ash fall will have a far greater impact than a 'one-off' event). Numerous AELG and other reports have been written about the impacts of volcanic ash on Auckland. Some of the potential impacts and information sources are outlined below:

Health (Lindsay and Peace, 2005 [10])

- Short-term exposures to ash are not known to pose a significant health hazard to people, although abrasion, inflammation and irritation injuries to the respiratory system (nose, throat, lungs) and eyes may occur, as well as accidents related to roof collapse, malfunctioning machinery, poor visibility and slippery roads, electric shocks and slips and falls (especially from ladders and roofs during ash clean up).

Social

- Minor to high social and psychological impacts, due to the infrequent nature of severe ash inundation, the high potential for disruption to lifeline facilities, and the real or perceived need for community relocation.

Economic

- Extremely high economic cost, due to: considerable cleanup costs ($50-250 million), damage to infrastructure; temporary closures of businesses (including airports); loss of exports and damage to export market, and short and long-term effects on Auckland as a tourism destination.
- Economic losses also due to damage or loss of horticultural and agricultural products: ash fall of less than 1 mm will have a limited impact on livestock (through contaminated water and food supplies, wear on teeth etc). 100mm of ash will affect vegetation and kill most pastures.

Infrastructure (Johnston and Becker, 2001; Johnston et al. 2004[12])

- The deposition of even a few millimetres or centimetres of ash in Auckland will be sufficient to cause disruption of transportation, electricity, water, sewerage and stormwater systems. Some of the main impacts will include
  - disrupted electricity supply, with power outages if the ash is wet (i.e. conductive),
  - widespread problems with transport infrastructure, possible closure of roads and airport,
  - disruption of fresh and waste water services,
  - distrupted communications due to interference, overloading or direct damage,
  - Minor clogging of air filters, and minor damage to machinery.

The following gaps in our knowledge need to be filled in order to better understand the hazard to Auckland from distal eruptions and reduce Auckland's vulnerability to distal ash fall:

- Our understanding of the frequency of past small ash fall events needs to be improved, through micro-analytical study of thin ash layers in sediment cores.
- The role of climate on controlling past and future tephra dispersal needs further investigation.

- Probabilistic hazard models incorporating the frequency of distal eruptions and present and future climatic conditions should be explored.
- All recommendations made in existing reports on the impacts of volcanic ash in Auckland need be followed.

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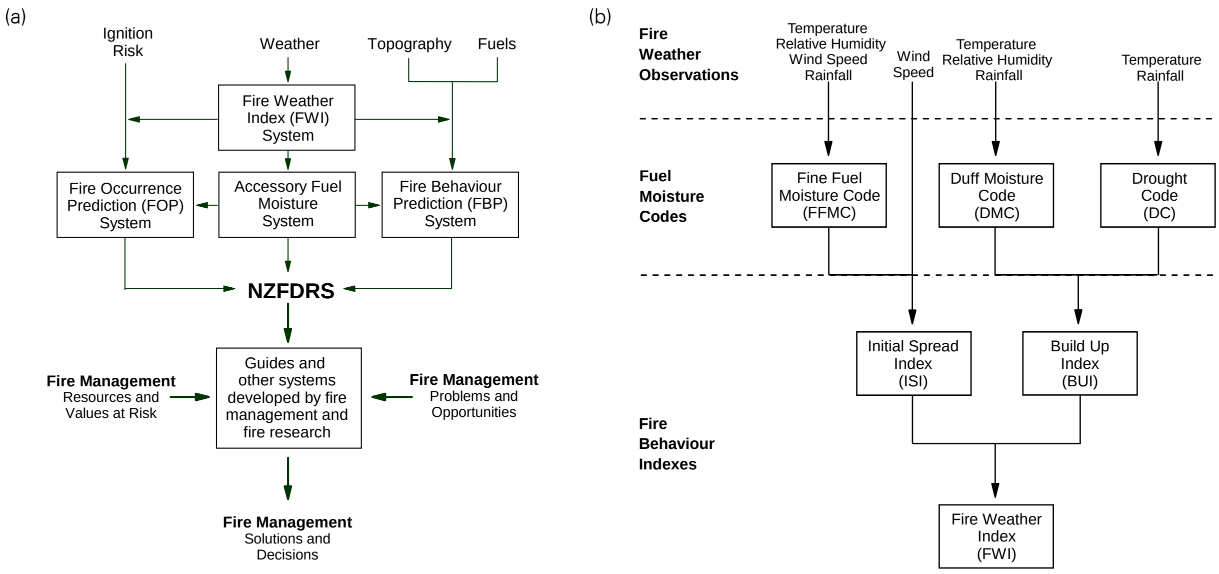
15. Wildfire

15.1 Hazard Characteristics

A wildfire (also known as a wild-land fire[1]) is an uncontrolled fire which can destroy infrastructure and devastate agricultural resources. Often occurring in wild-land areas the most common cause of wildfires are lightning, human carelessness, arson and less commonly, volcanic eruptions. Heat waves, droughts and cyclical climate changes such as El Niño all have a dramatic effect on the risk of wildfires.

Assessment of the effect of fire weather (and other fire environment factors of fuels and topography) on potential fire occurrence and fire behaviour in New Zealand is assisted by the use of the New Zealand Fire Danger Rating System (NZFDRS) (Figure 15.1a) which is based on the Canadian Forest Fire Danger Rating System (CFFDRS).

Figure 15.1 Simplified structure diagrams for (a) the New Zealand Fire Danger Rating System (NZFDRS), illustrating the linkage to fire management actions; and (b) the Fire Weather Index (FWI) System. *Source: Fogerty et al. 1998* [1].



The Fire Weather Index System (FWI System) provides numerical ratings of relative wildland fire potential (http://nrfa.fire.org.nz/firenet/regions/rural). The first three components are fuel moisture codes that follow daily changes in the moisture contents of three classes of forest fuel with different drying rates. Higher values represent lower moisture contents and greater flammability potential. The final three components are

[1] Wildfire is also sometimes called forest fire, brush fire, vegetation fire, grass fire, peat fire, bushfire and hill fire.

fire behaviour indexes representing rate of spread, amount of available fuel and fire intensity; their values increase as fire weather severity worsens. The system is dependent on weather only and does not consider differences in fire risk from fuel or topography. It provides a uniform method of rating fire danger throughout New Zealand.

15.2 Location, Frequency and Magnitude

Strong winds, high temperatures, low humidity and seasonal drought can combine to produce dangerous fire weather situations. These features fluctuate seasonally and from year to year. In the Auckland region the total number of wildfires occurring annually in the forested areas to the west (Waitakere Ranges), south (Hunua Ranges), northwest (Woodhill Forest), north (Mahurangi Forest) and east (Gulf Islands) is usually low. The main causes of forest fires have arisen from agricultural burn-off going out of control, careless actions or natural causes such as lightning strikes. There is an increase of forest fire risk during prolonged drought conditions indicating climate is also a key factor.

Severe fire seasons experienced in Auckland have been attributed to various synoptic climatic features, such as El Niño and La Niña events. The National Rural Fire Authority has reported variable success in their endeavour to uncover factors that cause high seasonal fire risk. Pearce (1996) [2] provides summary tables showing the long term averages and extremes by month and year for each of the weather inputs and FWI system codes and indices, showing, for Auckland, a mean Cumulative Daily Severity Rating (CDSR) of 413, a Daily Severity Rating ranging between 0 and 71.39 and a mean Monthly/Seasonal Severity Rating MSR/SSR of 1.31. This is important as detection of discernible trends coupled with seasonal climate prediction allows some anticipation of possible higher region fire risk seasons.

Linkages between regional circulation and weather patterns and the monthly (MSR) and seasonal (SSR) fire severity ratings in the Auckland region have been analysed (Salinger et al. 1998[4]; Heydenrych and Salinger, 2002[5]). The findings suggest fire danger is enhanced in the Auckland region by south-easterly wind flows or in persistent anticyclonic situations. Two fire climate regions have been delineated in the Auckland region: Auckland West-Waikato (Gosai et al. 2003[6]) and Auckland East-Coromandel (Griffiths, 2004[7]). These are described in more detail below.

15.2.1. Auckland General

Significant correlations between Auckland Airport monthly and seasonal fire danger values (MSR and SSR) and a number of climate predictors were found for summer (fire season) months. In general, high fire danger on a seasonal basis is associated with a predominance of south easterly winds and a progression of anticyclones across northern New Zealand. Low fire danger seasons are generally associated with troughs in westerly-quarter wind flows.

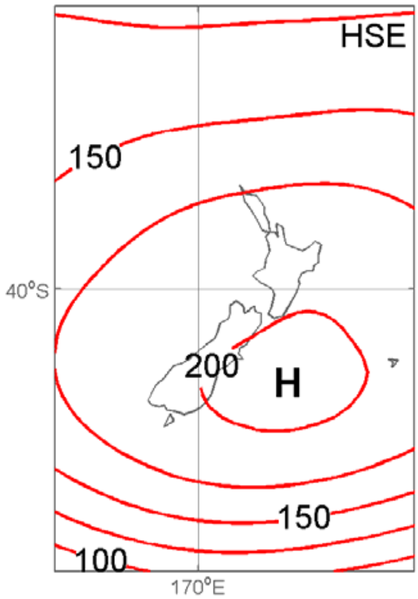
Figure 15.2 'Fire regions' of New Zealand including the Auckland West-Waikato and Auckland East-Coromandel fire regions. *Source: Heydenrych and Salinger, 2002*.

15.2.2 Auckland West-Waikato

The Auckland West-Waikato extends south of Dargaville down to the Marakopa River. Due to the narrow Auckland isthmus this area is influenced by both westerly and easterly wind flow. The region shows similarities and differences with other local west and east coast sites though analysis of fire rating data indicates an "Auckland West" and "Auckland East" fire risk area could be considered.

As for Auckland Airport, high seasonal fire danger in Auckland West-Waikato is associated with south-easterly wind flows and lower fire danger with troughs to the northwest. High monthly fire danger is associated with anticyclones located to the south and with dry northerly to westerly quarter winds. Low monthly fire danger is associated with westerly quarter wind flows. Figure 15.3 shows the dominant synoptic weather type (HSE) for this fire region for all of the extreme MSR months examined. It illustrates anticyclones east of the South Island with easterly flow over the region.

Figure 15.3 Dominant (most frequent) weather type for the extreme MSR months at all stations in the Auckland West/Waikato fire region.



Extreme fire danger in Pukekohe and Woodhill areas occurred when easterly quarter winds are coupled with anticyclonic conditions to the south (Tables 15.1 and 15.2). The prevalent daily weather type and synoptic flow for days with extreme fire risk occurred in anticyclones with an easterly flow over the region. At a broad scale, dominant weather type for Auckland/Waikato for all extreme MSR months is, a strongly anticyclonic pattern bringing easterly flows onto the North Island.

Table 15.1 Comparison of wind flow affecting Pukekohe between the current study and long-term correlations. *Source: Pearce, 1996*.

Extreme Fire Risk Months	Prevalent Wind Flow based on Daily Synoptic Weather Types	Prevalent Wind Flow anomalies based on Monthly Synoptic Weather Types (Heydenrych et al. 2001)
December 1994	Easterlies or south-easterly	South-westerly
January 1995	Easterlies	Easterly
January 1996	Easterlies	Easterly
January 1999	Easterlies	Easterly
February 1999	Easterlies	Easterly
March 1999	Easterlies	No relationship

15.2.3 Auckland East - Coromandel

Auckland East-Coromandel extends south from Whangarei down to Waihi Beach. High fire risk seasons occur with south-westerly quarter winds and anticyclones in the North Tasman Sea. Low SSR values are associated with northeasterly flow (NE) and troughs over New Zealand with northwesterly flow (TNW). Low MSR is found with troughs to the west.

Table 15.2 Comparison of wind flow affecting Woodhill between the current study and long-term correlations. *Source: Pearce, 1996*.

Extreme Fire Risk Months	Prevalent Wind Flow based on Daily Synoptic Weather Types	Prevalent Wind Flow anomalies based on Monthly Synoptic Weather Types (Heydenrych et al. 2001)
November 1996	Easterly and North-easterly	South-westerly
January 1997	Easterlies	Easterly
January 1998	Easterlies, North-westerly and North-easterly	Easterly
January 1999	Easterlies and North-westerly	Easterly
February 1997	Easterlies	Easterly
February 1998	Easterlies and North-westerly	Easterly
February 1999	Easterlies	Easterly
March 1997	Easterlies and North-westerly	No Relationship
March 1999	Easterlies	No Relationship

15.3 Key Vulnerabilities and Potential Impacts

Although the number of wildfires occurring annually in the Auckland Region is low, the large number of lives, forestry, horticulture and property exposed to the wildfire hazard increases the overall threat. To effectively manage fire risk, Auckland's regional fire managers require timely and reliable knowledge of the likely severity of seasonal fire weather and fire danger conditions at a range of scales from short-term forecasts to long-range seasonal predictions.

Impacts from fire hazard are largely in the rural and exotic forests of the Auckland region. During periods of low humidity, seasonal drought and/or strong drying winds during summer, dangerous fire weather situations can be produced. These risks can be exacerbated by accidental and intentional ignition across the region. Information on the vulnerability of urban development to wildfire is absent in the Auckland region. Future hazard and risk assessments are required to assess if this wildfire is a significant threat to the community[2].

[2] IPCC climate change projections signal an increase in fire danger in New Zealand. By the 2080's, 10-50% of more days with very high and extreme fire danger are likely in eastern areas of New Zealand, the Bay of Plenty, Wellington, and Nelson regions. Overall, the fire season length is likely to be extended, with the window of opportunity for controlled burning shifting toward winter.

13.4 References and Additional Reading

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