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More flood disasters in New Zealand

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Abstract
Most New Zealanders reside in coastal regions and many communities are situated on active floodplains. In the last decade there have been many storm events with rainfall annual exceedance probabilities of 1/150 or rarer and there have been many flood-related disasters. Insurance claim statistics suggest that the frequency of floods is increasing. Such statistics are a concern for local government authorities, insurance companies and populations in low-lying areas. Some underlying physical and hydrologic causes of the flood disasters are investigated. It is found that the present numbers of rare rainfall events are not unexpected and there does not appear to be any significant trend evident in the occurrence of river floods. For the areas studied, the river floods appear to cluster in certain decades. The clusters do not occur at the same time in different parts of the country and high rainfalls (required to cause floods) in the southwest of New Zealand are associated with El Niño conditions. Recently there has been more flooding in the north, which is where more of the population lives. The general increase in population has also seen more houses built in locations prone to flooding. Thus the increase in flood-related insurance claims is attributed to more floods in populated areas and to more people getting in the way of floods, rather than to any increase in the number of floods that have occurred. Wise regulation of future infrastructure development will be required to prevent more flood disasters in the years to come.

Introduction
When moisture-laden on-shore winds encounter cooler air masses or are uplifted, flooding can occur. New Zealand is surrounded by ocean, has mountain ranges reaching altitudes over 2,400 m in the North Island and 3,700 m in the South Island and most of the population resides in coastal regions. Many of our communities are founded on active floodplains (Eriksen, 1986). This combination of circumstances has resulted in flooding being New Zealand's most costly natural hazard (McSaveney, 2009).

Around the world there have been many recent flood-related disasters. Although New Zealand has only 15 persons per square kilometre on average, it has also had a spate of such disasters. More comprehensive data is available on rainfall which causes floods and on insurance claims arising from flood damage than on floodplain flows or flood inundation depths. The records show that from the end of the 1990s there have been many 1/150 AEP (annual exceedance probability) rainfall events. Considering the most critical durations of extreme rainfall events, New Zealand suffered from two '150 year' storms in 1999, two in 2004, one in 2005 and one in 2007. Insurance company flood damage statistics reveal that between 1999 and 2007 there were 14 flood-related events (12 in the North Island) which each caused damages exceeding one million dollars (ICNZ, 2009). Such statistics are of concern to the insurance industry, local government authorities and populations in low-lying areas.

This paper addresses the questions of what is causing this apparent increase in flooding and what can be done to reduce flood damage. The first question is tackled as three separate problems: *Are floods occurring more frequently than could be statistically expected? Are there more large floods than in the past?* And, *is there any apparent trend or pattern to the flooding?*

Are floods occurring more frequently than statistically expected?

A comparison of insurance payouts over three decades shows that the number of events causing flood-related insurance claims has been steadily increasing (1976-1985: 12 events, 1986-1995: 16 events, 1996-2005: 27 events). This is shown graphically in Figure 1. Because claims relate to infrastructure, this apparently suggests there has been an increase in the number of floods in developed areas.

To investigate the number of floods that can be expected in populated areas of New Zealand, it is necessary to define 'populated'. New Zealand has many thousands of rural catchments containing individual dwellings, but the dwellings may be sited away from flood-prone areas. According to the 1984 census there were 36 New Zealand catchments with over 500 inhabitants. More specific data is difficult to compile (for example, the town of Kaeo in Northland has around 480 inhabitants and is so flood-prone that there are plans to re-locate it). Following discussions with hydrologic colleagues, for an indicative present-day statistic it is estimated that New Zealand now has around 100 catchments with significant infrastructure.

If separate storms cause floods in separate catchments, the binomial distribution gives the overall probability of floods occurring somewhere in New Zealand in any year. Applying the binomial distribution to 'populated' catchments gives the results as listed in Table 1.

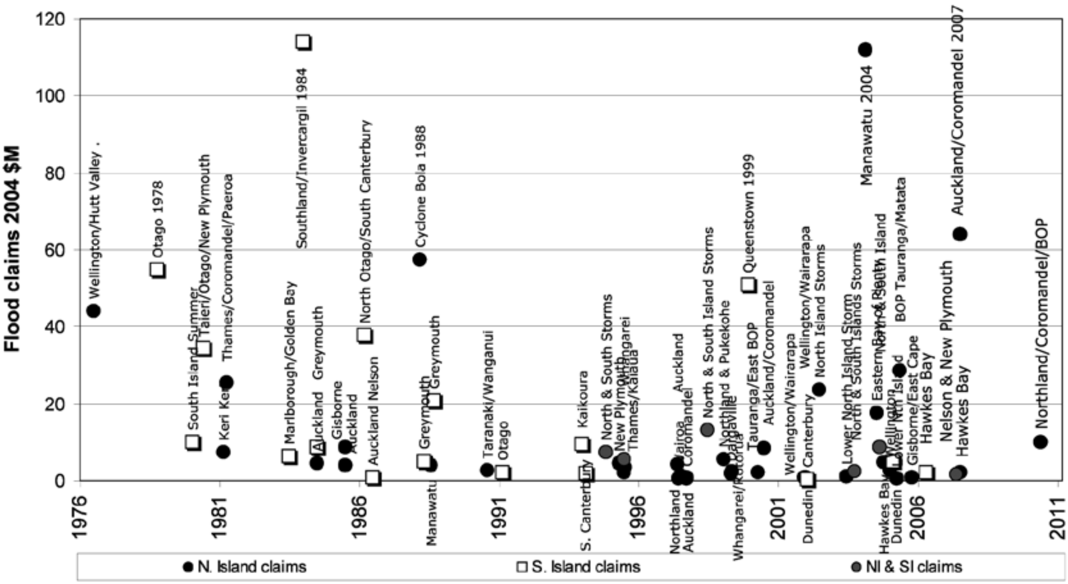

Figure 1 – Insurance claims for flood damage in New Zealand since 1976. Data form ICNZ (2009).

Table 1 – Probability of floods in 100 'populated' New Zealand catchments. Values in brackets show the probabilities for the case of 75 such catchments.

	AEP		
Number per year	**1/150**	**1/100**	**1/50**
1 or more	.49 (0.39)	.63 (0.53)	.87 (0.78)
2 or more	.14 (0.09)	.27 (0.17)	.60 (0.44)
5 or more	.001 (0.0002)	.003 (0.001)	.05 (0.02)

These probabilities increase if the estimate of 100 populated catchments is too low and decrease if the number is too high. The bracketed figures in the table are for 75 populated catchments and indicate the sensitivity of flood occurrence to population expansion. The 100 catchments data show that in any year there is a 60% chance of at least two 1/50 AEP events and a 63% chance of at least one 1/100 AEP event occurring in New Zealand's populated catchments in a given year. There are 'even odds' (p = 0.49) of having one or more 1/150 AEP events in a given year and a 14% chance of two or more. There is a 5% chance of five or more 1/50 AEP events. These figures suggest that the recent numbers of 150-year storms that were mentioned in the introduction are not unusual.

Population and infrastructure growth

As the population of New Zealand has grown, more people have settled in the north of the country than in other regions (Fig. 2). From 1982 to 2006 the population in the Rodney district north of Auckland increased by 90% (Statistics New Zealand, 2008 a).

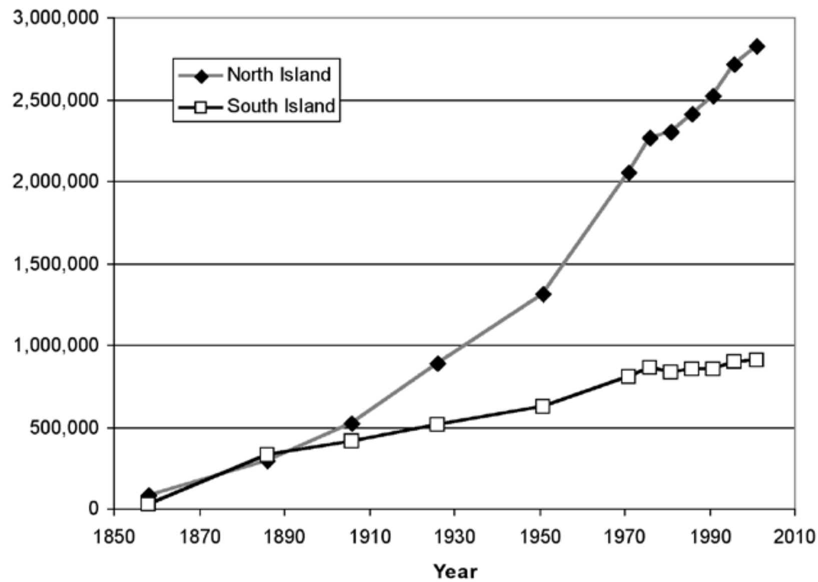

Figure 2 – Growth in North and South Island populations of New Zealand (Statistics New Zealand, 2008b).

As the population expands more houses are built on floodplains, as was foreseen by Eriksen (1986). Local government authorities use planning rules and flood control works in an attempt to protect the population from floods. The planning rules usually restrict development in areas subject to flood hazard. On the other hand, property development advocates can claim compliance with the Building Act (2004) Building Code, which requires that surface water, resulting from an event having a 2% probability of occurring annually, shall not enter buildings. The definition of surface water includes 'that flowing from a drain, stream, river, lake or sea'. In other words, building in areas subject to floods that are greater than a 2% (or 1/50) AEP magnitude is permitted under this aspect of the Building Code. Consequently, development is occurring in areas which are subject to a considerable flood risk. With the calculations given in Table 1, there is an 87% chance of one or more 1/50 AEP events in populated New Zealand every year. Thus the Building Act apparently tolerates an 87% chance of flood damage in New Zealand in any year. While the Building Act may offer tolerable protection from shallow ponding from local rainfall, it is not commensurate with the serious, potentially fatal consequences of a major river flood.

Are there more large floods than in the past?

So far, detailed data analysis has been carried out for the northern South Island, about a quarter of New Zealand's area. Funding priorities mean that it will be some years before specific statistics are available for the whole country. Annual maxima series of stream flow records from the 38 main catchments covering the northern half of the South Island have been analysed to derive 1/5, 1/10, 1/50, and 1/100 AEP flood flows. In Figure 3 dark bars show the number of occurrences per year of floods larger that the

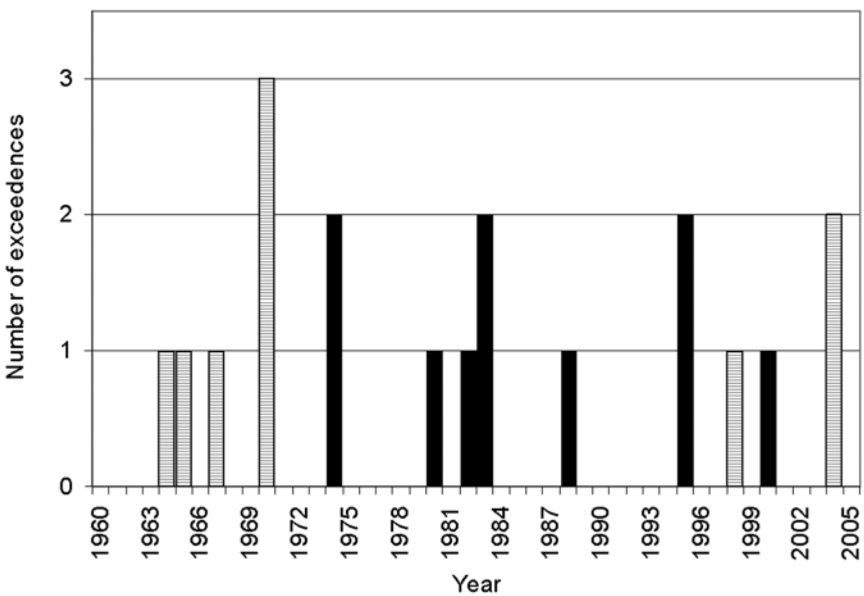

Figure 3 – Dark bars show the number of floods larger than 1/100 AEP occurring in 38 catchments in the top half of the South Island. The ladder bars show the number of floods larger than 1/5 AEP occurring in the Whakatane River, eastern North Island. (Note: some smaller northern South Island rivers do not have complete records for the entire period).

1/100 AEP threshold. For this period, there is no evidence that more frequent 'hundred year' floods are occurring than could be expected, and there does not appear to be any significant trend evident in this figure.

Are there trends or patterns?

Figure 4 shows annual flood maxima series data from the northern South Island split into two equal periods, 1979-1991 and 1992-2004. The figure shows that, for the northern half of the South Island, there were fewer floods over the 1992-2004 period compared to the 1979-1991 period (see also McKerchar and Henderson, 2003). The ratio of the number of 1/5 AEP floods over the 1992-2004 period compared to the number in the 1979-1991 period was 0.7. For 1/20 AEP floods the ratio was also 0.7. This ratio is relatively constant when the numbers of floods in the two different periods are compared at the other AEP levels. Consequently, the northern South Island data set implies that the frequency of smaller floods (e.g., 1/5 AEP floods) can be used to indicate the frequency of larger floods (say 1/100 AEP floods).

Although comprehensive recent statistics have not yet been compiled for other parts of New Zealand, it is assumed that the frequency of smaller floods in other regions can be used to indicate the frequency of larger floods in these regions. In Figure 3 ladder bars show floods larger than 1/5 AEP which occurred in the Whakatane River (1500 km^2 catchment) on the east coast of the North Island. For this river, from 1971 to 1997, no floods exceeded the 1/5 AEP level. There was a similar absence of floods in neighbouring rivers (Rangitaiki, Waioeka and Kaituna) from the mid 1970s to the late 1990s. The statistical probability of such a lull in floods is calculated to be 1% (Blackwood, 2002). Figure 3 shows that the Whakatane 1/5 AEP floods are clustered but there is no increasing trend with time in the number of floods. The floods larger than 1/100 AEP in the northern South Island (dark bars) occurred during the lull in floods in the eastern North Island. Figure 3 indicates that floods tend to occur clustered in groups, but the northern South Island floods did not coincide with the eastern North Island floods. The pattern suggests that climatic effects may be responsible.

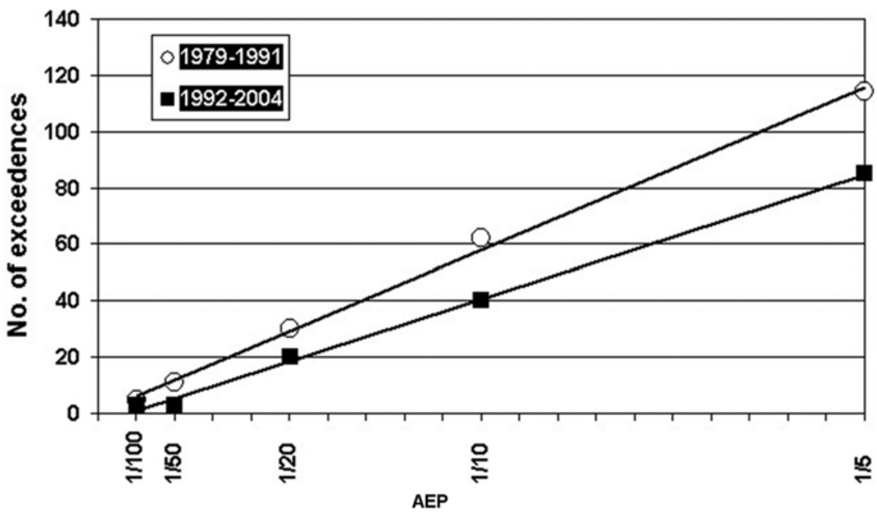

Figure 4 – Number of floods in 38 main catchments of the north of the South Island in successive 13-year periods

Climatic effects

Warmer air can carry more moisture than cooler air and potentially give rise to larger floods. Figure 5 shows average temperatures in New Zealand since 1930. A trend line indicating an increase of around 0.01 degree Celsius every year can be fitted, but the data show some dramatic shifts in average temperature over only two or three years. Particular examples are from 1938 to 1940 when the change was -1.57 degrees and from 1990 to 1992 when the change was -1.25 degrees (due to the 1991 eruption of Mt Pinatubo).

The inter-annual changes are one to two orders of magnitude greater than the warming trend and this variability may obscure any gradual change in flood magnitude due to the warming trend. When Figure 5 is compared with Figure 3 (see the insert on Fig. 5), there does not appear to be any clear relation between the temperature fluctuations and the location or occurrence of river floods in the northern South Island or eastern North Island.

The location of floods is partly determined by atmospheric circulation patterns and the effect of global climate indices on these patterns is now investigated. Figure 6 shows the Southern Oscillation Index (SOI) and the state of the Inter-decadal Pacific Oscillation (IPO) since 1930 (Salinger *et al.*, 2001, updated). A negative IPO phase occurred from 1946-1977 and a positive phase followed. The negative phase was accompanied by more frequent and intense La Niña conditions and the positive phase saw more frequent and intense El Niño conditions. Under El Niño conditions more moist airflows than usual approach New Zealand from the west. Under La Niña conditions there are more north-easterly winds than usual, with the result that the west of the South Island receives less rain than normal.

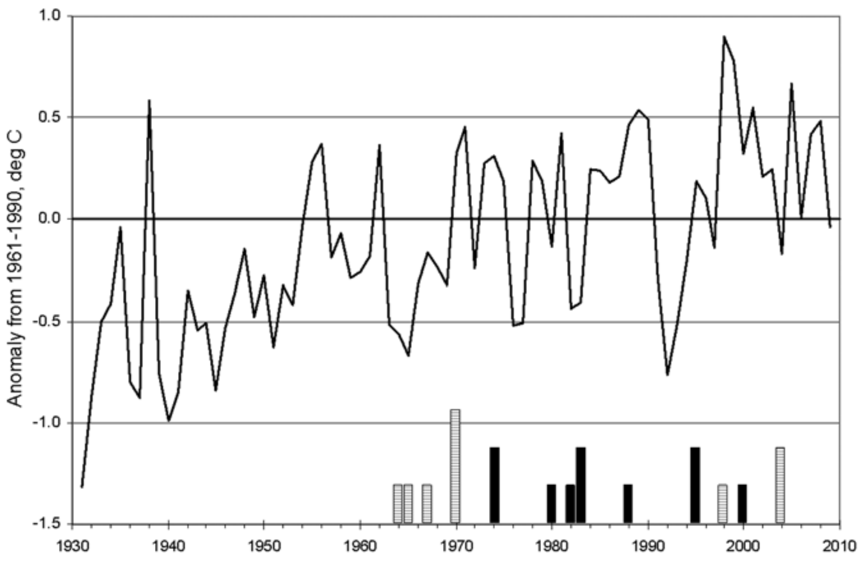

Figure 5 – Temperature departures from the 1961-90 normal, averaged over eleven representative New Zealand sites. Source: www.niwa.co.nz/our-science/climate/news/all/nz-temp-record. The insert at lower right shows the floods shown in Figure 3.

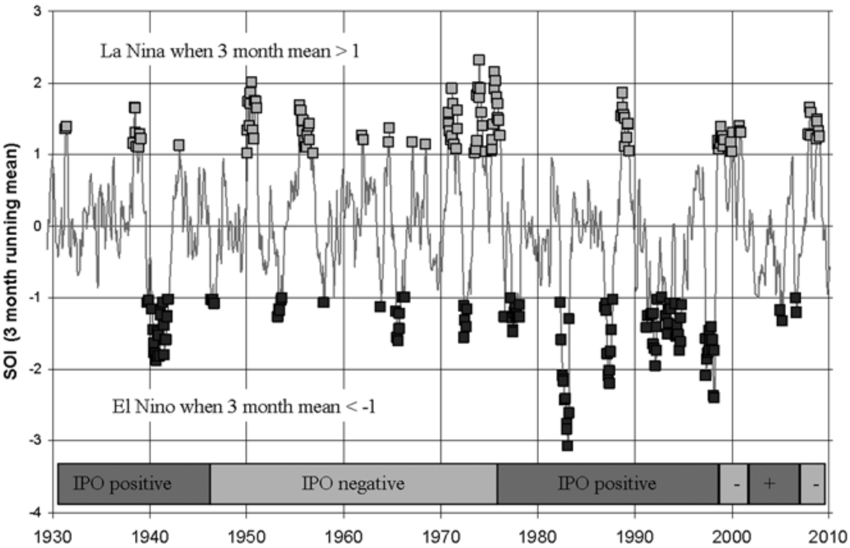

Figure 6 – Southern Oscillation and Interdecadal Pacific Oscillation indices since 1930. The black squares show El Niño events and the grey squares show La Nina events. Dark grey horizontal bars show the positive phase of the IPO and light grey bars show the negative IPO phase.

To investigate any effect of the IPO, rainfall totals from all parts of New Zealand are compared in Figure 7, which shows areal and temporal rainfall differences between 1978-1998 in the positive IPO period and 1960-1977 in the negative period. The east and north of the North Island had less total rainfall post-1977 compared to the 1946-1977 negative period. The north of the South Island had more total rainfall during the 1978-1999 positive period. The north east of the North Island had less rainfall during the positive 1978-1999 period. Comparing Figure 7 with the examples of Figure 3 confirms the intuitive conclusion that changes in rainfall locations correspond to changes in the location of floods. This analysis

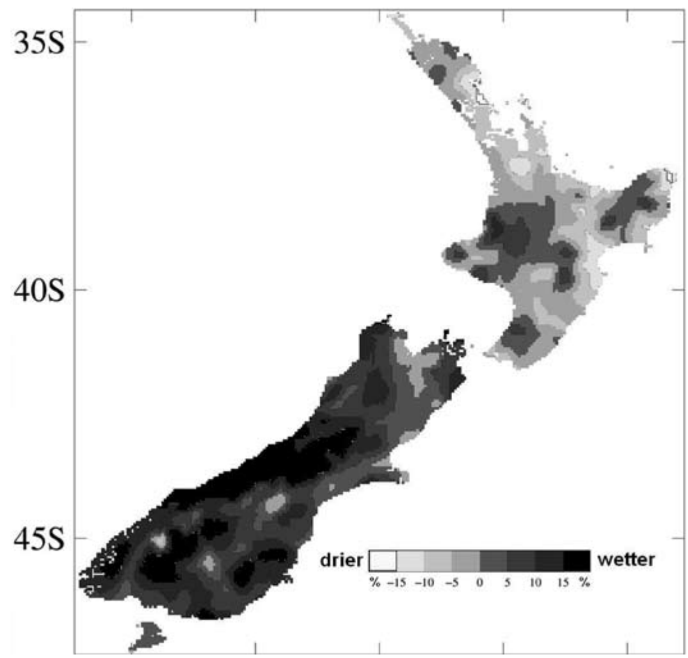

Figure 7 – Rainfall from 1978-1998 compared with rainfall from 1960-1977 (adapted from MfE, 2008).

suggests that inter-decadal global circulation patterns affect where floods occur in New Zealand. Blackwood (2002) and McKerchar and Henderson (2003) reached similar conclusions.

These long-term shifts in precipitation are evident retrospectively, but shorter-term relations between climate indices and extremes of rainfall are not immediately obvious. To see the effect of frequent El Niño conditions on rainfall it is necessary to derive a comparable rainfall index. The SOI results if the monthly mean sea level pressure difference between Tahiti and Darwin, less the long-term average pressure difference for the month in question, is divided by the long-term standard deviation of the pressure difference for the month (Troup, 1965). An El Niño event is defined when the 3-month running mean of this monthly SOI series is less than -1.0. A comparable Milford Rainfall Index (MRI) can be defined for the southwest of New Zealand, based on monthly maximum daily rainfalls at Milford Sound. The MRI is calculated as the difference between the monthly maximum daily rainfall and the long-term average of maximum daily rainfalls for the month in question, divided by the long-term standard deviation of the month's maximum daily rainfalls. A significant Milford rainfall month is defined if the 3-month running mean of the MRI exceeds 1.0 (called an 'El Milfo' month). Figure 8 shows a comparison of the number of El Niño months per year with the number of El Milfo months per year since 1930. From Figure 8 it is clear that in the southwest of New Zealand, there is a close correspondence between years with many El Niño events and years with high rainfall events.

Reducing flood damage

To reduce the amount of flood damage that is occurring it will be necessary to reduce the flood hazard or move infrastructure away from the hazard. Flood hazards can be reduced or avoided only if it is known where and/or when floods will reach dangerous levels. The 'where' can be achieved through the production of flood inundation maps to assist long-term planning, and the 'when' by flood forecasts for shorter-term evacuation planning and climate forecasts for longer-term preparations.

Provided the data are available, inundation maps can be based on measurements of historic floods. As New Zealand does not have long-term inundation records and land surface levels are changing due to anthropomorphic and tectonic effects, it is

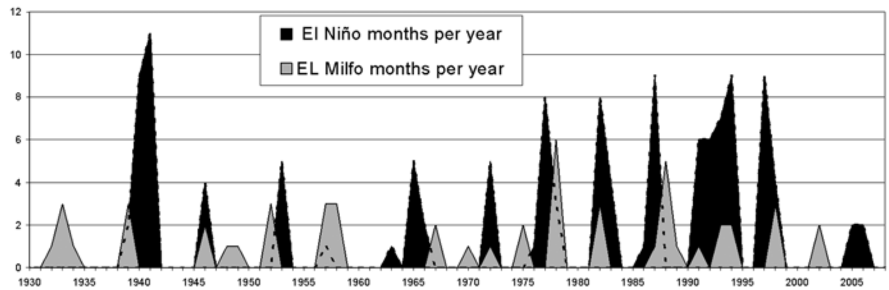

Figure 8 – Influence of long-term trans-Pacific pressure differences on heavy rainfalls in the South-west of New Zealand. An El Niño month occurs when the 3-month running mean of the Southern Oscillation Index (Troup, 1965) is less than -1. An El Milfo month is defined when the 3-month running mean of standardized monthly maximum daily rainfall at Milford Sound exceeds 1.

necessary to calculate where flood inundation could occur. This is currently facilitated by airborne laser surveys that accurately map ground topography and by high resolution, two-dimensional computational hydraulic models that predict inundation extent, depths and velocities. Floods can now be forecast up to two days in advance using atmospheric circulation models, and research into climate change is being given world-wide priority.

Unfortunately, although flood hazard is being better quantified and forecast, more flood disasters are going to occur if development continues in locations that are at risk. There is a proposal to change the New Zealand Building Code to require that surface water from 1/100 AEP events shall not enter housing. The assumptions for Table 1 indicate that, if the proposed requirement is implemented nationwide, the probability of flooding housing in a 'populated catchment' would eventually reduce from the present indicative estimate of an 87% chance per year to a 63% chance per year; i.e. there will remain a very high probability of New Zealand housing suffering from flood damage in any given year.

Discussion and conclusions

While there has been an increase in flood-related insurance claims in New Zealand, for the sites studied there has not been a noticeable overall increase in extreme rainfalls or flood frequency. It appears that the locations of extreme rainfalls change with inter-decadal global circulation patterns and, in southwestern New Zealand, heavy rainfalls tend to coincide with El Niño events on an annual basis. During the lull in El Niño events from 1999 to 2007, there were frequent floods in the north of New Zealand, which is where more of the population lives. In addition, the general increase in population has seen more houses built in locations prone to flooding. Because there is no evidence of an increase in flood size or overall frequency, the increase in flood-related insurance claims is attributed to the recent floods having occurred in the more populated parts of New Zealand and to increased development on floodplains.

In locations that are protected by flood banks, the local population do not suffer from frequent, smaller floods and therefore people forget that these are potentially hazardous zones. In general, the higher the level of flood protection, the greater the damage that will occur when the protection level is exceeded. New Zealand's planners therefore need to seriously consider the probabilities and consequences of super-design events if future disasters are to be avoided.

Flood maps are being computed to identify flood hazard in several parts of New Zealand and it is hoped that future flood risk and damage can be reduced. This will require upgrading of some river control schemes and tighter regulations on where development is permitted. The authorities should recognise that many flood disasters are 'man-made' and regulations protecting against flood hazard should be consistent with the safety levels applied to other dangerous events and activities in our society, such as bulk chemical storage requirements, building design to resist earthquakes and strict rules governing transportation of dangerous goods. To put flooding in perspective, if river routes could be planned and city locations were fixed by nature, it is extremely unlikely that a Resource Consent could ever be obtained to route up to 4,500 tons of water per second at velocities of over 3 m/s with an overtopping safety allowance of 50 cm through a densely populated urban area. This example represents a design flood in the Manawatu River passing through Palmerston North city (where riparian development is continuing, as in many other parts of New Zealand). The hazard, risk and potential loss of lives from a flood disaster do not depend on whether the river pre-dated the building development or *vice versa*, yet this example illustrates that a much higher level of flood risk is tolerated under the conventional flood planning perspective.

In summary,

- The location of New Zealand floods is affected by climatic conditions.
- There is no apparent increase in flood size or frequency at the sites studied.
- The risk of flood disasters has increased due to increasing development within floodplains.
- Tools are available to accurately evaluate flood risk.
- The present regulatory framework allows a high level of flood risk.
- Even if proposed flood-related improvements to the Building Code are implemented, there will still be a very high probability of flood damage to New Zealand housing in any year.

Acknowledgements

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