**Submission by WILLEM PIETER de LANGE**

Executive Summary

1. This submission was prepared at the request of the Matarangi Future Coastal Protection Line Objection Group and assesses the methodology and assumptions used to determine the Current Coastal Erosion Line (CCEL) and Future Coastal Protection Line (FCPL) by Dahm and Munro (2002) and FOCUS (2012).
2. The CCEL and FPCL are uniform setback distances whose extent depend on the type of beach: either a pocket beach, which is short, narrow and relatively steep; or a sand barrier beach, which is long wide and relatively flat. The CCEL represents the sum of a natural dynamic fluctuation term, which represents the maximum historic storm erosion for that type of beach, and a protection dune buffer term, which is intended to provide a residual dune width between the beach and development following a worst case storm. The FCPL is the sum of the CCEL and the maximum calculated shoreline recession due to sea level rise for that type of beach.
3. The approach used is described as precautionary and does not quantify the probability of coastal erosion occurring, the frequency/magnitude relationships associated with any of the processes that drive coastal erosion, or consider any impacts of climate change other than an assumed sea level rise. The absence of an assessment of climate change impacts contradicts the title of the FOCUS report.
4. Apart from the maximum historic erosion for each type of beach, there is no consideration of historic trends or sediment budgets for any of the beaches. Peer reviewers noted that both, particularly sediment budgets, should have been considered. This is an integral component of the proposed best practice for New Zealand.
5. The shoreline recession due to sea level rise was calculated using the Bruun Rule. This method is not appropriate, and should not have been used. The available observations indicate that shoreline erosion for Matarangi Beach is driven by infrequent storm events and historic sea level rise has had no detectable impact.
6. The projected sea level rise of 0.9 m suggested by MfE (2008) guidelines for consideration was adopted. A range of sea level scenarios was not evaluated, and the maximum calculated recession was adopted as a standard value. This approach does not quantify the probability of the assumed sea level rise occurring, and very likely overestimates the risk of coastal erosion.
7. The methodology adopted does not provide the information required by the New Zealand Coastal Policy Statement 2010 on the risk of coastal erosion, and in particular does not identify areas of high risk. The methodology followed also does not conform to the suggested best practice for determining coastal erosion hazard.
8. Therefore, the proposed FCPL and existing CCEL are not fit for the purpose of informing planning decisions on coastal erosion hazard.

Scope of Submission

1. I have prepared this submission at the request of the Matarangi Future Coastal Protection Line Objection Group (Appendix 1). In this submission I will assess the methodology and assumptions used to determine both the Current Coastal Erosion Line (CCEL) and the proposed Future Coastal Protection Line (FCPL). In particular, I will consider the use of the Bruun Rule, the assumed sea level rise projections, possible impacts of climate change, the assumed response of Matarangi Beach to future sea levels and climatic conditions, and finally the risk of coastal erosion

CCEL and FCPL

1. Dahm and Munro (2002) estimated the CCEL and FCPL (Figure 1) as the Primary Development Setback (PDS) and Secondary Development Setback (SDS) respectively. The CCEL included generic values for natural dynamic fluctuation (storm cut and fill cycles) and a protective dune buffer (10 m) to provide a residual dune following a worst-case storm event. No allowance was made for long-term trends in shoreline position as it was assumed that there was no significant source of sediment, and, therefore, no significant trend was present.

|  |
| --- |
|  |
| Figure 1 – Derivation of estimated CCEL (Primary Development Setback) and FCPL (Secondary Development Setback) from Dahm and Munro, 2002). |

1. Beaches were grouped into two types, mostly on the basis of beach length (Figure 1): as short, steeper, narrow pocket beaches; or long, flatter, wide dune barrier beaches. The assumed natural dynamic fluctuation was 25 m and 30 m for these respectively. The FCPL included an additional term for the effect of sea level rise over 100 years based loosely on the Bruun Rule as 15 m for steeper pocket beaches and 20 m for flatter dune barrier beaches.
2. Strictly both the dune barrier beaches and pocket beaches are classified as pocket or embayed beaches, where headlands at both ends of the beach system restrict or prevent the exchange of sediment (Horikawa, 1988). Therefore, the distinction between the two groups appears to be predominantly based on the size of the beach and not a true geomorphic classification.
3. The FCPL and CCEL appear to be derived using the same methodology, the difference being the time period over which the coastal erosion is estimated. The only factor that appears to be different between the two lines is the amount of erosion estimated in response to projected sea level rise. It is not clear what allowance has been made for the long-term trends in shoreline position at any of the beaches considered. This submission will consider long-term trends as part of the discussion on shoreline response.

The Bruun Rule

1. Dr Hilton in his peer review of the FOCUS (2012) report stated, “The Bruun Rule has been discredited by the world’s leading geomorphologists”. This is a correct interpretation of the weight of evidence presented in the literature. Tonkin and Taylor Ltd (T&T), argued that the Coromandel beaches meet the requirements for the application of the Bruun Rule, without providing justification, but observed that an assessment of the sediment budget was required. Two studies by Everts (1985) and Zhang *et al* (2004) were cited as support for the applicability of the Bruun Rule. Both studies considered the east coast of the USA, and both studies excluded sites similar to the Coromandel beaches: the studies only considered long straight beaches with a net littoral drift on a tectonically stable coastline, at sites that were not in proximity to tidal inlets or structures, and predominantly sites with a long-term trend of erosion.
2. The Everts (1985) study developed a sediment budget model as an alternative to the Bruun Rule. This study only showed that a negative sediment budget results in erosion trends as predicted by the Bruun Rule. It should be noted that the Bruun Rule can only predict erosion.
3. The Zhang *et al* (2004) study indicates that for the sites examined, the shoreline erosion rate is 50-120 times the rate of sea level rise. In contrast, the FOCUS (2012) report suggests that for the Coromandel beaches it is 19-37 times the rate of sea level rise. The difference arises due to the way the slope of the nearshore zone is determined. Zhang *et al* (2004) in effect estimated the slope that predicted the observed shoreline erosion from the observed sea level rise, assuming that all of the erosion was due to sea level rise. Their ratios of 50-120 are the reciprocals of the gradient of the nearshore zone, and correspond to typical gradients for the continental shelf, even though Zhang *et al* (2004) suggest that the gradient for the Bruun Rule should be determined for depths less than about 10 m.
4. The FOCUS (2012) report bases the Bruun Rule ratios on the slope out to a depth defined by the Hallermeier Limit. There are two different Hallermeier limits: an inner limit that corresponds to the seaward limit of the active surf zone; and an outer limit that corresponds to the seaward limit of the extreme surf zone during storm conditions that are exceeded for less than 12 hours per year. Interestingly, Zhang *et al* (2004) argue that storm conditions are not a good indicator of long-term shoreline erosion for the sites they considered, which is borne out by their ratios. If the FOCUS (2012) report ratios are valid predictors of shoreline erosion for the East Coromandel beaches, then they indicate that storm processes and not sea level rise dominate coastal erosion.

|  |
| --- |
| matarangi.png |
| Figure 2 – Shoreline change at Matarangi Beach between 1979 and 2011  (http://www.waikatoregion.govt.nz/Environment/Environmental-information/Environmental-indicators/Natural-hazards/Coastal-hazards/co16-report/) |

1. There is sufficient data to undertake an analysis similar to Zhang *et al* (2004) for the East Coromandel beaches. Wood (2010) has partially done such an analysis, although it was primarily based on beach volume and not shoreline erosion. The key findings of this study were presented by Wood et al (2009), and indicate that beach volume is influenced primarily by storm events. Dahm and Gibberd (2009) suggest that coastal erosion for these beaches is the result of the cumulative effect of several storms. However, Wood (2010) suggests that the East Coromandel beach volume changes are predominantly the consequence of isolated storm events, separated by general beach recovery. This is consistent with the findings of Healy, Dell and Willoughby (1981) based on aerial photographs between 1945 and 1978, and the summary of shoreline changes for Matarangi based on beach profiles between 1979 and 2011 posted by the Waikato Regional Council on their website (Figure 2).
2. The maximum sea level rise between 1979 and 2009 based on Auckland tide gauge records (Hannah *et al*, 2010) was 13 cm (sea level peaked in 2001 over this time interval). Therefore, the estimated shoreline erosion due to sea level rise for Matarangi Beach based on the Bruun Rule is 3.77-4.81 m. From Figure 2, it is clear that storm events have significantly larger impacts than sea level rise over the 32 years of record. Further, the sites not affected by the tidal inlet (CCS13 and CCS14) display an underlying trend of accretion and not erosion. However, the time series starts after a severe storm induced erosion event in 1978, so it is possible the observed accretion is solely due recovery following the storm if there are no additional sources of sediment. Likely additional sediment sources are discussed below.
3. In summary, the available evidence for the East Coromandel beaches indicates that shoreline erosion is predominantly driven by storm events, and, therefore, assessment of coastal erosion risk should be based on a sediment budget approach. The Bruun Rule is not an appropriate method to assess the sea level rise component of shoreline change, and as noted by the T&T, should only be applied when sediment budgets are accounted for. This was not done by the FOCUS (2012) report, and no evidence was provided to support the assertion that the Bruun Rule is suitable for the purpose of determining the FCPL for East Coromandel Beaches.

Sea level rise projections

1. The FOCUS (2012) report assumes a sea level rise of 0.9 m over the next 100 years based on the MfE (2008) guideline for planning purposes of 0.8 m by AD 2100 and an additional 0.1 m by AD 2110. For Matarangi Beach this equates to 26.47 m of erosion based on the Bruun Rule (approximately 10 times the erosion that should have occurred between 1979 and 2009). FOCUS (2012) increased the value to 30 m to allow for uncertainty and “fairness”. It was argued that the 0.9 m value does not represent an upper level or worst-case sea level. This assertion is incorrect.
2. Prior to MfE (2008) a value of 0.5 m per century was generally adopted for sea level rise (As in Dahm and Munro, 2002) following the setting of a legal precedent in a case at Ohope Spit involving the Whakatane District Council in 1984. This case involved the determination of a coastal hazard zone that I undertook. At that time 0.5 m was the accepted flood freeboard for the Whakatane District and I included it in the coastal hazard zone because the location involved was inside the estuary. It was included in addition to a predicted sea level rise of 0.25 m per century based on observed rates of sea level rise. Following the High Court decision, the 0.5 m flood freeboard was treated as a sea level rise factor, even though it was only about 25% of the EPA (1983) most likely sea level projection (Figure 3). Further, the predicted 0.25 m sea level rise was omitted, resulting in an overall reduction in assumed future water level increase from 0.75 m to 0.50 m.

|  |
| --- |
| SeaLevelProjections.pdf  SeaLevelRise |
| Figure 3 – Ranges of predicted and projected sea level rise by AD 2100 from EPA and IPCC sea level assessments. Also tabulated are naïve predictions based on observed 20th Century sea level rise. |

1. Coincidentally the 0.50 m sea level value corresponded to the most likely projected sea level by AD 2100 of 0.49 m for the IPCC Second Assessment Report in 1995 and 0.44-0.485 m for the IPCC Third Assessment Report in 2001 (Figure 3).
2. The MfE (2008) Guidance Note changed from the most likely projected sea level used previously, to the maximum sea level projected by the IPCC AR4 report in 2007 (0.59 m) plus an additional 0.20 m to allow for ice sheet dynamic collapse, and 0.01 m of rounding. Subsequent research indicated that the 0.20 m for ice sheet dynamic collapse was not justified, but it is still incorporated in the 0.8 m of the MfE (2008) sea level rise by AD 2100.
3. Hannah *et al* (2010) suggest that the absolute sea level rise projections for the UK are an appropriate proxy for projecting sea level rise for the Auckland Region (Figure 4). These projections indicate that the MfE (2008) value of 80 cm is an extreme value lying beyond the upper 95% value for the worst-case emission scenario.

|  |
| --- |
|  |
| Figure 4 – Projected sea level by AD 2090-2099 with 90% confidence limits from Hannah et al (2010) |

1. FOCUS (2012) note that some sea level projections are higher than 0.9 m as reported by RSNZ (2010). All of the higher projections cited by RSNZ (2010) are based on semi-empirical methods that attempt to scale sea level directly from projections of global temperature. Gregory *et al* (2012) in their review of 20th Century sea level rise evaluated these projections and concluded that the methods “depend on the existence of a relationship between global climate change and the rate of GMSLR [*Global Mean Sea Level Rise*], but the implication of the authors’ closure of the budget is that such a relationship is weak or absent during the twentieth century.” In other words, there is not a strong cause and effect relationship between global temperature changes and the rate of sea level rise (or fall) at centennial time scales.
2. The IPCC AR5 assessment in 2013 also concluded that there is no consensus on the reliability of semi-empirical methods that project higher sea levels and assigns low confidence to their projections. The methodology for assessing the ranges of sea level projections was changed for the AR5 assessment, which makes it difficult to directly compare the 2013 projections (Figure 5) with the earlier values (Figure 3). Importantly, the mid-point rise is now quoted instead of the most likely or median rise. Since the distribution of values for each scenario is asymmetrically distributed (most projections cluster towards the minimum rise in the range), the mid-point rise is higher than both the mean and median. Further, the IPCC AR5 projections are based on emission scenarios and not economic activity scenarios. However, for the purposes of comparison, the most likely sea level rise is consistent with emission scenario RCP2.6, showing a further reduction in the projected sea level rise by AD 2100.

|  |
| --- |
|  |
| Figure 5 – IPCC AR5 2013 sea level projections for different emission scenarios (RCP), compared to the IPCC AR4 2007 SRES A1B scenario used to set the MfE (2008) planning sea level projections |

1. RSNZ (2010) and Hannah *et al* (2010) both report that the rate of sea level rise around New Zealand has decelerated over the 20th Century and has continued to do so this Century. This is consistent with the findings of Gregory *et al* (2012) who report a global slowing in the rate of sea level rise, leading in part to the poor relationship between global temperature and sea level rise, and Chen *et al* (2014), who found that despite decadal scale fluctuations in the rate of sea level rise, the rate of sea level rise has continued to slow in the 21st Century. A reduction in the projected sea level rise by AD 2100 is consistent with the observed slowing in the rate of sea level rise.
2. The IPCC sea level projections are preferentially based on deterministic modelling of assumed processes contributing to sea level rise based on the global temperature projections produced by models based on radiative forcings derived directly from emissions scenarios (AR5) or indirectly from economic scenarios (earlier assessments). The results are referred to as projections because they strictly do not have any associated likelihood of occurrence, which is inherent to predictions. There are several issues that arise from the dependence of projecting sea level rise on the projected global temperature.
3. The review by Gregory *et al* (2012) found a poor relationship between global temperature and sea level that results in *low confidence* in semi-empirical models that directly predict sea level from global temperature. The same problem arises for deterministic models, although it is argued that there is higher confidence in process-based deterministic modelling. It is clear from the published literature that there is ongoing disagreement between different studies about the relative magnitude of different contributions to observed sea level rise (Gregory *et al*, 2012), which in part accounts for the range of sea level projections for any particular emissions scenario.
4. Meyssignac *et al* (2012) analysed sea level trends for the tropical Pacific Ocean and found no signal that could be linked to greenhouse gas forcing. Instead they attributed all the observed sea level trends to natural variability. Chambers *et al* (2012) reported a consistent 60-year cycle in sea levels, albeit with different timings in the major ocean basins, which indicates a strong internal variability driving sea level. This is consistent with the observed PDO signal in sea level data from Auckland (Bell *et al*, 2000). This pattern is not accounted for in sea level projections, particularly the semi-empirical methods that have used the 30-year rising part of the cycle as the basis of their projections. The lack of a clear greenhouse-forcing signal also raises doubts about the use of greenhouse gas projections to drive sea level rise in deterministic models.
5. There is a growing deviation between projected and observed global temperatures; with models projecting greater warming than has been observed over the last 2 decades (Fyfe *et al*, 2013; Fyfe and Gillett, 2014; Santer *et al*, 2014; Schmidt *et al*, 2014). This suggests that the projected temperatures based on the models, and hence projected sea levels derived by deterministic models, are too high. This was demonstrated by Houston (2013), who compared observed sea levels between 1993 and 2012, as measured by satellite altimetry, with the IPCC AR4 projections for the same period, and found that by 2012 observed sea level fell within the lowest 50% of the projections.

|  |
| --- |
| RCP8.5.tiff |
| Figure 6 – Summary of CO2 assumed CO2 emissions from fossil fuels and industry for Representative Concentration Pathways (RCPs) considered in Figure 5.  (https://www.wmo.int/pages/themes/climate/emission\_scenarios.php) |

1. The largest rise in sea level is associated with RCP8.5, and the maximum value for this scenario is the closest to the MfE (2008) planning guideline of 0.80 m. The RCP8.5 emissions scenario is based on the assumption that fossil fuel and industrial emissions of CO2 will steadily increase to 28 PgC.y-1 by AD 2100 (Figure 6). However, an analysis of potential CO2 emissions from these sources by Tans (2009) found that emissions associated with known reserves peak at 11.1 PgC.y-1 by AD 2029, and inclusion of estimated unconventional resources results in emissions peaking at 16.1 PgC.y-1 by AD 2044. This suggests that the RCP8.5 emissions scenario significantly overestimates the available CO2 resources, and hence exaggerates the potential radiative forcing in the future.
2. Therefore, the 0.9 m sea level rise adopted by FOCUS (2012) is an extreme value, and the higher values suggested by the peer reviewers are even more so. Note that for a risk-based assessment it is not appropriate to argue that this is reasonable because sea level may continue to rise for centuries. It would be equally valid, and unreasonable, to argue that it is likely that sea level will fall some time in the future due to the onset of the next glacial period. Such an argument is purely speculation. Suggested best practice is to consider a range of sea level scenarios, and not select a single value (Ramsay *et al*, 2012).
3. It should also be noted that sea levels around the New Zealand coastline over the last 8000 years have been higher than the projected future sea levels. Clement et al (2010) combined an earlier reconstruction of Holocene sea levels by Gibb (1986) with additional data, primarily from northern New Zealand, to produce a revised sea level curve (Figure 7).

|  |
| --- |
| NZ-Sealevel.png |
| Figure 7 - Revised New Zealand Holocene sea level curve (Clement et al., 2010). |

1. The revised curve (Figure 7) indicates that sea level may have reached approximately the present position up to 1000 years earlier than Gibb (1986), but most of this difference is due to a revision of the 14C dates since 1986. Clement et al (2010) also indicate that the eustatic sea level was likely 0.3 m higher than indicated in Figure 7 around 7500 BP. This would make the New Zealand curve consistent with the Zone V (most of Southern Hemisphere) eustatic sea level curve of Clark and Lingle (1979), the recent assessment of the Australasian eustatic sea level curve (Lewis et al, 2013), and the thermosteric sea level behaviour implied by recent reconstructions of Holocene Australasian ocean heat content (Rosenthal et al., 2013).
2. Dougherty and Dickson (2012) re-examined a key site used for sea level reconstructions at Miranda in the Firth of Thames. They found that sea level was approximately 2 m higher than the present 4000 years ago, which is higher than the reconstruction in Figure 7. Sea level then fell to approximately the present level about 1000 years ago, which is in agreement with Figure 7. They also found that the development of the coastal plain at Miranda was largely controlled by variations in storm activity, although falling sea levels influenced the development of shell ridges (*cheniers*), probably due to the reduction of sediment supply.

Projected climate change

1. NZCPS 2010 requires that the identification of high-risk coastal areas consider the impacts of climate change on coastal processes and sediment dynamics. Dr Hilton correctly pointed out in his review that the FOCUS (2012) report ignores a range of processes that affect coastal erosion, and ignores the impact of future climate change. As pointed out by T&T in their review, and in the discussion above, shoreline response in terms of erosion and accretion is dependent on the sediment budget, with long-term erosion being associated with a negative budget.
2. Zhang and Leatherman (2004) point out that sea level rise by itself does not cause erosion, because there is insufficient energy associated with sea level rise to drive the transport of sediment. Therefore, while a higher sea level may facilitate erosion, other processes are necessary for erosion to occur. If climate changes, then these processes may be affected.
3. In his peer review, Dr Hilton summarised projected climate changes for the north east coast of New Zealand from the OPMSAC (2013) report as:

i) Average precipitation will be up to 5% lower by AD 2040;

ii) Easterly winds will be more frequent;

iii) Temperatures will be hotter, with at least 40 extra “hot” days >25°C by AD 2100;

iv) An increase in extreme rainfall events; and

v) An increase in droughts.

1. Unfortunately, the OPMSAC (2013) report does not explain the methodology used to derive these projected changes except that it is based on numerical models and selected scenarios. If they are derived from the global climate models that also drive global sea level projections, then the same issues discussed above arise.
2. In terms of the coastal erosion hazard for the East Coromandel beaches, the projected increase in easterly winds and extreme rainfall events are likely to influence coastal processes driving erosion. For this coast, onshore winds (easterly) tend to transport sediment offshore over the inner continental shelf, whereas offshore winds (westerly) tend to transport sediment onshore (de Lange, 2001). Therefore, an increase in easterly winds associated with a decrease in westerly winds will tend to facilitate coastal erosion. An increase in easterly winds may also increase the mean wave height, which will result in a change in surfzone dimensions. Since the FOCUS (2012) use the seaward limit of the surf zone as the closure depth, changes in surfzone width due to increasing easterly winds should affect their results.
3. Intense rainfall events in the catchments leading to the East Coromandel Coast are typically associated with flooding. The floodwaters transport sediment to the estuaries and continental shelf. As will be discussed below, there is evidence that sediment is added to East Coromandel beaches as a consequence of flooding. Therefore, an increase in intense rainfall events may increase the rate of sediment supply to the beaches, and offset losses due to other factors.
4. Overall, the projected climate changes that are relevant to coastal erosion hazard are smaller in magnitude than observed interannual and decadal variations. Key drivers at these timescales include the El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) (de Lange, 2001). The PDO is also referred to as the Interdecadal Pacific Oscillation (IPO) in Australia and New Zealand (Power *et al*, 1999), but it affects the whole Pacific Ocean and was first defined as the PDO in the Gulf of Alaska (Mantua *et al*, 1997).
5. Wood *et al* (2009) demonstrate that changes in beach volume for East Coromandel beaches are in phase with the climate variations associated with the PDO. These changes are manifest as beach rotation in response to changes in dominant wave approach direction, and severity of storm impacts. All East Coromandel beaches were found to respond in phase with the PDO, but the magnitude of the responses varied with beach morphology and the length of the beach. Matarangi and Pauanui Beaches showed the strongest response.
6. The projected climate changes over the next 25 years outlined above are consistent with the cool phase of the PDO, and as noted by OPMCSA (2013) the projected climate changes for this period will be difficult to distinguish from natural climate variability. Beyond that, the projected climate variations are inconsistent with the PDO variations. Natural climate oscillations, such as the PDO, are not simulated by the global climate models (Goddard, 2014), and there is growing evidence that deviation between projected climate change and observed change is due to neglecting these oscillations (Kosaka and Xie, 2013). Dowdy *et al* (2014) report that downscaling of 18 global climate models predicts a reduction in the frequency and intensity of major extratropical storms for the east coast of Australia due to global warming, resulting in a reduction in severe wave events. The same type of storms are associated with coastal erosion for the east coast of the North Island (Hay et al, 1991; Dunn, 2010), and these results that there may also be a reduction in storm activity driving coastal erosion for the East Coromandel beaches.
7. The climate projections summarised by OPMCSA (2013) suggest that as a consequence of global warming the influence of the PDO will reduce, which would also imply a reduction in the frequency of severe coastal erosion for the East Coromandel beaches (*viz* de Lange, 2001). There is no long-term record of the PDO for New Zealand, but proxy records of storm activity provide an indication of PDO behaviour. These records are also a useful indication of storm activity changes for the Coromandel Peninsula.
8. Lake Tutira, Hawkes Bay, provides a record of North Island storm activity for the last 7200 years (Page *et al*, 2010), which was found to be a useful proxy for the discharge of sediment from the Waipaoa River catchment into Poverty Bay (Upton *et al*, 2013). The sediment discharge from the Waipaoa River was simulated over the last 5,500 years, and found to correlate well with continental shelf sedimentation determined by coring, and indicated that centennial to millennial scale precipitation fluctuations were the primary driver of changes in sedimentation rates. As noted by OPMSCA (2013) extreme precipitation is one of only 2 climate indicators that show a weak relationship with observed global warming for some areas of Earth.
9. Figure 8 shows the Lake Tutira storm activity measured as years between storm event deposits within the lake, climate proxy data derived from carbon (precipitation) and oxygen (temperature) isotopic ratios in speleothems from Waitomo, the dune phases preserved at Te Horo on the Kapiti Coast, and the ages of palaeotsunami deposits found on Kapiti Island by Goff *et al* (2000). Page *et al* (2010) identified 25 periods of increased frequency of major storms over the last 7,200 years, of which 9 were of at least 100 years duration (shaded bands in Figure 8). Dougherty (2013) reported 25 palaeo-beachfaces representing major erosive events preserved within Omaha Spit (which includes the 1978 event). Omaha Spit is similar to Omaro Spit (Matarangi Beach), although it is located further north, and is more sheltered from open ocean storm waves.
10. Page *et al* (2010) found no relationship between storm activity and ENSO (3-7 year) climatic variations, and speculated that storm behaviour may be influenced by the interaction of ENSO, PDO (50-60 year fluctuations) and the Southern Annular Mode (SAM). They also noted that, as is evident in Figure 8, Holocene climate for New Zealand has involved multiple periods of rapid change, particularly in terms of storm activity.
11. Gomez et al (2011) examined the Lake Tutira data in conjunction with climate proxy data from Ecuador, the Western Pacific Warm Pool, and Central Antarctica, in order to assess the combined role of ENSO and SAM climatic variations. They argue that La Niña (positive) conditions and a positive SAM both enhance rainfall and the incidence of extratropical storms and strong easterly to northeasterly winds for the eastern North Island. Hence, the storm activity record from Lake Tutira represents the relative phase of ENSO and SAM, with maximum storm activity occurring when both are positive. Although the data showed some support for this interpretation, it was also evident that the strength of the coupling between ENSO and SAM varied throughout the last 7,200 years. The variation in coupling was linked to the seasonal contrast in solar insolation, and therefore the precession component of Milankovitch Cycles, resulting in amplified responses around 5000 and 2000 BP.

|  |
| --- |
| Page-etal-2010-9.png |
| Figure 8 - Comparison between storm intensity at Lake Tutira (indicated by years between storms), precipitation and temperature proxy data from Waitomo, the dune phases at Te Horo, and palaeotsunami deposits on Kapiti Island. Open triangles on the vertical axis summarise key tephra markers (After Page et al., 2010; Hawke and McConchie, 2006; and Goff et al, 2000). |

1. Therefore, although there is good evidence that there are fluctuations in storm intensity over centennial to millennial time scales, there does not appear to be a simple relationship between global climate and the frequency and magnitude of storm events for the North Island. In particular, the projected pattern of climate change based on global warming summarised by OPMSCA (2013) is inconsistent with past warming events as observed at Lake Tutira.
2. In relation to Matarangi Beach, climate oscillations clearly affect beach volume and therefore should be considered within an analysis of coastal erosion hazard, but this was not done for either the CCEL or FCPL. Further, projected climate changes based on climate models do not appear to be consistent or reliable for the purposes of the FCPL, and certainly do not have any meaningful probability of occurrence.