Overview of Weather and Coastal Hazards in the Northland Region–Part II: Coastal

NIWA Client Report: HAM2003-114
October 2003

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Contents

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Executive Summary

As a long peninsular, the Northland region is exposed to significant risks from both weather and coastal hazards. The long coastlines and the exposure to intense weather systems, be they ex-tropical cyclones or north Tasman-Sea lows, results in a region often confronted by natural hazard events. These events can lead to damage to properties and infrastructure, disrupting transport and lifelines, impacting upon the regional economy and in extreme cases they can put peoples lives at risk.

This report (Part II) documents the current level of knowledge of coastal hazards for the Northland region, while Part I (Gray, 2003) covers the weather hazards.

These two reports form part of an overview of the knowledge base on natural hazards for Northland, carried out under the umbrella of the NIWA/GNS Natural Hazards Centre, and commissioned by Northland Regional Council.

The following sections provide a brief overview of the issues associated with coastal management in Northland, known information (publications and data) that exist on physical coastal environments and coastal hazards, and a broad outline of the effects of climate variability and climate-change.

Generally, there is a reasonable pool of knowledge on coastal sediment systems, particularly on the east coast, and latterly within the Kaipara Harbour (west coast), especially by university and NIWA researchers.

There are some gaps in developing fundamental databases on coastal “drivers”, such as wave climate, tides, winds and storms, to which these reports (Part I and II), partially address. Some projections are given for possible future impacts of climate change on the Northland region, with sea-level rise, effects on sediment supply to the coast and more intense storms likely to be the main impacts on coastal systems.

Future work firstly needs to fill some gaps in the databases on coastal “drivers” and secondly usher in a more integrated “all-hazards” approach to coastal hazards, which examines the hazards from several different sources, including flooding. The latter will hopefully will be spurred on by the new Guidance Note for territorial authorities (MfE, 2003), which is based on a risk-management framework.

1. Introduction

As a long peninsular, the Northland region is exposed to significant risks from both weather and coastal hazards. The long coastlines and the exposure to intense weather systems, be they ex-tropical cyclones or north Tasman-Sea lows, results in a region often confronted by natural hazard events. These events can lead to damage to properties and infrastructure, disrupting transport and lifelines, impacting upon the regional economy and in extreme cases they can put peoples lives at risk.

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These two reports form part of an overview of the knowledge base on natural hazards for Northland, carried out under the umbrella of the NIWA/GNS Natural Hazards Centre[1], and commissioned by Northland Regional Council.

The following sections provide a brief overview of the issues associated with coastal management in Northland, known information (publications and data) that exist on physical coastal environments and coastal hazards, and a broad outline of the effects of climate variability and climate-change.

[1] For more details and quarterly Update, see web site: http://www.naturalhazards.net.nz/

2. Coastal setting for the Northland region

Northland consists of a long, narrow peninsula, only 80 km across at its widest point, and 6 km at its narrowest point. It is bounded by the Tasman Sea on the west and Pacific Ocean on the east. Northland is dominated by rolling hill country, with modest areas of flat low-lying land are restricted to areas adjacent to the Awanui and Northern Wairoa rivers. Northland’s population of 140,130 (2001 Census) live mainly on the east coast, concentrated in Whangarei District and the Bay of Islands area.

Northland’s coastline is around 1,700 km long, with no part of the region more than 40 km from the ocean. Consequently, the economic, environmental, social and cultural “goods and services” derived from coastal environments is an important component of life in Northland.

Northland’s coast exhibits very contrasting types between the west and eastern coasts. The west coast of the region is a continuous sandy dissipative beach backed by active (transgressive) sand dune systems, broken only by the mouths of four harbours (Kaipara, Hokianga, Whangape and Herekino) and the rocky headland forming Tauroa Point (Ahipara). In contrast, Northland's eastern coast forms a very irregular shoreline with rocky headlands, sheltered deep-water harbours, sandy bays and mangrove forests. Also, there are numerous islands along the region's east coast that provide partial sheltering from easterly waves. The major island groups are those in the Bay of Islands, Poor Knights, Hen and Chickens and Cavalli Islands.

The east coast is sheltered from the prevailing west to southwest winds, resulting in a mild wave climate, but is exposed to high wave activity from occasional northeasterly gales and extra-tropical cyclones. In contrast, the west coast is continually subject to active seas and swell originating from the Southern Ocean.

3. What are the coastal issues in the Northland Region?

Some of the pressures and issues faced by NRC with regard to natural character and coastal hazards are, as outlined in (NRC, 2002):[2]

- Escalating demand for coastal subdivision and use of the coastal area has resulted in increased pressures on coastal margins, particularly foredune environments (especially where there is unformed access).

- Extraction of sand in the NRC region has concentrated around the entrances to the Kaipara, Paregarenga and Mangawhai harbours. There is potential for erosion on adjacent shorelines.

- Historically, development in coastal catchments, including land clearance and associated catchment development, has resulted in impacts on estuaries and harbours from sediment-laden waters (e.g., Fig. C.1)

Figure C.1: Land clearance and partial reclamation of an estuary tidal creek in Bay of Islands area in the early 1980s [*Photo: RG Bell*].

- The threat to existing and future communities from natural hazards, the potential and nature of which may be unknown.

[2] http://www.nrc.govt.nz/special/soe.2002/coastal/natural.character.of.the.coast/index.shtml
http://www.nrc.govt.nz/special/soe.2002/coastal/coastal.hazards/index.shtml

- Recognition and understanding of the range of existing natural hazard threats and the likely frequency and magnitude of particular events.

- Identification of areas of high hazard risk, especially those prone to erosion, flooding (river or sea) and land instability, and provision of related information on avoidance measures to people.

- Incorporation of comprehensive systems of hazard identification and analysis into the resource consent and building consent processes.

- Damage to natural systems through inappropriate hazard protection measures.

- The contribution that certain land-use activities have in increasing the hazard threat especially in high-risk areas. Such activities include:

    - clearance of vegetation by mechanical or other means in areas exposed to the elements and/or with poor soil structures;

    - changes to sediment load of rivers and streams (+ or –) due to changing land-use patterns;

    - earthworks, including mineral extraction, in sensitive foreshore and riparian areas;

    - erection of structures, especially buildings, in flood plains.

- Maintenance of existing protection works, including flood control schemes and coastal protection works, and their future effectiveness. Where coastal erosion has been a problem, the coastline has been armoured with hard materials, and this has significantly degraded the natural character of the coastline.

- Predominantly La Niña conditions of the past few years (apart from the recent El Niño), have resulted in erosion to the beach face and foredune of many east-coast beaches (e.g., Figure C.2). Conversely, west coast beaches are generally considered to be in a positive condition, combined with a lower risk arising from less coastal development on the west coast.

- Recognition of global warming and the effects of rising sea levels on future land use and subdivision activities along the coast.

- Recognition that small communities often cannot bear the costs associated with natural hazard disasters. Local authorities need to coordinate disaster recovery operations and where appropriate, seek financial assistance from central government.

Figure C.2: Erosion scarp along the Pakiri-Mangawhai coastline in 2001 at the end of a La Niña period. [*Photo: RK Smith*].

4. Responses by NRC

NRC's current responses to the above pressures, issues and current state of coastal environments are:

- Northland Regional and District Plans cover a range of issues related to coastal development and resource use.

- Studies are presently being undertaken to determine the sustainability of sand extraction in the Kaipara Harbour (along with NIWA and University of Auckland). Previous studies were undertaken from 1995 to 1997 on the effects of sand extraction in Pakiri–Mangawhai embayment.

- Methods are being developed to assess the state of health within estuarine environments.

- A number of community coast care groups have been formed throughout the region.

- The Regional Policy Statement defines objectives for the management of the coastal resource. These aim to minimise or avoid the effects of natural hazards on people, property, and other aspects of the environment.

- The Revised Proposed Regional Coastal Plan for Northland includes methods to manage coastal hazards. Principal options are categorised in the Plan as follows:

  - environmental planning (e.g., buffer zones in erosion-prone areas);

  - resource consent conditions;

  - dune management (e.g., revegetation of dunes, provision of boardwalks);

  - protection works and structures.

  The Plan encourages methods other than coastal protection works to manage coastal hazards, and these are only permitted where they are the best option, are in accordance with natural processes and are designed to avoid adverse environmental effects.

- NRC has defined coastal hazard zones, based on work by J. Gibb and M. Hicks (NRC 1988; 1991) for Whangarei District, parts of Far North District and Opononi/Omapere (Hokianga) as part of an ongoing project.

This literature-review report is a further response by NRC to take stock of and improve the knowledge base on coastal hazards in the region, and how they may be affected by climate change.

5. Coastal hazard "drivers"

Before we can assess the risk of extreme events causing damage at a particular coastal locality and how much global warming will exacerbate the situation, we need to identify and understand the different physical "drivers" or forcing agents that regulate or occasionally disrupt coastal and estuarine systems. These coastal hazard "drivers" also have behind them one or more fundamental causes. A breakdown of the main natural causes and hazard drivers that govern coastal erosion and inundation is shown schematically in Fig. C.3. The three main coastal hazards are:

- coastal inundation (due to storm-tides, waves and tsunami);
- coastal erosion (arising from long-term or short-term deficit in beach sediment volume);
- maritime/recreational hazards (e.g., oil or chemical spills, shipping and boating hazards from storms or waves, surf rips).

These three hazards arise from intricate interactions between several "drivers", also shown in Fig. C.3.

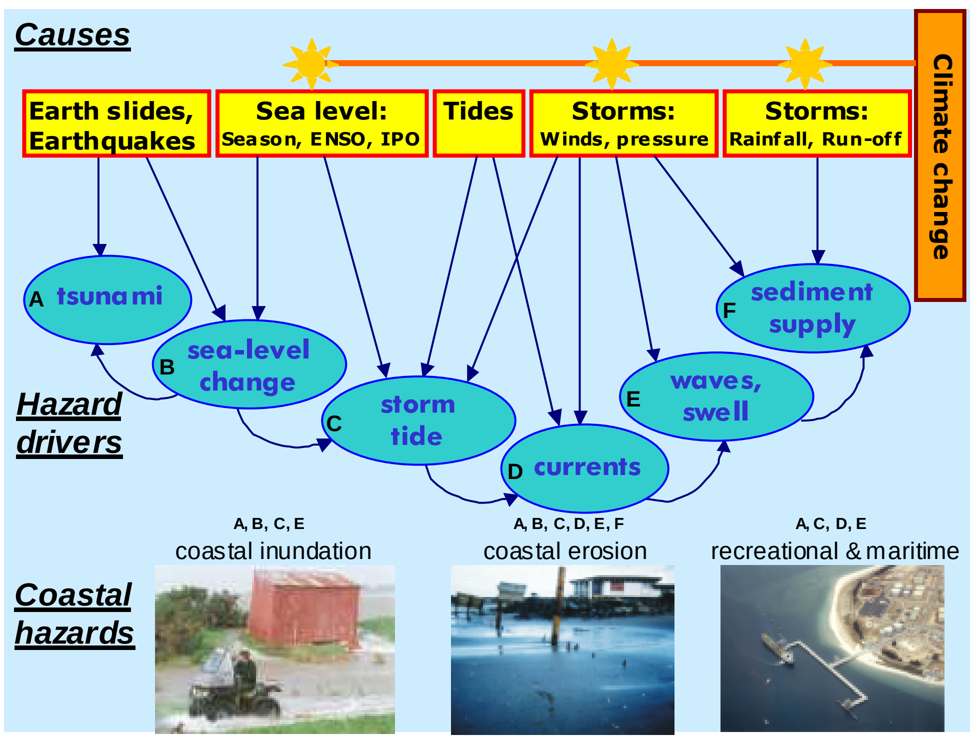

Figure C.3: Natural causes and hazard "drivers" for coastal inundation, coastal erosion, and maritime/recreational hazards, together with those causes and "drivers" affected by climate change (marked with a sun symbol). Note: ENSO= El Niño–Southern Oscillation cycle; IPO= Interdecadal Pacific Oscillation.

Besides earthquakes and underwater landslides (which can cause a tsunami or coastal subsidence) and ocean tides, the main causes of coastal hazards arise from extremes in weather such as storms and cycles in ocean-atmosphere response (sea level and currents). It is these weather and climate-related causes that will be altered most by climate change arising from global warming, mostly exacerbating the potential problems for the coast e.g., heightened storm tides, stronger winds and waves, sea-level rise. While geological causes such as earthquakes, underwater landslides and volcanic activity will not be directly affected by climate change (Fig. C.3), the coastal response of tsunami will be altered somewhat by sea-level rise, increasing the risk of coastal inundation.

Ocean tides will also not be directly affected by climate change, but tidal ranges in shallow harbours, river mouths and estuaries could be altered by deeper channels (following sea-level rise) or conversely shallower channels if increased run-off from more intense rainfall during storms increases sediment build-up (siltation) in estuaries.

Fig. C.3 only covers the "natural" causes of coastal hazards, but there are also human-induced factors that can worsen the risk posed by coastal hazards. Some relevant New Zealand-wide examples are the effects of: a) dams on rivers and irrigation abstraction that reduce sediment supply to the coast; b) ill-conceived shoreline protection works that worsen or shift the erosion problem "downstream"; c) dredging of entrances and harbour channels; d) removal of coastal vegetation; e) the artificial scraping and lowering of dunes for sea-views or access; and f) sand extraction from the nearshore for building aggregate.

Further descriptions of these hazard drivers and the implications for coastal planning are presently being prepared as a guidance note, *Coastal Hazards & Climate Change: A Guidance Note for Local Government in New Zealand*, and published by the Ministry for the Environment (2003). For the Northland region, known information or data on some of these coastal hazard "drivers" is now presented.

5.1 Tides

Tides are important for two reasons: a) the tidal height governs the likelihood of coastal inundation from storm surge or river flooding; and b) tidal currents at estuary (harbour) entrances play a key role in sediment supply to estuary beaches and adjacent open-coast beaches. Mean High Water Spring (MHWS) level and the Highest

Astronomical Tide (HAT)[3] are useful upper limits to assess coastal inundation hazards.

The development of a tide model by NIWA (Walters et al. 2001) has opened the way to determining tide heights and tide marks such as Mean High Water Spring (MHWS) anywhere along the open coast or ocean around New Zealand. Tide information for Northland can be located at:

- Standard Ports (Marsden Point, Whangarei)— http://www.hydro.linz.govt.nz/tides/majports/index.asp

- Secondary ports inside harbours and estuaries around Northland (east coast relative to Whangarei or Marsden Point, west coast relative to Port Taranaki)— http://www.hydro.linz.govt.nz/tides/secports/index.asp

- Any open-coast or ocean site along the Northland coast— http://www.niwa.co.nz/services/tides . The NIWA Forecaster is based on the tide model of New Zealand's EEZ, and can predict tides back to 1830 (useful for historic hazard events) or forward to 2006.

The tide model is also useful to generate plots of MHWS and highest astronomical tide (HAT) along the coast, relative to the present-day mean level of the sea (MLOS)[4] shown in Fig C.4. The lowest MHWS and HAT for Northland are on the east coast south of Cape Brett (0.92 m and 1.38 m above MLOS), while the highest MHWS and HAT are found off North Head (Kaipara) at 1.38 m and 1.93 m above MLOS respectively.

[3] HAT is the highest possible tide that can occur (excluding meteorological effects).
[4] This is the actual average sea level, as distinct from MSL, which is usually a survey datum. For example the present MLOS is around 0.1 m above the Auckland MSL Datum–1946.

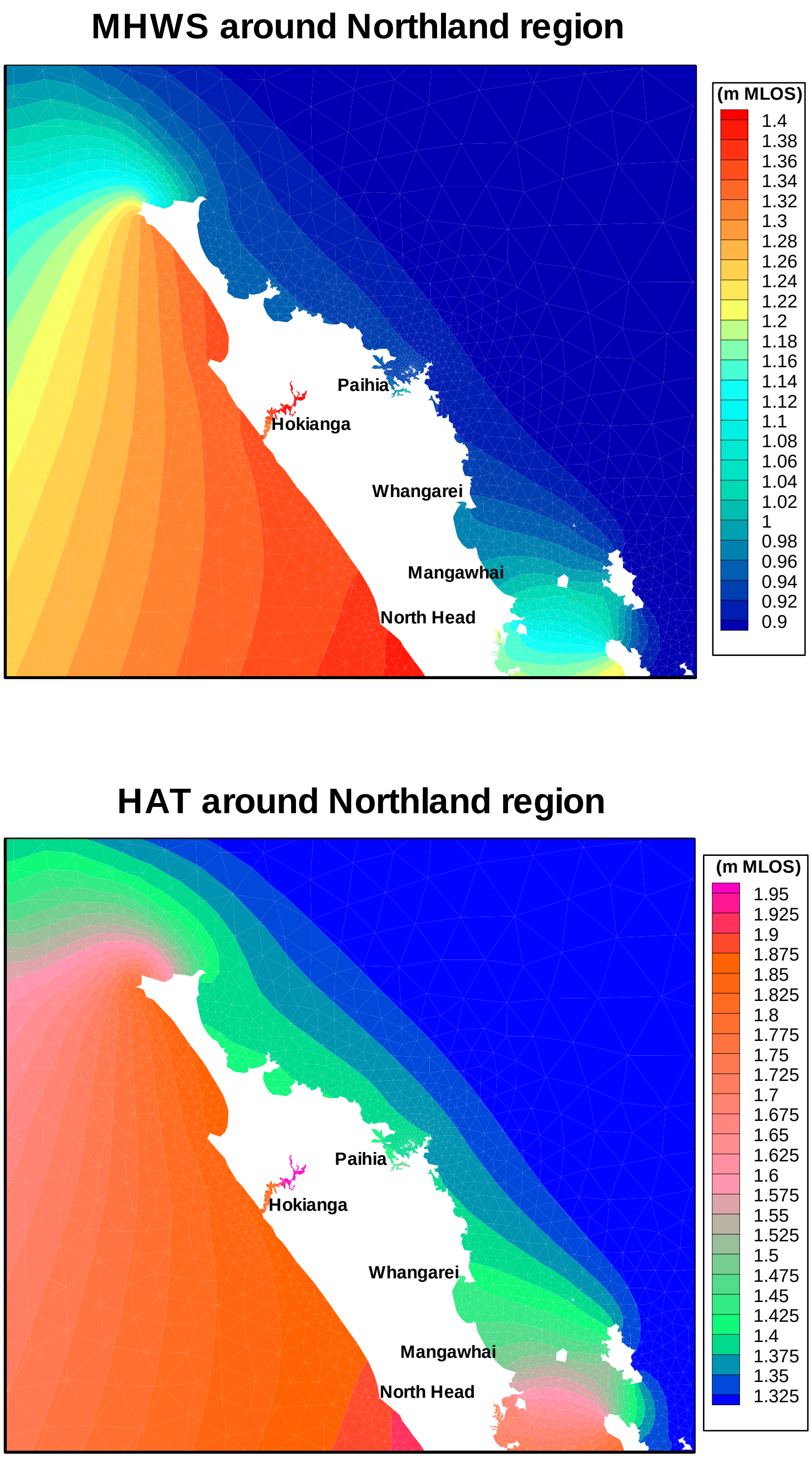

Figure C.4: MHWS and Highest Astronomical Tide (HAT) above the mean level of the sea.

HAT and MHWS are fundamental tide markers in assessing coastal inundation hazards for low-lying areas, either during very high tides in isolation, or in combination with storm surges (called a “storm tide”).

5.2 Sea-level fluctuations

Currently, NRC routinely monitors sea level around Northland via tide gauges at Opua, Marsden Point, Dargaville and Poutu Point (Kaipara), while a separate sea-level gauge at the Mokohinau Islands is operated by NIWA (with ARC support). Mardsen Point, Dargaville and Pouto Point data are also downloaded daily to a national network of sea-level gauges coordinated by NIWA (Goring et al. 2003), in cooperation with Regional Councils like NRC and port companies (Fig. C.5).

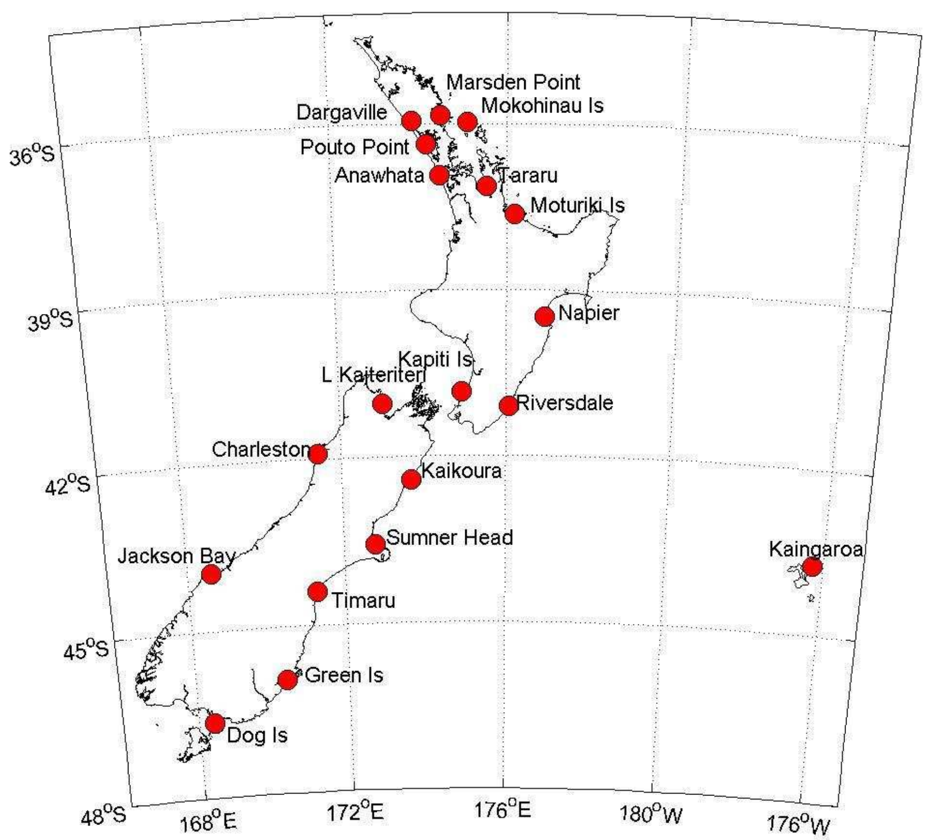

Figure C.5: The New Zealand open-coast sea-level recorder network as at June 2003.

Fig. C.6 for Pouto Point shows an example daily plot of tides and storm surge that will be made available to partners in the national sea-level network via the web.

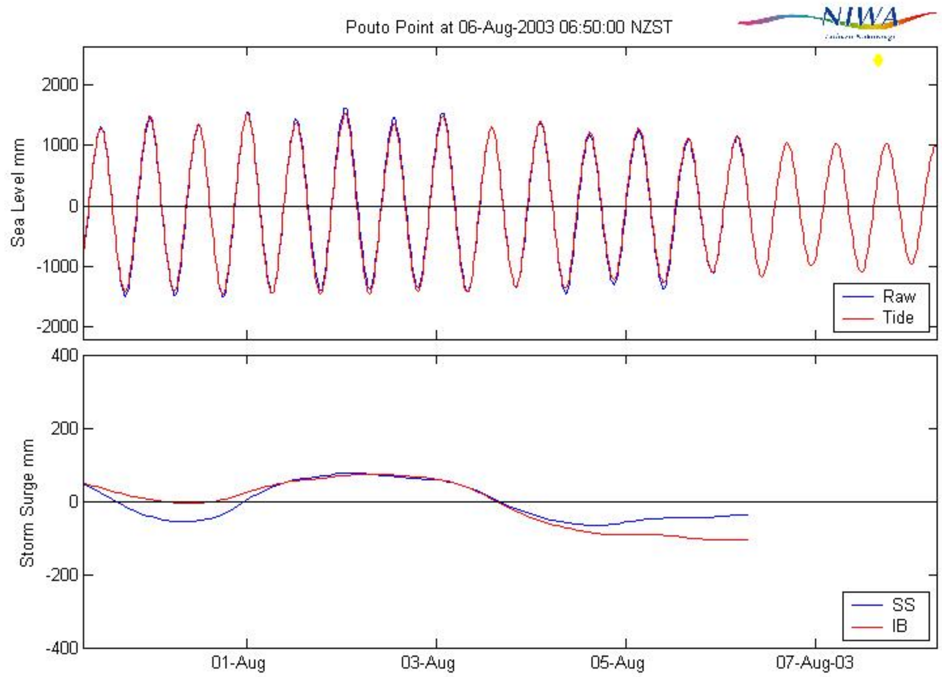

Figure C.6: Daily summary plots, such as this one for Pouto Point (Kaipara), are produced by the national sea-level network coordinated by NIWA. (TOP) shows the actual raw sea level (up until 0700h 6 Aug) plotted as an overlay on the predicted tide, that is forecast out to a further 3 days; (BOTTOM) the difference between the actual sea level and the predicted tide is the storm surge (SS) which is partly caused by changes in barometric pressure producing and inverted-barometer (IB) set-up or set-down.

"Sea-level fluctuations" refers to the fluctuations in the mean level of the sea, after taking out the influence of tides and without the influence of long-term sea-level rise. The main long-term fluctuations (excluding storm-driven fluctuations) are:

- seasons (annual heating and cooling cycle by the sun on the ocean surface);
- interannual (3 to 5 year El Niño-Southern Oscillation[5] cycles); and
- interdecadal (20 to 30 year Interdecadal Pacific Oscillation[6] or IPO cycles).

[5] Cycle of alternate El Niño and La Niña episodes that govern climate and sea-level variations around the Pacific and Indian Oceans—commonly called the El Niño–Southern Oscillation or ENSO system.

Seasonal fluctuations are relatively small, averaging around a range of 0.08 m over a year (but can range up to 0.16 m). The highest sea level occurs in late summer (January to April), when the expansion due to warmer seawater is greatest.

To investigate the long-term cycles for the northern region, NIWA has analysed the long record from the Port of Auckland (Queens Wharf) that goes back to 1899. The time series of annual mean level of the sea (MLOS) at the Port of Auckland since 1899 is shown in Fig. C.7.

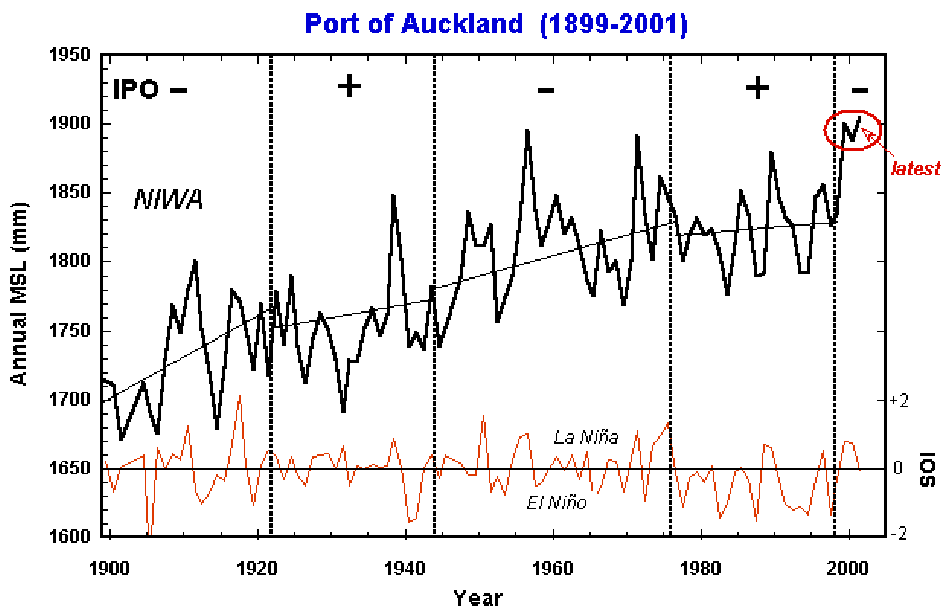

Figure C.7: Annual mean level of the sea at the Port of Auckland since 1899. The Interdecadal Pacific Oscillation (IPO) positive and negative phases are marked, with corresponding piece-wise linear fits to the sea-level data in each IPO phase. The bottom data series is the annual-mean Southern Oscillation Index (SOI) during the record, with positive values for La Niña episodes. {*Source: Ports of Auckland, Prof J. Hannah (Otago Univ.), NIWA).*

The long Port of Auckland series illustrates the two climate features that effect long-period sea-level fluctuations. Firstly, El Niño–Southern Oscillation (ENSO) is a quasi-periodic climate system on cycles of 2 to 5 years. During El Niño episodes (negative SOI), the mean level of the sea is depressed below normal levels by up to 0.12 m. The converse is true for La Niña episodes, where sea levels are higher than normal by a similar amount. Additional sea-level data from Mount Maunganui, Christchurch and

[6] Longer "El-Niño–like" 20–30 year cycles of alternate positive and negative phases that effect the wider Pacific Ocean region, abbreviated as IPO. Since 1998 the IPO has been negative.

Port Taranaki further confirm that this pattern occurs over much of New Zealand on both the east and west coasts, and by inference applies also to Northland.

Secondly, the IPO signal at 20–30 year cycles can be seen in the sea-level record from the Port of Auckland (Fig. C.7). The IPO facilitates sea-level fluctuations of up to ±0.05 m, as indicated by the piece-wise linear fits, with the higher sea levels being recorded during the negative phase of the IPO. These fluctuations are likely to be applicable to the eastern coast of Northland.

Combining all three long-term sea-level fluctuations (seasonal, ENSO, IPO) for coastal hazard assessments (coastal erosion or inundation) implies that the mean level of the sea could reach up to 0.25 m above the average sea level.

This combination is likely to occur in summer months during La Niña episodes for decades when the 20 to 30-year Interdecadal Pacific Oscillation (IPO) cycle is in a negative phase. In this respect, we are now in a negative IPO phase, which appears to have started in 1998 (see Fig. C.7), and may last until 2020 to 2030. This “sea-level fluctuation” factor should be considered when assessing coastal inundation hazards.

5.3 Storms

Storms lead to two main hazard drivers, that can occur separately, or in combination:

- waves and swell, which de-stabilise and move large quantities of sediment, leading to erosion, and cause coastal inundation and even structural damage; and
- storm surge, where adverse winds and low barometric pressure produced by storms temporarily elevate the ocean level well above the predicted tide level (up to an upper limit of just over 1 m for the north-east coast).

Storm-induced coastal erosion can also occur after a sequence of moderate storms, with minimal time for recovery between storms. “Storm tide” level is a useful measure for inundation from the sea, and an upper-limit scenario for a given Annual Exceedance Probability (AEP) would comprise MHWS (or HAT) + storm surge + wave set-up. Wave set-up is the increase in sea level inside the surf zone (landward of the first wave breaks) relative to the offshore storm-induced ocean level (storm surge).

Wave run-up is the extra height reached, over and above the storm-tide level, as the broken waves run up the beach and coastal barrier (if present) until their energy is finally expended. Wave run-up is normally treated separately from storm-tide level because it varies widely along the coast, even in the same locality. In contrast, storm-tide levels can be calculated for large stretches of coast within the Northland region using the MHWS information (Fig. C.4) and area information on coastal wave heights (see section below) and storm surge (from sea-level gauge data records).

5.3.1 Waves

The development of a New Zealand-wide deepwater wave model by NIWA, along with better global wind predictions back in time (called a hindcast), has paved the way to develop a regional wave climate that is consistent on a national scale. The wave climate at the New Zealand coast has been characterised by a hindcast spanning 20 years (1979–1998), using the WAM wave generation model (Gorman et al. 2003b; Gorman et al. 2003a).

The east and west coasts of Northland experience considerable differences in wave climate as referred to earlier. Waves are created by winds blowing over the ocean, and once they are well developed, can travel for thousands of kilometres. Hence the sea state seen at the New Zealand coast is a combination of waves originating from many sources, including both local wind sea and swell travelling across a wide expanse of ocean from storms in the Tasman Sea, and the Pacific and Southern Oceans. Of the more distant sources, winds are consistently strongest in waters to the south of New Zealand, where predominantly westerly winds produce high seas throughout the year. Swell from this region consistently reaches the Northland west coast, resulting in a wave climate dominated by waves from the southwest (Fig. C.8), with lesser contributions of waves from the western quadrant originating from Tasman Sea storms. Significant wave height, which is the average of the highest 33% of waves, is persistently greater than 1 m on the west coast (Fig. C.9). Currently, extreme wave heights (Fig. C.9) are not sufficiently well resolved by the model to use reliably for coastal hazard assessments, but further work is being done by NIWA to produce extreme wave climates for New Zealand. To continue evaluating extreme wave climate, the small NIWA wave buoy network needs to be extended through partnerships with regional authorities and commercial companies. Currently, partners are being sought to keep the ARC wavebuoy in place at the Mokohinau Islands (e.g., Northport, Ports of Auckland, ARC, NRC?).

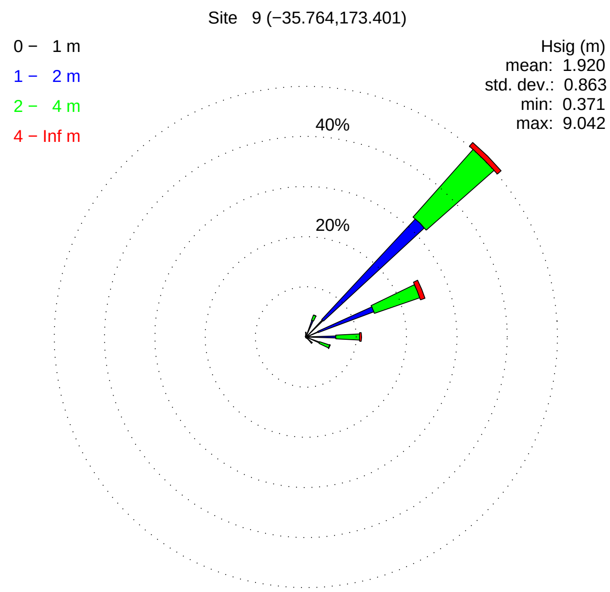

Figure C.8: Wave rose derived from 20-year NIWA wave hindcast at a site in 30 m water depth off Waipoua, on the west coast of Northland. Wave rose bars point in the direction TO which waves travel, and show % occurrence of waves in height ranges 0–1 m, 1–2 m, 2–4 m, >4 m (outermost bin).

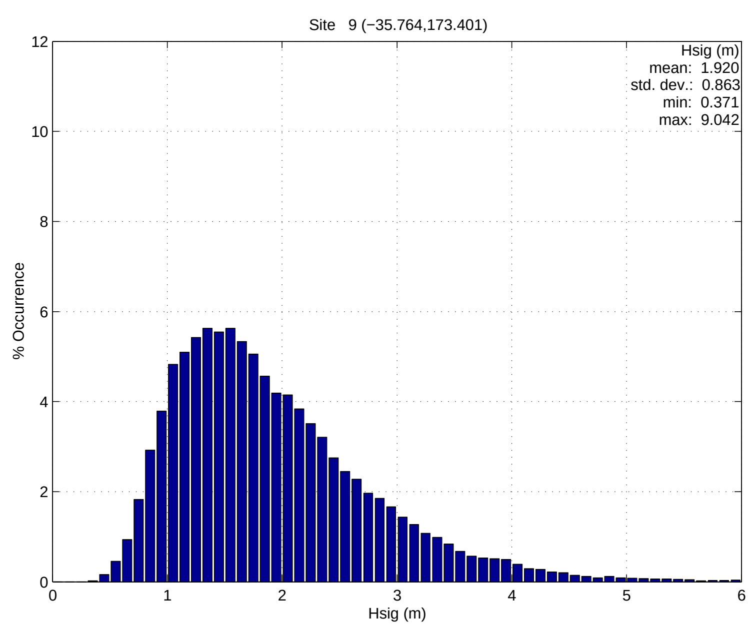

Figure C.9: Distribution of significant wave height derived from the 20-year NIWA wave hindcast at the site off Waipoua, on the west coast of Northland. (Maximum clipped to 6 m).

In contrast, the east coast of Northland is sheltered from these swell sources, being exposed instead to the Pacific Ocean. This does not provide a persistent source of wave energy comparable to the Southern Ocean, but is influenced by mid-latitude weather systems (generally travelling from west to east). Also, some of the most intense storm conditions result from tropical cyclones moving down from the tropics and re-generating, but these are infrequent (around one event per year), and largely restricted to the summer/autumn months. The result is that wave energy arrives from a wide range of directions (Fig. C.10), while the distribution of significant wave height (Fig. C.11) is weighted too much lower wave-height values than on the west coast.

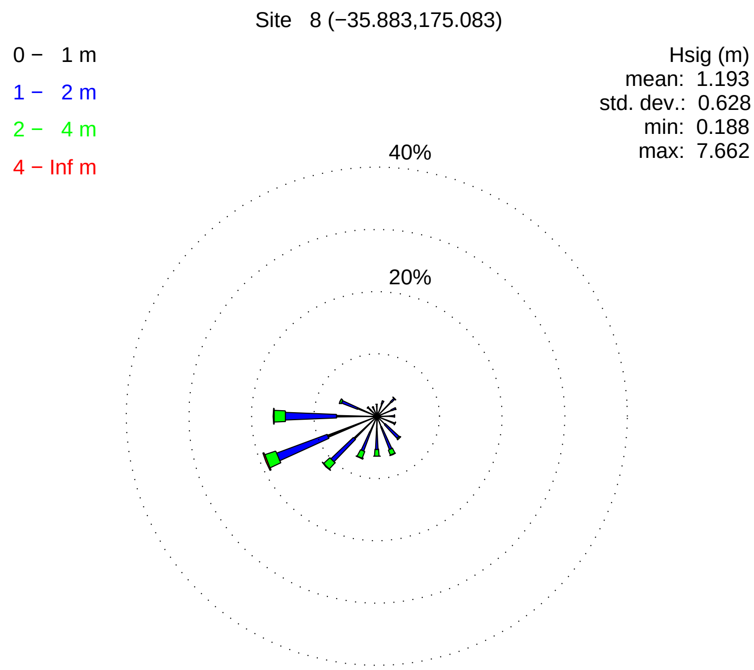

Figure C.10: Wave rose derived from 20-year NIWA wave hindcast at a site north of Mokohinau Islands. Wave rose bars point in the direction TO which waves travel, and show % occurrence of waves in height ranges 0–1 m, 1–2 m, 2–4 m, >4 m (outermost).

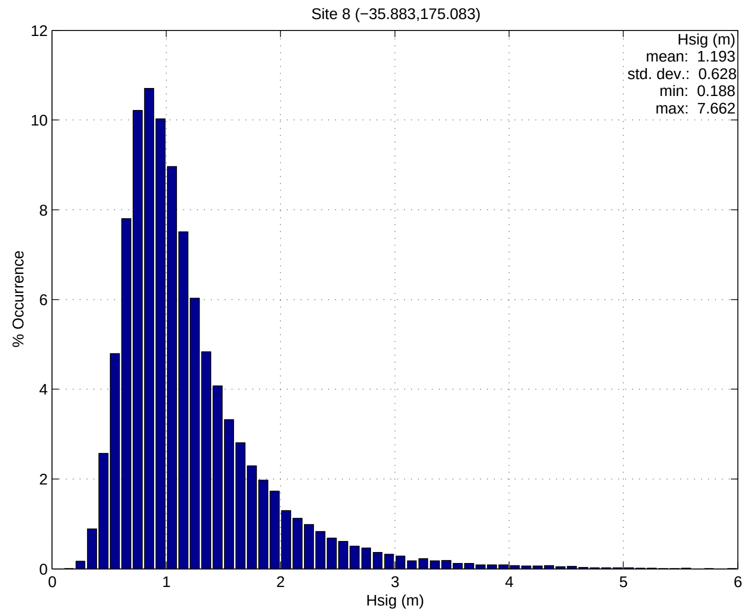

Figure C.11: Distribution of significant wave height derived from the 20-year NIWA wave hindcast at a site north of the Mokohinau Islands. (Maximum clipped to 6 m).

The orientation of Northland's west coast is nearly perpendicular to the predominant southwest wave direction (Fig. C.12). This means that longshore sediment transport processes, which are driven by any obliquity in the wave approach angle, tend to be close to equilibrium between upcoast and downcoast fluxes, except where the coastline orientation locally varies from the large-scale regional trend (e.g., Tauroa Point near Ahipara and Cape Maria van Diemen).

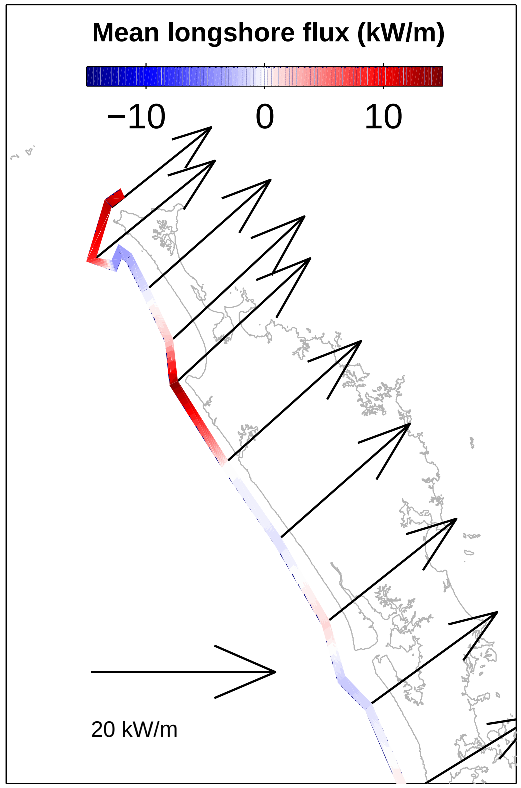

Figure C.12: Variation of the wave-energy flux in KW per metre of beach on the west coast of Northland, based on the 20-year wave hindcast. The arrows show the magnitude and direction of the mean wave energy flux at points along the 50 m depth isobath. The colour scale shows the component of the energy flux oriented parallel to the local orientation of the coast. Northward flux values are shown as positive (red) and southward (blue).

Nearshore wave modelling

The above results from the WAM wave model provide deep-water wave conditions in the form of directional wave spectra on a 1.125°×1.125° latitude/longitude grid. Wave statistics (e.g., Figs. C8–C12) for particular sites of interest are derived by interpolation of the spectrum, correcting for the effects of the coastline in limited fetch from certain directions. This is intended for use where wave conditions are affected by the nearby coastline, but where the water is sufficiently deep for refraction effects to be insignificant. For parts of the coast of more complex bathymetry where shallow water effects are significant, use of a nearshore model (e.g., SWAN) to refract offshore hindcast spectra into the nearshore areas results in a further improvement in the agreement between measured and hindcast wave heights. An example is shown in Fig. C.13 for the wave buoy that was deployed off Mangawhai in 35 m water depth.

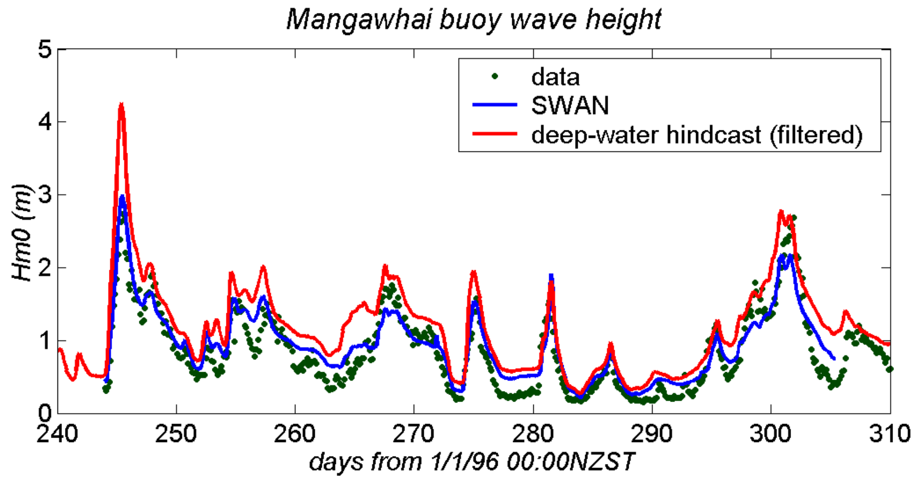

Figure C.13: Significant wave height measured at the Mangawhai wave buoy, compared with the results compared with the deep-water WAM model hindcast (filtered to adjust for limited fetch), and with the results of a nearshore (SWAN) refraction model (blue).

5.3.2 Storm tides

Storm surge is the rise in sea level in response to weather systems. There are four main contributing mechanisms:

- Low barometric pressure — 1 hPa fall in pressure results in a 1 cm rise in level (the "inverted barometer" or IB effect).
- Onshore winds — the water is piled up against the shoreline.
- Alongshore winds — increased water level to the left of wind stream due to Coriolis effects. For example, on Northland's east coast, SE winds will induce set-up at the coast, while on the west coast, it will be NW winds that induce set-up.
- Coastal-trapped long waves that propagate along the coast generated by storms outside the region.

A recent analysis of storm surge from the Marsden Point sea-level record was undertaken by Barnett (2002). Other known storm-tide events that have been analysed from data records were Cyclone *Bola* (Marsden Point gauge) in 1988, a storm in April 1999 that hit the Kaipara Harbour, and the storms of July 2000. Both the former events are described by Bell et al. (2000), while the latter two are described by NRC on their web site:

http://www.nrc.govt.nz/special/soe.2002/coastal/coastal.hazards/index.shtml

Extra-tropical cyclone *Bola* struck the North Island between 6–9 March 1988. This low-pressure system, with a nadir of about 980 hPa, moved due South from Fiji and hovered off North Cape for 4 days. The resulting storm surge at Marsden Point, over and above the predicted tide, is shown in Fig. C.14, that illustrates the interplay between low barometric pressure and wind set-up. Peak SE alongshore winds up to 25 m/s (50 knots) caused coastal set-up, combined with a peak inverted barometer (IB) set-up of 0.27 m, resulting in a peak storm surge of 0.63 m at Marsden Point around midnight on the 7 March. Other sea-level gauges operating at the time recorded lower storm surge extremes: Opua, Bay of Islands (+0.50 m) and Auckland (+0.40 m) reflecting the temporary stationarity of the storm off North Cape. Fortuitously the *Bola* storm surge coincided with a period of average tides, which kept the storm-tide level at the coast to manageable levels. This can be compared with the July 1978 storm when a moderate 0.5 m storm surge coincided with spring tides, causing substantial beach erosion.

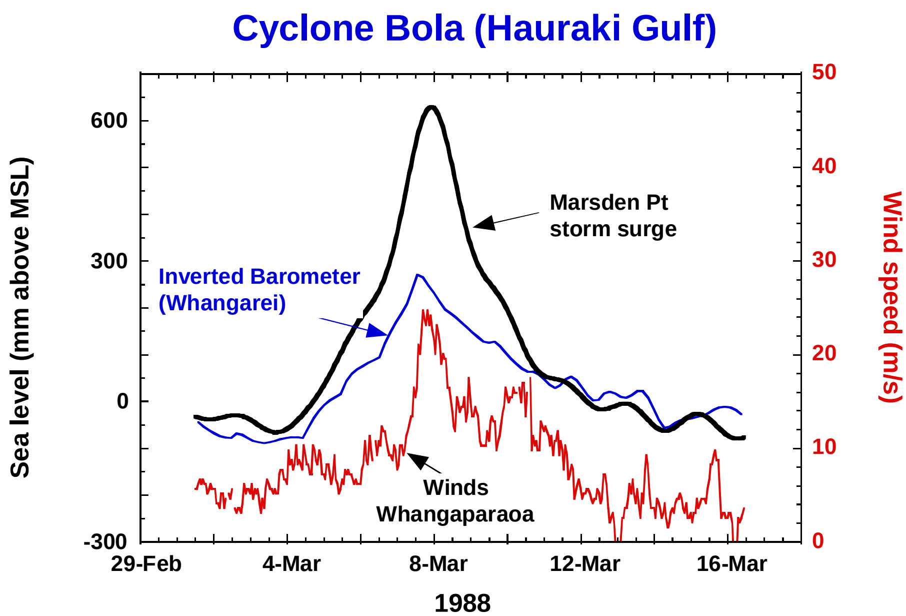

Figure C.14: Storm-surge event at Marsden Point generated by extra-tropical cyclone *Bola* in March 1988. The inverted barometer component of the set-up is calculated from barometric pressure measured at Whangarei Airport and wind speeds were only available from Whangaparaoa Peninsula.

A more recent storm-surge of occurred on the west coast (Kaipara Harbour) on 17 April 1999. Storm-tide levels exacerbated flooding in Dargaville. Fig. C.15 shows the situation measured at the open-coast Anawhata sea-level gauge near Piha (Fig. C.5). New Moon occurred on 16 April combining with the lunar perigee[7] on the 17 April, to produce a combined perigean-spring tide of 1.62 m above the mean level of the sea at 10:15 on 17 April 1999 (compare with a MHWS of 1.38 m and a HAT of 1.93 m in Fig. C.4). The tide was quite high, but not an unusual perigean-spring tide. Barometric pressure had a nadir of 988.9 hPa at 06:00 on 17 April. The corresponding inverted barometer (IB) set-up component of the storm surge was a maximum of 0.25 m around 4 hours prior to high water (Fig. C.15). The total storm surge was 0.5 m above the predicted tide, but was extremely sharp-peaked over just one tidal cycle (compare with the *Bola* event). Approximately half the storm surge height can be explained by the inverted barometer effect of the low-pressure system and the other half by wind set-up and other factors.

[7] Perigean tides occur every month (27.5 days) in conjunction with the position of the Moon in its elliptical orbit around Earth. When the Moon is closest to Earth, it is in its perigee and larger than normal perigean tides occur.

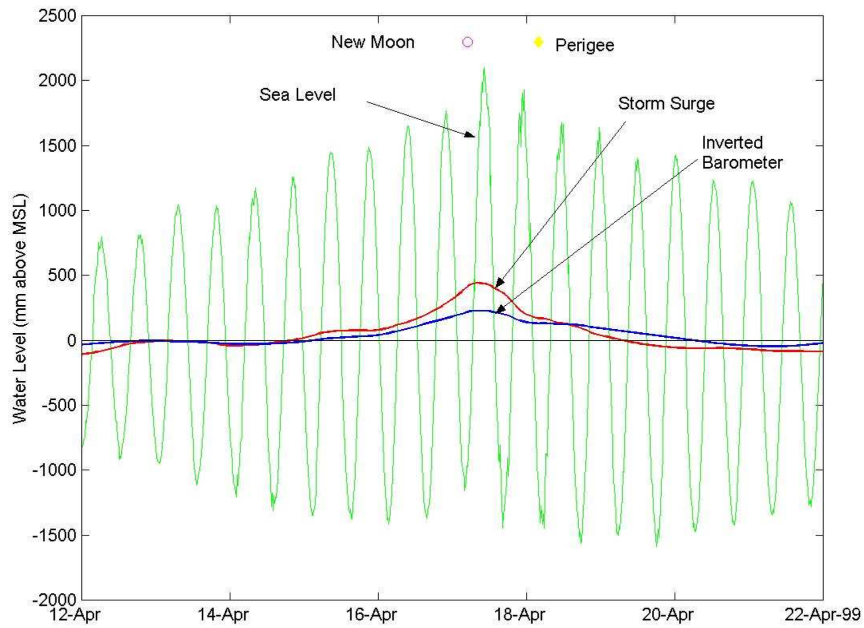

Figure C.15: Storm-tide event of 17-April-1999 measured on the open coast at Anawhata, near Piha (NIWA Sea-level Network).

The ocean storm-tide event unfortunately combined with a river flood event in the Wairoa River, causing flooding of the CBD of Dargaville. The delayed water level response is shown in Fig. C.16, peaking on the following high tide around midnight on the 17 April. Further information is available in a popular article in Aniwaniwa (Issue 11, 1999) http://www.niwa.co.nz/pubs/an/archived/aniwaniwa11_sealevels.htm

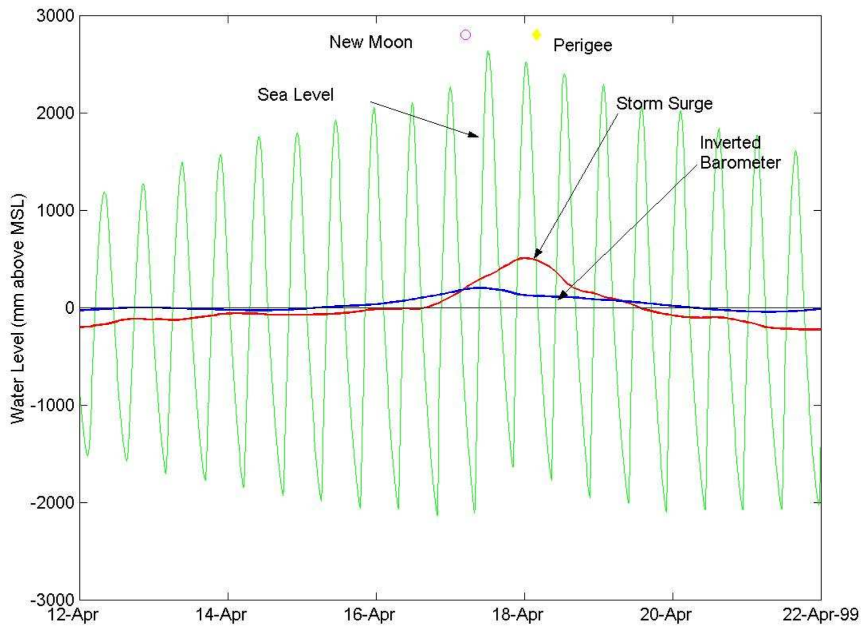

Figure C.16: Combined ocean storm-tide and Wairoa River flooding event of 17–18 April 1999 measured at Dargaville (NRC water-level recorder).

During July 2000, Northland (and most of the east coast of the northern half of the North Island) experienced three weeks of continuous easterly winds. Some of these were quite strong, reaching sustained mean velocities of 35 knots, reaching 50–60 knots at times. The first storm coincided with very high spring tides early in the month, which peaked on 4 July. The sustained southeasterly winds[8] resulted in a significant wind and wave set-up against the coast elevating sea levels and wave run-up around the coast. It also caused the sea level to back up in Whangarei Harbour by nearly 0.4 m above predicted tides. In Whangarei, the flooding experienced in and around sections of the Hatea River and Town Basin area on 4 July was caused by the wind set-up within the harbour on top of the large high tides. The increased sea-level elevation from the wind set-up, the wave set-up from the high sea state, coupled with the large high tides enabled waves to get further up the beach face. The result was a significant amount of erosion to many sections of the Northland coastline, particularly Matapouri and Bream Bay. Further erosion to these areas occurred in the two weeks following as the continuation of easterly winds (some very strong i.e., 60 knots) up until 21 August and associated waves pounded the already-impacted beaches causing further erosion of the backshore.

[8] Sustained easterlies (without substantial rain) can also cause severe "burning' of indigenous bush and shrub vegetation along the coastal margin, further reducing coastal dune stability.

6. Climate-change effects on coastal "drivers"

6.1 Sea-level rise

Since the early to mid 1800s, sea level around New Zealand has been rising at an average linear rate of 0.16 m per century. However, as global warming becomes established and the oceans begin to warm, the rise in sea level is projected to accelerate in the near future.

Figure C.17 combines the historic sea-level rise at Auckland (from Fig. C.7) over the past 100 years with the IPCC projected accelerating sea-level rise to 2100 due to global warming. The historic annual fluctuations in the mean level of the sea at the Port of Auckland are also plotted in Fig. C.17, illustrating the extent to which sea level can vary from year-to-year about the long-term trend, due to seasonal, El Niño–Southern Oscillation and IPO cycles. The most likely rates of global sea-level rise are between 0.14 and 0.18 m by 2050 and between 0.3 and 0.5 m by 2100, with an upper-limit projection of 0.88 m by 2100.

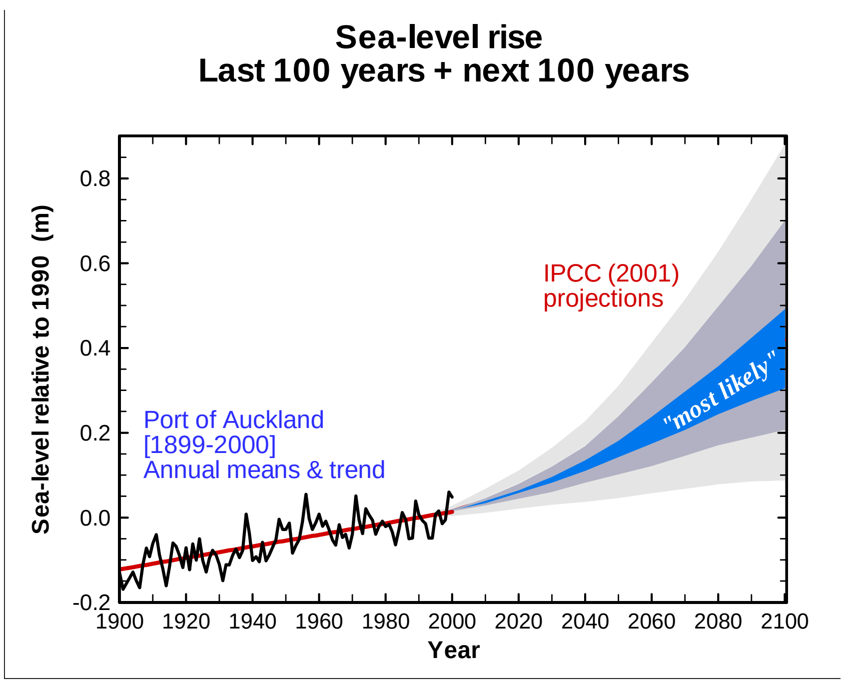

Figure C.17: Relative sea-level trend for Auckland since 1899 (red), superimposed on the annual variability in mean sea level (black), spliced with the predicted IPCC projections for global sea-level rise up to 2100. [*Sources: J. Hannah (Otago Univ.); Ports of Auckland, IPCC (2001)*].

The Northland landmass is tectonically stable, and if anything, may be uplifting at very slow rates (Berryman & Beanland, 1988). Also, little is known yet about the regional differences in the rise in ocean levels around the SW Pacific, compared to the global average rates given in IPCC (2001). Taken together, this means that relative sea-level rise around Northland and Auckland can be treated to be similar to the global average rate of rise. So until such time as further information to the contrary becomes available, the projected IPCC (2001) sea-level rise should be used for coastal hazard planning.

For the purposes of initial screening risk assessments for coastal hazards, it is recommended that future sea-level rises of **0.2 m by 2050** and **0.5 m by 2100** (relative to 1990 levels) are used in Northland.

It is important to note that IPCC expect sea level will continue to rise for several centuries, even if greenhouse gas emissions are stabilised. This is due to the long lag times needed for the deep oceans to respond to ocean surface heating and the expected contribution from polar ice sheets, particularly from the Greenland ice sheet after 2100. The expected continued melting of ice sheets or increase in iceberg calving from these land-based ice sheets is expected to lead to a sea-level rise in the order of several metres over the next several centuries to millennia, even for the lower range of projected future climate-change scenarios.

6.2 Climate change effects on ocean currents, winds, waves, and tides

Ocean currents affect our climate and can influence the way storms develop. In particular, Northland's east coast is influenced by the East Auckland Current that pinches closest to the mainland off Cape Brett, as shown by the higher average sea-surface temperature (February) along the east coast in Fig. C.18. For ocean currents, the most likely future outlook for New Zealand is for little change to the warm-ocean currents like the East Auckland Current, but perhaps some modification of cold-ocean currents e.g., Antarctic Circumpolar Current.

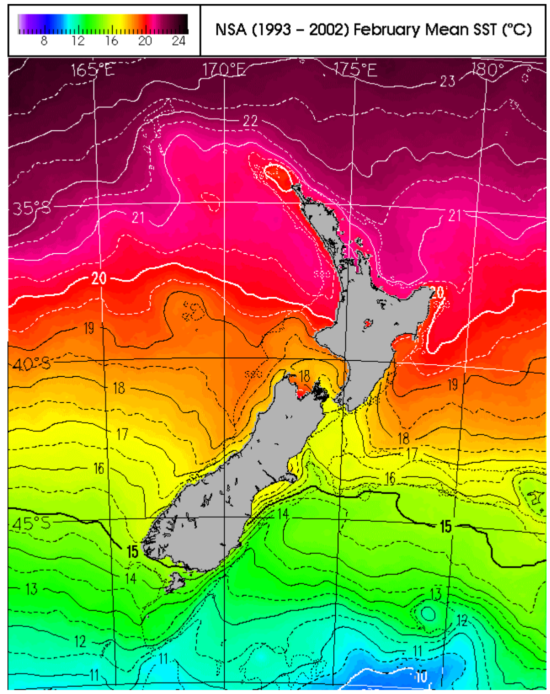

Figure C.18: Average sea-surface temperature for the month of February from 1993 to 2002. [© NIWA Ltd., 2002].

The average westerly wind component across New Zealand is suggested to increase by approximately 10% of its current mean value in the next 50 years. As a result, there would be an increase in the frequency of heavy seas and swell along western coast of Northland. There may also be higher extreme waves during the passage of ex-tropical cyclones and mid-latitude storms, if these storms become more intense with global warming.

Ocean tides will not be directly affected by climate change, but tidal ranges in shallow harbours and estuaries could be altered by deeper channels (following sea-level rise) or conversely shallower channels if increased run-off from more intense rainfall increases sediment build-up in estuaries.

7. Coastal sediment systems and coastal inundation in Northland

7.1 Overview of past studies and information

Northland exhibits a wide variety of coastal and estuarine features, which makes them interesting candidates for research investigations (e.g., numerous University theses and journal papers). However, this diversity and complexity also poses difficulties for NRC in managing coastal environments, as outlined in the Coastal Issues section, including implementation of land-use planning controls and hazard mitigation.

The following list of previous publications and reports over the last two decades, which builds on the extensive Bibliography by Hume & Harris (1981), provides a reasonable knowledge base on coastal sediment systems and coastal hazards in Northland. (Note: the section below is by no means an exhaustive list, which excludes many client consultancy reports.)

7.1.1 West coast Northland

Dune fields

An Inventory of New Zealand's Active Duneland's was published by Hilton et al. (2000) after three years of work. Large areas of active duneland were present along the Aupouri Peninsula, the Kaipara and Awhitu barriers. The area of active duneland in Northland (for example Fig. C.19), which contained almost half of the national total, has declined by 76%, mostly as a result of *Pinus radiata* plantings.

Figure C.19: Active sand dunes march inland over bush and scrub on the Kaipara North Head. [*Photo: RK Smith*].

Oceanography

Current-meter measurements in 60 m water depth to the southwest of Hokianga Entrance (off Waimamaku) in autumn 2000 showed currents at mid-depth are predominantly to the north, while at the bottom they were directed offshore (Bell & Liefting, 2000). Few other oceanographic or wave measurements are known for the west coast region.

Beaches

The distribution of sand characteristics along the west coast–North Island from Taranaki northwards to Bayleys Beach near Dargaville (Swales et al. 2001). Shoreline fluctuations at Ahipara suggest the coast is dynamically stable or accreting in the long-term for most places, but is subject to considerable short-term erosion (cut-back), particularly north of Wairoa Stream (NRC, 1991).

7.1.2 Harbours and estuaries of Northland

Of the four harbours/estuaries on the west coast, most studies have focused on the Kaipara Harbour (associated with sand-extraction investigations) and Whangape Harbour (various multi-disciplinary studies by Auckland University). Generally, most of the research and field investigations have focused on east-coast estuaries, where the pressures are more acute.

Mangawhai

Subject of three known MSc theses by McCabe (1985), Brand (1994) and Bunting (1996).

Whangarei Harbour

Various theses and publications by Barnett (2002) on storm surges, and Millar (1980), Black (1983), Black & Healy (1982, 1983, 1986) on sediment transport, side-scan sonar and oceanography, and Bell (1982) and McBride & Williams (1987) on harbour hydrodynamics and water quality. Nichol (1997) investigated the stratigraphy of relict coastal deposits along the margins of the harbour. Coastal hazard zone determinations (Gibb, beca etc).

Ngunguru

A thesis was undertaken on sediments and hydrodynamics of Ngunguru Estuary by Paton (1983).

Rangaunu Harbour

Detailed publications on the oceanography (tides, currents) and the sediment transport characteristics, particularly the tidal inlet dynamics, have been produced by Heath et al. (1983) and Pickrill (1985, 1986). Brookes (1991) investigated erosion at the Rangiputa beach near the tidal inlet.

Parengarenga and Kokota sandspit

Several theses, reports and publications have been undertaken in this region, where the silica sands have been extracted for glass manufacture. Works include Adam (1984), Murray-Brown (1984), Pritchard (1995), Parnell et al. (1997; 1999a,b; 2003).

Whangape

Publications by Gregory et al. (1999), Nichol et al. (1999; 2000), Creese et al. (1998) and Horrocks et al. (2001).

Hokianga Harbour

A thesis was undertaken on Omapere beach system in Hokianga Harbour by Fraser (1999).

Kaipara Harbour

NRC, Auckland Regional Council (ARC) and sand extractors have funded several studies by Dr R Grace, NIWA and the University of Auckland on the effects of sand extraction within Kaipara Harbour. The study sites are mainly focused on the area exposed to the tidal inlet to the Tasman Sea, including Tapora Island, the flood-tide delta and Pouto Point/North Head. These studies are currently written up in several client consultancy and progress reports of the current sand extraction study. Final reports are due out soon. Smith (1999) completed his thesis work on the evolution of the barrier island (Tapora).

7.1.3 Tidal inlets of Northland

Several references relating generically to tidal inlets and estuaries including those in Northland by Hume & Herdendorf (1988a,b; 1992; 1993). Monitoring for sand extraction at Mangawhai Inlet was investigated by Hume (1986), while Grant et al. (1982) looked at sand resources for extraction at tidal inlets. Kench (1990) and Kench & Parnell (1991) discussed the dynamics of the small Waipu tidal inlet in Bream Bay, while the tidal inlet to Rangaunu Harbour was investigated by Pickrill (1985, 1986).

Short and long-term coastal erosion and coastal hazard zones at sandspits and adjacent to tidal inlets of Rangaunu Harbour and Taipa River estuary were investigated by NRC (1991), and at Whananaki, Matapouri Bay, Ngunguru River estuary, Marsden Point, and Waipu River estuary were similarly discussed by NRC (1988).

Tidal gaugings in 1985 over a complete tidal cycle were undertaken by Hume et al. (1986a,b) at the tidal inlets of Whananaki, Ngunguru, Pataua and Mangawhai, with reports containing cross-section profiles, tide levels and tidal current velocities.

7.1.4 Embayments, pocket beaches and continental shelf (east coast)

Pakiri-Mangawhai

Several extensive reports were produced from 1996 to 2000 as outputs from a sand extraction investigation by the Working Party: Mangawhai–Pakiri Sand Study, comprising NRC, Auckland Regional Council, sand extraction companies, iwi and DoC representatives. The Reports are: Module 1–Onshore sands (Nichol et al. 1996); Module 2–Marine sands (Healy et al. 1996); Module 3–Morphodynamics (Hume et al. 1998); Module 4–Oceanography and sediment processes (Bell et al. 1997); Module 5–Numerical modelling (Black et al. 1998); Module 6–Final Report (Hume et al. 2000). Together, these reports contain a very detailed assessment of coastal drivers and sediment processes and budgets for the Mangawhai-Pakiri sand system.

These studies were complemented by further NIWA coastal research on offshore sediment transport, published by Swales (2002), Hicks (1999) and Hicks et al. (2002). Unpublished NIWA data comprises current meter deployments, salinity/temperature profiles and a wave-buoy deployment off Mangawhai in 35 m water depth from 1995 to 1997.

Anderson (1984) and Enright & Anderson (1988) described the recent evolution of the high Mangawhai-dune system.

Bream Bay

Bream Bay spans 40 km of coast, anchored in the north by Bream Head (Fig. C.20) and Bream Tail in the south. Bream Bay beach (23 km length) is broken only by Ruakaka and Waipu Rivers. Metcalfe & Duder (1985), Hume (1979), Duder (1980) and Duder & McCabe (1986) plus several other consultancy reports up to the present day, have been commissioned by power companies associated with Marsden A & B Power Stations or the Marsden Point oil refinery. These reports or publications address the general trends of sediment transport and long- and short-term shoreline change along Bream Bay, to address issues with foreshore protection of these major coastal developments. An overview of shoreline stability and coastal erosion hazard zones along Bream Bay from Marsden Point to Waipu Cove is presented in NRC (1988).

Osborne (1983) and Nichol (2002) studied the evolution and morphology of relict beach ridges along the Bream Bay coast, which provides an important geological context to modern coastal processes in Bream Bay.

Figure C.20: View of coastal dunes and beyond over Bream Bay from NIWA's Bream Bay aquaculture facility at Ruakaka. [*Photo: S Thrush*].

Northern Whangarei coastline (Bland Bay to Ocean Beach)

Shoreline stability and coastal erosion hazard zones for pocket beaches and embayments along the northern Whangarei open coast were described by NRC (1988). Most beaches appear to be in or close to a state of long-term dynamic equilibrium, but with the major hazard being short-term erosion during storms (NRC, 1988). A thesis on Matapouri Bay and estuary was undertaken by Dreadon (2001).

Bay of Islands

Farnsworth (2001) thesis on coastal processes and hazards at Paihia.

Paleo-tsunami deposits

Studies in Hendersons Bay and Great Barrier Island have focused on paleo-sediment deposits that probably arose from a pre-European tsunami event by Nichol et al. (1998; 2000; 2002; 2003),

Greater Hauraki Gulf

Review paper of the entire shelf sediment types and sediment transport in the Greater Hauraki Gulf and continental shelf up to Tutukaka was done by Manighetti &Carter (1999). Earlier studies on sand/gravel resources of this region are discussed below. The oceanography of the coastal and shelf upwelling and current velocities along the shelf south of Cape Brett is described in several papers including Sharples (1997), Sharples & Greig (1998), and Sharples et al. (2001).

Entire Northland coast

Gibb (1978) carried out a national survey of coastal erosion and accretion, including the east and west coasts of Northland. Hume & Harris (1981) complied a bibliography of much of the early publications and reports on oceanography and coastal sediment systems prior to 1981. Other resource management issues and sand/shingle resources were investigated by Cathcart (1970?), Schofield (1970), Gillie (1979), McCombs (1980), Hume (1983) and Grant et al. (1982).

7.2 Climate-change impacts on sediment supply and coastal erosion

Sediment is the "food" that sustains a coastal system. Climate change will impact the intricate array of factors that affect the supply of sediment to the coast – some factors leading to more sediment delivery, others to less. The overall future effects on sediment supply to the coast for regions of New Zealand is as yet unknown, as some of the factors will be negatively impacted by climate change, delivering less sediment to the coast, while other factors will lead to more sediment delivery (e.g., projected change to more intense rainfall events). However, the overall impact on sediment supply to the coast and estuaries needs to be assessed LOCALLY for vulnerable areas by detailed investigations, which involve not just the coastal system, but also contributing rivers and their catchments.

Coastal erosion hazards on sandy beaches are in general likely to be exacerbated by global warming, particularly if they already exhibit a long-term trend of erosion or are currently in a delicate state of dynamic equilibrium between successive storm cuts and slow beach building between storms. However, it is important to recognise that climate-change impacts on coastal erosion are not simply related to sea-level rise, but also involve the combined impacts on sediment supply to the coast, as outlined above.

8. Conclusions—Coastal hazards

A reasonable knowledge base exists on coastal sediment systems of Northland, particularly through the work of university postgraduates, targeted studies by NRC on issues such as sand extraction, and consultancy reports that supported resource consent applications, mainly focused on Whangarei Harbour, Bream Bay and Pakiri–Mangawhai. Several determinations for coastal erosion hazard zones based on existing knowledge and aerial photos have been accomplished by NRC (e.g., NRC, 1988, 1991) and coastal consultants working with district councils, particularly Whangarei District Council.

There are some gaps in developing fundamental databases on coastal “drivers”, such as wave climate, tides, winds and storms, to which these reports (Part I and II), partially address. One of the important aspects is a need to monitor and understand longer-term cycles in coastal drivers and resulting hazards e.g., the 3 to 5-year El Niño cycle and the 20 to 30-year Interdecadal Pacific Oscillation (IPO). Understanding and managing the effects of these cycles will markedly improve the ability to prepare for and manage even longer climate-change impacts. Some projections are given in this report for possible future impacts of climate change on the Northland region’s coast, with sea-level rise, effects on sediment supply to the coast and more intense storms likely to be the main impacts on coastal systems.

Future work firstly needs to fill gaps in the databases on coastal “drivers” (e.g., long-term cycles) and secondly usher in a more integrated “all-hazards” approach to coastal hazards, which examines the hazards from several different sources, including sea flooding and tsunami. The “all-hazards” approach will hopefully will be spurred on by the new Guidance Note for territorial authorities (MfE, 2003), which is based on a risk-management framework.

9. Acknowledgements

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