

Sea Level Rise – A New Zealand Context

Iain Dawe, Greater Wellington Regional Council

iain.dawe@gw.govt.nz

1.0 Introduction

It is estimated that 20% of the global human population lives in coastal cities and of these 100 million people live within 1.0 m or less above mean sea level. Most of New Zealand's population lives in coastally located cities and towns. Historically, permanent Maori settlements were almost exclusively in coastal areas because of access to kaimoana and ease of coastal travel on waka. European immigrants found harbours ideal places to settle because they afforded sheltered ports and access to sea transportation networks. Coastal areas are also appreciated as attractive places to live and recreate. Over the past 150 years holiday resorts and communities have developed in low lying areas close to the shoreline in many places around the New Zealand coast. However, these developments are vulnerable to coastal hazard events and sea level rise.

Sea level rise is a major effect stemming directly from changes in the global climate. In the past few years there has been a dramatic awakening in the public consciousness of the very real changes that are occurring in our local climate. This increasing awareness has seeped through to Central and Local Government, which is now starting to take the issue seriously. In the past six months Central Government has released a number of policy discussion documents on climate change issues facing New Zealand. Government is looking for significant input from the local government sector, that is also expected to be heavily involved in the implementation of these policies.

Coastlines form at the interface between oceans and terrestrial land. They are composed from a variety of rock and sediment types and present a wide range of geomorphologies from sheltered harbours, inlets and estuaries, to bold rocky and cliffed coasts, to long sandy dune coasts and exposed oceanic gravel beaches. They are extremely dynamic places and when left naturally, they have the ability to absorb vast amounts of wave and tide energy to which they are subjected ceaselessly day after day.

There are a number of important energy and sediment input agents that drive changes in the coastal system. At a first order level, geologic and climatic variables control sea levels, wind, waves and currents that in turn control beach geomorphology and sediment supply and transport. Sediments nourish a beach allow it to maintain its position against the ocean and its battering ram of waves. When there is ample sediment transported in a beach system, a beach will prograde or grow seaward. However, when sediment supplies to a beach are interrupted or naturally limited, a coast will erode. As discussed, sediment supply and transport is controlled by a number of environmental variables that are easily disrupted by human or natural activity. When we construct houses in sand dunes, construct causeways across inlets, reclaim land for development and roading, we interfere with the natural beach system and the flow of sediments that nourish a coastline. In doing so we place our communities, infrastructure, homes, businesses and assets at risk from coastal hazard events. Increasingly, sea level rise will add to this risk.

This paper discusses the history of sea level rise, the current state of knowledge, what rises might be expected in the future. It outlines the environmental processes that control sea level and the impacts

of sea level rise on coastal margins and communities. The paper finishes with a summary of the statutory tools and planning options that can be used to manage sea level rise in New Zealand.

2.0 Sea Level Controls

The level of the sea surface is controlled by a complex inter-relation of short, medium and long term variables. Sea level at a given coastal location is a relative measure made up of variations in both the oceanic and terrestrial environment. The actual water volume in the global ocean is referred to as global eustatic sea level, but this is only one component of what makes up local observed sea level. In the long term, local isostatic and tectonic adjustments can alter the land relative to the sea. In the medium term, annual and inter-decadal fluctuations in the sea surface can result from large scale tide and climate cycles. In the short term, there are monthly and daily fluctuations in the sea surface from lunar tide cycles and weather related effects.

2.1 Long Term Sea Level Controls

On a geological timescale, sea levels have fluctuated dramatically on a scale of 10s -100s of metres in response to long term variations in the global climate. Cold periods or ice ages are associated with lower sea levels, whilst warmer periods are associated with higher sea levels. Since the height of the last ice age, about 20 000 years ago, global mean sea level has risen by more than 100 m due to melting ice sheets, causing a marine transgression. Most the rise occurred between 12 000-6000 B.P., with a period of quasi-stabilisation since 4000 B.P. In the past 1000 years, sea level is estimated to have been rising at a rate of around 0.2 mm/yr, although there are many regional variations to this figure.

It is important to distinguish between these eustatic changes and adjustments to the land surface that cause relative local changes in sea level. There are two major processes responsible for this. The first is known as glacial isostatic adjustment or isostatic uplift. This occurs because large ice sheets, such as those that covered northern Europe, Canada and southern New Zealand and which currently exist in Greenland and Antarctica, exert massive force on the underlying land surface, causing it to be depressed. When an ice sheet melts, the land surface rebounds vertically as it distresses with the loss of overlying mass. This causes a local relative drop in sea level as the area that was covered in ice effectively rises up and out of the sea. An interesting example of this comes from Norway where archaeological investigations have revealed old fishing villages stranded high and dry above water level due to isostatic uplift over the past 10 000 years. Much of the southern part of New Zealand is experiencing isostatic uplift in the order of 0.5 mm/yr.

The second major process responsible for causing changes to the land surface are tectonic forces. These can cause long term increases or drops in relative sea through uplifting or subduction of the land surface. Much of the New Zealand coast is subject to tectonic adjustment. This process can occur gradually or catastrophically. For example, in the Wairarapa earthquake in 1855, one of the largest earthquakes in recent New Zealand history, land was uplifted 1-2 m around Wellington Harbour. This land has now been used to construct roads, the CBD and the airport. The 1931 Hawkes Bay earthquake caused uplift of 1.8 m at Westshore, Napier and the Bay of Plenty earthquake in 1987 caused about 0.4 m of subsidence along the Rangitaiki coast.

2.2 Medium Term Sea Level Controls

Annual and inter-decadal climatic oscillations affect sea levels around the New Zealand coast. When these fluctuations are factored into the local sea level measurement they produce what is referred to as the mean level of the sea (MLOS).

There are three main climatic effects:

- Annual seasonal heating and cooling of the sea surface from solar radiation. This occurs because water expands as it warms and contracts as it cools. The sea surface is typically around 0.04 m higher in the summer and any given year the variation can be as much as ± 0.08 m.
- El Nino/La Nina cycles (Southern Oscillation) that can alter sea levels by up to ± 0.12 m.
- The Interdecadal Pacific Oscillation (IPO) that occurs on a 20-30 year cycle and can alter sea levels by up to ± 0.05 m.

The combination of these factors means that local sea level can vary annually by as much as ± 0.25 m from the long term mean.

Tides vary in height due to the position and distance of the moon as it orbits earth that operate on a daily, fortnightly and monthly cycle. Tides are generally highest (and lowest) on the new and full moon - known as the spring tides. The average elevation of these tides above a chart datum is referred to as the mean high water springs. There is a 18.6 year tide cycle that produces what is known as the highest astronomical tide, sometimes called a king tide. King tides have been forecast to occur for parts of the New Zealand coast in April 2012. Tide height is strongly linked to the occurrence of coastal flooding and inundation during storm events.

2.3 Short Term Sea Level Controls

Storm surge is a short term elevation of the local sea level due to meteorological conditions and is due to three main factors; wind set-up, wave set-up and barometric lift. Wind and wave set-up occurs when strong winds and large waves force water onshore causing an elevation of water levels at the shoreline. Barometric lift occurs because, below air pressure of 1014 hPa, the sea surface rises *ca.* 1.0 cm for every 1.0 hPa drop in pressure. In a depression with air pressures of 980-985 at the centre, this equates to a localised elevation of 0.30-0.35 m.

In the New Zealand region storm surge is most commonly associated with southerly storms and ex-tropical cyclones that bring with them strong winds, large waves and low air pressure. Together these effects can cause a significant rise in local water level. The Wahine storm (an ex-tropical cyclone) and the southerly storms of 1976 & 1992 all produced storm surges in the order of 0.50-0.80 m above mean sea level. Storm surges have the capacity to cause significant damage, especially when they occur on top of high tides.

These medium and short term events will all continue to occur on top of a long term rise in global eustatic sea levels.

3.0 Sea Level Rise in the Past Century

Measurements of a recent rise in sea level come from historical tide gauge data. Tide gauges in harbours and ports around the world, record fluctuations in the sea surface on an hourly, daily, monthly and annual basis. The data collected from these gauges is then used to provide information about the tidal range and to define levels such as high and low water springs and mean water level. Over longer periods these data can reveal important inter-annual and inter-decadal variations in the tides and the sea surface. The oldest records date back to the mid 18th Century at the start of the Industrial Revolution. Reliable long term tide records have been collected continuously at ports around the world since the 1870s, and now form an invaluable record for examining longer term changes in the level of the sea.

Analysis of tide gauge records from around the world shows that over the last 150 years, sea level has risen at an average rate of 1.0-2.0 mm/yr or a total of 0.15-0.30 m. This is a significantly faster rate than at any stage in the past 1000 years. Measurements from the 20th Century alone, indicate that the rise has been in the upper end of this average at 1.7 ± 0.2 mm/yr. Over the period 1961-2003 the rate was 1.8 mm/yr with a range of 1.3-2.3 mm/yr. In the decade from 1993 to 2003 the rate was faster still, rising at around 3.1 mm/yr with a range of 2.4-3.8 mm/yr. It is unclear whether this reflects inter-decadal variability or an increase in the long term trend. Nevertheless, there is a high level of confidence that the rate increased from the 19th to the 20th Century.

3.1 Sea Level Rise in New Zealand

Sea levels have been recorded on tide gauges at ports around New Zealand for over 100 years. The earliest records come from Wellington Harbour and date back to 1891, but the longest and most reliable record comes from Auckland where there has been near continuous measurements since 1899. The first study of these records was conducted in 1988 by Professor John Hannah who is now head of the University of Otago Survey School. After correcting for isostatic, tectonic and inter-decadal variations, Hannah showed that since measurements began, all the records display a gradual linear increase in the height of the sea surface around New Zealand at rate of 1.7 mm/yr with a range of 1.30-2.08 mm/yr. Hannah recently updated this work to 2001 and included some older records uncovered in archives that have extended the historical record. The trends around New Zealand remain almost the same at 1.6 ± 0.2 mm/yr. This is in line with measured global sea level rise. The measured increases in sea level rise from the four ports examined in the study can be seen in Table 1.

Table 1: Sea level as measured from tide gauges at four ports around New Zealand 1891-2001.

City	Auckland	Wellington	Christchurch	Dunedin	Average
Rate (mm/yr)	1.30	1.78	2.08	0.94	1.60
Rise from 1900 (m)	0.14	0.19	0.22	0.10	0.16

4.0 What Is Causing Sea Level Rise?

Just as climate changes in the past were responsible for causing fluctuations in sea level, so too is global warming or ‘climate change’ directly responsible for causing the sea level rise we currently observe. The two biggest contributing factors to eustatic sea level rise are thermal expansion of the ocean and ice melt. Both these processes are being driven by an increase in the mean global surface temperature. The mean global temperature has increased by 0.74 °C in the past century and the warming over the past 50 years is double that over the previous 100 years. New Zealand has experienced a 0.4 °C warming since 1950.

Observations since 1961 show that the average temperature of the ocean has increased globally, and not just at the surface. Temperature increases have been detected at depths of over 3000 m. Water acts like a thermal sink and is very effective at absorbing and retaining heat. It is thought that the ocean has absorbed more than 80% of the temperature increases experienced since 1850. The side effect of this is that it causes the seawater to expand, effectively increasing the volume of the ocean and contributing to eustatic sea level rise. The relative contributions of the various inputs to sea level rise can be seen in Table 2.

Glaciers, icecaps and snow packs have receded on average in both the northern and southern hemisphere over the past 50 years, contributing to sea level rise. Large contributions have come from the Greenland and Antarctic ice sheets that have each contributed 0.21 mm/yr since 1993. New Zealand has lost a quarter of its ice mass since 1950.

Table 2: Contributing factors of sea level rise.

Rate of sea level rise (mm/yr)	1961-2003	1993-2003
Contributing Factor		
Thermal Expansion	0.42	1.60
Ice Melt (glaciers/ice sheets)	0.69	1.19
Other contributions	0.70	0.30
Total Observed	1.80	3.10

5.0 Future Projections

Sea level was 4-6 m higher during the last major inter-glacial or warm period about 125 000 years ago. At this time research indicates that global temperatures were 3-5 °C higher than at present. Future projections for global temperature increases are within the range 1.8-4.0 °C. Even if all the drivers of climate change were held constant at 2000 levels, there will be continued warming of 0.1 °C per decade for the next 20-30 years, due to the slow thermal response times of the oceans. In other words, we are locked into a certain amount of climate change and sea level rise for the next few decades. However, most realistic projections are for a warming of 0.2 °C for at least the next 25 years. The first temperature projections published by the IPCC in 1990, were for a warming of

0.15-0.30 °C per decade for the period 1990-2005. Measured values over this period indicate that the warming has been 0.2 °C, adding confidence to future projections. Global mean temperatures are higher now than they have been in the past 1300 years. Taking this into consideration, a range of scenarios were used in the IPCC 4AR to project sea level rise. They all point to continued sea level rise over the next century and indicate that we can expect sea levels to increase in the range 0.18-0.59 m by 2100.

Recently, satellites using radar altimetry methods have provided high quality measurements with nearly global coverage since 1993. These satellites can provide measurements of global sea level to an accuracy of several millimetres every 10 days. Data from these satellites indicate that sea level has been rising at a faster rate of 3.0 mm/yr, than the mean rate estimated for the 20th Century. This is higher than in all previous decades measured. For reasons that are unclear, the rise has been greater at the coastal margins, than in the deep ocean. The evidence indicates that there has been a small but significant acceleration over the period 1870-2004 in the order of 0.013 mm yr⁻². If this acceleration remains constant, then the rise in sea level expected by 2100 will be in the order of 0.28-0.34 m, which is within range of the latest estimates published in the IPCC Fourth Assessment Report (4AR).

6.0 Impacts of Sea Level Rise

There are a range of impacts that a rising sea level has on the coastal margin, but essentially they can be categorised under two main headings; erosion and inundation. The way in which a coastline responds depends upon its geomorphology and constituent materials (sand/gravel/rock) and its exposure to tide and wave and current conditions.

The most serious physical impacts of sea level rise on coastal areas will be:

- Coastal inundation causing landward movement of estuaries, inlets, lagoons and wetlands.
- Coastal erosion and shoreline changes due to alteration of sediment transport systems
- Increased vulnerability to coastal storm damage
- Increased coastal flooding on extreme high tides, during high wave conditions and storm surge events
- Increased difficulty in river drainage, especially during flood events that may increase flood duration around low lying delta areas
- Possibility of enhanced estuary infilling through increased sediment loads from flood events and runoff during intense rain storm events
- Increased tidal prisms of tidal inlets, estuaries and lagoons leading to possible scouring and erosion around inlet entrances and adjacent beaches
- Salt water intrusion into coastal aquifers and increased saline penetration along rivers

6.1 Flooding and Inundation

The most direct impact of sea level rise is flooding and inundation of low lying coastal areas, especially around estuaries, inlets and river mouths. A rising sea level allows more frequent coastal

flooding events from storms, storm surges and extreme high tides because it raises the background height water level on which these processes occur. Sea level rise effectively increases the probability or recurrence interval of a given flooding event. Higher sea levels allow wave run-up and water levels to reach further inland. Large waves, extreme high tides and storm surge events may all cause more frequent flooding.

Eventually, the flooding events may become so frequent, that it leads to permanent inundation of very low areas of the coast. This is a slow and gradual process, that starts with increasingly frequent flood events from high tides and storm events. Over time the flooding events become more common as the tide range advances inland until it reclaims a low lying area of land that becomes part of the inter-tidal zone. This is most likely to occur around the margins of estuaries and river mouths.

6.2 Erosion

Inundation on its own does not cause erosion, rather it is wave and current activity that removes sediment from a beach that causes erosion. High sea levels allow waves to run higher up a beach and scour sediment from the backshore area. The way in which a beach responds to this depends on its constituent materials, its geomorphology and its exposure to wave and current activity.

6.2.1 Prograding Shores

Sea level rise will occur on top of the range of natural processes that already occur in a beach. A beach may have one of three states. It may be prograding or growing, it may be actively eroding, or it may be stable (i.e. neither eroding or prograding). The state that a beach is in largely depends on the supply of sediments to a shoreline. Sediment may come from rivers that supply surrounding beaches, the continental shelf and transported onshore by waves, or it may come from material eroded from surrounding shorelines and transported in the beach system.

A beach that is prograding has a ready supply of sediments and the wave and current activity by which to transport those sediments onto the shore. These beaches will generally respond quite well to sea level rise and may experience very little effects aside from an adjustment in the rate of progradation. However, this very much depends on the continual supply of sediments which may be altered if climatic changes modify local meteorological and hydrological conditions.

6.2.2 Eroding Shores

A shoreline in net long term retreat is likely to continue eroding under a rising sea level and quite possibly at a faster rate as wave run-up reaches higher up the beach. Long term erosion of a shoreline occurs when the amount of sediment being removed from the beach is greater than that being supplied by waves and currents. Shorelines currently eroding are extremely vulnerable to enhanced erosion under rising sea levels.

6.2.3 Stable Shores

Stable beaches are a fine balance between the sediment inputs and the wave conditions. These beaches can be seen to have a dynamic equilibrium with the local environment. Changes to this equilibrium may cause the beach to move into a period of long term erosion or progradation. However, under a rising sea level these shorelines will be more vulnerable to erosion, particularly if there is an increase in storminess.

All beaches experience short term episodes of erosion from storm events but are usually able to recover from this in ensuing months as sediment is transported back onshore. A prograding shoreline is able to recover from these erosion episodes quite quickly. However a stable beach may take much longer as the sediment supply is lower. A shoreline that has long term stability has developed a balance between these storm events and the ensuing calm periods. In other words it has developed a balance between the removal and supply of sediment to the beach. If an increase in storminess leads to a greater number of erosive episodes the balance may be disrupted and the beach becomes unable to recover in time before the next storm. In this way a beach that was stable may begin to erode as the removal of sediment becomes faster than the supply.

6.2.4 Gravel Beaches

The way in which a coast responds to sea level rise depends not only on the supply of sediments but on the type of material that the shoreline is composed. A hard rock shoreline may experience nothing more than more frequent inundation. Gravel and mixed sand and gravel shorelines, which make up about 25% of New Zealand's coast, respond differently than sandy coasts. On the whole gravel beaches are able to respond well to small changes in sea level and in many locations where there is a large volume of gravel, there may be no appreciable change in the beach.

Gravel beaches commonly have a stepped profile, composed of a series of berms. Berms provide a indication of the wave run-up on the beach and respond quickly to changes in wave conditions and water levels at the shoreline. Gravel beaches respond to changes in water level by adjusting the profile to contain the wave run-up. This results in the berm elevation being adjusted upward slightly and may result in the highest berm, known as the storm berm, moving slightly inland. Gravel barrier beaches that commonly occur at river mouths and in front of coastal lagoons are rolled back landward under a rising sea level. Gravel beaches do not have material removed from them or loose volume. Rather, the whole beach is translated inland. This may result in the loss of some productive land immediately behind the beach or barrier. By contrast, when a sandy beach retreats under a rising sea level, it occurs through erosion of sand from the foreshore and subsequent deposition offshore.

6.2.5 Estuaries and Inlets

Estuaries and inlets are particularly sensitive to changes in sea level because it alters the amount of water flowing in and out of them on every tide - a volume known as the tidal prism. Increases in the tidal prism can alter the inlet mouth and channels by causing an increase in the current velocities. This may lead to a widening of the entrance and scouring of the surrounding area. Adjacent beaches may experience severe erosion as they adjust to a new current flow regime. Sand deposition patterns may be altered leading to changes in the flood and ebb tide deltas and the position of sand shoals and channels in the inlet. It is possible that sedimentation rates will increase in many estuaries due to increased runoff from streams and hillslopes. This may offset some of the sea level rise, but lead to a loss or degradation of important coastal habitats for marine flora and fauna, including fish and shellfish species and bird life. To date, sedimentation rates in estuaries around New Zealand, that averages around 2-3 mm/yr, have been keeping pace with rises in sea level. However, this may change if sea level rise accelerates over the next 50-100 years.

6.2.6 Developed Coasts

On developed coastlines, especially low lying areas around estuaries, sea level rise may result in the loss of the inter-tidal zone and natural habitat. Many sections of coast around cities are commonly

fixed in place by rock revetments, seawalls and road/rail causeways and are unable to naturally fluctuate. With rising sea level issues and increasing expensive assets at risk from erosion and inundation, there will be increasing pressure placed on local authorities to build more protection structures like these, thereby exacerbating the problem. There may be increased incidences of coastal flooding events as storm wave activity overtops walls and revetments. Enhanced scouring at the toe of these structures may undermine the wall and lead to its collapse. As the mean low and high water mark rises on a fixed coast the inter-tidal beach is unable to adjust naturally and the horizontal distance between the low and high water mark is squeezed, reducing the size of the inter-tidal area.

6.3 Climate Change Effects

Broader scale changes in the local climate may also alter the weather patterns of an area that has an impact on the incidence of storm wave events. For example, increased incidences of westerlies may lead to increased erosion activity along western parts of the New Zealand. Waves generated in the Tasman Sea tend to be steep, short period erosive waves that remove material from a beach. Increased storm events may lead to greater incidences of storm surge events and increased incidences of erosion and flooding.

7.0 Planning for Sea Level Rise

7.1 Statutory Regulations

The effects of sea level rise are largely hazards related and can be managed through the planning and hazard management mechanisms contained within national and regional legislation. The overarching piece of legislation is the Resource Management Act 1991. The Resource Management Act provides a mandate for Regional Councils to manage natural hazards:

- Section 30, 1(c) mandates Regional Councils to avoid or mitigate natural hazards.
- Section 31 states that Regional Councils must control any actual or potential effects of the use or development of the land including the avoidance or mitigation of natural hazards.
- Section 35 provides a mandate to conduct natural hazards research and maintain information on natural hazards.

A recent amendment to Section 7 states that particular regard shall be had to climate change effects.

Alongside the RMA, the Civil Defence and Emergency Management Act 2002 (CDEM) gives councils a mandate to identify, assess and manage hazards and to communicate information about the occurrence and effects of natural hazards. This can include the effects of sea level rise on coastal communities.

The RMA provided a mandate to produce the Zealand Coastal Policy Statement (NZCPS). This was completed in 1994. Section 3.4 of The New Zealand Coastal Policy Statement 1994 gives provisions for avoiding or mitigating the effects of coastal hazards. Policy 3.4.2 explicitly states that policy statements should recognise the possibility of a rise in sea level and should identify areas which would as a consequence be subject to erosion or inundation. As we have seen, there has been and continues to be a measurable rise in sea levels around the New Zealand coast. This Act is

currently under review and it is expected that sea level rise and climate change issues will feature more prominently in the revised legislation.

Beneath the RMA and NZCPS sits the Regional Policy Statements (RPS). Regional Councils are required to produce Regional Policy Statements, that provide regulatory and non-regulatory policies to govern the management of natural resources at a regional level. Within this framework, Regional and Territorial Authorities are able to manage coastal hazards through statutory instruments such as regional, district and coastal plans under the Regional Policy Statement, the RMA and NZCPS.

Regional Council's are now close to the or in the process of reviewing their RPS's. Climate change and sea level rise should be an important issue for policy makers to consider in this process. Greater Wellington is currently reviewing its RPS and climate change issues including sea level rise are an important part of the hazard and coastal planning provisions. There are strong directional policies in the draft Wellington RPS for district plans to include provisions that avoid development in hazardous coastal areas. There are also a range of coastal hazard considerations for resource consents and notices of requirement.

7.2 Planning Responses

How a shoreline responds to climate change and sea level rise is a complex inter-relation between beach geomorphology, sediment supply and transport and the wave and current conditions. Shoreline response will also be affected by potential changes in the magnitude and frequency of storm events. Any management plans implemented to deal with sea level rise must be flexible enough to deal with coastal locations on a case by case basis, because different shore types react differently to changes in sea level. As a first step this may require some scientific research to provide a clearer picture of how a beach system may react, before implementing any planning and response programmes.

There are a number of responses that can be made to sea level rise:

1. *Modify the hazard.* In this case the aim is to reduce greenhouse gas emissions, with the main target being CO₂. However, there a long lag time between reducing CO₂ emissions and seeing a stabilisation of sea levels. In the mean time other measures will be required to deal with sea level rise impacts.

2. *Modify the losses.* This includes the damages resulting from sea level rise effects. This is primarily achieved through insurance mechanisms which can be through individual policies or collective/government schemes, such as EQC. This may be valid in the short term, or where the losses are low impact and infrequent, but it may not be a viable option in the long term.

3. *Modify the human element.* There are a range of options here that can be considered.

- Accommodation. This is a do nothing or very little response. This may be an option in areas with low level assets or where the impacts from sea level rise are expected to be low.
- Protection (e.g. seawalls, levees). This may be an option for very high level development, key infrastructure and high value property and assets, where the costs of loss or damage outweigh the cost of protection. In some areas this may be perfectly feasible. For example in main centres such as Auckland or Wellington where CDB's are adjacent sheltered harbours, the costs of protection will be found to outweigh the costs of no protection. Indeed, many of these areas already have a measure of protection. In some cases protection may be best

achieved through natural engineering methods such as, sand renourishment, dune planting and enhancing the natural buffering abilities of the coastal system.

- Adaptation. Some measure of adaptation will be required regardless of what happens over the next few years, because we are already locked into a certain amount of climate change and sea level rise. This may be a case a raising minimum floor levels to cope with increased coastal flooding, having setback distances from the coast, or by engineering deeper foundations to deal with possible erosion events. This may be an option where there is only occasional flooding and erosion. Another important aspect of adaptation is public education.
- Policy controls (e.g. avoidance, managed retreat). Avoidance can occur by preventing development in hazardous areas. This is possible with new development, through generous setback distances that allow the beach to adjust naturally to sea level rise without the need for engineering intervention. This may be an option in areas subject to repeated chronic flooding and ongoing retreat of the shoreline. Managed retreat will require bold and innovative policies by Regional and Territorial Authorities. Managed retreat may be an option for residential and industrial development that can be situated elsewhere, either further back on the section or further inland. Another option is buy back schemes, whereby Government or Local Authorities slowly purchase coastal properties and turn the land into reserve. Other methods for Local Authorities include non-renewal of resource consents, not allowing subdivision, new building or large scale renovations and only allowing owners to maintain their dwellings in a reasonable condition until the end of useful life of the building. In a worst case scenario it may require abandonment of the land, especially if it is eroding into the sea and the costs of protection outweigh the costs of the properties.
- Modify human behaviour. This can involved public education, by teaching people about the hazards of buying coastal property. This is one of the biggest challenges facing Local Authorities and government organisations, because coastal property is both both highly desirable and highly lucrative. Other methods include, placing hazard alerts on LIM and PIM reports or increasing insurance premiums. In extreme cases, it may be necessary to remove insurance cover altogether for high risk property locations.

Planning responses may involved a combination of these factors. For example, a solution may involve construction of a rock revetment to protect property in the short to medium term, with a longer term policy of retreat after the buildings and protection structures have reached the end of their usable life.

No single measure will solve all coastal planning issues related to sea level rise and climate change impacts. Planning for and dealing with the effects of sea level rise will involve a coordinated effort that involves a full spectrum of planning, education and engineering programmes from Central Government and Local authorities in cooperation with business's and communities.

8.0 References

Bell, R.G., Goring, D.G. & Walters, R.A. (2001), Advances in understanding sea level variability around New Zealand. *Proceedings of the 27th International Conference on Coastal Engineering*, Vol. 2, 1490-1500.

- Bell, R.G., Hume, T.M. & Hicks, D.M. (2001), *Planning for Climate Change Effects on Coastal Margins*. A report prepared for the Ministry for the Environment as part of the New Zealand climate change programme. 73pp.
- Church, J. (2001), How fast are sea levels rising? *Science*, 294, 802-803.
- Church, J. & White, N. (2006), A 20th Century acceleration in global sea level rise. *Geophysical Research Letters*, 32, L01602.
- Church, J., White, N., Coleman, R., Lambeck, K. & Mitrovica, J. (2004), Estimates of the regional distribution of sea level rise over the 1950-2000 period. *Journal of Climate*, 17 (13), 2609-2624.
- Davidson-Arnott, R.G.D. (2005), Conceptual model of the effects of sea level rise on sandy coasts. *Journal of Coastal Research*, 21 (6), 1166-1172.
- Hannah, J. (1990), Analysis of mean sea level data from New Zealand for the period 1899-1988. *Journal of Geophysical Research*, 95 (B8), 12,399-12,405.
- Hannah, J. (2004), An updated analysis of long term sea level change in New Zealand. *Geophysical Research Letters*, 31, L03307.
- Holgate, S. & Woodworth, P. (2004), Evidence for enhanced coastal sea level rise during the 1990s. *Geophysical Research Letters*, 31, L07305.
- IPCC (2001), *Climate Change 2001: The Scientific Basis*. Summary for Policymakers and Technical Summary of the Working Group Report I. Part of the working group I contribution to the third assessment report of the IPCC.
- IPCC (2007), *Climate Change 2007: The Physical Science Basis*. Summary for Policymakers. Contribution of working group I to the fourth assessment report of the IPCC, 18pp.
- Lambeck, K. (2002), Sea level change from mid-Holocene to recent time: An Australian example with global implications. In Mitrovica, J. & Vermeersen, B. (eds), *Ice Sheets, Sea Level and the Dynamic Earth*, Geodynamics Series, 29, pp33-50.
- Larsen, C. & Clark, I. (2006), A search for scale in sea level studies. *Journal of Coastal Research*, 22 (4), 788-800.
- Walsh, K., Betts, H., Church, J., Pittock, A., McInnes, K., Jackett, D. & McDougall, T. (2004), Using sea level rise projections for urban planning in Australia. *Journal of Coastal Research*, 20 (2), 586-598.