Impacts of Climate Change on Urban Infrastructure & the Built Environment

A Toolbox

Toolbox 2.2.1 – Guidance on assessing sea-level rise in New Zealand

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1. Guidance on assessing sea-level rise in New Zealand

1.1 Introduction

Eustatic (absolute) sea levels have been steadily rising globally since the mid to late 1800s. Since 1900 up to present (2009), the global-average rate of rise has been 1.7 ± 0.2 mm/year (Church & White 2011). In New Zealand since 1900, the average relative sea-level rise (relative to the land mass) has been at a similar rate (Hannah 2004; Hannah et al. 2010).

The Intergovernmental Panel for Climate Change (IPCC) released its Fourth Assessment Report in April 2007. It found for sea level that rises by the 2090s are projected to be in the range 0.18 and 0.59 m, which included ice-sheet discharges from Greenland and Antarctica at the same rates observed for the decade 1993-2003. If this ice-sheet contribution were to grow linearly with global average temperature change, the upper ranges of sea-level rise would increase by an additional 0.1 to 0.2 m (IPCC 2007). Because understanding of some important effects driving sea level rise is too limited (especially the polar ice-sheet response), the report (IPCC 2007) did not assess the likelihood, nor provide a best estimate or an upper bound, for sea level rise. Further studies since the IPCC assessment have indicated that sea levels could reach or exceed one metre by 2100 – see summary by Royal Society of New Zealand (RSNZ 2010). Sea levels are projected to continue to rise well beyond this century because of long lag effects between changes in levels of greenhouse gases in the atmosphere and ice sheet and ocean responses.

Sea-level rise is caused by several factors, but the dominant contributors are an:

a) increase in ocean water mass due to discharges from polar ice sheets and glaciers on land. There are also small net differences in exchange of water masses with the ocean through management of freshwater resources e.g., reservoir storage, pumping groundwater.

b) expansion in ocean volume caused by a decrease in ocean density from warmer waters. Much smaller increases in ocean volume will also occur from freshening by land-ice melt water, reducing salinity in some ocean regions.

1.2 Planning timeframes

Sea-level rise is a progressive or "creeping" upwards trend that is affecting daily through to extreme sea levels around most of the world's coasts.[1] Last century, the rate of sea-level rise was relatively slow. Planning and engineering design rightly focused on storm extremes in the context of climate variability. For example, designing for an average recurrence interval (ARI) event of 50 or 100 years, for variables such as water level, flood levels or rainfall which remained stationary (i.e., no trend) with time, as shown by the annual mean sea-level series at the bottom of Figure 1.1. However as the rise in sea level continues to rise and accelerate, there is an increasing imperative to consider the effects of a rising trend in mean sea level as well as storm extremes when planning for future development. This upwards trend also means the definition of realistic (rather than nominal) planning timeframes becomes much more important than it was in the past, as shown by the top curve in Figure 1.1. So any future projection needs to be explicitly linked to a timeframe.

Over the next few decades, the trend will continue to be masked in the short-term by natural variability in sea level due to interannual and decadal climate cycles such as El Niño–La Niña phases (Figure 1.1).

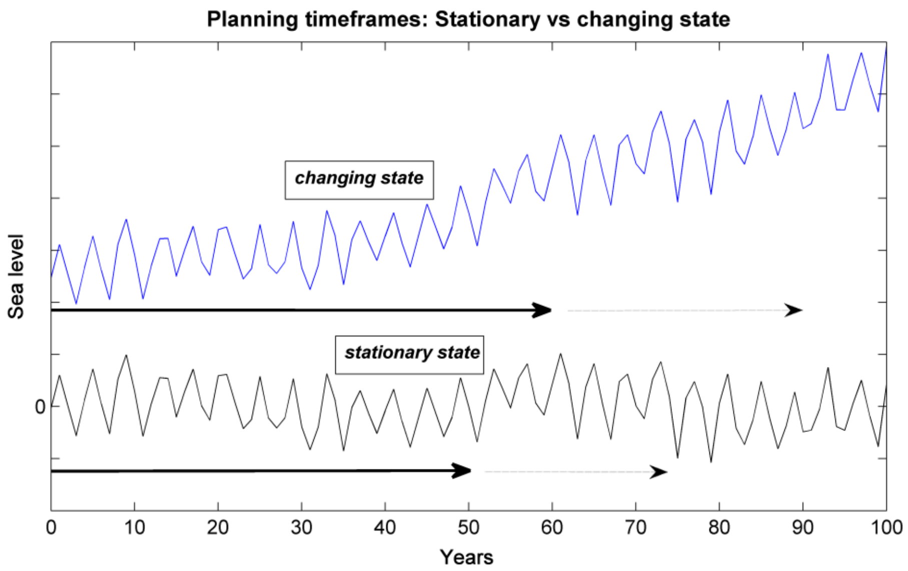

Figure 1.1: Example of a stationary sea-level time series with no long-term trend (bottom trace), compared with the same time series on the back of a rising sea-level trend. It illustrates the importance of selecting an appropriate planning timeframe for a changing state, as well as being aware of timeframes when defining an ARI extreme sea-level.

[1] Some parts of the world have negative trends in relative sea-level rise due to the uplift of the land mass from crustal rebound following the last Ice Age e.g., parts of Scandinavia.

1.3 Historic and recent sea-level rise

The global average sea-level rise from 1880 to 2009 is about 0.21 m (Church & White 2011) and shown in Figure 1.2.

Sea-level rise (SLR) was relatively slow in New Zealand from 1500s to late 1800s at an estimated rise of 0.3±0.3 mm/yr (Gehrels et al. 2008). Over the past century (1900–2000), sea level rose at a higher rate, with an average relative SLR of 1.6±0.2 mm/yr across New Zealand's four main ports (Hannah 2004), which is an average rise of 0.16 m in that time period. A recent update indicates the average relative SLR has crept up to 1.7±0.2 mm/yr for an analysis to 2009 (Hannah et al. 2010).

Adding an estimated 0.3 mm/yr, for crustal rebound in the New Zealand region since the last ice age (Hannah et al. 2010), to the average relative SLR for New Zealand up to present means an estimate of the absolute (eustatic) SLR is around 2.0 mm/yr. This is within the global-mean range of 1.7±0.5 mm/yr for the absolute SLR last century (Bindoff et al. 2007).

Satellites with radar altimeters such as TOPEX/Poseidon, Jason-1 and Jason-2 have also provided new insight into the complex geographical patterns of sea-level change. The New Zealand region is responding at around or slightly above the satellite-derived global mean SLR[2] again confirming that sea-levels in the New Zealand area are responding at close to global average rates (Figure 1.2).

In the satellite period post-1993 (up to July 2011), measurements[2] show that the global average sea-level rise has increased to 3.1 ±0.4 mm/yr. It is unclear if this post-1993 trend reflects short-term variability in global-mean sea-level rise or indicates a systematic acceleration in the rate of global-mean sea-level rise or both: this is a question that further monitoring will eventually resolve.

[2] CSIRO: http://www.cmar.csiro.au/sealevel/sl_hist_last_15.html

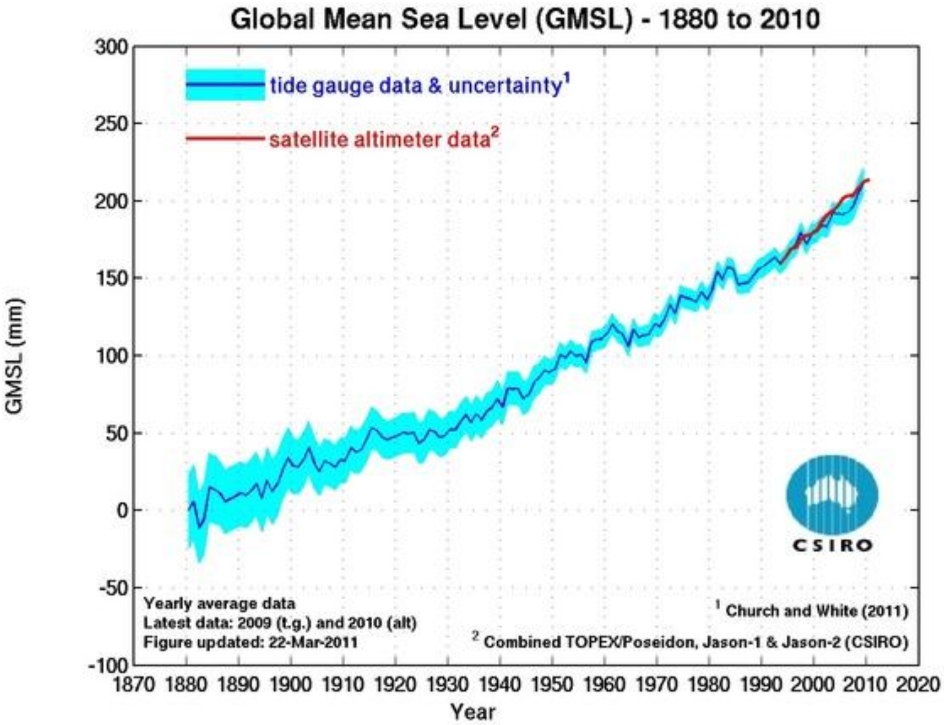

Figure 1.2: Global mean sea level between 1880 and 2009 from a network of long-term tide gauges (updated from Church & White (2006) compared to recent measurements from satellite altimeters from 1993 to 2010. [*Source:* CSIRO Marine & Atmospheric Research].

1.4 Projected sea-level rise by 2100

Relative to past IPCC projections (in the 1st to 3rd Assessment Reports completed in 1990, 1995 and 2001 respectively), the global mean sea level has so far been tracking at the higher end of the projected range which were derived from the more fossil-fuel-intensive emission scenarios (Figure 1.3).

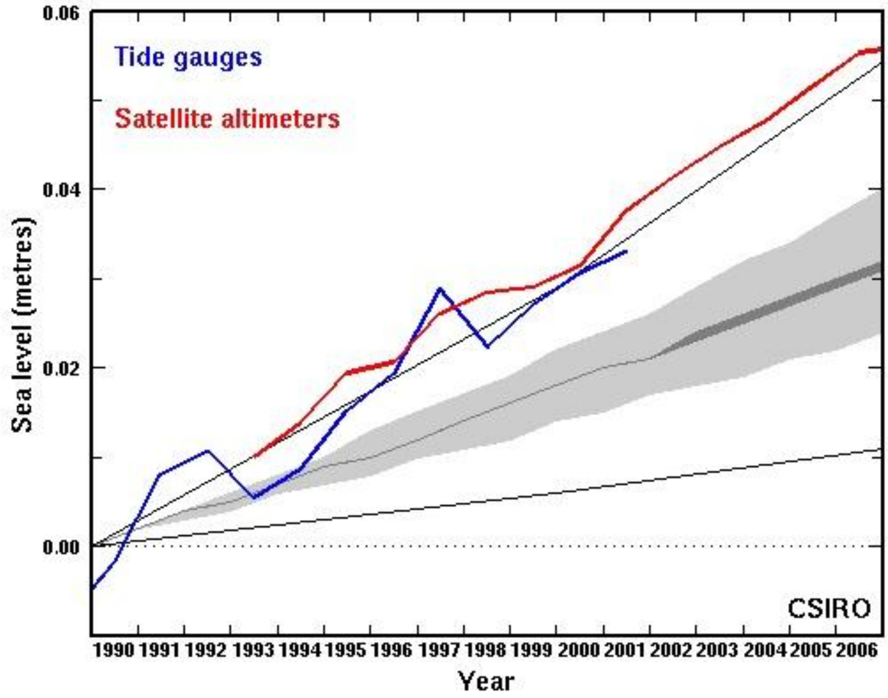

Figure 1.3: Recent observations show the observed global average sea level from tide gauges (blue) and satellites (red) are tracking near the upper bound (black line) of the 2001 IPCC 3rd Assessment Report projections (grey shading and black lines) since the start of the projections in 1990 (Rahmstorf et al. 2007). [*Source:* CSIRO Marine & Atmospheric Research].

These observational data underscore the concerns about global climate change. Previous projections, as summarized by IPCC, have not exaggerated but may in some respects even have underestimated the change for sea level (Rahmstorf et al. 2007).

As SLR in New Zealand is tracking close to the global average, it is reasonable that the IPCC projections can be applied directly to the New Zealand situation. However, outputs from global climate models show the departure of SLR from the global average in the New Zealand region is estimated to be a further 0.05 m above the global-mean SLR by the 2090s. This has been factored into the Ministry for Environment guidance on sea-level rise (MfE 2008; 2009), reproduced in Section 1.6 of this document.

The basic range of projected sea-level rise estimated in the Fourth Assessment Report (IPCC 2007) is for a rise of 0.18 m to 0.59 m by the decade 2090–2099 (2090s) relative to the average sea level over the period 1980 to 1999 (Figure 1.4). This is based on projections from 17 different global climate models for six different future emission scenarios shown by the bars on the right-hand side of Figure 1.4 for a 5 to 95% interval characterising the spread in model results. The highest projection by the 2090s is for the fossil-intensive emission scenario A1FI (Figure 1.4).

However, these SLR projections (light blue shading in Figure 1.4) exclude uncertainties in carbon-cycle feedbacks and the possibility of faster than expected ice loss from Greenland and Antarctica ice sheets.

While the basic set of SLR projections do include sea-level contributions due to ice melt from Greenland and Antarctica remaining at the rates observed between 1993 and 2003, it is expected that these rates will increase in the future particularly if greenhouse gas emissions are not reduced. Consequently, an additional 0.1 to 0.2 m rise in the upper ranges of the emission scenario projections (dark blue shading in Figure 1.4) would be expected if polar ice sheet contributions were to only grow linearly with global temperature change (IPCC 2007).

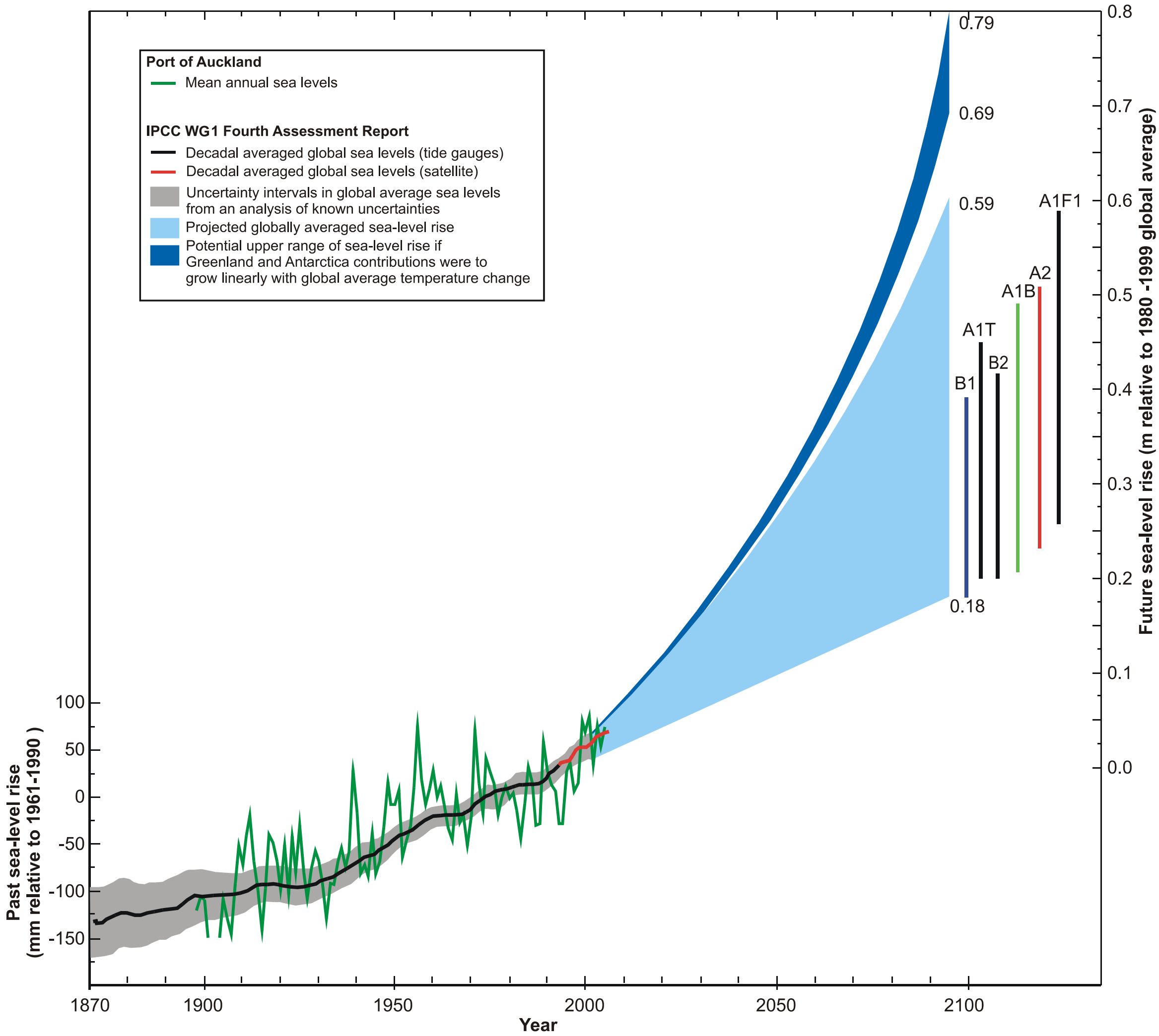

Figure 1.4: Global mean sea-level rise projections to the mid-2090s. The black line and grey shading on the left hand side show the decadal averaged global sea levels and associated uncertainty respectively, as measured by tide gauges throughout the world. The red line is the decadal averaged sea levels as measured by satellites since 1993. The green line is the mean annual relative sea level as measured at the Port of Auckland since 1899. The light blue shading shows the range in projected mean sea level out to the 2090s. The dark blue line shows the potential additional contribution from Greenland and Antarctica Ice Sheets if contributions to sea-level rise were to grow linearly with global average temperature change (IPCC 2007). The vertical colour lines on the right-hand side show the range in projections from the various global climate models for six emission scenarios.

While large sea-level rise scenarios above 1 metre, resulting from accelerated ice loss of the polar ice sheets, are generally considered as having lower probability during the 21st century, they cannot be ruled out based on current scientific understanding. Since the 2005 cut-off period for peer-reviewed literature considered by IPCC in their 4th Assessment Report, there have been several scientific papers published on ice-sheet dynamics and mass budgets and their possible contribution to a range of possible higher SLR values by 2100. A summary of these more recent projections for SLR are provided by a Royal Society of New Zealand Emerging Issues paper (RSNZ 2010) and in Figure 1.5. It is important to remember that the magnitudes of the potential impacts associated with high SLR scenarios are of sufficient concern to merit consideration in impact, vulnerability and adaptation studies (Nicholls & Cazenave 2010).

Most of these more recent projections, based on a semi-empirical techniques or assessment of physical constraints, are shown in Figure 1.5 and compared to the projections from the 4th IPCC Assessment Report. While largely based on semi-empirical approaches (where past surface temperature series are correlated with lags in sea-level rise), these recent studies indicate that a sea-level rise of 1 m or more by 2100 cannot be ruled out. Much further research is now required on modelling ice-sheet dynamics and quantifying ice mass losses through observations to provide more definitive projections of upper-bound SLR in future IPCC Assessment Reports.

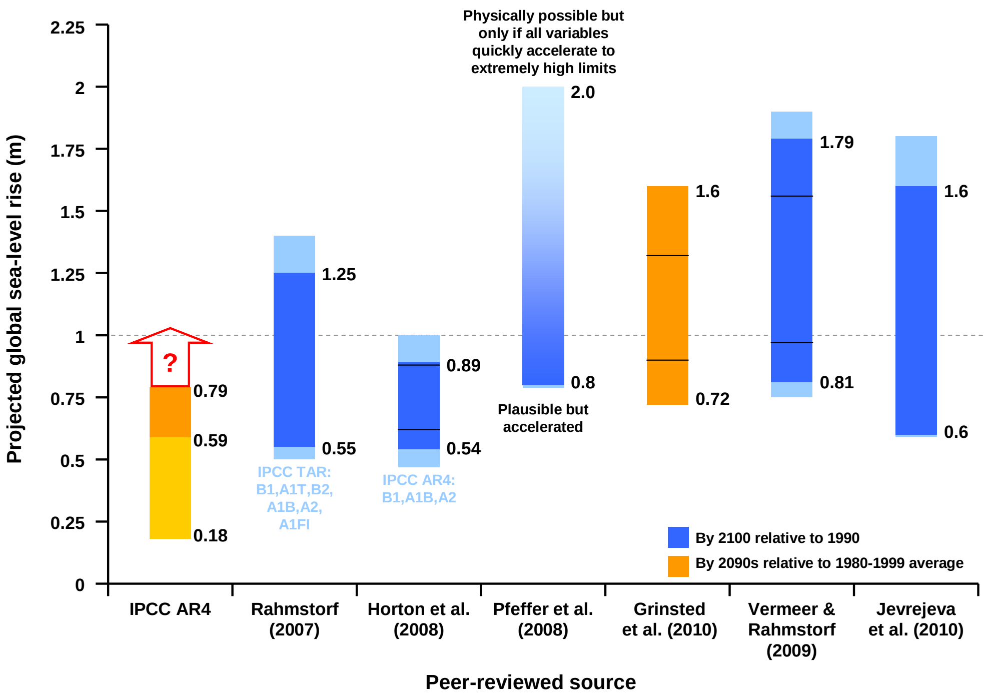

Figure 1.5: Comparison of sea-level rise projections from recent peer-reviewed papers and the IPCC 4th Assessment Report (AR4). Projections out to the 2090s are orange and those out to 2100 are blue. Light blue shading indicates confidence limits. The AR4 (IPCC 2007) projections include a caveat for inclusion of a limited ice-sheet component, but IPCC were not prepared to provide any upper limit (hence ? mark). Citations can be found in References section.

1.5 Projections for sea-level rise beyond this century

Sea-level will not stop rising at 2100. The New Zealand Coastal Policy Statement (NZCPS) requires assessment of climate change effects on the coast out to at least 100 years, which effectively now means nominally out to 2115.

Sea level is likely to continue rising for at least next century or beyond, even if some stabilisation of emissions is achieved in the next few decades. This delayed response is due to the long lag times in the deep ocean's heating response to climate warming from past emissions compounded by on-going future emissions (e.g., Figure 2.6 in MfE 2008).

The degree of stabilisation of future emissions will also play an important role in determining the potential contribution from ice discharge from the Greenland and Antarctic ice sheets. Catastrophic contributions to sea-level rise from collapse of the West Antarctic Ice Sheet or the rapid loss of the Greenland Ice Sheet are not considered likely to occur this century. However, the occurrence of such catastrophic changes becomes increasingly more likely in the next century if greenhouse gas concentrations continue to rise, and could contribute several metres to SLR over the next few centuries (IPCC 2007; MfE 2008). Figure 1.6 shows a plausible range of sea-level rise estimates out to 2300 used for strategic planning of coastal adaptation measures by the Delta Commission in the Netherlands and the German Advisory Council on Global Change.

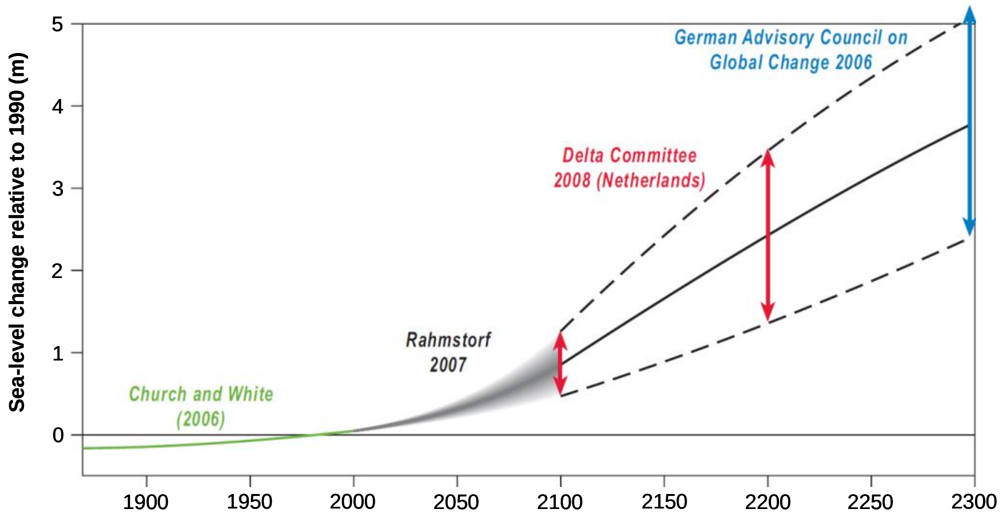

Figure 1.6: Indicative projections of global sea-level rise up to 2300 (relative to 1990) adapted from Dept of Climate Change (2009) and Copenhagen Diagnosis (2009). Initial line for 1900s is trend for global-average observed data (after Church and White, 2006); Grey shaded area, Rahmstorf (2007), based on IPCC 3rd Assessment Report temperatures; Red bar, after Deltacommissie (2008); Blue bar after German Advisory Council on Global Change (2006).

1.6 Guidance on selecting appropriate SLR values

Given that New Zealand-wide sea levels are rising at similar rates to the global average rate, and reviewing both the IPCC (2007) projections and upper-bounds from studies up to 2008, the MfE Guidance Manual and Summary (MfE 2008; MfE 2009) recommends the following approach to assessing a range of SLR values for New Zealand locations based on risk (i.e., what's at stake?).

Box 1: Sea-level rise guidance within a risk-assessment framework

The MfE (2008) guidance manual *Coastal hazards and climate change* recommends for planning and decision timeframes out to the **2090's** (2090-2099):

1. a **base** value sea-level rise of **0.5 m relative to the 1980–1999 average** should be used, **along with**
2. **an assessment of potential consequences from a range of possible higher sea-level rises** (particularly where impacts are likely to have high consequence or where additional future adaptation options are limited). At the very least, all assessments should consider the consequences of a mean sea-level rise of **at least 0.8 m** relative to the 1980–1999 average. Guidance is provided in Table 2.2 [*of the guidance manual*] to assist this assessment.

   Note: Table 2.2 in the MfE (2008) guidance manual covers a range of sea-level rise projections by 2100 with upper bounds from 0.8 m from IPCC (2007) to 1.0–1.4 m (based on three empirical studies from 2007 and 2008 described in the Table 2.2), to which values from more recent studies outlined in the Royal Society of New Zealand Emerging Issues paper could also be considered within the risk-based assessment. (RSNZ, 2010).

For longer planning and decision timeframes where, as a result of the particular decision, future adaptation options will be limited, an allowance for sea-level rise of **10 mm per year beyond 2100** is recommended (in addition to the above recommendation).

(MfE 2008)

Box 2: Commentary on the MfE sea-level guidance

The risk assessment should be based on a broad consideration of the potential consequences (direct impacts, loss of assets and amenity) from different sea-level rise magnitudes on a specific decision, objective or issue. The particular sea-level rise adopted in each case should be based on the acceptability of the potential consequences and likelihood of that sea-level rise combination (=risk) and the potential future adaptation costs that may be incurred, especially if sea-level rise is *higher than anticipated.*

Each risk assessment should also take into account the physical shore-type context (e.g., gravel, sandy or cliffed coasts) and the adjacent land-uses. In particular, upgrading existing development should be treated differently from new developments ("greenfields"), where risk avoidance and a precautionary approach are paramount (e.g., Policies 3(2) and 25(b) of the New Zealand Coastal Policy Statement (NZCPS), 2010) along with the need to recognise the permanency of such developments and that sea level will continue to rise for possibly several centuries. Therefore in undertaking a risk assessment and appraising future adaptation for greenfield developments, sea-level rises well over 0.8 m should be considered. The MfE guidance (MfE, 2008), as it stands, recommends assessing a range of sea levels, starting any appraisal with a 0.5 m rise (by 2090s) and with the "at least 0.8 m" as a minimum higher sea-level rise to consider when assessing future consequences. Using this set of two benchmark values is therefore a minimum to consider, but assessments should not to be limited to those values.

Hence the risk assessment process, as recommended in the MfE guidance manual (MfE, 2008), is an enduring approach, although it will need updating periodically in terms of planning timeframes. For example, the 2010 NZCPS requires assessments of hazards for "at least 100 years" (Policies 10(2)(a),24, 25). So already the range of sea-level rises that should be considered needs to take into account the presently recommended extension of 10 mm per year beyond 2100 e.g., the equivalent benchmarks by 2115 (nominally the next 100 years relative to the 1980–1999 average) would be for an assessment starting at a base value of 0.7 m (equivalent to 0.5 m rise by 2090s) and considering a range of possible higher values including at least a 1.0 m rise (was a 0.8 m rise by 2090s). Both these 2115 values have been rounded to the nearest 10 centimetres, taking into account the present guidance is for the 2090s decade with mid-point at 2095.

(Britton et al. 2011)

As demonstrated, there are uncertainties associated with sea-level rise and especially the upper bound by the end of this century. Nevertheless, local government needs to continue making decisions that either implicitly or explicitly make assumptions about what sea-level rise will be over the lifetime of a particular project, community assets or infrastructure.

Risk management is a prudent and pragmatic approach for incorporating uncertainties such as those associated with future sea-level rise. Using a risk management approach involves broad consideration of the potential impacts or consequences of sea-level rise on a specific decision or issue.

Any decision on the extent of sea-level rise to plan for, should consider (MfE 2009):

- the possibility and consequences of particular sea levels being reached within the planning timeframe or design life;
- the potential costs that could be incurred in future adapting to a particular sea-level rise;
- how any residual risks would be managed for consequences over and above a particular sea-level rise threshold, or if the sea-level rise that is planned for is underestimated.

Guidance on which sea-level rise value to adopt for existing development needs to integrate short-term requirements for upgrading buildings and assets within a long-term adaptation plan for the wider coastal community or suburb. Such integration can then flow through to appropriate planning and building requirements e.g., minimum ground levels, minimum floor levels, style of foundation, relocatability of assets, sustainable coastal hazard protection measures, limits on existing use rights to facilitate eventual managed retreat etc (Britton et al. 2011).

A different set of sea-level rise values may also be used for strategic adaptation planning, particularly for existing vulnerable coastal suburbs or settlements. A starting point would be quantitative vulnerability assessments for perhaps a wider range of sea-level rises, to develop a range of possible futures as a lead in to participatory consultation with stakeholders (e.g., infrastructure and utility operators) and the wider community.

Some of these principles were contained in advice on sea-level rise and coastal hazard guidance to Nelson City Council (Stephens & Bell 2009) and more generic guidance on coastal adaptation in the New Zealand context is covered in more detail in *Coastal Adaptation to Climate Change: Pathways to Change* (Britton et al. 2011). IPCC have recently published a guidance document: *Constructing sea-level scenarios for impact and adaptation assessment of coastal areas* (Nicholls et al. 2011), which provides guidance on developing local/regional scenarios for sea-level rise for a range of vulnerability and impact assessments.

1.7 Climate change effects on coastal inundation

Changes in future exposure to coastal-inundation hazards is not just about sea-level rise, but is also likely to involve climate-induced changes in other physical drivers such as storm intensity, winds and barometric pressure, which will produce changes in waves and storm surges. The frequency of high tides exceeding present-day crest elevations will also increase.

1.7.1 Climate-change effects on tides

On the open coast of New Zealand, sea-level rise won't significantly alter the tide range. However in estuaries and shallow harbours the tidal characteristics may well be altered, depending on the interaction between sea-level rise, seabed sedimentation rates (linked to catchment run-off) and the response of benthic flora (e.g., marshes, mangroves, wetlands). What will change substantially as sea-level rise accelerates are the occurrences when high tides exceed a specific elevation such as the present-day mean high water spring (MHWS) mark.

This is shown in Figure 1.7, where the high–tide exceedance curve for the existing situation at Sumner Head is compared with equivalent high-tide exceedance curves for sea-level rises of 0.5 m and 0.8 m (assuming no change in tidal range). The comparison shows that with a sea-level rise of 0.5 m or 0.8 m, the present highest astronomical tide (HAT) elevation would be exceeded by 40% and 97% of all high tides respectively.

In summary, as sea-level rise increases, the incidence of higher high-tides exceeding shoreline crest elevations will increase substantially as the tide rides on the back of the elevated sea level. The effect will be more accentuated in areas with small tide ranges e.g., Wellington, and somewhat less where the tide range is larger e.g., Tasman and Golden Bay.

1.7.2 Climate change effects on storm-tide exceedances

Changes in storm surge (produced by low barometric pressures and adverse winds) will depend on changes in the frequency, intensity and/or tracking of low-pressure systems, and occurrence of stronger winds associated with these systems. Due to uncertainties over changes to storms in New Zealand by 2100, it is often assumed that climate-change will have only a minor effect on storm surges.[3] Since tidal

[3] A 4-year NIWA research programme *Waves and Storm-surge Projections* (funded by the Ministry of Science + Innovation) has commenced with a specific goal of translating potential changes in winds and storm intensities into what changes may occur for storm surges and wave climate at a regional level. Completion date is 2012.

characteristics on the open coast are also expected to remain largely unchanged by future sea-level rise, storm tide characteristics are expected to remain similar. Therefore, to predict future extreme storm tides, present practice is to simply add sea-level rise to the present-day storm tide analysis [see Toolbox 2.2.3].

Sea-level rise will cause an upward translation of the extreme storm-tide exceedance curve, as shown in Figure 1.8 for Sumner Head sea levels (similar to that for the high-tide exceedance curves in Figure 1.7). For present-day MLOS, there is a 1% chance per year (0.01 AEP) of a storm tide that equals or exceeds 1.87 m Lyttelton Vertical Datum-1937 or LVD-37 (marked by the green line). In other words, a storm tide equal to or bigger than 1.87 m LVD-37 is presently expected to occur only once, on average, every 100 years. As shown by the translated storm tide curves in Figure 1.8, for sea-level rises of 0.5 or 0.8 m, there would be a high probability that the 1.87 m elevation would be exceeded in any given year. In fact, the tide exceedance curve in Figure 1.7 shows us that under these sea-level rise scenarios the highest astronomical tide alone is likely to exceed the present-day 1% AEP level of 1.87 m. Therefore as sea-level rise increases, the incidence of higher storm tides exceeding shoreline crest elevations will increase substantially to become common events, because the storm-tide rides on the back of the elevated sea level.

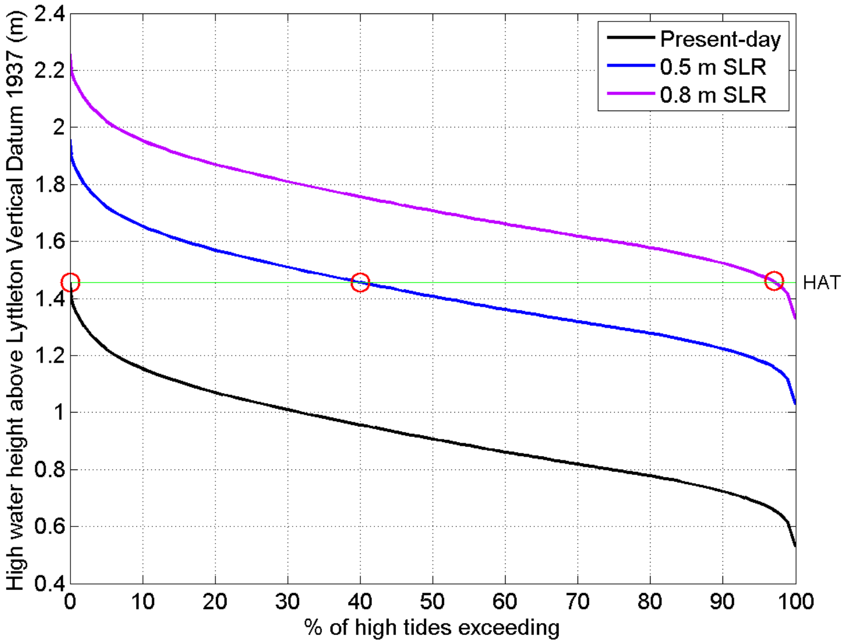

Figure 1.7: High tide exceedance at Sumner Head relative to Lyttleton Vertical Datum 1937 (LVD-37), for the present mean level of the sea (bottom curve) compared with the exceedance curves for sea-level rises of 0.5 m and 0.8 m (top two lines respectively). The highest astronomical tide (HAT) elevation is presently 1.46 m (LVD-37). With sea-level rise of 0.5 m or 0.8 m, this same elevation would be exceeded by 40% and 97% of all high tides. The green line marks present-day HAT.

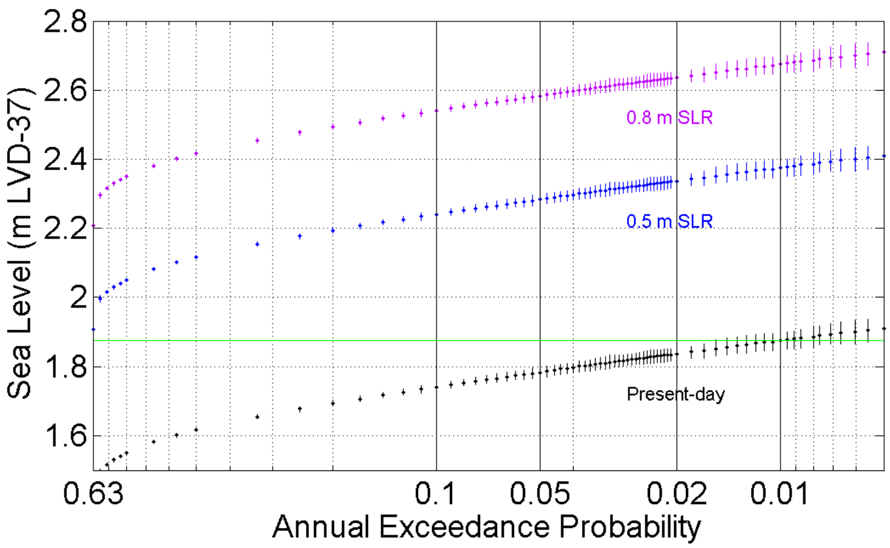

Figure 1.8: Sumner Head extreme-value storm-tide occurrence probabilities for present-day MLOS compared with vertical translations of the extreme curve for sea-level rise values of 0.5 and 0.8 m.

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