Sea-level rise synthesis for Auckland (2011)

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Executive summary

Auckland Council contracted NIWA to provide a synthesis of the evidence base for projected changes in sea level that could be applied to the Auckland region, incorporating the latest consensus on global sea-level change up to the present (mid-2011). The synthesis should explain the positions of current peer-reviewed literature and the consensus held by international sea-level change experts, alongside evidence for Auckland, and the best options for dealing with a changing sea level into the future.

In response to this Brief, this Report is provided specifically to assist council in developing the Auckland Unitary Plan, rather than for detailed engineering design or asset management which may have different design timeframes and risk or serviceability requirements.

Auckland (Waitemata Harbour) has experienced an average rise in sea level of 1.5 mm/year or 0.15 m in the last 100 years, which is relative to the regional landmass. Adding an additional ongoing rebound of 0.3 mm/year for past glacial loading of the crust, means that Auckland sea-level rise is very close to the global average of 1.7 ±0.3 mm/year. This means that projections of global-average sea-level rise can be more or less applied directly to Auckland (both coasts), until such time that Auckland sea-level monitoring shows otherwise.

In summary, taking a more cautious approach to upper-range estimates, the latest monitoring results indicate that benchmark sea-level rises of 0.8 to 1.1 m by 2100, adopted within planning instruments by various planning agencies in Australia, UK, Netherlands and including the Ministry for the Environment (2008) guidance manual, are credible upper-range estimates to work with in an adaptive management framework in Auckland. However, using such estimates, particularly for existing coastal development, needs to be strongly coupled with regular monitoring and reviews. The equivalent band of sea-level rises potentially reached by 2115 would be 1.0 to 1.35 m, relative to 1990 sea levels.

An ARC-commissioned report, ARC (2010) surmised that a slightly lower range of 0.5 to 1.0 m was plausible by 2100, supported by similar sea levels during the mid-Holocene climatic optimum when temperatures were warmer by 2℃ or more than at present. The same range of 0.5 to 1.0 m sea level rise by 2100 (but relative to 2000) was synthesized as being plausible by the recent Australian Climate Commission synthesis, in the light of the latest downward revision of estimates for the recent loss of ice-sheet mass. However, it is now generally accepted that ice sheet loss will accelerate this century, so higher values of sea-level rise can't be ruled out.

To work around this uncertainty in the upper range of projections for sea level, an adaptive management approach is recommended for existing development. Start out with credible rate of sea-level rise more likely to be attained in the planning timeframe (e.g., 1.0 m by 2115) and periodically adjust adaptation plans according to future monitoring of Auckland sea level and associated reviews. This value could be lowered to 0.7 m if it can be shown that the consequences (risk) of an activity are low or limited in time.

For greenfield developments, sea levels at the highest end of the current projections should be adopted (e.g., minimum of 2.0 m above 1990 levels by 2115) given the permanency of such developments, having regard to sea-level rise continuing for a few centuries, and aligns with the mandate in the 2010 NZ Coastal Policy Statement to avoid hazards and adopt a precautionary approach. This value could be cautiously lowered to say 1.7 m if the consequences of a new activity are low, limited in time or an isolated asset (rather than a subdivision) can be readily relocated or retro-fitted.

Vulnerability assessments for existing development should consider 4 possible sea-level futures for rises by 2115 of 0.7 m (low), 1.0 m (medium), 1.5 m (high) and 1.85 m (high-plus) with timing for implementation of staged adaptation plans tied in the interim to the medium scenario (equivalent to a rise of 0.85 m by 2100).

Monitoring of Auckland sea-level trends (both east and west coasts) and monitoring the development and implementation of adaptation plans, along with regular reviews, will be an essential step in any adaptive management approach to assist coastal communities or suburbs to stage their response to the impacts of climate change.

1 Introduction

Auckland Council contracted NIWA to provide a synthesis of the evidence base for projected changes in sea level that could be applied to the Auckland region, incorporating the latest consensus on global sea-level change up to the present (mid-2011).

The synthesis should explain the positions of current peer-reviewed literature and the consensus held by international sea-level change experts, alongside evidence for Auckland.

Auckland's best options for dealing with a changing sea level into the future should also be considered.

This information is provided specifically to assist council in developing the Auckland Unitary Plan, rather than for detailed engineering design or asset management which may have different design timeframes and risk or serviceability requirements.

2 Context for the synthesis

2.1 Geographical context

Auckland region straddles the west coast (Tasman Sea) and east coast (Hauraki Gulf). However, the long-term sea-level record for the region is derived from the Ports of Auckland gauge in Waitemata Harbour. The record for the Manukau Harbour is patchy and not amenable for deriving historic rates of sea-level rise. So this synthesis will be focused on the east coast rates of sea-level change, with the reasonable assumption that west coast rates will be similar.

2.2 Coastal hazard and present sea-level rise context

Auckland's coastal margins will increasingly be impacted physically by changes in our climate arising from not only sea-level rise, but also changes in winds, rainfall and storm intensity. These changes will affect storm surges, waves, extreme storm-tide levels, drainage and salinity of lowland streams or creeks.

Impacts will initially manifest as an increase in frequency of coastal inundation and shore erosion events. Such events will become more prevalent in low-lying areas that have in the past been affected episodically. Some previously unaffected coastal areas may also begin to be impacted, depending on their hazard exposure, beach type and topography. Generic information on the effects of climate change on coastal hazards is available in the Ministry for the Environment (MfE) guidance manual for local government: *Coastal hazards and climate change* (MfE, 2008).[1]

Auckland (Waitemata Harbour) has experienced an average rise in sea level of 1.5 mm/yr or 0.15 m in the last 100 years, which is relative to the regional landmass movement (ARC, 2010). Allowing for a small ongoing rebound of ~0.3 mm/yr in the landmass elevation, due to past glacial loading of the crust, means the absolute rise in sea levels has been ~1.8 mm/yr (Table 2; ARC, 2010), which is within the range for the global average sea-level rise of 1.7 ±0.3 mm/yr (Church & White, 2006; Bindoff et al., 2007; Church & White, 2011).

This result shows that any future projections of global-average sea-level rise can be more or less applied directly to obtain reasonable projections of sea-level change for Auckland, until such time that Auckland sea-level monitoring shows otherwise.

2.3 Planning context

The effects of climate change need to be given particular regard to in Part II matters of the RMA [s. 7(i)]. Both regional and territorial authorities have as one of their functions, the control of any actual or potential effects of the use, development or protection of land, including for the purpose of avoidance or mitigation of natural hazards [s. 30 & 31].

The 2010 NZ Coastal Policy Statement (NZCPS) requires consideration of climate change effects covering at least a 100-year planning horizon in Policies 3 (precautionary approach), 24, 25, 27 (hazards and coastal development). In terms of planning time frames, given that

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[1] http://www.mfe.govt.nz/publications/climate/coastal-hazards-climate-change-guidance-manual/

the Unitary Plan may take a few years to become operative and the NZCPS specifies a minimum timeframe to be considered (at least 100 years), a planning horizon of 2115 has been adopted for this report.

2.4 Built-environment context

Adaptation to climate change, particularly sea-level rise and associated effects on coastal hazards, will require substantially different approaches depending on whether the coastal margin comprises existing urban development or is largely undeveloped land, other than for agricultural uses, that is earmarked for future development (e.g., green-fields). These different approaches are recognised in Objective 5 of the NZCPS.

Existing coastal development including infrastructure will require incremental or staged plans to adapt to rising sea levels to keep hazard risk to tolerable levels until a point when managed retreat becomes the only sustainable option for buildings or infrastructure. This situation pertains to most of the urbanised coastal fringes of Auckland City. In contrast, risk avoidance is promoted by the NZCPS (Objective 5 and Policy 25) for green-field developments such as new subdivisions, backed up by a need to take a precautionary approach to cover uncertainties in the effects of climate change (Policy 3).

Where a reclamation is considered a suitable use of the coastal marine area, its form and design should have particular regard to the potential effects on the site of climate change, including sea-level rise, over no less than 100 years (Policy 10).

3 Relevance of MfE guidance manual

The effect of climate change and sea level rise on coastal areas of New Zealand is discussed in detail in the MfE guidance manual Coastal hazards and climate change (MfE, 2008). It should underpin any coastal adaptation journey.

This coastal hazards guidance manual identifies that a high proportion of New Zealand's coastal edges have been settled by urban development particularly cities such as Auckland. Some of this development has been located in areas currently vulnerable to coastal hazards (such as coastal erosion and inundation by storm-tides and wave overtopping, drainage problems, saltwater intrusion into landward areas and estuaries). Climate change effects, while gradual, will increasingly exacerbate these coastal hazards and begin to affect previously untouched areas.

Locally managing the effects of coastal hazards along with the progressive influence of climate change, through monitoring, reviewing and appropriate implementation of adaptation plans, are fundamental to maintaining or developing sustainable and resilient communities.

The coastal hazards guidance manual specifically:

- provides information on the key effects of climate change on coastal hazards in the New Zealand context
- provides a risk assessment framework for incorporating coastal hazard and climate change considerations into decision-making processes (policy, planning, consenting)
- promotes the development of long-term adaptive capacity for managing coastal hazard risk through adoption of adaptive management[2] and no-regrets[2] or low-regrets[2] response options.

3.1 Risk-based approach

The use in the MfE guidance manual of a risk assessment framework is the fundamental basis for selecting which sea-level rise to accommodate for any locality, project or objective. Let's look at two extreme examples. An activity where the future consequence of being inundated is low e.g. new or upgraded boat ramp or toilet block may only be required to accommodate a modest sea-level rise such as 0.5 m. However, a new subdivision or strategic bridge crossing, where the future consequences of inundation are very high, may need to accommodate a much higher sea level rise of 1.5 to 2 metres or more depending on the anticipated permanency and investment associated with the activity. [*Note:* values only used at this stage to illustrate the approach].

A risk-based approach contrasts with a coastal planning approach where a single sea-level rise value over a particular time-frame is adopted for land-use activities e.g., a 0.8 m sea-level rise by 2100 in the Queensland Coastal Plan (Dept. of Environmental & Resource Management, 2011). This one-size fits all approach does provide regional consistency and is

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[2] see Glossary

much easier to communicate, but has no flexibility to consider the scale of future consequences as illustrated in the previous paragraph. Objective 5 of the NZCPS also signals that different approaches should be applied to green-fields and existing developments, implying different sea-level rise values and timeframes are considered in each situation to avoid or mitigate risk respectively.

3.2 Sea-level rise guidance

At its 2008 publication date, the MfE guidance manual was based mainly on the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) which was released in 2007 (Bindoff et al., 2007; IPCC, 2007). However, the guidance also encapsulated additional peer-reviewed scientific studies on sea-level rise that appeared after the 2007 IPCC report was published. These follow-on studies indicated sea levels may rise higher than the upper levels presented by IPCC (notwithstanding that IPCC were not prepared to provide a best estimate or an upper bound, due to the understanding of some effects was too limited, particularly the response of polar ice-sheets).

In terms of climate-change impacts, the 2008 MfE guidance manual advocates planning for:

- A range of sea levels by the 2090s (2090-2099) using a risk assessment process to circumvent uncertainties in the timing of future sea-level rise. The full rendition of the 2008 MfE sea-level rise guidance is shown in Box 1 below with a commentary on its usage.
- Climate change impacts on tides, storm surges, waves, swell and sediment supply; both the magnitude of the effect and changes to the frequency of occurrence.
- The present mean high water spring (MHWS) level will be exceeded more frequently in the future and increasingly so.

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

The 2008 MfE 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 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 RSNZ (2010) could also be considered within the risk-based assessment.

3. 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).

3.3 Commentary on the 2008 MfE sea-level guidance:

Risk assessments, that underpin the guidance, 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 (=risk) and the potential future adaptation or protection costs that may be incurred at that sea-level rise.

Each risk assessment should also take into account the land-use and physical shore-type context (e.g. gravel, sandy or cliffed coasts). In particular, improving the resilience of existing development should be treated differently from new developments ("green-fields"). For the latter, risk avoidance and a precautionary approach are paramount, along with the need to recognise that sea levels will continue to rise for possibly several centuries (rather than some arbitrary 100-year "design life"). So 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, as it stands, is for assessing a range of sea levels, starting any appraisal with a 0.5 m rise (by 2090s) and the "at least 0.8 m" was inserted as a minimum higher sea-level rise to consider, but not to be limited to that value.

Hence the risk assessment process, as recommended in the MfE guidance manual, is an enduring approach, although it will need updating periodically in terms of timeframes. As mentioned in Section 2.3, the 2010 NZCPS requires assessments of hazards for "at least

100 years”. So already (in 2011) the range of sea-level rises that should be considered needs to take into account the recommended extension in the MfE guidance of 10 mm per year beyond 2100. Based on a planning time frame out to 2115, the equivalent benchmarks for sea-level rise (relative to the 1980–1999 average) would be (Table 1) 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 decimetre, taking into account the present guidance is for the 2090s decade with mid-point at 2095.

Table 1: Equivalent benchmark sea-level rise values to at least be considered from the MfE guidance manual (MfE, 2008) <u>extended out to 2115</u>.

Benchmark	SLR (m) to consider
Start risk assessment at:	0.7 m
At least also consider at least:	1.0 m

4 Planning values used internationally

A survey of sea-level rise values being used for planning purposes in Australia, the UK and The Netherlands was undertaken. This review extends and updates the results presented in the Royal Society of New Zealand's emerging paper on sea-level rise (RSNZ, 2010) and provides some context as to how other jurisdictions are incorporating sea-level rise into coastal planning. Sea-level values embedded in plans and policies are identified separately from those values used in broader-scale "what-if" or scoping scenarios.

4.1 Australia

4.1.1 National scoping study and 2011 review

At a national level, the Australian Government has developed a series of sea-level rise maps[3] to help communicate the risks of sea-level rise up to 2100 from climate change.

The three scenarios developed by CSIRO for Department of Climate Change (2009) for sea-level rise between 2030-2100 (relative to 1990) were:

- The *low scenario* (B1): considers sea-level rise in the context of a global agreement which brings about dramatic reductions in global emissions and represents the upper end of the range for sea-level rise by 2100 which is likely to be unavoidable.
- The *medium scenario* (A1FI): Represents the upper end of IPCC 4th Assessment Report (IPCC, 2007) projections and is in line with recent global emissions and observations of global average sea-level rise.
- The *high-end scenario*: considers the possible high end risk identified in the AR4 and more specifically in post IPCC AR4 research. This scenario factors in recent publications up to 2009 that explore the impacts of recent warming trends on ice sheet dynamics beyond those already included in the IPCC projections.

The benchmark values for these three scenarios are listed in Table 2 along with an extrapolation of the curve fit to 2115 by NIWA to align with the timeframe being considered in this report.

Table 2: Three sea-level scenarios developed by CSIRO for Dept. of Climate Change (2009) for assessing national risk to coastal communities relative to 1990 levels. Sea-level rises by 2115 (italics) have been extrapolated by NIWA from curves fitted to the 1990 (0 m), 2030, 2070 and 2100 values.

Year	Scenario 1: B1	Scenario 2: A1FI	Scenario 3: High-end
2030	0.13	0.15	0.2
2070	0.33	0.47	0.7
2100	0.50	0.82	1.1
2115	*0.6*	*1.05*	*1.35*

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[3] http://www.ozcoasts.org.au/climate/sd_visual.jsp

The sea-level rise values (Table 2) used in the 2009 national study for Australia were chosen as being appropriate for a first-pass nationwide risk assessment to illustrate diagrammatically on maps, the potential effects of such a rise superimposed on the highest astronomical tide. It was not intended for use by local councils and states in their land use planning processes.

Recently, the federal government Climate Commission Secretariat released a review of climate change science, risks and responses (Dept. of Climate Change & Energy Efficiency, 2011) entitled *The Critical Decade*. Their key messages on sea-level rise were:

- A plausible estimate of the amount of sea-level rise by 2100 compared to 2000 is 0.5 to 1.0 m. [*Note 1*: relative to the more commonly-used 1990 baseline, the difference (increase) in sea-level rise is only about 0.03 m; *Note 2*: the equivalent range by 2115 would be around 0.6 m to 1.25 m].
- Very recent sea-level rise projections such as those using semi-empirical methods of 1.5 to 2.0 m (see Section 4 of this Report) seem high in the light of recent questions surrounding estimates of the current rate of mass loss from polar ice sheets.
- Much more has been learned about the dynamics of large polar ice sheets in the last decade but critical uncertainties remain, including the rate at which mass is currently being lost, the constraints on dynamic loss of ice and the relative importance of natural variability and longer-term trends.
- The impacts of rising sea-level will mostly be experienced through “high sea-level events” when a combination of sea-level rise, a high tide and a storm surge or excessive run-off trigger an inundation event.

4.1.2 Australian state coastal plans and policies

Australian state governments have or are reviewing and changing their state policy and plans to account for rising sea levels and other climate change impacts. States have adopted sea-level rise policies, which have benchmark sea-level rise values as listed in Table 3. In prescribing a 2100 benchmark, the states that have finalised their plans or policies have for the present settled on SLR values of 0.8 to 1.0 m by (2100) that straddle CSIRO Scenarios 2 and 3 in Table 2. Extended out to 2115, this is equivalent to a sea-level rise between 1.0 to 1.25 m (interpolating the last row of Table 2).

The reliance on a single benchmark sea-level rise value adopted by most States in Australia does provide regional consistency and is much easier to communicate. However, there is little flexibility to consider the scale of future consequences or risk, nor distinguish between differing requirements for existing development compared with greenfield developments.

Most state government agencies have also indicated in their policy documents that they are not intending to update these benchmark values further until the IPCC 5th Assessment Report is published in 2014.

Table 3: Sea-level rise benchmark values used in various Australian state plans and policies. [*Source*: adapted and updated http://www.ozcoasts.org.au/climate/supporting.jsp]

State	2050 (on 1990 levels)	2100 (on 1990 levels)	Plan/Policy Reference
QLD	–	0.8 m	State Planning Policy for Coastal Protection, Queensland Coastal Plan (Dept. of Environmental & Resource Management, 2011)
NSW	0.4 m*	0.9 m*	NSW Sea Level Rise Policy Statement (Dept. of Environment, Climate Change and Water, 2009), and the NSW Coastal Planning Guideline: Adapting to SLR (Dept. of Planning, NSW, 2010)
VIC	–	≥0.8 m	Victorian Coastal Strategy (Victorian Coastal Council, 2008)
TAS	–	TBD	State Coast Policy 1996, with review in progress of draft State Coastal Policy released 2008 (Dept. of Premier & Cabinet, 2009). The Tasmanian Government has commenced work on a Climate Change Project to facilitate the development of adaptation strategies for Tasmania
SA	0.3 m	1.0 m	Coast Protection Board Policy Document (Coast Protection Board, 2002)
WA	–	0.9 m (by 2110)	State Coastal Planning Policy 2003 (West Australian Planning Commission) and sea-level rise position statement (Bicknell, 2010)
NT	–	TBD	Northern Territory Climate Change Policy–2009. Developing a climate-change Adaptation Action Plan by 2011.

* Includes an allowance for an extra 0.1 m for regional NSW differences relative to the global average SLR

4.2 UK guidance

In the United Kingdom, the Department for Environment, Food and Rural Affairs (DEFRA) have published national projections of climate change (Jenkins et al., 2009) to support decision makers in adapting to climate change. Part of the Briefing Report contains projections for sea-level rise.

SLR projections were updated in a number of ways, primarily through using results from the most recent IPCC Fourth Assessment Report. Jenkins et al. (2009) give projections of UK coastal absolute sea level rise (not including land movement) for three emission scenarios out to 2095 that range from approximately 0.12–0.76 m (relative to 1990). The upper end of this range (rounded to 0.8 m) is the same as one of the 2090s benchmark values in the MfE guidance manual (MfE, 2008), which extrapolated to 2115 would be a SLR of 1.0 m (Table 1)

One significant component of future SLR is from the melting of large ice sheets. Due to a lack of current scientific understanding of some aspects of ice sheet behaviour, Jenkins et al. (2009) also provided a low-probability High-plus-plus (High++) scenario for sea level rise of between 0.93 m and 1.9 m by 2100 around the UK in addition to their main scenarios described above. The IPCC Fourth Assessment Report (IPCC, 2007) provides some illustrative possibilities of how this lack of understanding of ice sheet dynamics might affect sea level projections, and the bottom of the H++ scenario range (0.93 m) was set by Jenkins et al. (2009) from the maximum global mean sea level rise value given by the IPCC Fourth Assessment Report. The top of the H++ scenario range (1.9 m) was derived by Jenkins et al. (2009) from indirect observations of sea level rise in the last interglacial period, at which time the climate bore some similarities to the present day, and from estimates of maximum glacial flow rate. The upper part of the range of sea level increase is thought to be highly unlikely by 2100, but Jenkins et al. (2009) provided the scenario as some users may find it useful to aid contingency planning and to test the limits of adaptation.

In terms of local council plans in the UK, the Thames Estuary flood risk management plan (Box 2) was the first to utilise the scenarios produced by Jenkins et al. (2009).

4.3 Netherlands

The Delta Commission in their report *Working together with water: A living land builds for its future* (Deltacommissie, 2008) provided sea-level rise projections for planning out to 2100 of 0.55 m to 1.2 m, assuming an atmospheric temperature increase of 6℃. The recommended planning value was 1.1 m by 2100 (RSNZ, 2010).

However, sea level will continue to rise for several centuries. Research conducted for the Delta Committee for longer-term planning shows that by 2200 we can expect a global maximum sea level rise of around 1.5 to 3 m (see Figure 1), depending on the method used (Deltacommissie, 2008). Figure 1 also shows the long-range estimates by the German Advisory Council on Global Change (2006) which suggest very approximate sea-level rise of 2.5 to 5 m by 2300.

While these long-range estimates will continue to change, Figure 1 has been included mainly to illustrate the ongoing rise in sea level for at least the next few centuries. This trend needs to be factored into values of sea-level rise adopted for new greenfield developments or new high-risk infrastructure. This is addressed specifically for Auckland in Section 6.

BOX 2: Adaptive management approach: Thames Estuary, UK

Thames Estuary 2100 is an Environment Agency-led flood risk management project set up to protect London and the tidal reaches of the Thames. The project called for an adaptive plan able to protect up to a 1.9 metre rise in sea level predicted in the High++ scenario as well changes in the frequency and severity of North Sea storm surges and water drainage from the Thames and its tributaries.

The plan has developed different flood management options for different reaches of the Thames. The plans include adaption to different future climate scenarios on short (2010-2034), transition period (2035-2049) and long (2050 and beyond) timescales. The final time horizon (from 2050) will see the end of the century option, planned, designed and constructed taking the flood risk management in the Thames estuary into the 22nd century (all dates based on current climate change guidance).

These scenarios have been evaluated to find the most effective and cost beneficial solution. From this process, thresholds have been determined specifying when decisions need to be made to adequately prepare in time for future sea level and climate changes. The plan also provides detailed recommendations should the most extreme projections be realised.

Specifically, for upgrading the Thames Storm-Surge Barrier, adaptation planning has been structured around uncertainty using a scenario-neutral analysis, based on how much sea-level rise can be absorbed before each stage needs to be in place. Then an adaptive decision-pathway approach has been adopted, where the timing for the various stages is initially based on a plausible trajectory for sea-level rise that is benchmarked to a 0.9 m rise by 2100 (T. Reeder, Environment Agency, pers. com.). With such large infrastructure projects, where lead times are critical, this needs to be underpinned by a robust monitoring and review process. If sea-level rise accelerates beyond that trajectory, then plans will be brought forward and vice versa if sea-level rise is less than anticipated.

Sources:

http://www.environment-agency.gov.uk/research/library/consultations/106100.aspx

http://resilient-cities.iclei.org/fileadmin/sites/resilient-cities/files/Resilient_Cities_2011/Presentations/E/E5_and_F5_Reeder.pdf

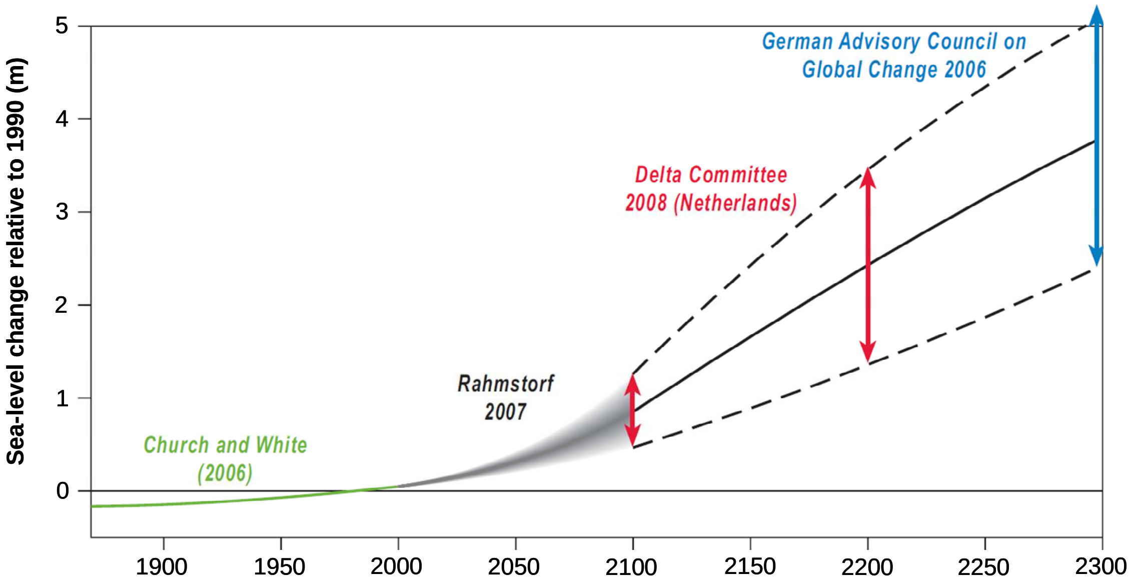

Figure 1: Recent indicative projections of global sea-level rise up to 2300 (relative to 1990) adapted from Dept of Climate Change (2009) and Copenhagen Diagnosis (2009). Initial line for 1900s is trend for global-average observed data (after Church and White, 2006); Grey shaded area, Rahmstorf (2007), based on IPCC 3rd Assessment Report temperatures; Red bar, after Deltacommissie (2008); Blue bar after German Advisory Council on Global Change (2006).

5 Peer-reviewed literature & monitoring update

5.1 Estimates of sea-level rise (post IPCC AR4)

A review of recent peer-reviewed papers (up to mid-2010) on sea-level rise was presented by a Royal Society of NZ Emerging Issues paper (RSNZ, 2010). Further reviews were provided to Council by ARC (2010) and Manning (2011). A brief summary and comparison follows.

Since the 2006 cut-off point for science publications to be considered within the IPCC Fourth Assessment Report process, further scientific papers have been published containing projections on global sea-level rise. These papers add to the array of information on potential future sea-level rise over this century and include:

- Consideration that sea levels are tracking close to the upper end (e.g., A1FI emission scenario) of the AR4 projections (Rahmstorf et al., 2007; Copenhagen Diagnosis, 2009)– currently global average sea level (section 5.2) is tracking along the projection trajectory that would lead to a 0.8 m rise by the 2090s;
- Confirmation that the loss of mass from Greenland and Antarctic ice sheets may be occurring more rapidly than from surface melting alone (e.g., Rignot et al., 2008, 2011; Shepherd & Wingham, 2007; Bamber et al., 2009).
- Revision of some earlier estimates of the recent contribution from polar ice sheets. Wu et al. (2010) and summarised by Bromwich & Nicolas (2010) show that present-day ice sheet mass losses previously calculated from GRACE satellite measurements (e.g., Figure 2 of RSNZ, 2010) have been overestimated by a factor of two (due to a revised estimate of vertical land movement from past glaciation) although there remain uncertainties due to the sparse network of coastal GPS measurements.

The increasing contribution of present-day sea-level rise due to ice-sheet losses has led to a number of more recent estimates of sea-level rise over the 21st century (Rahmstorf, 2007; Horton et al., 2008; Pfeffer et al. (2008); Vermeer and Rahmstorf, 2009; Grinsted et al., 2010; Jevrejeva et al., 2010).

The overall ranges of these more recent sea-level rise estimates by 2100 or in some cases the 2090s (2090-2099) are summarised in comparison to the projections from the IPCC Fourth Assessment Report (IPCC, 2007) in Figure 2, including available confidence limits.

Aside from the IPCC AR4 (IPCC, 2007) and Pfeffer et al. (2008), the other projections are based on semi-empirical methods that calibrate sea-level to atmospheric temperature for past and present climate reconstructions, then project forwards using IPCC projections for temperature from the Third Assessment Report (TAR), as undertaken by Rahmstorf (2007), or for the other studies, the Fourth Assessment Report (AR4). However, there is still debate over the robustness of these semi-empirical methodologies adopted in making these projections (Holgate et al., 2007; IPCC, 2010; Price et al., 2011). A recent workshop of Working Group I of the IPCC in Kuala Lumpur (IPCC, 2010), attended by the author, considered the ability of semi-empirical approaches to estimate future sea-level rise. In summarising, they concluded that a major limitation of these approaches is the inability to calibrate them on a climate-system behaviour expected later this century, and therefore “the physical basis for the large estimates from these semi-empirical models is therefore currently lacking’’ (p. 2, IPCC, 2010).

Pfeffer et al. (2008) took a different tack, looking at the possibly largest constraints on ice sheet mass loss. They concluded that the glaciological conditions required for a sea-level rise of 2 metres by 2100 are very unlikely to occur (i.e., physically possible but only if all variables quickly accelerate to extremely high limits) and that a more plausible, but still accelerating ice sheet contributions, lead to a sea-level rise by 2100 of about 0.8 m. Price et al. (2011), using a 3-dimensional dynamic ice flow model for Greenland that accounts for periodic variability, determined that the dynamic mass flow contribution from Greenland Ice Sheet would be up to 0.045 m by 2100 (half the upper bound estimate by Pfeffer et al., 2008), and also including the time-varying change in ice-sheet surface mass balance, up to 0.085 m by 2100. Rignot et al. (2011) summarised recent accelerations in ice sheet loss over the last 18 years and concluded that if present trends in ice sheet accelerations persist, polar ice sheets could contribute up to 0.56 m sea-level rise by 2100 and become the dominant contributor to sea-level rise this century.

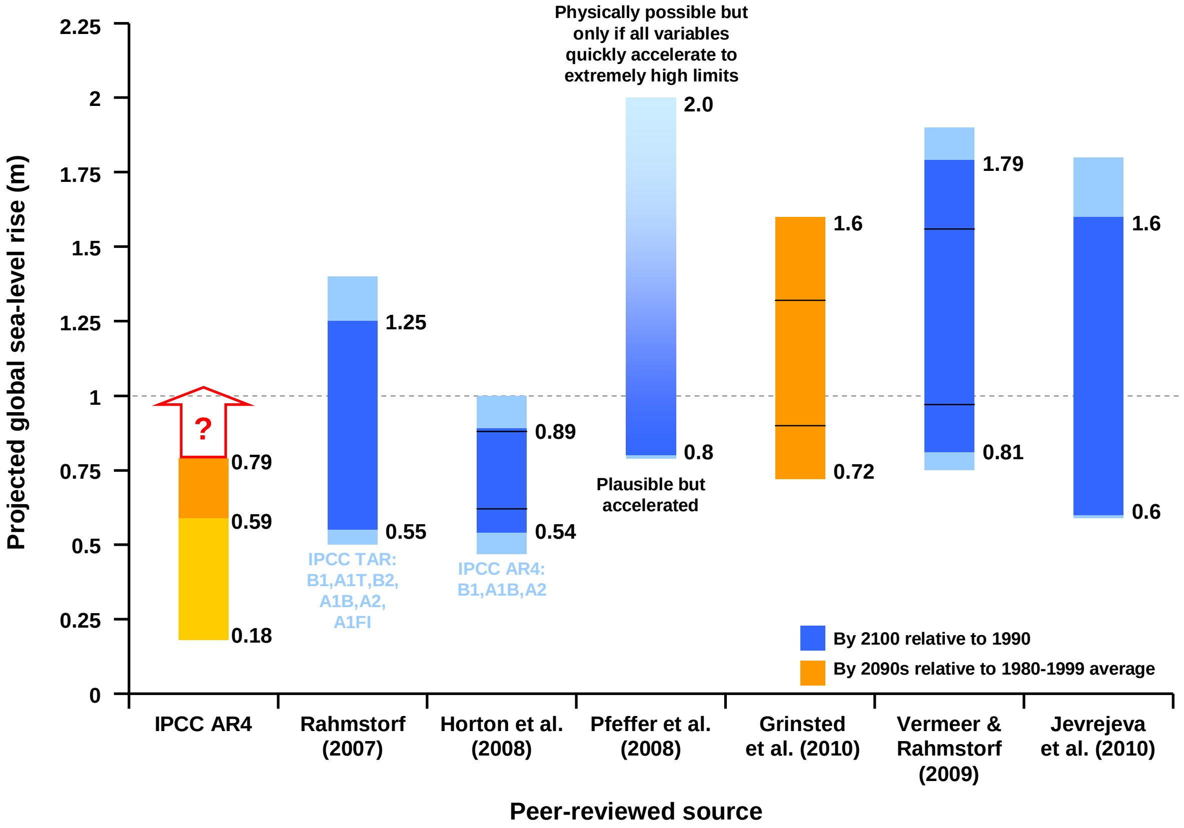

Figure 2: Comparison of sea-level rise projections from recent peer-reviewed papers and the IPCC Fourth Assessment Report (AR4). Projections out to the 2090s are orange and those out to 2100 are blue. Light blue shading indicates confidence limits. The AR4 (IPCC, 2007) projections include a caveat for 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.

5.2 Update on monitoring of sea level and ice sheets

Satellite altimeters (based on radar) have been used to monitor the mean level of the sea since 1993 over most of the globe (0–66°N & S). Figure 3 shows the latest trend in the global average sea level for the "satellite period" (1993 to present). The satellite altimeter data has shown an increase in global mean sea level (GMSL) of around 3.2 mm/year over that period up to April 2011. In the slightly shorter period 1993 to 2009, the GMSL from altimetry had the same trend (3.2 ± 0.4 mm/year) compared to in-situ tide gauge data of 2.8 ± 0.8 mm/year (Church & White, 2011). These rates are around 65–90% higher than the longer-term global average rise of 1.7 ± 0.2 mm/year from 1900 to 2009 (Church & White, 2011). Whether or not this represents a further increase or acceleration in the rate of sea level rise is not yet certain, as the satellite record is relatively short (18 years) and also coincided with a shift around 1999-2000 of the 20–30 year Interdecadal Pacific Oscillation[4] (IPO) cycle. Normally, for tide gauge data, at least 50 years of data is required to fully resolve these longer decadal cycles. However, Church & White (2011) resolved a small rise in the rate of sea-level rise up to 2009 from 1.7 mm ± 0.2 mm/year (starting from 1900) up to 1.9 mm ± 0.4 mm/year (starting from 1961).

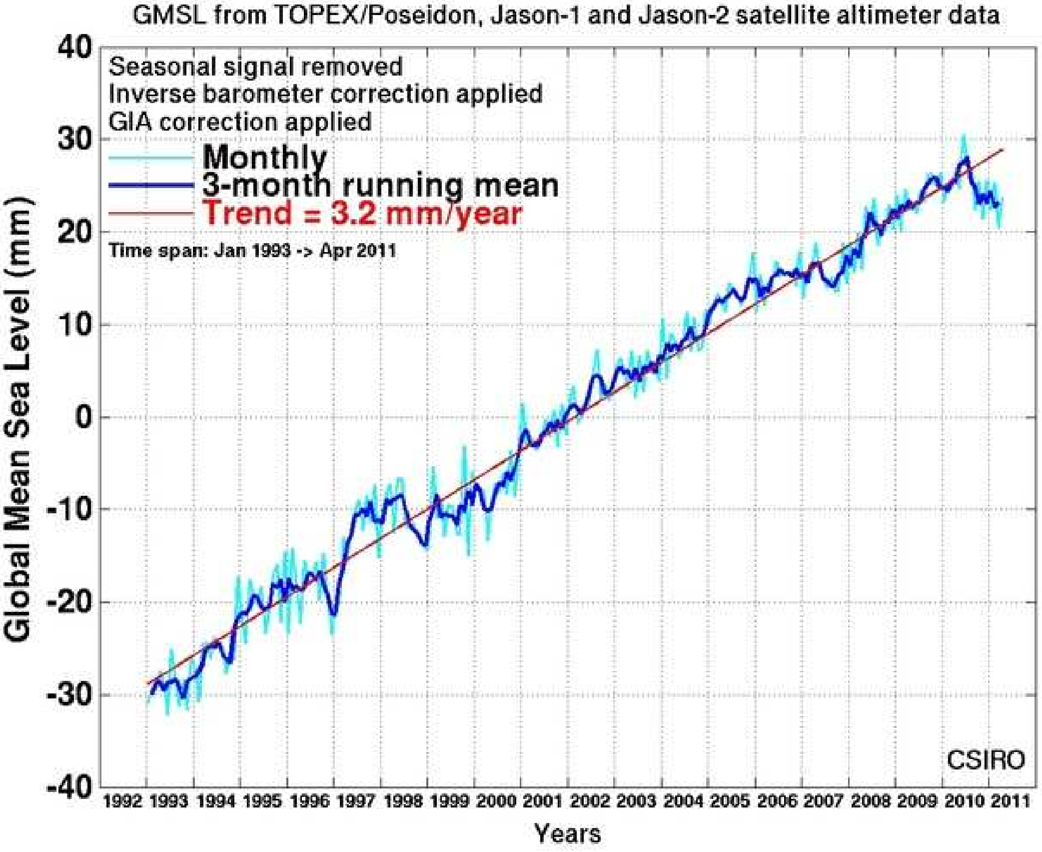

Figure 3: Global average mean sea-level trend since 1993 to April 2011 as measured by satellite altimeters [Source: CSIRO, Australia]. Based on data from TOPEX/Poseidon (launched August, 1992), Jason-1 (launched December, 2001) and Jason-2 (launched June, 2008). The annual seasonal cycle has been removed and a Glacial Isostatic Adjustment (GIA) applied to remove ongoing variations in the Earth's crustal movement.

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[4] A Pacific-wide climate/ocean variation that operates at decadal time frames (20-30 years) that also modulates El Niño/La Niña climate variability e.g., the current (since 1999) negative (cool) phase of IPO diminishes the effect of El Niño events.

The rise in global mean sea level is in some ways an artefact of averaging over the entire globe, but regionally, the mean sea level can and will exhibit substantial spatial differences. For instance the western Pacific Ocean has shown higher rate of rise over the "satellite period" since 1993, while in the north-eastern Pacific (Bromirski et al., 2011), sea level has either been static or shown a slight fall (light blue/green areas), as shown in Figure 4. The New Zealand region, for this period, mirrors the global-average rate, but it is important to continue monitoring sea levels in Auckland to check for variances with the global average rate of rise.

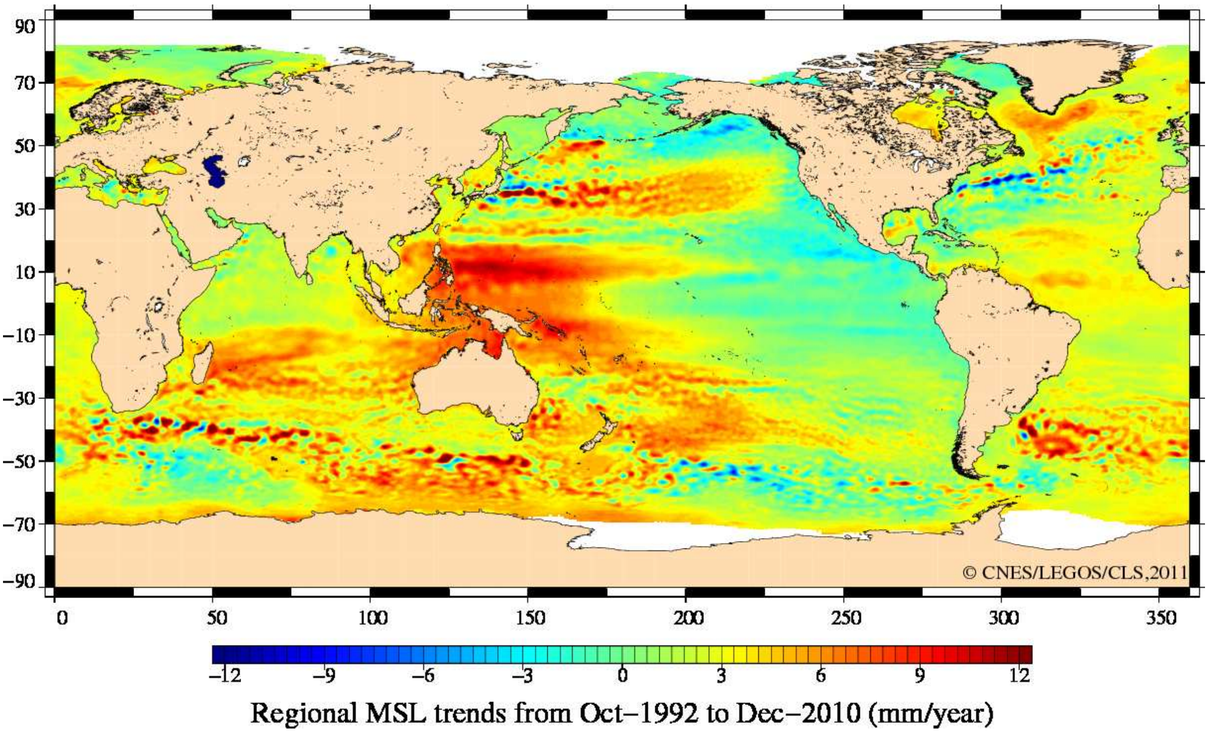

Figure 4: Global distribution of the rates of absolute sea-level rise between October 1992 to December 2010 as measured from satellite altimeter data. Source: http://www.aviso.oceanobs.com/en/news/ocean-indicators/mean-sea-level/index.html .

These latest monitoring results indicate that the rate of sea-level rise has accelerated during the satellite era (1993 to present), compared with the longer period since 1900, although it has been holding at a more-or-less steady linear rise. The spatial variability of the modern sea-level trend in the Pacific shown in Figure 4 is similar to the horse-shoe pattern of higher sea levels (and sea-surface temperature) around both hemispheres of the western Pacific characteristic of the Pacific-wide negative (cool) phase of the IPO which changed regimes around the turn of the century. The IPO regime shift also affected the sea levels in Auckland, with a step-jump occurring in 1999 (ARC, 2010 and Figure 5). This suggests that the recent rise in the rate of sea-level rise for the satellite period may be partially attributable to inter-decadal variability as well as ongoing sea-level rise.

Extrapolating the "satellite-period" trend of 3.2 mm/year for another 40 years would mean a sea-level rise of only 0.2 m by 2050, relative to 1990. Therefore, it is clear that a substantial acceleration and possibly a climate tipping-point response will be required to achieve a rise of more than 1 m by 2100.

At present (Figure 5), sea level at the Port of Auckland (Waitemata) centred on 2007 (averaged over the period 2005–2009) is tracking just above the trajectory that would lead to a sea-level rise of 0.85 m by 2100 (which is equivalent to ~1.0 m by 2115). However, as stated, part of the recent rise in sea level at Auckland was due to the jump in sea level, primarily in 1999, when the IPO switched regimes, and annual sea levels have since been lower than the 1999 annual mean. To reach the highest projections discussed in the previous section (Figure 2) and the higher scenarios in Figure 5, it will require a large acceleration that is one or two orders of magnitude above the present small rate of 0.009 ± 0.004 mm/year per year observed in global sea-level trends from 1900 to 2009 (Church & White, 2011).

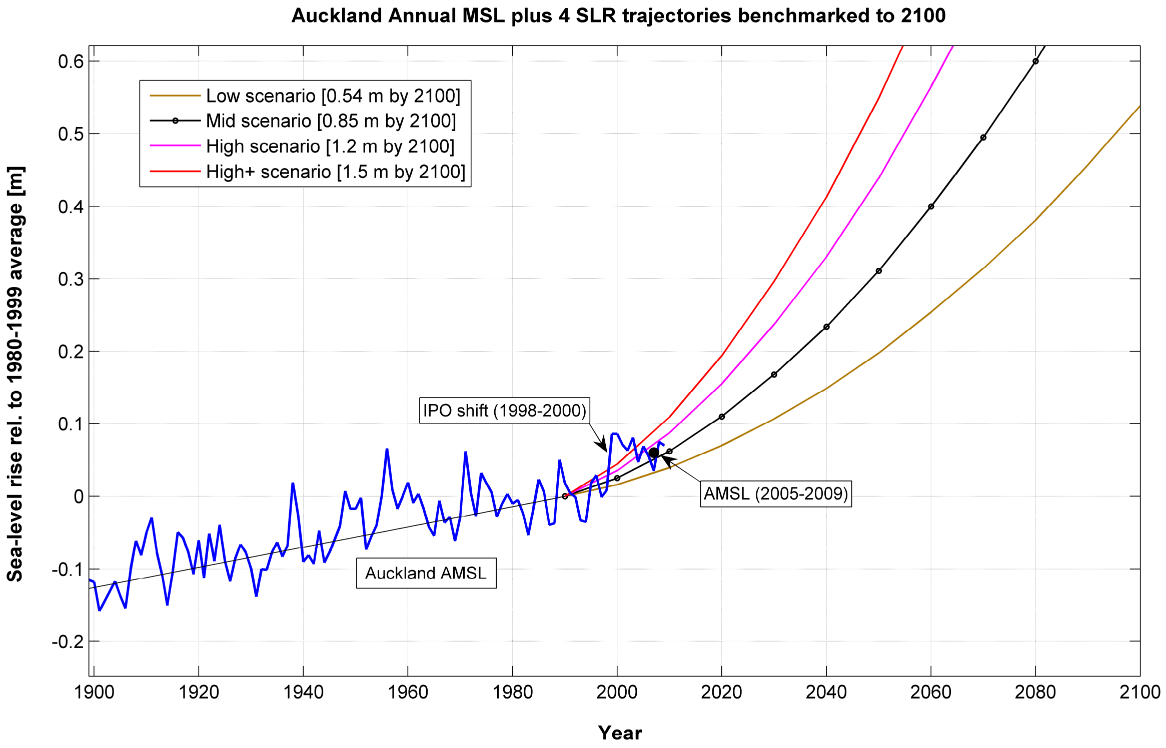

Figure 5: Comparison of past annual mean sea level (AMSL) at Auckland with four possible sea-level rise scenarios relative to 1990. Sea-level rise scenarios for comparison are benchmarked to 0.54, 0.85, 1.2, and 1.5 m by 2100, the black line is the trend of annual mean sea level (blue) from 1899 to 1990, and the larger black dot is the average sea level for 2005–2009, centred on 2007. The IPO-driven step jump in annual sea level from 1998 to 2000 is annotated.

In most cases, though, you are taking a precautionary approach and assigning a reasonable upper limit – but because this limit is so uncertain due largely to ice-sheet melt, there is a range in the upper limit.

In summary, taking a more cautious approach to upper-range estimates, these latest monitoring results indicate that benchmark sea-level rises of 0.8 to 1.1 m by 2100, adopted within planning instruments by various planning agencies in Australia, UK, Netherlands and including the MfE (2008) guidance (Section 4), are credible upper-range estimates to work with in an adaptive management framework in Auckland. However, using such estimates, particularly for existing coastal development, needs to be strongly coupled with regular monitoring and reviews (see Thames Estuary case study—Box 2). The equivalent band of sea-level rises potentially reached by 2115 would 1.0 to 1.35 m, relative to 1990 sea levels, which are very similar to Scenarios 2 and 3 developed by CSIRO (Table 2).

ARC (2010) surmised that a slightly lower range of 0.5 to 1.0 m was plausible by 2100, supported by similar sea levels during the mid-Holocene climatic optimum when temperatures were warmer by 2℃ or more than at pre sent. The same range of 0.5 to 1.0 m sea level rise by 2100 (but relative to 2000) was synthesized as being plausible by the recent Australian Climate Commission synthesis (Department of Climate Change & Energy Efficiency, 2011), in the light of the latest downward revision of estimates for the recent loss of ice-sheet mass (Wu et al., 2010; Bromwich & Nicolas, 2010). However, it is now generally accepted that ice sheet mass loss will accelerate this century (Rignot et al., 2011), so higher values of sea-level rise can't be ruled out.

To work around this uncertainty in the upper-range of sea-level projections, an adaptive management approach is recommended for areas of existing development, starting with credible rates of sea-level rise more likely to be attained in the planning timeframe and periodically adjusting adaptation plans according to future monitoring of Auckland sea level and reviews. For greenfield developments, higher plausible sea levels towards the top end of current projections should be adopted, given the permanency of such developments and having regard to ongoing sea-level rise for at least a few centuries (Figure 1) and the NZCPS mandate to avoid hazards and adopt a precautionary approach.

6 Synthesis: Planning for sea-level rise in Auckland

6.1 Auckland in the global context

From Sections 2.2 and 5.2, it was shown that any future projections of global-average sea-level rise, sourced from either IPCC or peer-reviewed papers or syntheses, can be more or less applied directly to Auckland in the foreseeable future, based on similarities in historic rate of sea-level rise.

The measured relative sea-level rise, which is the sea-level change relative to the local landmass, is strictly what needs to be planned for. In Auckland, while the recent-past relative sea-level rise of 1.5 ± 0.1 mm/year (1900 to 2009) is slightly lower than the absolute global-average rise for the same period (1.7 ± 0.2 mm/year), in future this will be countered by the expectation that sea levels in the wider New Zealand region are likely to be around 0.03–0.05 m higher than the global-average rise by the 2090s (Ackerley et al., in prep). Again, this confirms the approach that absolute global-average projections can be applied directly to Auckland until such time as subsequent monitoring and analysis shows otherwise.

Based on very limited long-term monitoring of mean sea levels on the west coast, mainly at Port Taranaki where the historic rate of sea-level rise is similar to Port of Auckland, the guidance for eastern Auckland can be applied to the western coasts of Auckland until such time that monitoring shows otherwise.

6.2 Principles for sea-level rise guidance

Rather than adopt a single sea-level rise value for planning purposes, as undertaken by some Australian states (Section 4.1), it is recommended that a more flexible risk-based approach is taken that aligns with the overall thrust of the MfE guidance manual (MfE, 2008). This should include a differentiation between existing and greenfield developments and maintaining a partially flexible risk-based approach for assets and buildings. One such approach is to set a default sea-level rise to be accommodated within the planning timeframe (2115 in this case) but where it can be demonstrated that the future consequences (=risk) are low, limited or can be circumvented in the future (e.g. easily relocatable) for certain asset categories, then a slightly lower sea-level rise can be accommodated.

Some of these principles were contained in advice on sea-level rise and coastal hazard guidance to Nelson City Council (Stephens & Bell, 2009).

6.2.1 Existing *vs* Greenfield development

As discussed in Section 2.4 in relation to the 2010 NZCPS, a different set of guidance should be developed for existing legacy development compared with greenfield development. In relation to greenfield developments and associated new infrastructure:

- It is now well established that sea levels will continue rising for several centuries (Figure 1), and
- There is a mandate in the 2010 NZCPS for risk avoidance (Objective 5 and Policy 25) for green-field developments such as new subdivisions, backed up by

a need to take a precautionary approach to cover uncertainties in the effects of climate change (Policy 3).

Conversely, adaptation of existing development and infrastructure requires an adaptive management approach that is integrated across different timeframes and spatial scales such as: a) individual buildings or assets requiring upgraded or re-developed; b) long-term strategic adaptation plan for the entire suburb or community. Setting sea-level rise values too high, particularly for individual properties, can result in unintended mal-adaptation. This can lead to local distortions such as run-off and drainage issues for neighbouring properties (if minimum ground levels are set too high in relation to accommodating sea-level rise and coastal hazards), compromised landscape values (from elevated buildings in relation to minimum floor levels) and discontinuities in elevation of utility services across low-lying sections of communities.

Therefore, guidance on which sea-level rise value to adopt in 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).

6.2.2 Risk-based flexibility

While it is recognised that a single sea-level rise value is easier to understand and communicate, nevertheless some flexibility should be retained to allow a risk-based approach to be used where appropriate. For planning purposes, one suggestion is that a credible default sea-level rise value is adopted, but if the risk or consequences of sea-level rise on an activity can be demonstrated to be limited in time, small in magnitude or the asset can be readily relocated, then a slightly lower sea-level rise value could be applied. Potential examples could include small utility buildings (e.g., garage, shed) and council assets on reserve or esplanade strips (e.g., toilet blocks, playgrounds, boat ramps etc).

6.3 Sea-level guidance for Auckland

6.3.1 Plans and Policies

The following guidance in Box 3 on benchmark sea-level rise values are suggestions to consider in formulating objectives, policies and rules for the proposed Auckland Unitary Plan.

BOX 3: Suggested planning guidance on sea-level rise for Auckland

Planning horizon: Out to 2115

Baseline sea level: Based on 1980-99 average (centred on 1990) from Port of Auckland (Waitemata) gauge of +0.085 m Auckland Vertical Datum–1946.

Sea-level rise guidance:
For existing communities and developed areas plan for a sea-level rise of at least 1.0 m by 2115 (*Note 1*). If the risk or consequences of sea-level rise on an activity can be demonstrated to be limited in time, small in magnitude or the asset can be readily relocated, then a sea-level rise of 0.7 m by 2115 could be applied. Potential examples could include small utility buildings (e.g., garage, shed) and council assets on reserve or esplanade strips (e.g., toilet blocks, playgrounds, boat ramps etc).

Any activity (whether new or an upgrade) in a potentially-impacted existing coastal area should also be integrated into a strategic long-term adaptation plan for the relevant coastal suburb or community. Such a plan needs to be developed in conjunction with the local community and supported by vulnerability assessments for both coastal hazard exposure and socio-economic sustainability (see Section 6.3.2).

For new greenfield developments or new infrastructure projects, plan for a sea-level rise of at least 2.0 m above the 1990 baseline, in conjunction with a full assessment of coastal hazard exposure (Policies 24 & 25, NZCPS). If the risk or consequences of sea-level rise on a new activity in a largely undeveloped area can be demonstrated to be limited in time, small in magnitude or an isolated asset (rather than a subdivision) can be readily relocated or retro-fitted, then a lower sea-level rise of 1.7 m could be cautiously applied.

New developments that could eventually be exposed to the impacts arising from mean sea levels of up to say 2.5 m higher than 1990 levels, should also incorporate an element of future-proofing in building requirements such as minimum floors levels, style of foundation (e.g., piles or perimeter wall rather than poured slab) and ease of retrofitting or removal to provide low-regrets adaptation options to future generations (including reduction of risk from tsunami inundation).

Coastal-hazard guidance:
Adaptation to climate change in coastal areas is not simply focused on changes in mean sea-level. Assessment of risk to coastal inundation or coastal erosion needs to incorporate the above sea-level rise values into a coastal-hazard assessment that includes appropriate storm-tide and wave extreme levels. Stephens et al. (2011) provides a consistent set of storm-tide levels around the Manukau and inner Hauraki Gulf that can be used in conjunction with the sea-level rise values adopted for the Unitary Plan.

Note 1: From Table 1, the value of 0.8 m by the 2090s translates to ~1.0 m by 2115 and the rise of 0.5 m by 2090s translates to ~0.7 m by 2115 (see Figure 6).

6.3.2 Possible sea-level futures for vulnerability assessments

It is recommended that an adaptive management approach is undertaken, not only for updating sea-level rise guidance (Box 3), but also for strategic adaptation planning, particularly for existing vulnerable coastal suburbs or settlements. This can be undertaken once critical adaptation tipping points (thresholds) of sea-level rise have been assessed for each community in relation to the built environment and associated coastal protection measures (e.g., Kwadijk et al., 2010; Neumann et al., 2010; and Reisinger et al. (in press), which is based on an Auckland case study). The timing of when the stages for adaptation are implemented can be based on the same sea-level rise trajectory being used for the sea-level guidance for existing development (see dotted line in Figure 6) and updated to a revised trajectory as necessary from monitoring updates.

Box 4 outlines guidance on monitoring and reviewing how sea-level rise is tracking and a suggested range of possible sea-level futures for the purposes of undertaking strategic adaptation planning for coastal communities or suburbs supported by socio-economic vulnerability studies, asset planning, assessing the sustainability of coastal protection measures etc to complement the guidance within plans and policies (Section 6.3.1).

BOX 4: Credible sea-level futures for assessing coastal vulnerability in Auckland

Assessment horizon: Out to 2115

Baseline sea level: Based on 1980-99 average (centred on 1990) from Port of Auckland (Waitemata) gauge of +0.085 m Auckland Vertical Datum–1946.

Credible sea-level rise trajectories:
To underpin vulnerability assessments or development of strategic adaptation plans for existing coastal communities as well as monitoring the progression of sea-level rise for Auckland, the following four (4) sea-level rise scenarios can be considered as a suite of possible trajectories to work with (Figure 6):

Low scenario – *equivalent to base value of 0.5 m by 2090s (MfE, 2008)*:
0.54 m by 2100 and 0.67 m by 2115 (rounded to 0.7 m in above guidance)

Medium scenario – *equivalent to 0.8 m rise by 2090s (MfE, 2008)*:
0.85 m by 2100 and 1.05 m by 2115 (rounded to 1 m in above guidance)

High scenario – *covers a number of consistent upper-range projections*
1.2 m by 2100 and 1.5 m by 2115

High-plus scenario – *towards the higher end of upper-range projections*
1.5 m by 2100 and 1.85 m by 2115

Monitor & review:
A key part of any adaptive management approach to coastal adaptation is selecting a credible sea-level rise trajectory on which to base the timing for implementation of successive stages. Then over time, through monitoring sea levels in the Auckland region (east and west coasts) and monitoring the implementation of plans, policies and adaptation plans, undertake periodic reviews of the requirements and any adjustments to timing of stages until the next review period. If sea level rise has accelerated, then the next stage of the relevant adaptation plan will need to be advanced in council's long-term adaptation plan for a particular location, or vice versa, delay the implementation if sea-level rise is slower than anticipated. As shown in Figure 6, current sea level at the Port of Auckland is tracking at present along the 2nd-lowest trajectory (0.85 m by 2100), taking in to account that the sharp rise due to the 1998-2000 shift in the IPO is primarily due to climate variability. Therefore in the interim, it would be reasonable to base implementation of successive stages (which are pegged to specific sea-level height thresholds or tipping points) to this sea-level trajectory that would reach ~1 m by 2100. For example, if Stage 1 of an adaptation plan needs to be implemented when mean sea level reaches 0.5 m (above the 1990 baseline), then from the 2nd lowest curve in Figure 6, this would indicate possible implementation around 2070.

Ongoing monitoring of sea level can be compared with the four trajectories in Figure 6 and the trajectory used for timing implementation of stages can be changed as necessary.

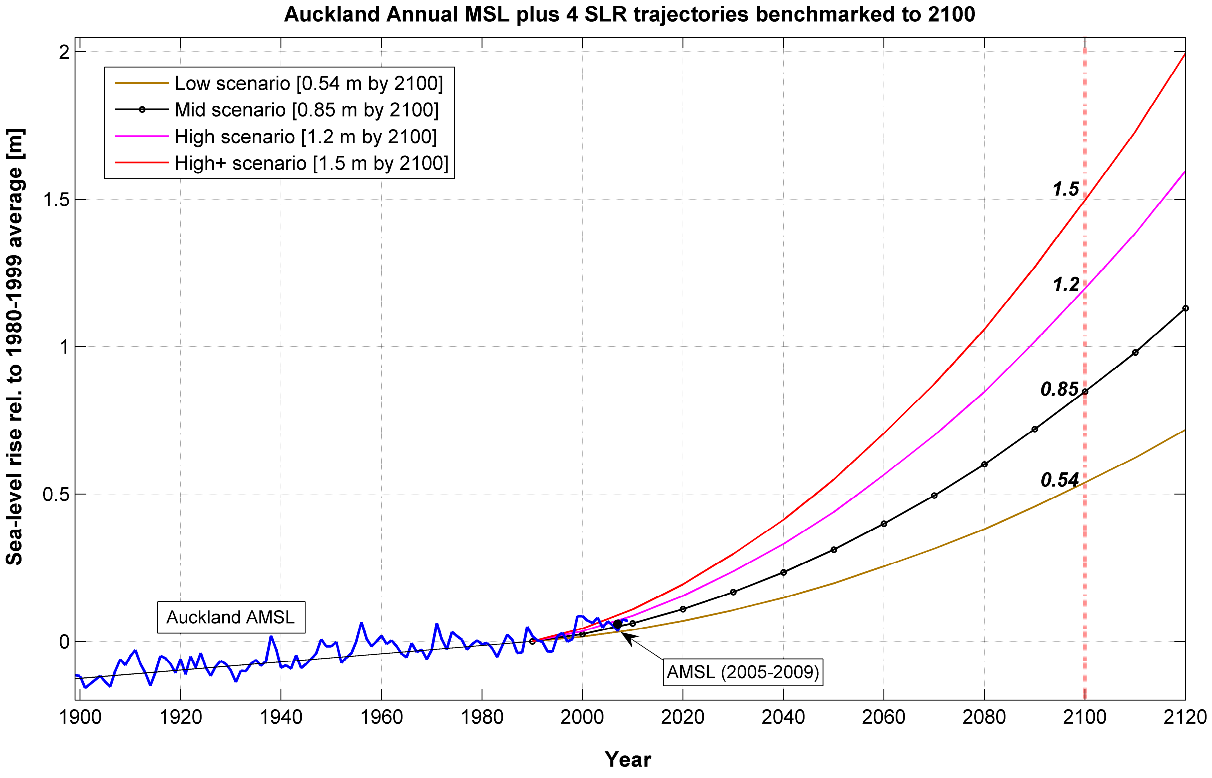

Figure 6: Comparison of past annual mean sea level (AMSL) trend at the Port of Auckland with four possible trajectories of sea-level rise out to 2120 relative to the 1990 level. Possible sea-level rise trajectories are for scenarios benchmarked to 0.54, 0.85, 1.2, 1.5 m by 2100, the black line is the trend of annual mean sea level (blue) from 1899 to 1990, and the larger black dot is the average sea level of +0.06 m for 2005–2009, centred on 2007.

7 Glossary of abbreviations and terms

Absolute sea-level rise	The rise in long-term mean sea level of the ocean to an absolute or fixed elevation, such as monitored by satellite altimeters from a fixed orbit. Past and projected global-average sea-level rise are provided as absolute values.
Adaptive management	A structured, iterative process of optimal decision making in the face of uncertainty, with an aim to reducing uncertainty over time via system monitoring. In this way, decision making simultaneously maximizes one or more resource objectives and, either passively or actively, accrues information needed to improve future management [Source: Wikipedia].
AMSL	Annual mean sea level
Emission scenarios	A family of emission scenarios used in the 3rd and 4th IPCC Assessments that are storylines of different global/local socio-economic futures associated with likely trends in carbon emissions. The 6 commonly used scenarios are labelled B1, B2, A1B, A1T, A2, and A1FI. http://www.ipcc.ch/ipccreports/sres/emission/index.htm
GMSL	Global mean sea level (also called absolute global sea level)
IPCC	The Intergovernmental Panel of Climate Change (a panel set up by the UN and the World Meteorological Organization (WMO))
Low-regrets adaptation	Low-regret adaptation options are those where moderate levels of investment increase the capacity to cope with future climate risks. Typically, these involve over-specifying components in new builds or refurbishment projects. For instance, installing larger diameter drains at the time of construction or refurbishment is likely to be a relatively low-cost option compared to having to increase specification at a later date due to increases in rainfall intensity. [Source: The World Bank]
MfE	Ministry for the Environment
No-regrets adaptation	Adaptation options (or measures) that can be justified under all plausible future climate scenarios and even discounting anthropogenic climate change [Source: The World Bank]
NZCPS	New Zealand Coastal Policy Statement 2010 http://www.doc.govt.nz/conservation/marine-and-coastal/coastal-management/nz-coastal-policy-statement/
Relative sea-level rise	The rise in long-term mean sea level relative to the landmass on which a monitoring sea-level gauge sits, irrespective of whether the landmass is rising or subsiding. It is also the SLR that needs to be locally adapted to.
SLR	Sea-level rise

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Appendix A Various projections of global sea-level rise from peer-reviewed publications

Researchers	Method used	Projected range (m)	Confidence limit range (m)	Timeframe
IPCC (2007)	Based on several Global Atmosphere/Ocean Circulation Models and several emission scenarios	**0.18–0.59 m** (mainly thermal and glacier contributions) **+ 0.1–0.2 m** for limited ice-sheet dynamics (highest value = **0.79 m**),	**No upper bound** (so larger values can't be excluded) nor a best estimate	2090–99 AD
Rahmstorf (2007)	Empirical techniques that relate sea level to historical average temperatures and project forward based on global mean surface temperature projections	**0.55 to 1.25 m** across surface temperatures from six emission scenarios used in the IPCC 3rd Assessment Report,	Including the statistical error of the fit, the range extends from **0.5 to 1.4 m**	2100 AD
Horton et al. (2008)	*ditto*	**0.54 to 0.89 m** across surface temperatures from three emission scenarios used in the IPCC 4th Assessment Report (B1, A1B, A2),	Including uncertainty in statistical error of the fit - range expands to **0.47 to 1.00 m**	2100 AD
Vermeer & Rahmstorf (2009)	*ditto*	**0.81 to 1.31 m** (lowest B1 emission scenario) to **1.13 to 1.79 m** (A1FI scenario) assessing 6 emission scenarios,	±7% (1 standard deviation)	2100 AD
Grinsted et al. (2010)	*ditto*	Using the best historic calibration across 6 emission scenarios, the **5-percentile** ranged from **0.72 to 1.1 m** and the **95-percentile 1.07 to 1.60 m**	Highest values in range for A1FI emission scenario, lowest for B1 emission scenario	2090-99 AD
Jevrejeva et al. (2010)	*ditto*	Estimated sea level rise of **0.6–1.6 m** across 6 emission scenarios,	Confidence limits of **0.59 m** and **1.8 m**	2100 AD
Pfeffer et al. (2008)	Applied glaciological constraints on ice loss required for larger sea-level rise to occur by 2100	More plausible, but still accelerated, conditions lead to a **0.8 m** sea level rise. Increases above of **2 m** are physically untenable.	Net eustatic sea-level rise from other combinations explored fell within the range **0.79 to 2.01 m**	2100 AD
Rohling et al. (2008)	Based on paleo-climate evidence (stable oxygen isotopes of planktonic foraminifera from Red Sea and age constraints from coral data) to estimate rates of sea-level change from past interglacial periods	Found that a rise rate of up to **1.6 m** per century is possible based on paleo-climate evidence,	**±1.0 m** per century	100 years
Kopp et al. (2009)	Based on paleo-climate evidence from the previous interglacial period when sea levels reached 6.6 to 9.4 m. Used an extensive compilation of local sea level indicators and a statistical approach for estimating global sea level, local sea levels, ice sheet volumes and their associated uncertainties	During the last interglacial period, when global sea level was close to its current level, determined a 1,000-year average rise rate is very likely to have exceeded **0.56 m** per century but is unlikely to have exceeded **0.92 m** per century,	Based on 1000-year average rates. *Note: have been converted to equivalent 100-year rate (but could be larger in any 100-year timeframe)*	100 years