

Derivation of the Tasmanian Sea Level Rise Planning Allowances

Technical Paper

August 2012

CONTENTS

List of Tables and Figures	3
Acronyms	3
1. Summary.....	4
2. Background.....	5
3. Global greenhouse gas emissions and sea level rise	7
4. Historical changes in sea level.....	8
5. Long-term sea level rise projections.....	10
6. Tasmanian sea level rise planning allowances.....	12
Glossary of terms.....	14
References	16
Attachments	18
Attachment 1 – Formula for deriving sea level rise planning allowances.....	18
Attachment 2 – The return period, the exceedance probability and the expected number of exceedance events.....	19

LIST OF TABLES AND FIGURES

Table 1: IPCC projected global average sea level rise by 2050 and 2095, based on the NSW sea level rise planning benchmarks technical note (Source: NSW 2009).

Figure 1: Observed fossil-fuel and industrial emissions of carbon dioxide and corresponding emission scenarios (Source: after Raupach et al. 2007, as updated in GCP, 2012).

Figure 2: Global mean sea level from 1880 to 2011 (Source: CSIRO 2010 and Church and White 2011).

Figure 3: Projected sea level rise for the 21st century. Plotted lines are from IPCC (2001) and coloured bars are from IPCC (2007a) (Source: CSIRO 2010).

ACRONYMS

ACE CRC – Antarctic Climate and Ecosystems Cooperative Research Centre

AR4 – IPCC Fourth Assessment Report (2007)

CSIRO – Commonwealth Scientific and Industrial Research Organisation

DPIPWE – Department of Primary Industries, Parks, Water and Environment

IPCC – Intergovernmental Panel on Climate Change

SRES – Special Report on Emissions Scenarios

TAR – IPCC Third Assessment Report (2001)

1. SUMMARY

This Technical Paper outlines the approach taken to determine sea level rise planning allowances for Tasmania.

Establishing sea level planning allowances is important to support planning authorities to consistently consider the impact of sea level rise and impacts in land use planning and other coastal decision-making.

The Tasmanian Government has used a peer reviewed methodology developed by Dr John Hunter of the Antarctic Climate and Ecosystems Cooperative Research Centre (ACE CRC) to develop the following sea level rise planning allowances for Tasmania:

- For 2050, 0.2 metres (relative to 2010 levels); and
- For 2100, 0.8 metres (relative to 2010 levels).

It should be noted that sea level is expected to continue to rise beyond 2100. However, the Tasmanian sea level rise planning allowances are provided up until 2100 to align with projections provided by the IPCC.

Both the 2050 and 2100 sea level rise planning allowances will be reviewed following the release of the IPCC's Fifth Assessment Report and / or the making of an Australian intergovernmental agreement that addresses sea level rise figures for decision making purposes.

This paper has drawn on the work of the Intergovernmental Panel on Climate Change (IPCC) and expert advice from the ACE CRC and the Commonwealth Scientific and Industrial Research Organisation (CSIRO).

2. BACKGROUND

2.1 PURPOSE OF THIS TECHNICAL PAPER

This Technical Paper is designed primarily for potential users of the sea level rise planning allowances. This will include State and Local Government policy and planning officers, as well as people involved in infrastructure management and renewal in coastal areas.

The Paper provides general background regarding coastal hazards, and outlines the relationship between greenhouse emissions, global warming and sea level rise. It also explains the purpose of sea level rise planning allowances and describes the methodology used to derive the Tasmanian allowances.

Finally, the Paper explains what the planning allowances mean and how they may be used when planning for the future.

2.2 UNDERSTANDING COASTAL HAZARDS AND WHY SEA LEVEL RISE IS IMPORTANT

Coastal hazards are sources of potential harm that occur in the coastal zone, specifically coastal inundation and coastal erosion.

Coastal inundation is the inundation of a portion of the coast, and it may be permanent or temporary. **Temporary inundation** is a storm tide which includes the following factors; regional storm surge, local storm surge, tides, wave setup, wave runup and climate change (including sea level rise and the changing likelihood of storm events). **Permanent inundation** is the mean high tide mark and changes to the mean high tide resulting from sea level rise.

Associated with coastal inundation and sea level rise is **coastal erosion**, which includes hazardous erosion and coastal recession. **Hazardous erosion** is a result of storm tide events, occurring in areas that are susceptible to erosion based on the coastal geomorphology, geology and soils. **Coastal recession** is caused by permanent inundation occurring in areas that are susceptible to erosion based on the coastal geomorphology, geology and soils, and low lying areas that become permanently inundated.

The rate of erosion or recession is dependent on coastal process including permanent inundation, storm frequency and severity, tidal, and current variations, all of which are expected to change with climate change. Future inundation and erosion are anticipated to increase the vulnerability of low lying coastal areas to these hazards.

Sea level rise is one of several coastal processes that contribute to coastal hazards.

2.3 WHAT IS A SEA LEVEL PLANNING ALLOWANCE?

Sea level rise planning allowances are estimations of future sea level rise to be applied primarily through land use planning instruments and tools, including codes and standards.

The purpose of sea level rise planning figures is to inform and promote consistent decision making concerning future land use and development; and reduce the level of uncertainty for communities and individuals who need to manage the future impacts of sea level rise on coastal areas.

In determining a particular planning allowance, projection figures must be derived from a robust methodology and reliable data, and be expressed in a form and timeframe that can be easily understood and practically applied to both existing and future planning approaches.

3. GLOBAL GREENHOUSE GAS EMISSIONS AND SEA LEVEL RISE

3.1 GLOBAL EMISSIONS SCENARIOS

Greenhouse gas emissions scenarios are used by the scientific community to describe alternative images of how the future may unfold, depending on the rate of human induced production of carbon dioxide and other greenhouse gases. They are used as a tool to examine the driving forces that influence future emissions outcomes and associated uncertainties (IPCC 2000). Emissions scenarios are not designed to be forecasts or predictions (Garnaut 2011), but can be used to inform projections of climate variables.

The most commonly used and accepted set of emissions scenarios comes from the IPCC and were first developed in 1992 and then updated in 2000. They are known as the 'SRES scenarios', as they were reported in the IPCC's Special Report on Emissions Scenarios (SRES) (IPCC 2000).

The SRES scenarios comprise four scenario 'families', each with a different combination of demographic change and social, economic and technological development.

In the decade following the release of the SRES report in 2000, observed emissions have been tracking at around or above the high emissions 'A1FI' scenario (see Figure 1). This being the case, the A1FI scenario is now commonly used by decision-makers as the basis for responses to sea level rise and is used as the basis for the Tasmanian sea level rise planning allowance.

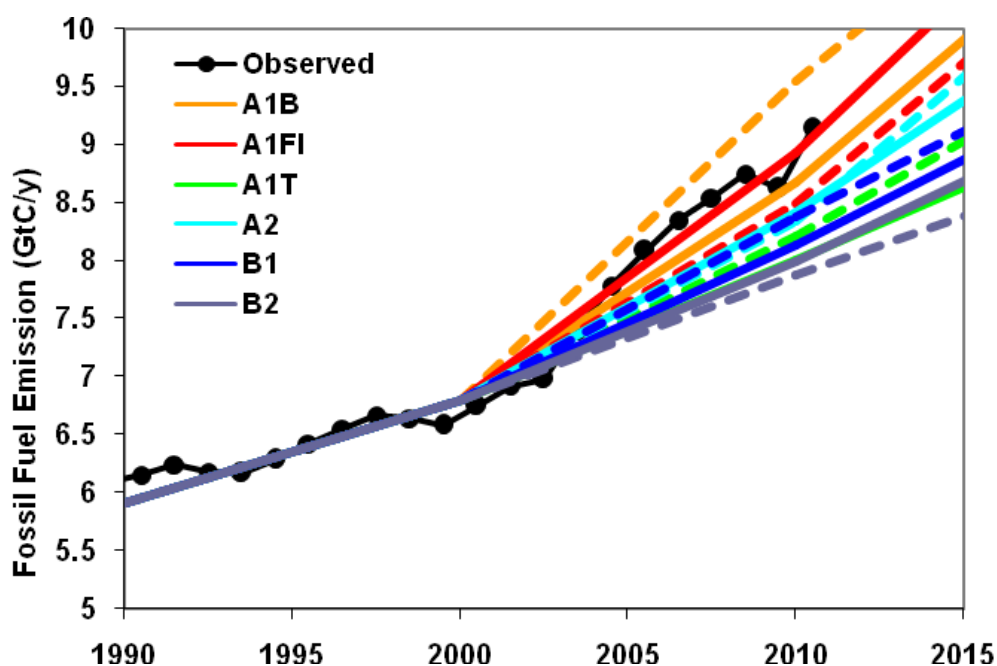


Figure 1: Observed fossil-fuel and industrial emissions of carbon dioxide and corresponding emissions scenarios. Dashed lines are the IPCC Marker and Illustrative Scenarios; continuous lines are average overall emission models used for each scenario (Source: after Raupach et al. 2007, as updated in GCP, 2012).

4. HISTORICAL CHANGES IN SEA LEVEL

4.1 GLOBAL SEA LEVEL CHANGE

Over the last 140 000 years, global sea level has varied over a range of more than 120 metres. The most recent large change in sea level occurred at the end of the last ice age, when sea level increased by more than 120 metres (Lambeck and Chappell 2001).

Around 6 000 years ago, the rate of rise had fallen to less than 3 millimetres per year. Over the past 2 000 years, until the late 19th century, sea level was stable to within approximately 0.2 metres (Lambeck and Chappell 2001). Sea level rise then accelerated, giving an average rate of rise of 1.7 millimetres per year over the 20th century (Church and White 2011).

Since 1993, global sea level has been accurately measured from satellites. Before that time, the data came mostly from coastal tide gauges from around the world. Figure 2 presents an estimate of global mean sea level for the period 1880 to 2011, showing a steady increase over time.

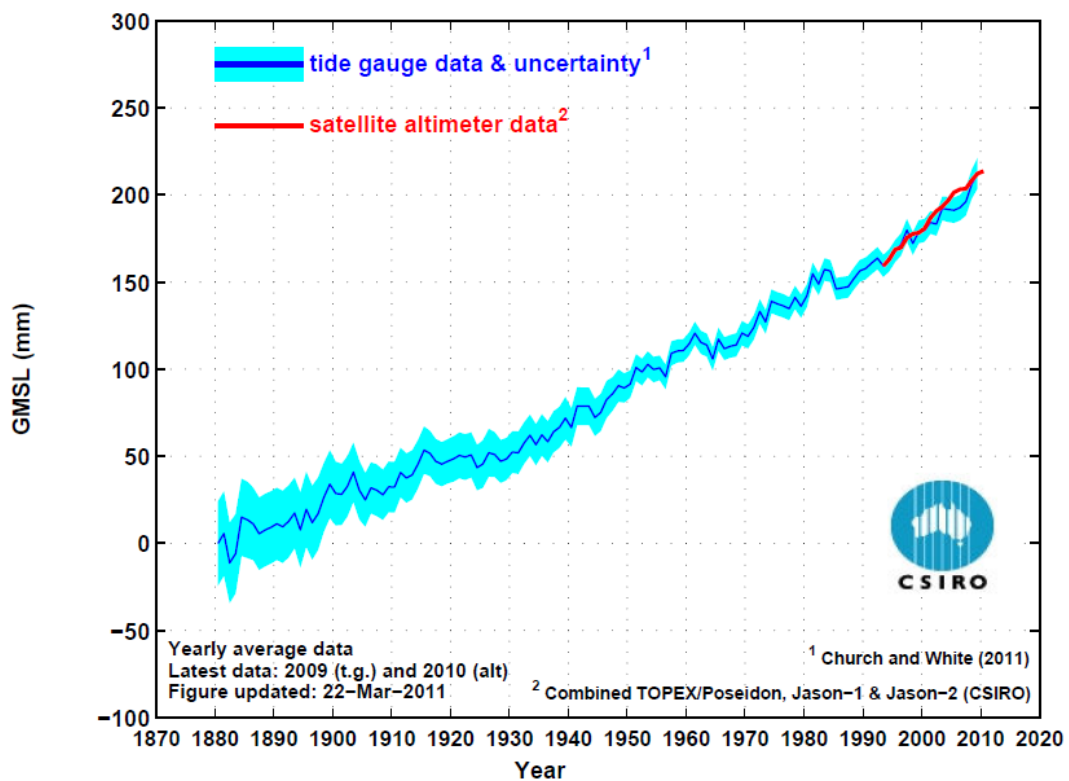


Figure 2: Global mean sea level from 1880 to 2011 (Source: CSIRO 2010 and Church and White 2011).

The average rate of sea level rise, measured from satellites, for the period 1993 to 2008 was 3.1 millimetres per year (CSIRO 2012). Although this is larger than the average rate over the past century, it is evident from Figure 2 that there were several times during that period when the rate was of a similar magnitude. From 1993, tide gauges have also given a rate which is higher than the 20th century average.

The rate of sea level rise is closely correlated with temperature: the warmer it gets, the faster sea level rises (Rahmstorf 2007). As the atmospheric temperature increases, so does the ocean temperature through heat transfers. As the oceans warm, they expand and take up more space. An increase in atmospheric temperatures can also increase the melting of land-based ice into water that flows into the ocean, although this is at least partially counteracted by an increase in precipitation over the ice sheets.

5. LONG-TERM SEA LEVEL RISE PROJECTIONS

5.1 GLOBAL SEA LEVEL RISE PROJECTIONS

The IPCC Fourth Assessment Report 2007 (AR4) provides estimates of projected global average sea level rise for the IPCC SRES scenarios. Table 1 provides an indication of the lower and upper limits of projected global average sea level rise for a number of IPCC emissions scenarios by 2050 and 2100, relative to 1990 levels.

The IPCC AR4 estimates a sea level rise of 0.26 metres to 0.59 metres by 2100, relative to 1980-1999¹ for the A1FI emissions scenario (IPCC 2007a) (see Table 1). The IPCC AR4 estimated that the contribution of melting ice sheets this century due to “rapid dynamical changes” may increase the upper end of the projections by 0.1 to 0.2 metres, depending on the actual emissions trajectory (IPCC 2007b).

This would provide an indicative upper ‘limit’ of 0.76 metres for the A1FI scenario, although the IPCC AR4 also indicated that larger contributions from rapid dynamical changes to ice sheets could not be excluded (IPCC 2007a; IPCC 2007b). It should be noted that the ‘limits’ of the IPCC projections are statistical and do not represent hard boundaries. The upper ‘limit’ of these projections indicates the 95-percentile value, implying that there is a 5% chance of the actual rise being above this ‘limit’. Figure 3 illustrates these concepts.

Table 1: IPCC projected global average sea level rise by 2050 and 2100, based on the NSW sea level rise planning benchmarks technical note (Source: NSW 2009)

Emissions scenario	Sea level rise 1990 to 2050 (m); (IPCC 2001)	Sea level rise 1990 to 2100 (m); (IPCC 2007a, excluding rapid ice melt)
B1 scenario	0.05 – 0.26	0.18 – 0.38
A1T scenario	0.07 – 0.29	0.20 – 0.45
B2 scenario	0.06 – 0.28	0.20 – 0.43
A1B scenario	0.06 – 0.28	0.21 – 0.48
A2 scenario	0.06 – 0.27	0.23 – 0.51
A1FI scenario	0.06 – 0.30	0.26 – 0.59

All values are the relative increase to 2090–2099 from average levels at 1980–1999. The projections for 2100 exclude contributions from future rapid dynamical changes in ice flow.

¹ Henceforth, the two-decadal average 1980-1999 will be labeled as “1990” and the decadal average 2090-2099 will be labeled as “2100”.

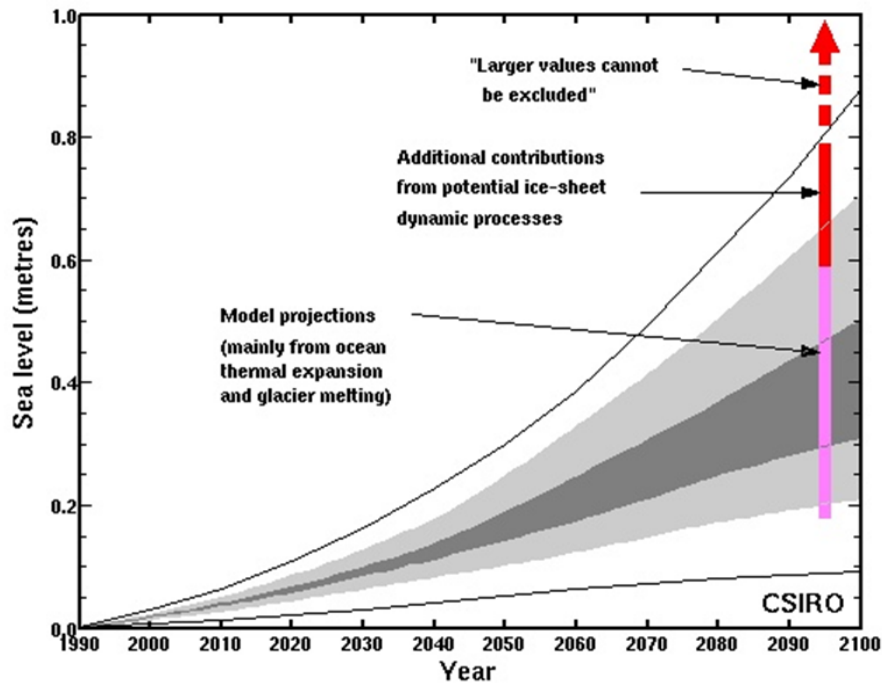


Figure 3: projected sea level rise for the 21st century. Plotted lines are from IPCC (2001) and coloured bars are from IPCC (2007a) (Source: CSIRO 2010).

In addition to the IPCC's sea level rise projections, alternative (semi-empirical) models of sea level rise have been developed. One model developed uses simple empirical relationships between observed global sea level and temperature to simulate future sea level based on projections of future temperature (Vermeer and Rahmstorf (2009)). These alternative models all give larger rates of sea level rise during the 21st century than the IPCC projections. The reliability of some of these alternative models is not yet clear, and Garnaut (2011) advises that these estimates be used with caution.

It is also important to consider that sea level will continue to rise for many centuries after global temperatures are stabilised, as it will take that length of time for the oceans and ice sheets to fully respond to a warmer climate (Allison et al. 2009).

The IPCC's Fifth Assessment Reports are due to be released in late 2013 and 2014. These reports will provide revised global emissions, temperature and sea level rise projections.

5.2 REGIONAL VARIATION IN SEA LEVEL RISE PROJECTIONS

Another important consideration is the regional variation in sea level rise projections. The IPCC (2007a, Fig. 10.32) indicates there is no agreed pattern for the regional distribution of projected sea level rise over the longer term. However modelled projections have several features in common. For example, a maximum sea level rise is expected in the Arctic Ocean and a minimum rise in the Southern Ocean, south of the Antarctic Circumpolar current.

The model projections for the Australian region indicate a higher than the global average sea level rise from ocean thermal expansion off the south-east coast of Australia near New South Wales (CSIRO 2010). These regional variances in sea level can also be increased or reduced by uplifting or sinking of land masses owing to complex geological processes (Hunter 2012).

6. TASMANIAN SEA LEVEL RISE PLANNING ALLOWANCES

6.1 APPLICATION OF A SEA LEVEL RISE PLANNING ALLOWANCE

Owing to the fact that sea level rise is additional to other coastal hazards, sea level rise planning allowances must be considered along with coastal planning and management instruments that address those other coastal inundation hazards. It is important to note that the allowances only relate to inundation, and not erosion of soft shorelines, or impacts associated with this erosion.

The Tasmanian sea level rise planning allowances for 2050 and 2100 have been derived using an approach developed by the ACE CRC (Hunter 2011). As stated in Hunter et al (2012),

an 'allowance' is, in this case, the vertical distance that an asset needs to be raised under a rising sea level so that the present likelihood of flooding does not increase...

In other words, any asset raised by this allowance would experience the same frequency of flooding events under sea level rise as it would without the allowance and without sea level rise.

This being the case, if the current level of precaution or risk tolerance (which is also expressed as 'freeboard' in Building Standards) changes in the future, the sea level rise planning allowances can be directly applied to the new level of precaution. Likewise, if future investigations determine that higher (or lower) allowances are required to maintain the level of precaution, the current allowances can be amended as appropriate.

Sea level rise, like the change of many other climate variables, will mainly be evident as an increase in the frequency or likelihood (probability) of what are currently regarded as extreme events, rather than simply as a steady increase in an otherwise constant state (Hunter 2011).

As the frequency of exposure to extreme events over a given time period is important in planning, methods used for planning purposes to account for future sea level rise usually incorporate statistics which describe the likelihood of extremes, such as exceedance probabilities and / or return periods (or average recurrence intervals). The exceedance probability is the chance of having one or more exceedance events² in a given period and the return period is the average time between exceedance events (DPIPWE 2008). The method used in this approach incorporates a frequency approach, using the 'expected number of exceedances', which is the average number of exceedance events in a given period.

² An exceedance event occurs when a given height is flooded once.

Attachment 1 provides further detail regarding the formulation of the allowances and Attachment 2 explains the use of statistical approaches in accounting for future sea level rise levels for planning purposes.

6.2 2050 SEA LEVEL RISE PLANNING ALLOWANCE

The sea level rise planning allowance for Tasmania for 2050, relative to 2010 is 0.2 metres. This allowance is based on:

- the statistical distribution (defined by the 5-percentile to 95-percentile limits of 0.08 to 0.22 metres) of the IPCC AR4-adjusted TAR projections for the 21st century for the AIFI emissions scenario; and
- the variability of present local tides and storm surges.

6.3 2100 SEA LEVEL RISE PLANNING ALLOWANCE

The sea level rise planning allowance for Tasmania for 2100, relative to 2010 is 0.8 metres. This allowance is based on:

- the statistical distribution (defined by the 5-percentile to 95-percentile limits of 0.25 to 0.76 metres) of the IPCC AR4-adjusted TAR projections for the 21st century for the AIFI emissions scenario; and
- the variability of present local tides and storm surges.

It should be noted that sea level is expected to continue to rise beyond 2100. However, the Tasmanian sea level rise planning allowances are provided up until 2100 to align with projections provided by the IPCC.

Both the 2050 and 2100 sea level rise planning allowances will be reviewed following the release of the IPCC's Fifth Assessment Report and / or the making of an Australian intergovernmental agreement that addresses sea level rise figures for decision making purposes.

GLOSSARY OF TERMS

Coastal hazards – Sources of potential harm which occur in the coastal zone, specifically coastal erosion and coastal inundation (sea level rise inundation and storm tide inundation).

Coastal inundation – The inundation of a portion of the coast that may be permanent or temporary.

Coastal recession – Caused by permanent inundation occurring in areas that are susceptible to erosion based on the coastal geomorphology, geology and soils, and low lying areas that become permanently inundated.

Exceedance event – The time when a given height is flooded once.

Exceedance probability – The chance of having one or more exceedance events in a given period.

Emissions scenarios – A plausible representation of the future development of *emissions* of substances, such as *greenhouse gases*, based on a consistent set of assumptions about driving forces (such as demographic and socio-economic development, technological change) and their key relationships.

Hazardous erosion – The result of storm tide events, occurring in areas that are susceptible to erosion based on the coastal geomorphology, geology and soils.

Inundate – To cover with water.

Mean sea level – The average *relative sea level* over a period, such as a month or a year, long enough to average out transients such as waves, storm surges, tides, and seasonal and interannual variations.

Number of exceedances – The number of times a certain level is exceeded in any given period.

Permanent inundation – The mean high tide mark and changes to the mean high tide resulting from sea level rise.

Relative sea level rise – Relative sea level rise occurs where there is a local increase in the level of the ocean relative to the land, which might be due to ocean rise and/or land level subsidence.

Return interval – Usually the average time between exceedance events. Sometimes also referred to as the average recurrence interval or ARI. Note that there can be differences in the way return period is calculated, so caution may be required if the method of calculation is not clear.

Sea level rise – An increase in the mean level of the ocean.

Sea level rise planning allowance – An estimation of future sea level rise.

Storm surge – Elevated sea level at the coast caused by the combined influence of low pressure and high winds associated with a severe storm. Includes wave run up and wave set up.

Temporary inundation – A storm tide which includes the following factors; regional storm surge, local storm surge, tides, wave setup, wave runup and climate change (including sea level rise and the changing likelihood of storm events).

Wave runup – The ultimate height reached by waves after running up the beach and coastal barrier.

Wave setup – The super-elevation in water level across the surf zone caused by energy expended by breaking waves.

REFERENCES

- Allison, I., Warner, R., Haward, M., Hilkemeijer, A. and Sandford, R. 2009, *Position analysis: polar ice sheets and climate change: global impacts*, Antarctic Climate and Ecosystems Cooperative Research Centre.
- Church, J. A. and N.J. White 2011, *Sea-level rise from the late 19th to the early 21st Century*. Surveys in Geophysics, doi:10.1007/s10712-011-9119-1.
- Church, J.A., J.M. Gregory, N.J. White, S.M. Platten, and J.X. Mitrovica. 2011, *Understanding and projecting sea level change*. Oceanography 24(2):130–143, doi:10.5670/oceanog.2011.33
- Climate Commission 2011, *The Critical Decade: Climate science, risks and responses*. <http://climatecommission.gov.au/topics/the-critical-decade/>.
- CSIRO (Commonwealth Scientific and Industrial Organisation) 2012, *Sea level rise: understanding the past, improving projections for the future*. <http://www.cmar.csiro.au/sealevel/index.html>
- Corney S.P., Katzfey J.J., McGregor J.L., Grose M.R., Bennett J.C., White C.J., Holz G.K., Gaynor S.M. and Bindoff N.L. 2010, *Climate Futures for Tasmania: climate modelling technical report*, Antarctic Climate and Ecosystems Cooperative Research Centre, Hobart, Tasmania.
- DPIPWE (Department of Primary Industries, Parks, Water and Environment) 2004, *Information Paper: Sea level change around Tasmania*.
- DPIPWE (Department of Primary Industries, Parks, Water and Environment) 2008, *Sea-Level Extremes In Tasmania Summary and Practical Guide for Planners and Managers*
- Department of Transport Western Australia 2010, *Sea level change in Western Australia: application to coastal planning*.
- Garnaut, R. 2011, *Update Paper Five: the science of climate change*. <http://www.garnautreview.org.au>
- GCP 2012, Global carbon budget, Global Carbon Project. <http://www.globalcarbonproject.org/carbonbudget/index.htm>
- Hunter, J., Coleman, R. and Pugh, D. 2003, 'The sea level at Port Arthur, Tasmania, from 1841 to the present', *Geophysical Research Letters*, 30(7), 1401, doi: 10.1029/2002GL016813.
- Hunter, J. 2010, Estimating sea-level extremes under conditions of uncertain sea-level rise, *Climatic Change*, 99:331-350, doi: 10.1007/s10584-009-9671-6.
- Hunter, J. 2011, 'A simple technique for estimating an allowance for uncertain sea-level rise', *Climatic Change*, doi: 10.1007/s10584-011-0332-1.
- Hunter, J., Church, J., White, N., and Zhang, X. 2012, *Towards a Global Regionally-Varying Allowance for Sea-Level Rise*. Submitted to *Ocean Engineering* 30 May 2012.
- IPCC (Intergovernmental Panel on Climate Change) 2000, *IPCC Special Report on Emissions Scenarios: summary for policy makers*, Intergovernmental Panel on Climate Change.

IPCC (Intergovernmental Panel on Climate Change) 2001, *Climate Change 2001: The Scientific Basis*, Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge.

IPCC (Intergovernmental Panel on Climate Change) 2007a, *Climate change 2007: The Physical Science Basis*, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge.

IPCC (Intergovernmental Panel on Climate Change) 2007b, *Climate change 2007: The Physical Science Basis*, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Summary for Policymakers, Cambridge University Press, Cambridge.

Lambeck, K. and Chappell, J. 2001, Sea level change through the last glacial cycle, *Science*, 292, 679-686.

NSW (State of NSW and Department of Environment, Climate Change and Water) 2009, *Derivation of the NSW Government's sea level rise planning benchmarks, technical note*.

Rahmstorf, S. 2007, 'A semi-empirical approach to projecting future sea level rise', *Science*, vol. 315, no. 5810, pp. 368-370. http://www4.ncsu.edu/~gary/mea214/ppt/Rahmstorf_science_2007.pdf

Raupach M.R., Marland G., Ciais P., Le Quéré C., Canadell J.G., Klepper G. and Field C.B. 2007, Global and regional drivers of accelerating CO₂ emissions, *Proc. Natl. Acad. Sci. USA*, 104:10288-10293.

Vermeer, M. and Rahmstorf, S. 2009, 'Global sea level linked to global temperature', *Proceedings of the National Academy of Sciences of the United States of America*, 106(51), pp. 21527-21532, doi 10.1073/pnas.0907765106.

ATTACHMENTS

ATTACHMENT 1 – FORMULA FOR DERIVING SEA LEVEL RISE PLANNING ALLOWANCES

The sea-level allowance is given by (Hunter 2011):

$$Allowance = \langle z \rangle + (sd)^2 / (2 sp)$$

Where $\langle z \rangle$ is the central value of the sea level rise projection,

sd is the standard deviation of the sea level rise projection,

sp is the *scale parameter* of the Gumbel distribution describing present local tides and storm surges,

and, given that little is known about the actual uncertainty distribution, it is assumed that the uncertainty in the projections follows a normal distribution.

The values of $\langle z \rangle$ and sd were derived from the AR4 adjusted TAR projections and the value of sp was derived from analyses of observations from the Hobart tide gauge. Tasmania's other long term coastal tide-gauge record at Burnie gives a very similar but slightly larger value of sp and therefore a slightly smaller allowance. Using the Hobart data is therefore a conservative approach.

The values used in the above equation are shown in the following table:

Period	$\langle z \rangle$ (m)	sd (m)	sp (m)	Allowance (m)
2010-2050	0.190	0.057	0.092	0.207 (rounded down to 0.2m)
2010-2100	0.590	0.170	0.092	0.748 (rounded up to 0.8m)

ATTACHMENT 2 – THE RETURN PERIOD, THE EXCEEDANCE PROBABILITY AND THE EXPECTED NUMBER OF EXCEEDANCE EVENTS

Flooding events from the sea are often described as *exceedance events*. An exceedance event occurs when the sea level exceeds a specified height (for example, the floor level of a building).

The most common measure of present-day sea level extremes is the *return period* or *average recurrence interval*. This is the average time between exceedance events. In the absence of future sea-level rise and its related uncertainty, the return period may be directly related to something called the *exceedance probability*. The exceedance probability is the probability of having *one or more* exceedance events at a given height over a given period. The *one or more* is important; if the exceedance probability is greater than about 0.6 (60 per cent), then it becomes quite likely that there will be *more than one* exceedance event during the period. From the point of view of estimating *risk*, it is generally necessary to have some knowledge of the likely number of flooding events. While, in the absence of uncertain sea level rise, this number can be directly estimated from the exceedance probability, it may be shown that in the presence of uncertain sea level rise this is no longer possible (Hunter 2011).

An alternative metric which is applicable under conditions of uncertain sea level rise is the *expected number of exceedance events*. It is simply a measure of the effective average number of flooding events in a given time. In the absence of uncertain sea level rise, this is just related to the return period by the relationship:

$$(\text{expected number of exceedance events}) = (\text{time period})/(\text{return period})$$

where the *time period* is the time span over which the expected number of exceedance events is defined. These are tabulated in Table A1.

The expected number of exceedance events may be multiplied by the *cost per event* to give an estimate of *risk*. Where the expected number of exceedance events is less than one it may be thought of as the *probability of experiencing a single exceedance event*.

In the presence of uncertain sea level rise, the values in Table A1 may be used to provide an indication of the *approximate* equivalence between the *expected number of exceedance events* and the *return period*, although as shown by Hunter (2011), it must be emphasised that this is only an approximation.

Table A1: The *expected number of exceedance events* for a range of *time periods* and *return periods*.

Time Period (years)	Return Period (years)		
	50	100	200
1	0.02	0.01	0.005
5	0.1	0.05	0.025
10	0.2	0.1	0.05
50	1.0	0.5	0.25
100	2.0	1.0	0.5
500	10.0	5.0	2.5